Equivalent nosing force for a steel railway bridge based on in situ measurements

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Abstract

The weight and design speed of the railway vehicles increases in time. As a result, the values of design loads grow up. In old Bulgarian standard [1] the equivalent nosing force is prescribed as 60kN. In the present EN1991-2 [2] this value is 100kN. Meanwhile, a significant part of the very old bridges is not designed for nosing forces. In cases of long span between cross girders of the “open type” deck and lack of nosing braces, the load bearing capacity of longitudinal girders, concerning out of plane bending moments due to nosing forces, is insufficient. To investigate the value of equivalent nosing force are provided “in situ” measurements on the longitudinal girders of “open type” deck of a steel riveted railway bridge in exploitation in the Republic of Bulgaria. The strains and horizontal linear deformations are measured in the midspan of the longitudinal beams for real trains. The equivalent nosing force is calculated using developed procedures.

Keywords: steel bridge, longitudinal girders, “in situ” measurements, deformations, nosing force

1 Introduction

Due to the imperfections of the track and the railway vehicles, when the trains run in the longitudinal direction, there are also movements in a transverse direction. As a result, the wheel flanges, which do not allow the trains to derail, touching the rail’s head, cause forces transverse to the road axis. According to the "Standard for the design of road and railway bridges and culverts" by 1990 [1], the transverse horizontal force in railway bridges has a characteristic value Q_{sk} = 60 kN. According to the European standard EN1991-2: 2006 [2], the nosing force has a value Q_{sk} = 100 kN, and when taking into account the coefficient for classified loads α = 1,21, specified in BDS EN 1991-2: 2006/NA:2015 [3], the characteristic value increases to Q_{sk} = 121 kN. The difference in Q_{sk} is more than twice. The question arises as to which of the above normative documents prescribes more realistic values. In an attempt to obtain an answer to this question, a research team from the University of Architecture, Civil Engineering and Geodesy (UACEG) has performed field measurements and calculations of the corresponding values of the transverse horizontal forces, caused by real railway trains, crossing a steel bridge with an “open type” deck.

2 Type and basic data for the researched bridge

The bridge, on which the values of the equivalent horizontal nosing forces have been experimentally determined, is a double span steel railway bridge, see Fig. 1, located above the river Iskar. In each span are placed two truss main girders, simply supported on the lower chord by fixed and linearly movable steel bearings. The deck is classic, “open type” (rails and wooden sleepers step directly on the longitudinal beams). Pin joined longitudinal and transverse beams, having approximately similar height, construct it.

Figure 1. General view of the researched steel bridge - on km. 18^{+985}

The transverse beams of the road structure are supported in the nodes along the upper chord of the truss main girders, see Fig. 2. Railway sleepers are wooden and are fastened by bolts or angle sections to the upper flange of longitudinal beams.

Figure 2. "Open type" deck structure

The main dimensions of the deck structure of the researched steel bridge are shown in Fig. 3.
The cross-sections of the longitudinal beams and the numbering of the strain sensors, placed on them, are shown in Fig. 4.

The bridge is a part of national road infrastructure of Republic Bulgaria. It is owned by the state National Railway Infrastructure Company. Nevertheless, the authors of the article did not find more information about the bridge as a designer, design standards, used steels, year of commissioning.

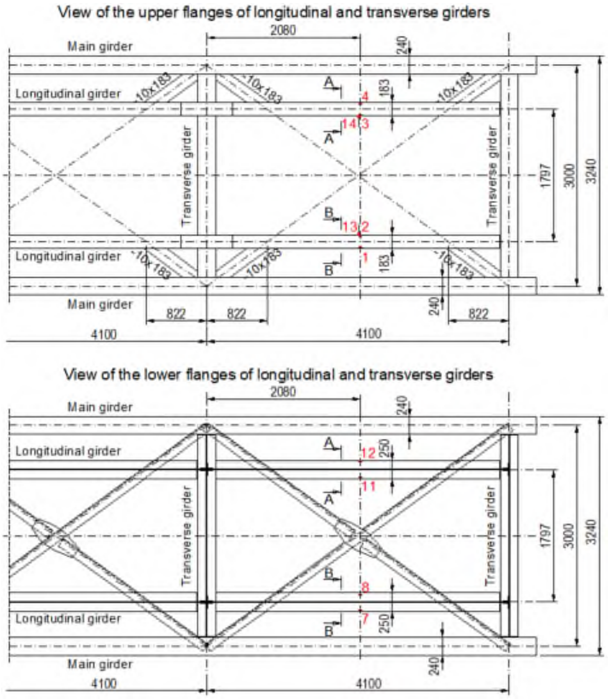


Figure 3. Main dimensions of the deck structure of the bridge and points of placement of the sensors

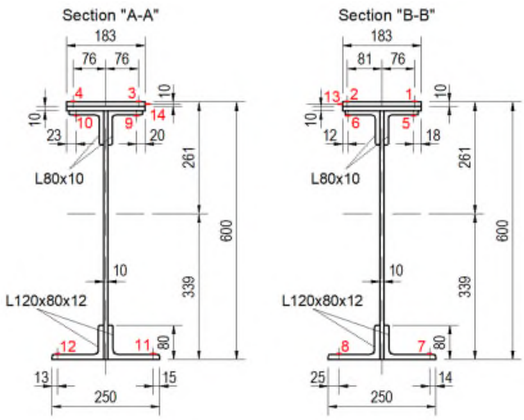


Figure 4. Sections of the longitudinal girders and points of placement of the strain sensors

3 Determination of the transverse nosing forces, based on measured transverse displacements of the longitudinal beams

In the middle of the last span of the road deck, next to each of the upper flanges of longitudinal beams, are placed sensors №13 and №14, see Fig. 3 and Fig. 4, measuring the movement in the transverse direction. When real trains pass, this movement is accounted and recorded at a frequency of 200 records per second. Then, using a program for spatial analysis of building structures, a computational model of one of the longitudinal beams (LB) was built, see Fig. 5. Its features are as follow:

a) a steel St37-2 (1.0037) according to DIN17100 [4] is used. It has the following characteristics:

- density - ρ = 7 850 kg/m^3;
- yield strength- f_y=235 MPa at thickness t≤16 mm;
- tensile strength - f_u = 340 MPa at a thickness t ≤ 100 mm;
- modulus of elasticity - E_a = 210 000 MPa.

b) the flanges and the webs of the longitudinal beams are modelled by shell elements, having the dimensions, shown in Fig. 4;

c) to reduce the computer time, required for the calculation, only three fields of the open deck have been simulated;

d) the horizontal braces with a single angle section L150x12, supporting the upper and lower flanges of longitudinal beams, are simulated;

e) the upper flanges of the longitudinal beams (LB) are united by plates, passing over the flange of transverse beams (TB). At the same time, the lower flanges of these beams are left free. As a result, the lower and upper flanges of the longitudinal beam have a different number of horizontal supports;

f) all elements in the numerical model work elastically, i.e. we have a linear relationship between forces and deformations.

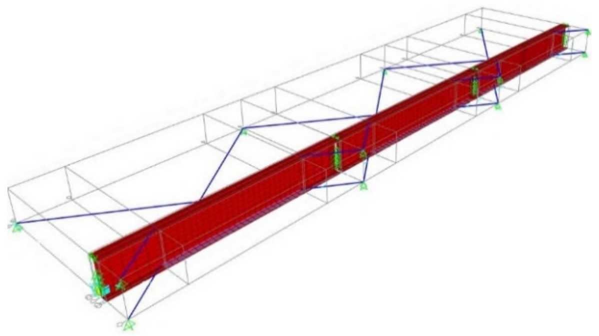
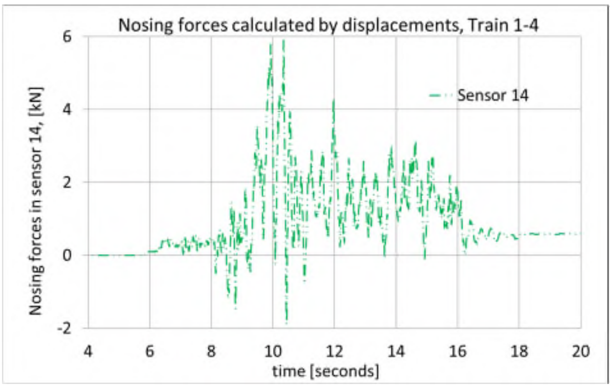
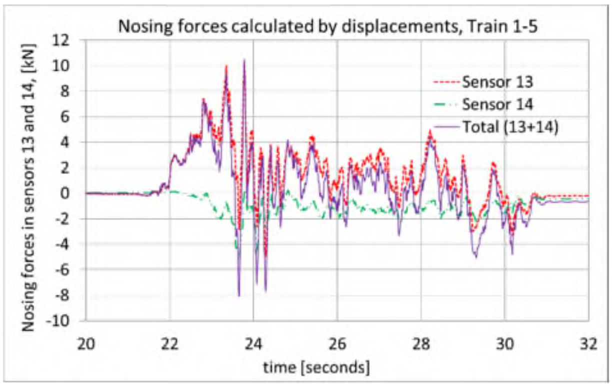


Figure 5. A numerical model of longitudinal girders

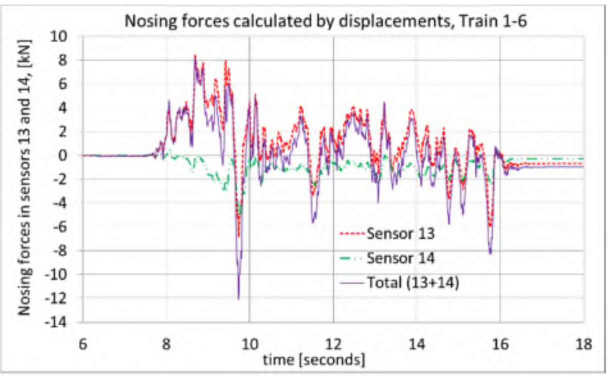
In the numerical model, on the same field and the same place, where the sensors №13 and №14 are placed, is applied a concentrated horizontal force with intensity F_1 = 1 kN. The horizontal displacement $\Delta_{1,h}$ of the upper flange of LB, caused by single force F_1, is accounted for. The ratio of the measured by sensors №13 and №14 horizontal displacements $\Delta_{r,h}$, and the displacements $\Delta_{1,h}$, generated by the single force $F_{1,h}$, gives the value of the real transverse horizontal force in the upper flange of LB, caused by the passing trains. Sensor №13 is placed next to the upper flange of the right LB in the direction of train movement and sensor №14 - to the left, see in Fig. 3 and 4. The values of the obtained nosing forces are shown in Fig. 6.



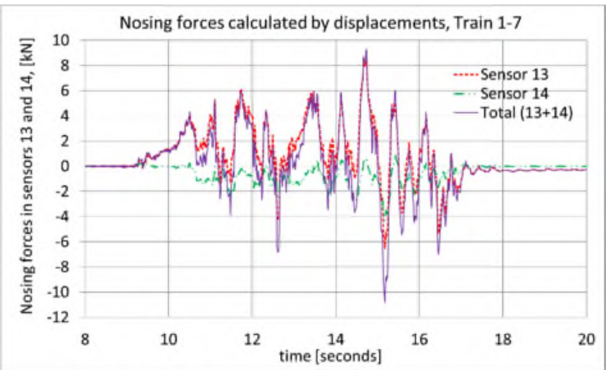
a) nosing forces from train 1-4, accounted by displacement of sensor №14



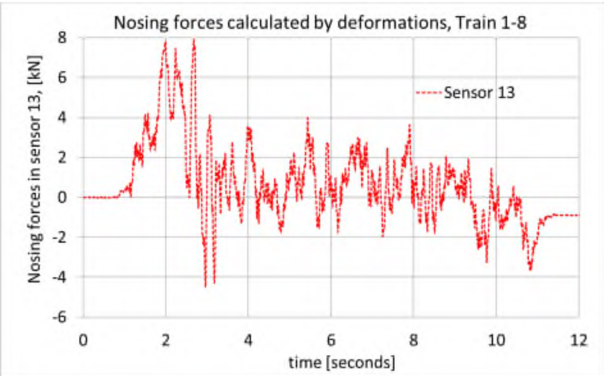
b) nosing forces from train 1-5, accounted by displacement of sensors №13 and №14



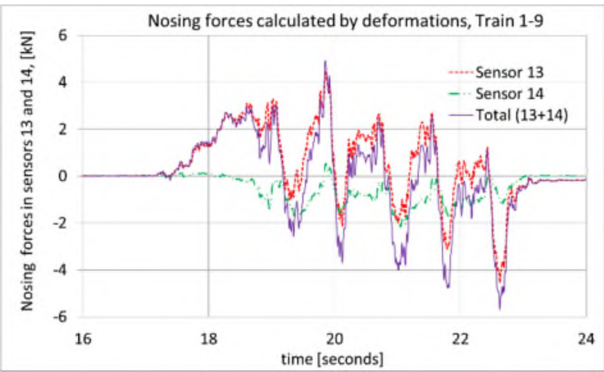
c) nosing forces from train 1-6, accounted by displacement of sensors №13 and №14



d) nosing forces from train 1-7, accounted by displacement of sensors №13 and №14



e) nosing forces from train 1-8, accounted by displacement of sensor №13



f) nosing forces from train 1-9, accounted by displacement of sensors №13 and №14

Figure 6. Nosing forces in the two longitudinal beams of the bridge, accounted by the horizontal displacement of the upper flanges

From the graphs in Fig. 6, obtained from the six passenger's trains, the following conclusions could be drawn:

a) the maximum values of the transverse nosing forces do not exceed 10 kN per longitudinal beam;

b) the total nosing force, applied to both longitudinal beams, does not exceed 12 kN;

c) at the beginning of the train passage, the upper flanges of LB are moved horizontally in contrary directions. Then, when passing the wagons, a simultaneous movement in the same direction is observed, but not with the same values;

d) the presence of nosing forces with a various sign in each of the longitudinal beams, as well as the coincidence of the peaks of the diagrams over time, show that the wooden sleepers have a certain redistributive role. However, they failed to equalize the transverse forces in the two longitudinal beams, probably due to slipping and corresponding activation of the fixing bolts after overcoming the existing clearance.

4 Determination of the transverse nosing forces, based on measured strains in the flanges of the longitudinal beams

Here, using strain gauge sensors 1-XY-6/120, are measured the strains in the flanges of the longitudinal beams. They are used to determine the bending moment in LB in transverse direction, from which the nosing force can be calculated. Used equations are:

$$L_{calc} = k_L{}^{-1}.R_{[3,1]} \qquad \{R\} = E_a[A]^{-1}.\{e\} \tag{1}$$

where:

$$\{R\} = [N, M_y, M_z]^T \tag{2}$$

$$\{e\} = [\varepsilon_i, \varepsilon_j, \varepsilon_k]^T \tag{3}$$

$$[A] = \begin{bmatrix} A_{longg}^{-1} & z_i.I_{longg,y}^{-1} & y_i.I_{longg,z}^{-1} \\ A_{longg}^{-1} & z_j.I_{longg,y}^{-1} & y_j.I_{longg,z}^{-1} \\ A_{longg}^{-1} & z_k.I_{longg,y}^{-1} & y_k.I_{longg,z}^{-1} \end{bmatrix} \tag{4}$$

in which:

$A_{longg}, I_{longg,y}, I_{longg,z}$ are the cross-section and moments of inertia about axes "y-y" (horizontal) and "z-z" (vertical) of the longitudinal beam in the "open type" deck;

i, j, k – the numbers of the strain gauge sensors, used to measure the strain in the longitudinal direction for the respective points of the cross-section of the longitudinal beam, see Fig.3 - 4;

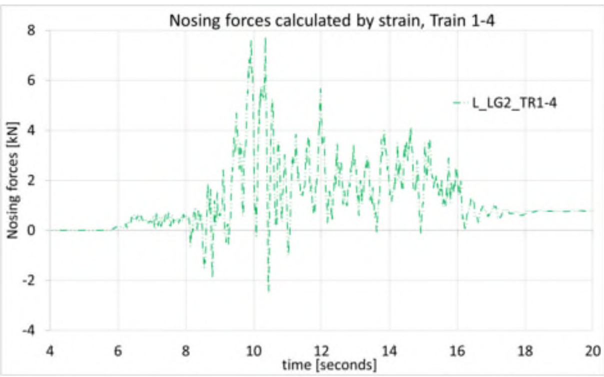
z_i, z_j, z_k, y_i, y_j, y_k – the ordinates of points *i, j, k* to axes "z-z" and "y-y";

k_L – the bending moment to the vertical axis "z-z" in the cross-section of longitudinal beam, caused by single force F_1 = 1 kN, applied in a horizontal direction on the level of the upper flange;

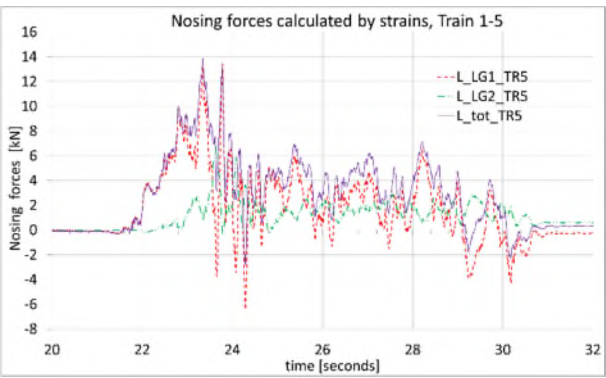
$R_{[3,1]}$ – element in 3 row, 1 column of the vector $\{R\}$;

E_a = 210 000 MPa – modulus of elasticity of the steel.

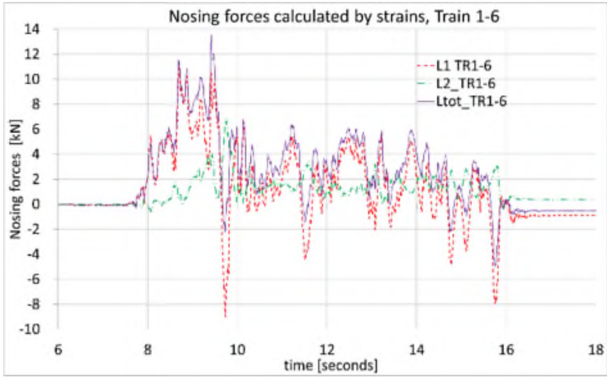
Subsequently, the corresponding internal forces were calculated from the measured strains. On this basis, a fictitious nosing force can be determined, which will lead to the same internal forces.
Accounted nosing forces by the strains of the flanges of longitudinal beams, are shown on Fig. 7:



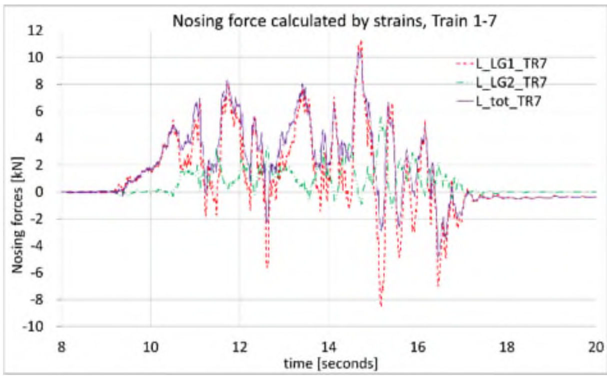
a) nosing forces from train 1-4, accounted by strains in flanges of longitudinal beams



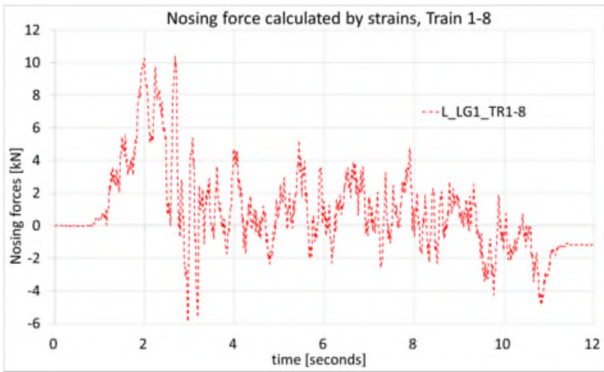
b) nosing forces from train 1-5, accounted by strains in flanges of longitudinal beams



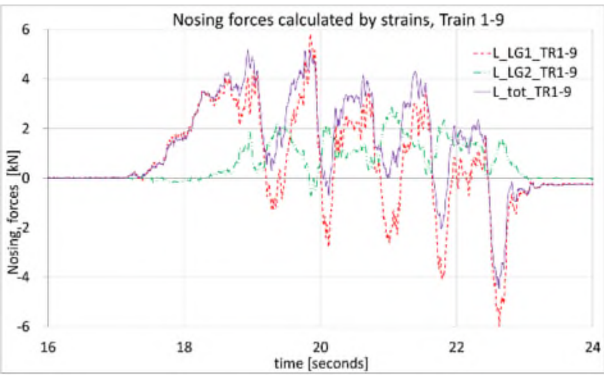
c) nosing forces from train 1-6, accounted by strains in flanges of longitudinal beams



d) nosing forces from train 1-7, accounted by strains in flanges of longitudinal beams



e) nosing forces from train 1-8, accounted by strains in flanges of longitudinal beams



f) nosing forces from train 1-9, accounted by strains in flanges of longitudinal beams

Figure 7. Nosing forces in the two longitudinal beams of the bridge, accounted by the strains of their flanges

From the graphs in Fig. 7, obtained from the six passenger's trains, the following conclusions could be drawn:

a) the maximum values of the transverse nosing forces do not exceed 13 kN per longitudinal beam;

b) the total nosing force, applied to both longitudinal beams, does not exceed 14 kN;

c) no simultaneous movement of the upper flanges of LB in the same direction;

d) the presence of nosing forces with a various sign in each of the longitudinal beams indicates the wooden sleepers have some redistributive role. But they fail to equalize the transverse forces in the two longitudinal beams.

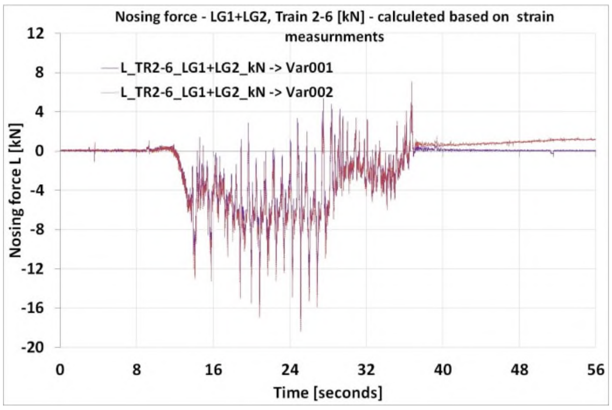


Figure 8. Nosing forces in both longitudinal beams of the bridge, due to freight train 2-6

Two freight railway trains were registered during the measurements. Fig. 8 - 9 represent the nosing force as a function of the time, calculated on the base of the measured strains in the longitudinal beams for the respective groups of sensors. The maximum values of transverse forces are approximately 18 ÷ 30 kN.

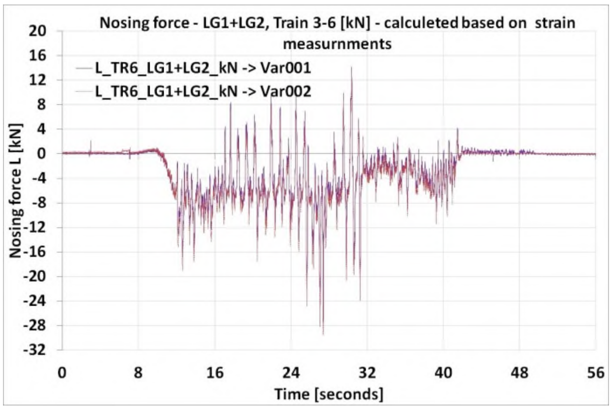


Figure 9. Nosing forces in both longitudinal beams of the bridge, due to freight train 3-6

5 Conclusions

The horizontal impact of the fluctuation movements of the railway vehicles in the transverse direction has a complex character and impact on the elements of the "open type" deck. The consideration of this complex in nature impact in the design standards is realized by applying in the most unfavourable position of the transverse horizontal force. The prescribed values in the standards vary widely - 60 kN [1], 121 kN [2,3], without taking into account the nature of traffic and the design speed of railway vehicles. When determining the corresponding nosing forces for a specific old steel riveted bridge from the Second Railway Line (Sofia - Mezdra - Varna) in Bulgaria, with a maximum speed of trains 80 km/h, values of 12 ÷ 14 kN for passenger trains and 18 ÷ 30 kN for freight trains are accounted. It is evident that under the specific conditions of the experiment, the requirements of [2] and [3] are too conservative. The normatively prescribed values are 3 ÷ 4 times higher than the ones determined for the real railway traffic, based on the performed "on situ" measurements.

Almost all steel railway bridges in Bulgaria were designed and put into operation at the end of the 19th and the beginning of the 20th century, when the nosing forces were untaken into account at all. Currently, these bridges are in good condition, without the need for additional reinforcement of the "open type" deck structure. It gives us reason to recommend the value of the nosing force Q_{sk} to be reduced in the future editions of EN 1991-2. Or at least to be in relation with the speed of passage.

Acknowledgements

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6 References

[1] Standard for the design of road and railway bridges and culverts. Fifth part. Sofia, 1990.

[2] EN 1991-2:2006. Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges. European Committee for Standardization, Brussels.

[3] BDS EN 1991-2:2006/NA:2015. Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges. National Annex to EN 1991-2:2006. BIS, Sofia.

[4] DIN17100:1980. Steels for general structural purposes. German Institute for Standardization.