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THE ANALYSIS OF RAIL SLEEPER DISPLACEMENTS IN THE FUNCTION OF SUBGRADE PARAMETERS

Andrzej SUROWIECKI[*], **Piotr SASKA**[**], **Marcin WASIAK**[***]

[*] *Faculty of National Security, the General Tadeusz Kościuszko Military Academy of Land Forces*
e-mail: a.surowiecki@wso.wroc.pl

[*] *Faculty of Management, the General Tadeusz Kościuszko Military Academy of Land Forces*
e-mail: p.saska@wso.wroc.pl

[***] *Wrocław University of Environmental and Life Sciences, Institute of Building*
e-mail: marcin.wasiak@up.wroc.pl

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Abstract:

The paper concerns the quality of interaction between the basic elements of the railroad surface, based on digital modeling. A map of vertical displacements of railroad subgrade was developed in the function of changing conditions in the subgrade load capacity. These conditions were characterized by the indicator value of the subgrade density and the location of subgrade density zones. The article presents the continuation of research, which at the introductory stage was focused only on the analysis of normal stress and shear stress in the railway sleeper.

Keywords:

track structure, vertical displacements, digital modeling

1. INTRODUCTION

The paper discusses the issue of the quality of interaction between the basic elements of the railroad surface: the railway sleeper and the ballast in which the sleeper is immersed. The proper functioning of the various structural elements of the railroad tracks and their interconnection, the effect of which is the transfer of the operational load to the subgrade in the elastic range of stress, takes on particular relevance in the light of the ongoing modernization of the rail lines in Poland [Id-3 2009; Sancewicz 2012; Surowiecki 2011, 2012; Towpik 2011]. Its aim is to increase the speed of trains and improve the comfort of travelling [15]. The main attention was focused on the development of the so-called maps of vertical displacement of numerical models of the railway sleeper, in the function of changes both in the density index and the location of density zones of the sleeper subgrade [9, 18].

The theoretical model of railway sleepers is a rectangular beam modeled with a disc component, continuously supported (over the length) in the granular medium of the type of crushed stone ballast. Two types of railway sleepers are taken into consideration. They completely differ with respect to mechanical characteristics and reactions to structural changes in the subgrade.

The evaluation of the railway sleeper models under varying conditions of support was made based on the graphs showing the distribution of values of movements in the longitudinal profile of the sleeper. The load of models was implemented by simulating the operational pressure applied as static vertical force in the rail fastening zones. The tool for the simulation and the analysis of the results was the digital program Autodesk Robot Structural Analysis 2010 [Surowiecki 2011; Wasiak 2011], the use of which allowed to generate a computational construction model, with parameters significantly similar to the real ones.

The content of the paper includes the presentation of models and the synthesis of research results.

2. DIGITAL MODELS AND THE RESEARCH METHOD

The simplifying assumption that the vehicle axis is stationary and the pressure is taken over by a single railway sleeper was made for the purpose of research. Another assumption refers to the straight section of a track, in order to eliminate the problem of the so-called cant, which appears in a horizontal arc.

The shape of pre-stressed concrete sleepers was simplified and they were treated as beams with invariable cross-section lengthwise. The following sleepers were analyzed: pre-stressed concrete ones of the types PS - 94 and PS - 83, as well as the wooden of the type C40 (pine wood) and D70 (oak wood).

Figure 1 represents the research models consisting of two parts: the sleeper and the subgrade (granular medium) [Surowiecki 2011; Wasiak 2011].

The subgrade of the sleeper is the 0.4m thick layer of granular material (the crushed granite ballast of the fraction of 31.5/63 mm). The location of density zones is presented in Figure 1. Whereas the values of density index were adopted in the range between 0.9-1.0. The designed density indicators (I_s) correspond to the following values of the subgrade stiffness K:

$I_s = 0.9 \rightarrow K = 134.47$ MPa; $I_s = 0.90 \rightarrow K = 134.47$ MPa; $I_s = 0.92 \rightarrow K = 135.76$ MPa; $I_s = 0.94 \rightarrow K = 137.05$ MPa; $I_s = 0.95 \rightarrow K = 137.68$ MPa; $I_s = 0.96 \rightarrow K = 138.31$ MPa; $I_s = 0.98 \rightarrow K = 139.56$ MPa; $I_s = 1.00 \rightarrow K = 140.79$ MPa.

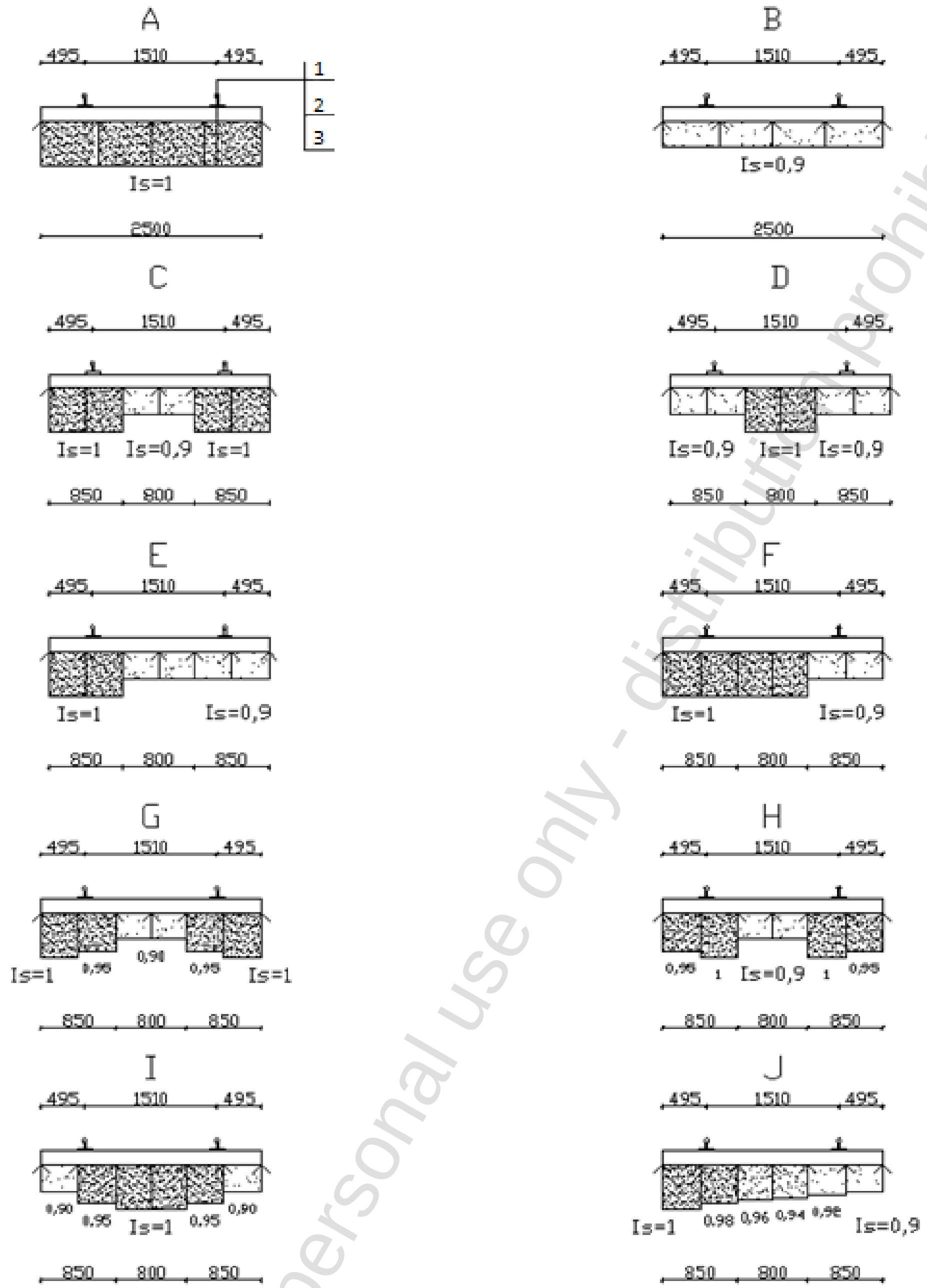

Fig. 1. Research models consisting of two parts [9-11, 18]: the sleeper and the subgrade (the modeled cross-section of railway track), *1* – 60E1 rail, *2* – sleeper, *3* – ballast

Source: own elaboration

The problem of modeling the operational load (the vehicle axle load Q = 221 kN) was solved after transforming the value 0.5 Q into two uniformly distributed load bands of the intensity q = 750 kN/m. The bands were applied to the upper subgrade surface at the locations of the rails, over the length equal to the dimensions of the rail baseplate width.

The estimation of values of the sleeper displacements was performed in specific points of the longitudinal section, which were installed on the horizontal axis, on the upper and lower edges of the sleeper, on the vertical axis of symmetry of the sleeper, in the vertical cross-sections of the sleeper under the axes of symmetry of the rails, and on the outer edges of the sleeper. The scheme of the layout of measurement points in the longitudinal section of the sleeper is given in the studies [Surowiecki 2011; Wasiak 2011].

In the case of pre-stressed concrete sleepers the process of pre-compressing is of significant importance. The effect of pre-compressing was modeled by introducing virtual compressive forces into the zone of the longitudinal axis of the sleeper [Surowiecki 2011; Wasiak 2011]. From the information received from the producer it appears that the force compressing the PS – 83 and PS – 94 sleepers is respectively (after taking the losses into account): 300 kN and 310 kN. Thus, the compression in the sleeper of the type of PS – 83 was modeled in the longitudinal axis of the sleeper with the use of 13 elementary compressive forces of the value of Q_i = 12 kN, located in two horizontal trajectories, formed by the axes of centers of gravity of the upper and lower reinforcement.

3. RESULTS OF DIGITAL ANALYSIS REGARDING VALUES OF VERTICAL DISPLACEMENTS OF SLEEPER MODELS

The results are shown in the drawings as the state of strain of the numerical models of sleepers (the presentation of the vertical longitudinal cross-section):

- Figure 2 *a, b*: the state of strain of the wooden sleeper models C40; *a* – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*:
- Figure 3 *a, b*: the state of strain of the wooden sleeper models D70; *a* – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*
- Figure 4 *a, b*: the state of strain of the pre-stressed concrete sleeper models PS-83; *a* – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*:
- Figure 5 *a, b*: the state of strain of the pre-stressed concrete sleeper models PS-94; *a* – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*:
- Figure 6: the variation of the maximum displacement z_{max} [10^{-2} m] of measurement points in sleeper models, depending on the density of the subgrade, characterized by diagram *A, B, C, D, E, F, G, H, I, J*.

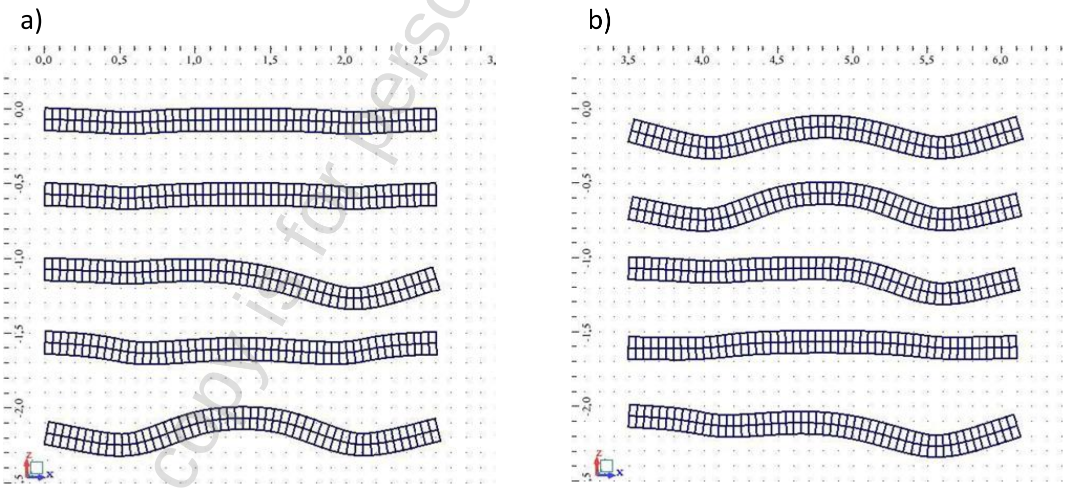

Fig.2. *a, b.* the state of strain of the wooden sleeper models C40 [9-11, 18]:
a – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*

a) b)

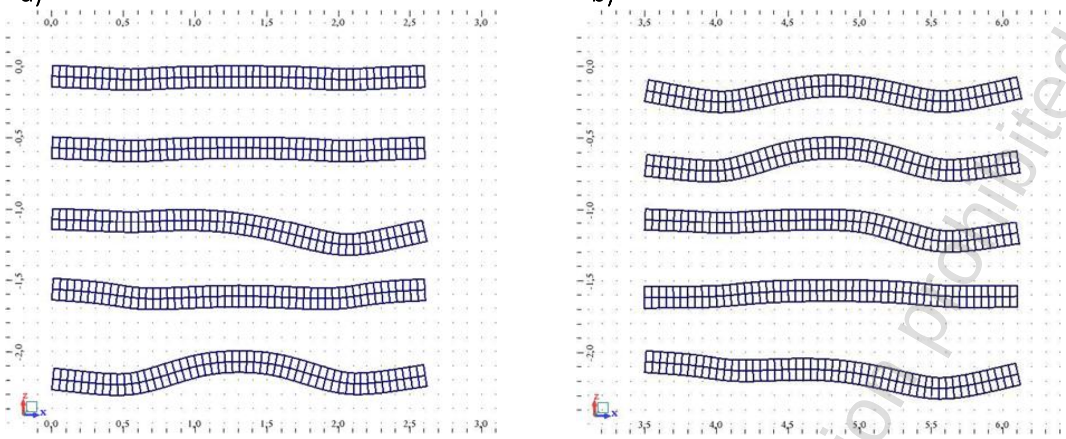

Fig. 3. *a, b*. the state of strain of the wooden sleeper models D70 [9-11, 18]:
a – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*

a) b)

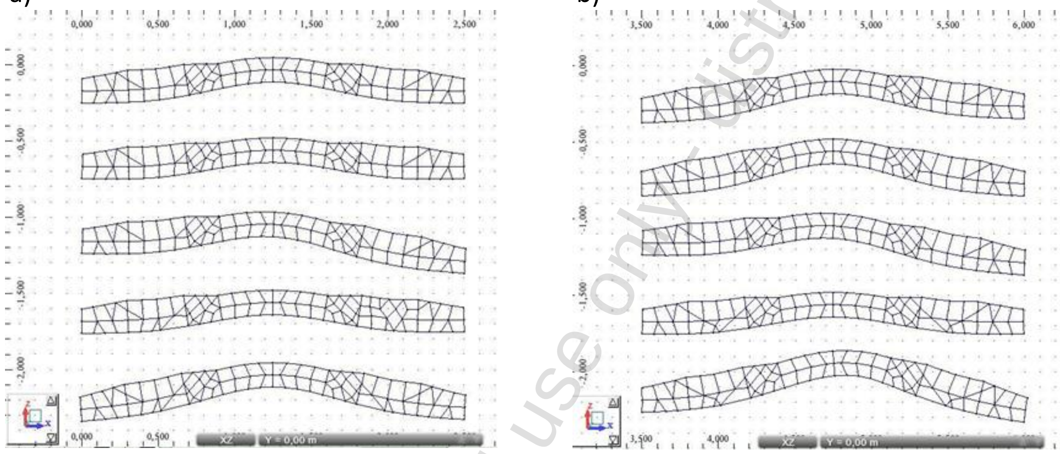

Fig. 4. *a, b*. the state of strain of the pre-stressed concrete models PS-83:
a – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*

a) b)

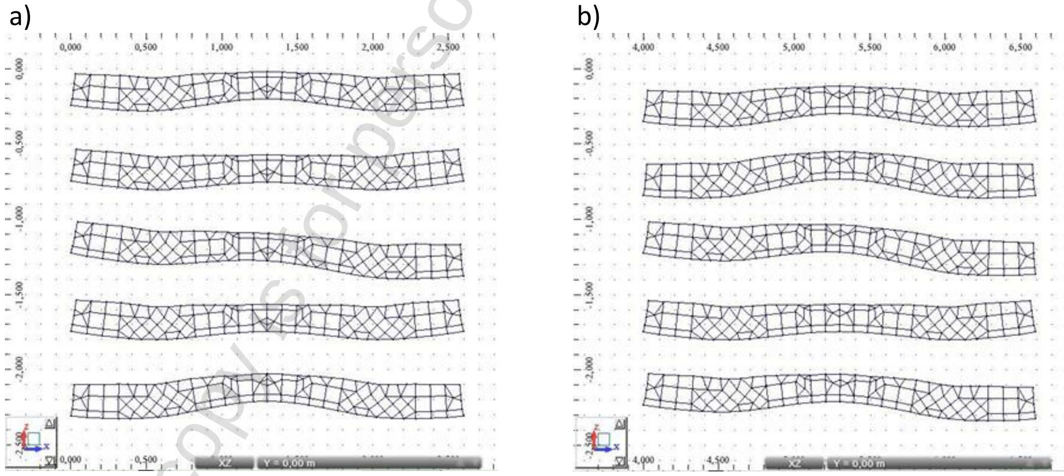

Fig. 5. *a, b*. the state of strain of the pre-stressed concrete models PS-94:
a – models *A, C, E, G, I*; *b* – models *B, D, F, H, J*

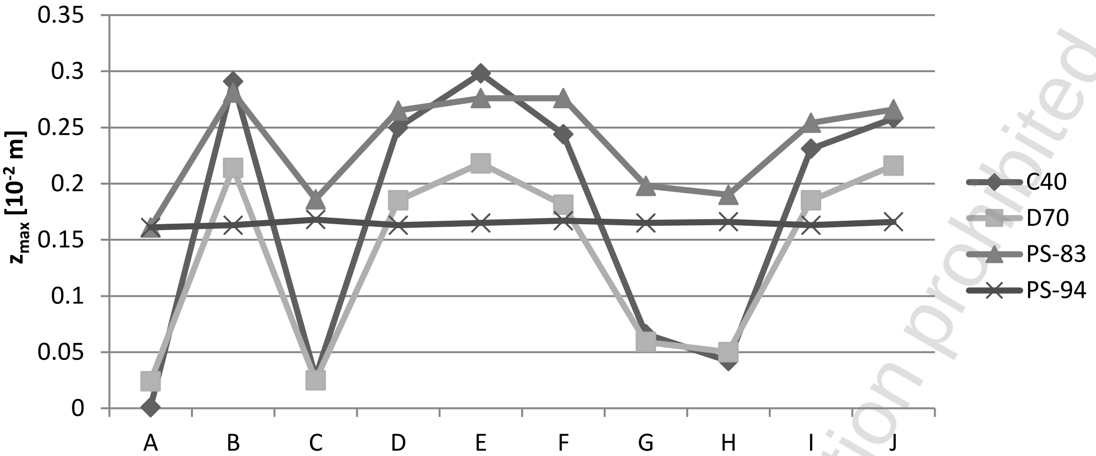

Fig.6. The maximum displacement z_{max} [10^{-2} m] of measurement points in the models of sleepers, for the subgrade diagrams: *A, B, C, D, E, F, G, H, I, J*

CONCLUSIONS

Models A, C, H were rated as the most advantageous, due to the sleeper displacement values. In these models, the maximum subgrade density occurs in the zone below the applied load.

The most adverse schemes of the ballast density under the sleepers are models:

- B, D, I, in which the degree of the ballast density in the areas under the rails is below 1.0;
- E, F, J, which are characterized by the asymmetry of the ballast density zones with regard to the vertical symmetry axis of the sleeper.

The lowest values of displacement were recorded in the sleepers C40 (soft wood), in the case of the homogeneous density of the maximum value of I_S = 1.0 along the sleeper (diagram A). However, in this type of sleeper there were found the highest values of displacements for the model *E*, which is characterized by asymmetrical distribution of the ballast density zones.

The displacement values of the sleeper C40 indicate generating the highest amplitude of displacements. This type of sleeper does not work fully stably under varying conditions of the subgrade density, which may occur throughout the process of operation.

Due to the fact that the sleeper D70 is made of higher quality wood (oak) it demonstrates more stable operation under varying conditions of support compared to the sleeper C40 (pine wood). The displacement values and the amplitude were significantly reduced in the first sleeper.

Pre-stressed concrete sleepers PS – 83 (produced in the 1980s) have the much lower amplitude of displacements compared to the amplitude of wooden sleepers. It proves good-quality functioning in the process of operation. However, the displacement values are quite high and they are at the same level as the displacement values, which were present in the most negatively assessed C40 wooden sleepers.

The lowest amplitude of displacement values was observed in pre-stressed concrete sleepers PS-94. This sleeper remains fully stable (Fig. 7) in all tested subgrade density schemes: symmetrical, i.e. desired; asymmetrical or demonstrating the-low density ratio in the zone below the applied load.

The sleeper PS – 94, the new-generation product, owing to favorable operational characteristics, constitutes a stable element of a railway track and is recommended for installation in main railway lines, where vehicles with axial pressures of 221 kN and the speed of over 160 km / h are introduced.

The results of the examination of displacement values and amplitudes regarding pre-stressed concrete PS – 83 and the new generation sleeper PS – 94 (higher class of concrete and different compressing system in comparison with the previous sleeper) lead to the conclusion that the evolution of pre-stressed concrete elements of the railway surface is going in the right direction.

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BIOGRAPHICAL NOTES

Andrzej SUROWIECKI, DSc, Eng. – the graduate of the University of Technology in Wroclaw, the Faculty of Civil Engineering. Currently, he is the professor at the Faculty of Civil Safety Engineering at the Military Academy of Land Forces. Scientific interests: mechanics of surface and subgrade, roads and railways, as well as design of communication earthen structures in terms of operational reliability.

MAJ Piotr SASKA , DSc, Eng. – the author of over 50 scientific publications on broadly understood military engineering. His main area of interest is the impact of an explosion on the environment, including military vehicles, and problems associated with transport infrastructure engineering, in particular the construction of roads and railways.

Marcin WASIAK – the graduate of transport infrastructure engineering at the University of Life Sciences. His main area of scientific interests is the modernization of the communication systems within urban areas.

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