ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1137043

NUMERICAL ANALYSIS OF LOAD DISTRIBUTION IN RAILWAY TRACK UNDER WHEELSET

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Abstract

The results of numerical analysis of a load distribution in a railway track under wheelset are presented in the paper. Dynamic analysis was carried out using LS-DYNA computer code. Ballasted track with the rectilinear rail-line axis was taken into consideration. Finite element model of the track section was developed. The model included two rails, fastening systems, sleepers, ballast and the embankment. Fasteners and the ballast layer were modelled using 1-D massless discrete elements – springs and dampers. Sleepers were modelled as elastic beams. The embankment was reflected approximately by a rectangular prism with unmovable side and bottom boundary surfaces. Moving load was applied using simplified FE models of railway vehicles. Vertical forces were put in the wheel – rail contact points. Two types of the vehicles, and loads consequently, were considered – the first one including two single wheelsets whereas the second one was equipped with two classic 2-axle bogies. RAIL_TRACK and RAIL_TRAIN LS-DYNA's modules were applied for simulating the vehicle – track interaction. Displacements of selected nodes as well as other characteristic values were registered during the numerical simulation. Contours of stress and displacements for selected moment of time were also presented as a result of the FE analysis. The study gave information about the behaviour of the railway track and foundation under load caused by single axle and 2-axle bogie. Obtained results were compared to those available in the literature and the technical instructions of railway design.

Keywords: *railway rack, wheelset, bogie, moving load, numerical analysis*

1. Introduction

Durability of the track superstructure elements depends mainly on the relative deformation and mutual displacements. Degradation and destruction of rail joints, fastening systems and the ballast is strictly related with the rails bending. Modern rail fastening systems consist of several components made of different materials to ensure optimal operating conditions for a railway superstructure and to reduce above mentioned disadvantages. Moreover, they reduce the dynamic effect of the rolling railway vehicle on the concrete sleeper and ensure the load distribution along successive sleepers. Therefore, the sleeper under loading supports only a part of the total axle load.

For ages, railway engineers – e.g. Awoleye [1] – have been accustomed to the assumption that the sleeper directly below the wheelset supports 50% of the axle load and each of the neighbouring sleepers supports another 25%, see Fig 1a. Later on, stress measurements and FE analyses have shown that load distribution along successive sleepers is slightly different. Values suggested by Watanabe [2] are depicted in (Fig. 1b). Similar values can be found in Technical Instructions, e.g. [2] (Fig. 1c).

The aim of this study was to simulate the test rail track subjected to moving load and to verify above-mentioned values of the load distribution. In addition, 2-axle bogie was considered instead of single axle case taken into account in [1–3]. Displacements of selected nodes of the FE model as well as other characteristic values were registered during the numerical simulation. Moreover, contours of stress and displacements for selected moment of time were also presented as a result of the FE analysis. The study gave information about the behaviour of the considered railway track under load caused by a single axle and 2-axle bogie.

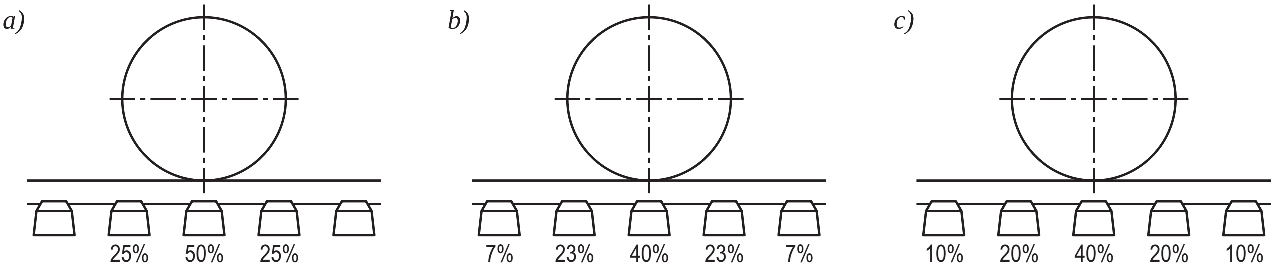

Fig. 1. Load distribution along successive sleepers: suggested by Awoleye (a), Watanabe (b), and the US Army Corps of Engineers (c) [1–3]

2. Dynamic FE analysis

Dynamic FE analysis was performed in LS-DYNA computer code and it was focused on the load distribution along successive sleepers. Numerical model of the test track (Fig. 2) included [4]:

- *rails* – two parallel sets of beam elements. Rails were considered as prismatic beams deformable in flexure and shear, made of linearly viscoelastic material;
- *fastening system* – simulated using massless 1-D discrete non-linear spring and damper elements vertically oriented;
- *sleepers* – placed with spacing of 0.6 m, modelled as elastic beams vibrating only vertically using beam finite elements and respective constraints;
- *ballast* – reflected by a set of vertical nonlinear spring and damper elements;
- *sand-gravel mix layer* and *subsoil embankment* – modelled as a linearly viscoelastic material continuum.

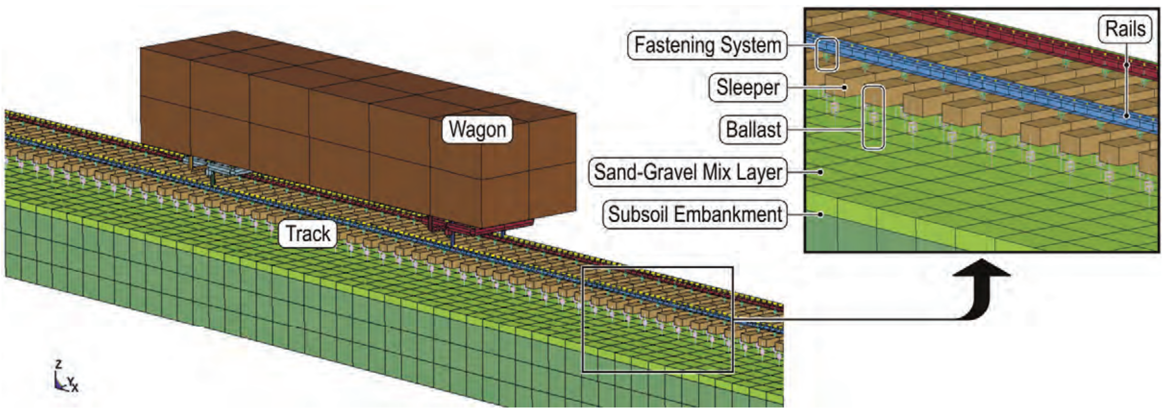

Fig. 2. FE model of the test track and wagon used in LS-DYNA dynamic analysis [4]

All necessary parameters of the track FE model are provided in Tab. 1. Data were taken from Authors' previous studies and they are based on values available in Ref. [5–8].

RAIL_TRACK and RAIL_TRAIN modules available in LS-DYNA [9] were applied for approximate modelling the vehicle – track interaction (without simulation of wheels' rotation). Simplified models of the wagon equipped with two single wheelsets and two classic 2-axle bogies were developed. Schemes of the considered railway vehicles are presented in Fig. 2.

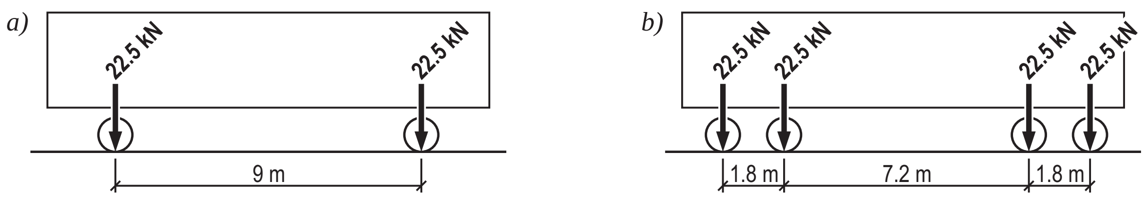

Fig. 3. Schemes of the considered wagons equipped with two single axles (a) and two 2-axle bogies (b)

Tab. 1. Values of the geometrical and mechanical parameters of the ballasted track components [4–7]. Values provided in one of the consistent set of units recommended in LS-DYNA [8]

Component	Parameter, Symbol, Unit	Value
Rail	principal geometric moment of inertia, I_y (mm^4)	$30.383 \cdot 10^6$
	cross-section area, A (mm^2)	7,670
	mass density, ρ (Mg/mm^3)	$7.85 \cdot 10^{-9}$
	Young's modulus, E (MPa)	210,000
	Poisson's ratio, ν (–)	0.30
Fastening system	static stiffness at compressing for load 0–18 kN, k_{f1} (N/mm)	17,000
	static stiffness at compressing (for load 18–53 kN), k_{f2} (N/mm)	30,000
	static stiffness at stretching for load < 0, k_{f3} (N/mm)	3,000
	equivalent viscous damping coefficient, c_f (N s/mm)	2.5
Sleeper	mass (including fasteners), m_s (Mg)	0.366
Ballast	mass density, ρ (Mg/mm^3)	$2.00 \cdot 10^{-9}$
	summer-time static stiffness at compressing, k_{bs} (N/mm)	60 000
	summer-time static stiffness at breaking away, k_{bs0} (N/mm)	0
	equivalent viscous damping coefficient, c_{bs} (N s/mm)	14.0
Sand-gravel mix layer	mass density, ρ (Mg/mm^3)	$1.90 \cdot 10^{-9}$
	Young's modulus, E (MPa)	150
	Poisson's ratio, ν (–)	0.20
Subsoil embankment	mass density, ρ (Mg/mm^3)	$1.80 \cdot 10^{-9}$
	Young's modulus, E (MPa)	82
	Poisson's ratio, ν (–)	0.20

The maximum permissible static axle load – 22.5 kN – was taken into account. The wagon was moving at the speed of 10 m/s (36 km/h). Axle spacing and bogie wheelbase as well as the travel speed corresponded to dimension of the track FE model especially to the sleeper spacing which was equal to 0.6 m. Such approach ensure that each wheelset was located exactly above the one sleeper for considered moment of time.

3. Results of the FE analysis

Total deflection of the track along successive sleepers are depicted in Fig. 4. Figure shows differences between load caused by single axle and 2-axle bogie. Rail deflection below the wheelset is equal to 2.37 mm (1-axle case) and 2.53 mm (2-axle case). Maximum rail deflection in 2-axle case (about 2.59 mm) occurs between sleepers.

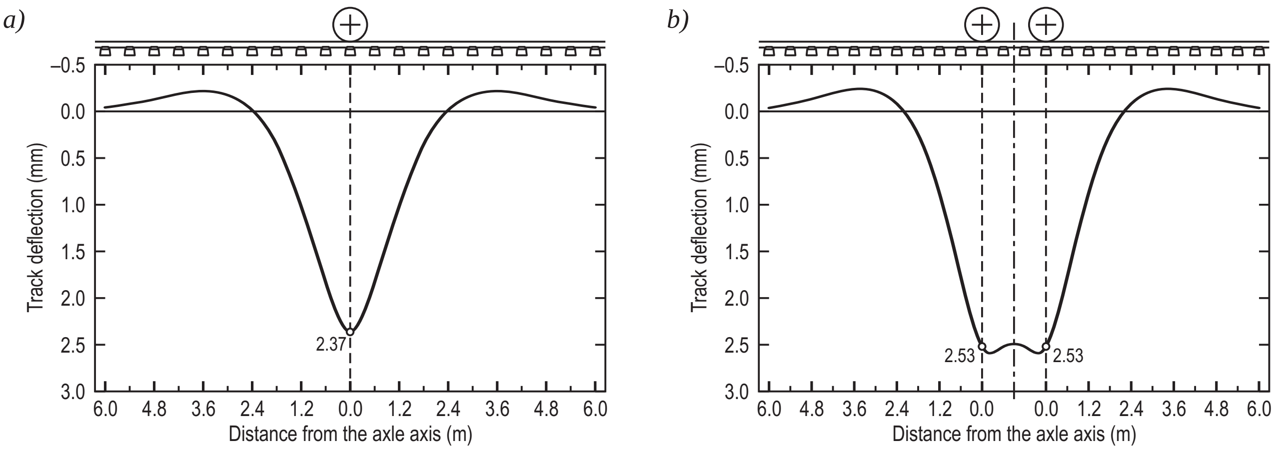

Fig. 4. Total deflection of the track along successive sleepers under single axle (a) and 2-axle bogie (b)

Total deflection of the track is a sum of deflection of the embankment, ballast and the fastening system. FE analysis allowed to separate and predict the deflection of each component (Fig. 5). It can be seen that deflection in the fastening system is dominant, whereas the lowest values were recorded for the ballast. It is worth to mention that obtained results are true for considered values of the track parameters (provided in Tab. 1) and cannot be generalized.

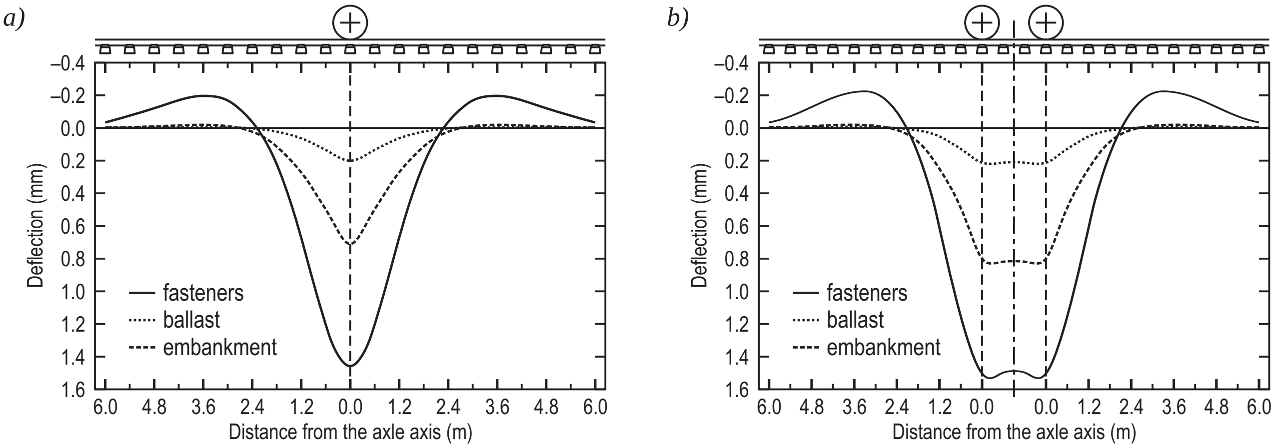

Fig. 5. Components of the track deflection along successive sleepers under single axle (a) and 2-axle bogie (b)

Figure 6 presents the load distribution along successive sleepers for both considered cases. Obtained results are slightly different from those recommended in literature [1–3]. For the first case, the sleeper located directly below the wheelset supports about 32% of the axle load, whereas the rest is supported by three sleepers on either side – 21%, 10% and 3%, respectively. The load/unload distributed on the remaining sleepers – the 4th and subsequent – can be omitted.

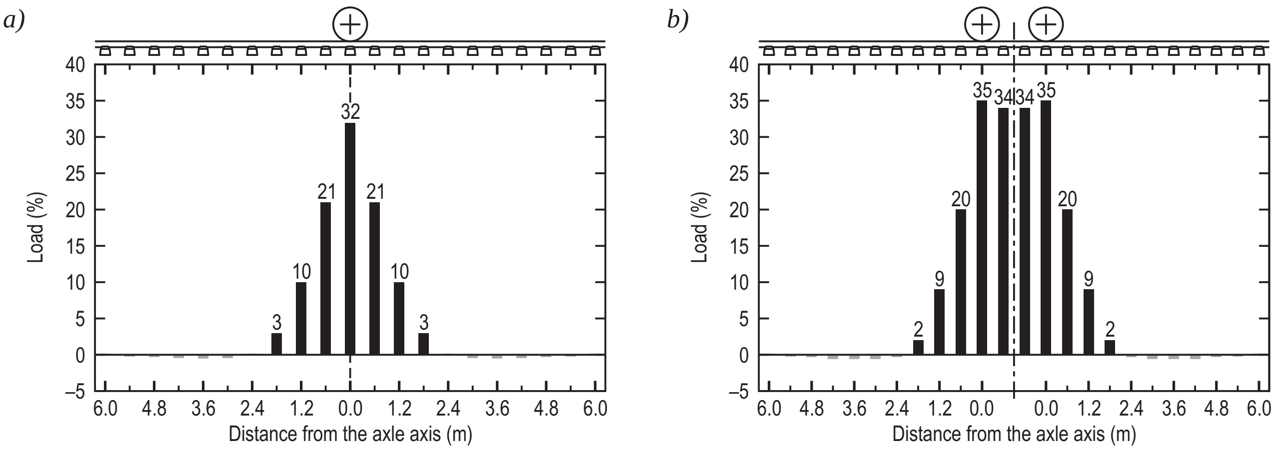

Fig. 6. Distribution of the load along successive sleepers under single axle (a) and 2-axle bogie (b)

For the second case, the sleeper directly below the each wheelset supports about 35% of the axle load and the rest is supported by three sleepers on one side – 20%, 9% and 2%, respectively. Sleeper between axles supports about 34% of the load.

Contours of the resultant displacement in the track under considered types of load are presented in Fig. 7. Obtained data correspond to those depicted in Fig. 4. Scale factor (100×) for displacements was applied, therefore deflections of the track components are noticeable. Contours of the equivalent von Mises stress in the embankment under considered types of load are shown in Fig. 8. Higher values are observed for the 2-axle bogie, however values obtained for the single axle load show a local stress concentration under the sleeper directly below the axle load. Therefore, the influence of the single axle load is more damaging for the track component than the 2-axle bogie case.

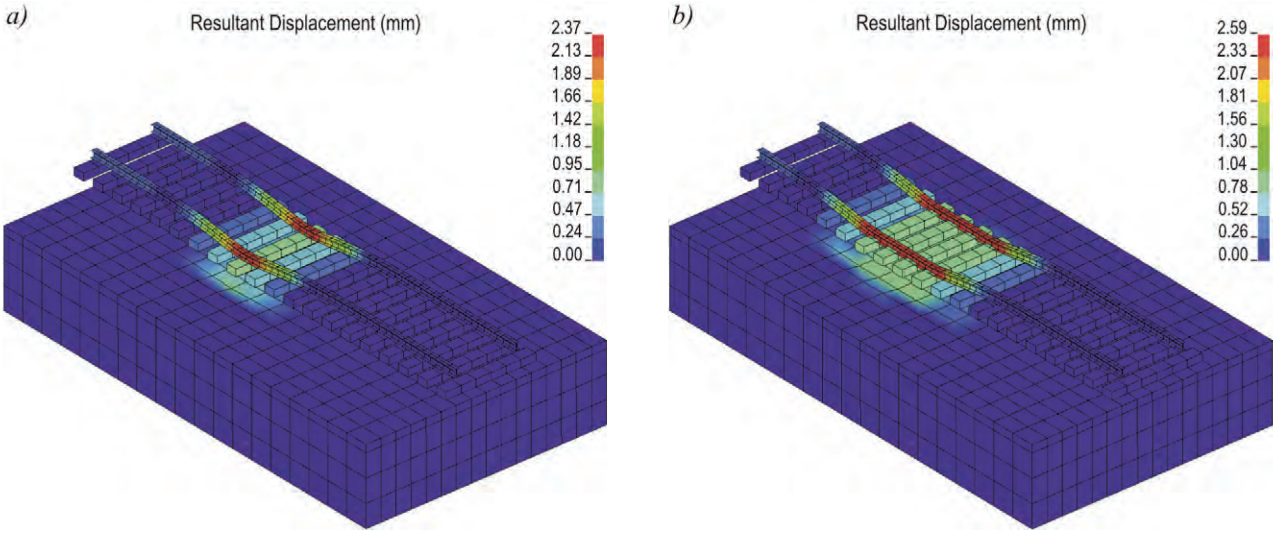

Fig. 7. Contours of the resultant displacement in the track under single axle (a) and 2-axle bogie (b)

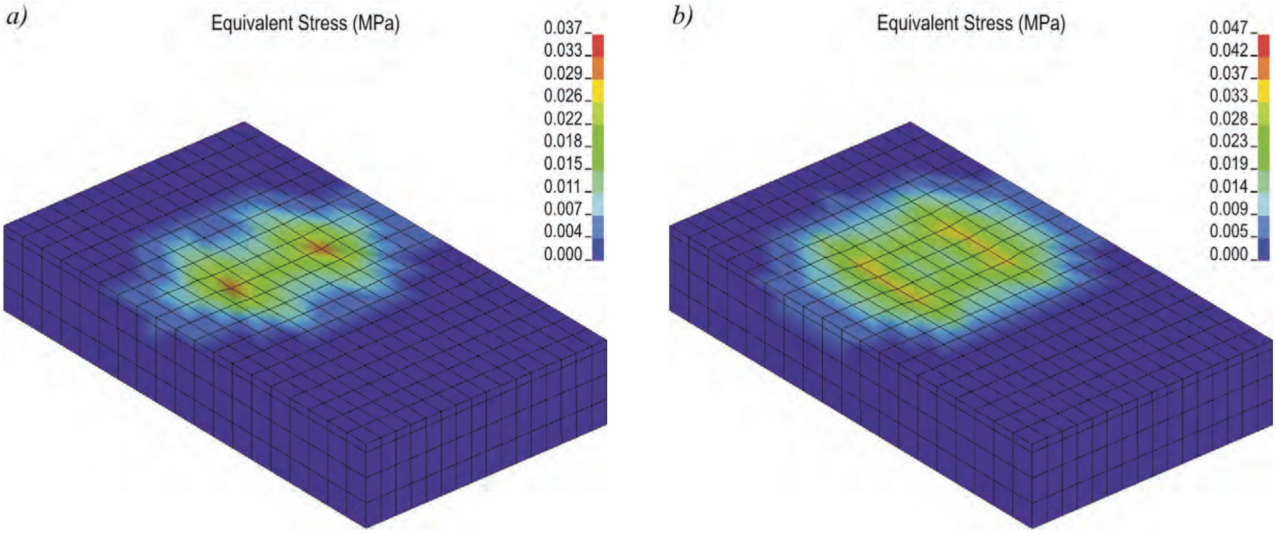

Fig. 8. Contours of the equivalent stress in the embankment under single axle (a) and 2-axle bogie (b)

Results of the FE analysis gave also information about the state of stress in the rail. Contours of the equivalent stress for the rails are shown in Fig. 9. Values obtained for the wheel – rail contact points directly under the wheelset are about 25–30% higher for the single axle load in comparison to the classic 2-axle bogie load. It is confirmed again that less damaging influence on the rail track components is coming from the 2-axles loads.

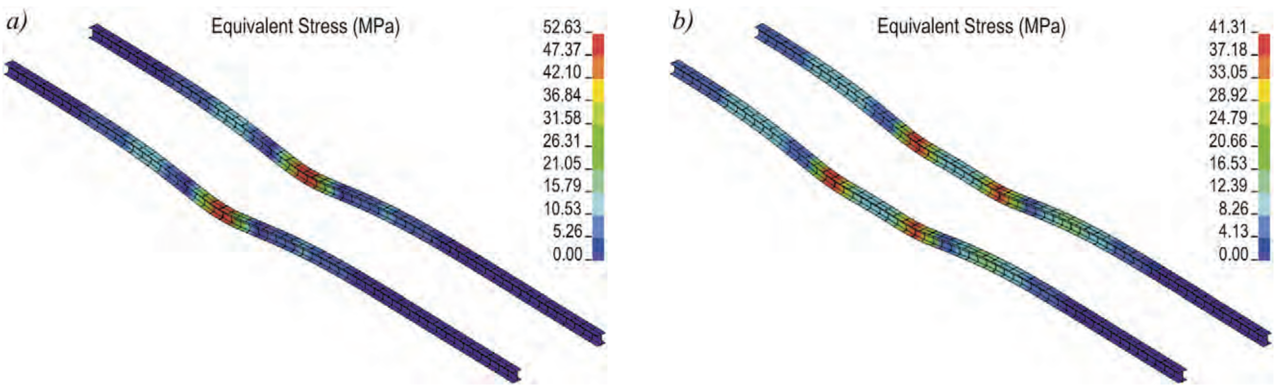

Fig. 9. Contours of the equivalent stress in rails under single axle (a) and 2-axle bogie (b)

Conclusions

The paper presents results of numerical analysis of a load distribution in a railway track under wheelset. Obtained results are similar to those recommended in literature [1-3], however a slight difference in values and the character of the load distribution is observed. The sleeper located directly below the wheelset supports the maximum part of the load obviously. But the rest is distributed along three neighbouring sleepers on either side instead of two sleepers suggested in [2, 3]. However, the results are true for the track under consideration and cannot be generalized.

The state of stress in selected components of the rail track presented in the paper confirmed that less damaging influence is coming from the 2-axles loads than from the single axle. Moreover, a local stress concentrations in the embankment under the sleeper directly below the wheelset are observed for the single axle case.

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