CETRA[2018]

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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CETRA[2018]
5th International Conference on Road and Rail Infrastructure
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TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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VIBRATIONAL ACCELERATION DISTRIBUTION IN RAILWAY BALLAST IN TERMS OF HEAVY AXLE LOAD OPERATION

Anastasia Konon
Emperor Alexander I St. Petersburg State Transport University

Abstract

Railway track stability depends not only on the subgrade sustainability, but also on the quality of ballast itself. Ballast bearing capacity depends on limit stress state of ballast layer and subgrade, characterized by limit stress in ballast under sleeper. Ballast bearing capacity in terms of rolling stock vibrational dynamic impact is evaluated using limit equilibrium theory. This theory incorporates inertial forces, generated in soil media by vibrational dynamic impact. Inertial forces depend on vibrational accelerations of soil particles. This paper presents the results of railway ballast field tests. Tests were aimed to study vibrational acceleration (VA) of ballast particles in terms of train traffic with heavy axle loads. Tests were held at Russian Railway Research Institute experimental track. A set of RA 021 accelerometers were put into ballast layer at two levels: 10 and 55 cm below the sleeper. The test results are vibrational acceleration distribution in ballast layer and experimental relationships of vertical and horizontal vibrational accelerations damping in terms of train operation with axle load up to 294 kN. Increasing of rolling stock axly loads leads to rise of vibrational dynamic impact on railway track. Axle load growth from 225 to 294 kN provides increased vibrational acceleration under the sleeper. Maximal values of vertical vibrational accelerations are registered at the underrail section. Maximal values of horizontal VA are registered at the section near the center line. Stated test results provide references for calculation of ballast and subballast bearing capacity.

Keywords: ballast, vibrational acceleration, vertical stress, heavy axle load

1 Introduction

One of Russian railway transport development area is car axle load increasing. JSC “Russian Railways” acquires cars with axle loads up to 250 kN per axle. New car types with axle loads up to 270 kN per axle are developed. This course sets the task of track stable performance under the increased train dynamic load. Worldwide operating experience and in-situ tests [1] show that increasing axle load and train speed induce growth of defect amount in ballast, subballast and subgrade [2].

Railway track stability depends not only on the subgrade sustainability and quality of ties, fastenings and rails, but also on the quality of all subballast elements and the ballast itself. The main cause of ballast reliable performance is its bearing capacity. It depends from the level of vibrational dynamic load applied to ballast layer [3] and subballast characteristics. Ballast layer bearing capacity and deformability depend on ballast cohesion and friction angle, moduli of deformation and elasticity. These characteristics depend on vibrodynamic load level under the sleeper pad, ballast granulometric composition, fouling, density, roundness, subsleeper damper existence and its stiffness and so on. Values of these characteristics and their change according tonnage accumulation allow to predict ballast bearing capacity, deformability and overhaul life.

Imparting force impulse from a rolling stock wheel to rail tread surface causes similar impulses imposed to sleeper, ballast and subgrade and causes oscillation of track structure and rolling stock. Ballast and subballast oscillations are polyharmonic waves, spreading into ballast, sudgrade and beyond. Previous research [4, 5, 6] showed that superstructure and subgrade oscillations are stochastic. Oscillation parameters are due to various factors (rolling stock axle load and speed, track superstructure deterioration, strength and deformation properties of subgrade soil and many more) and can be predicted using statistics and probability theory methods. The most reliable values of rolling stock vibrational impact to railway track should be obtained from in-situ tests on operating railway lines. Ballast bearing capacity depends on limit stress state of ballast layer and subgrade, characterized by limit stress in ballast under sleeper. Ballast bearing capacity in terms of rolling stock vibrational dynamic impact is evaluated using limit equilibrium theory [7, 8]. This theory incorporates equations of soil media motion. The stated equations include following components: $\rho\frac{\partial^2 U}{\partial t^2}$ and $\rho\frac{\partial^2 V}{\partial t^2}$, where $\rho = \gamma/g$ – soil density, g – free fall acceleration, 9,81 m/s^2; U, V – oscillation displacement along Z and Y axes respectively. Components $\rho\frac{\partial^2 U}{\partial t^2}$ and $\rho\frac{\partial^2 V}{\partial t^2}$ are inertial forces, generated in soil media by vibrational dynamic impact. Derivatives $\frac{\partial^2 U}{\partial t^2}$ and $\frac{\partial^2 V}{\partial t^2}$ describe soil particles vibrational accelerations. This fact determined the oscillation parameter to test.

2 Materials and methods

Emperor Alexander I St. Petersburg State Transport University (PGUPS) researchers held in-situ tests of vertical and horizontal vibrational accelerations (VA) of ballast particles. Rolling stock on the site had axle loads from 225 to 294 kN and 70 kmph speed. Tests were held at Russian Railway Research Institute experimental track. Track structure on the site was the following: 65 kg/m rails, concrete sleepers (2000 items/km), tension clamp fastenings ARS-4, thickness of granite ballast was 55 cm under the sleeper. Ballast consisted of 25-60 mm particles. VA were measured with RA 021 accelerometers. These sensors provide measuring of accelerations up to 200 m/s^2 and frequency 5 – 5000 Hz. Accelerometers were connected to seismic station ZET 048. Sensors were put under the sleeper and in the ballast layer. Along the sleeper sensors were set at the sleeper end, at underrail section, and near centre line of a track and 55 cm below the sleeper (at the sleeper and). Sensors placement in ballast layer is shown in Fig. 1.

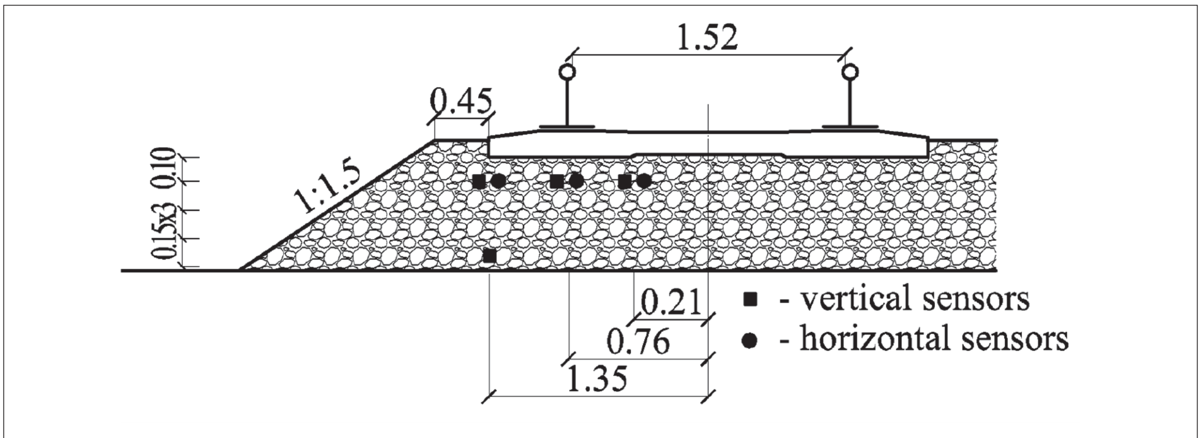

Figure 1 Sensors placement in ballast layer (all measurements in metres)

3 Results and discussion

Vertical VA distribution charts at level of 10 and 55 cm under the sleeper are shown in Fig. 2-3.

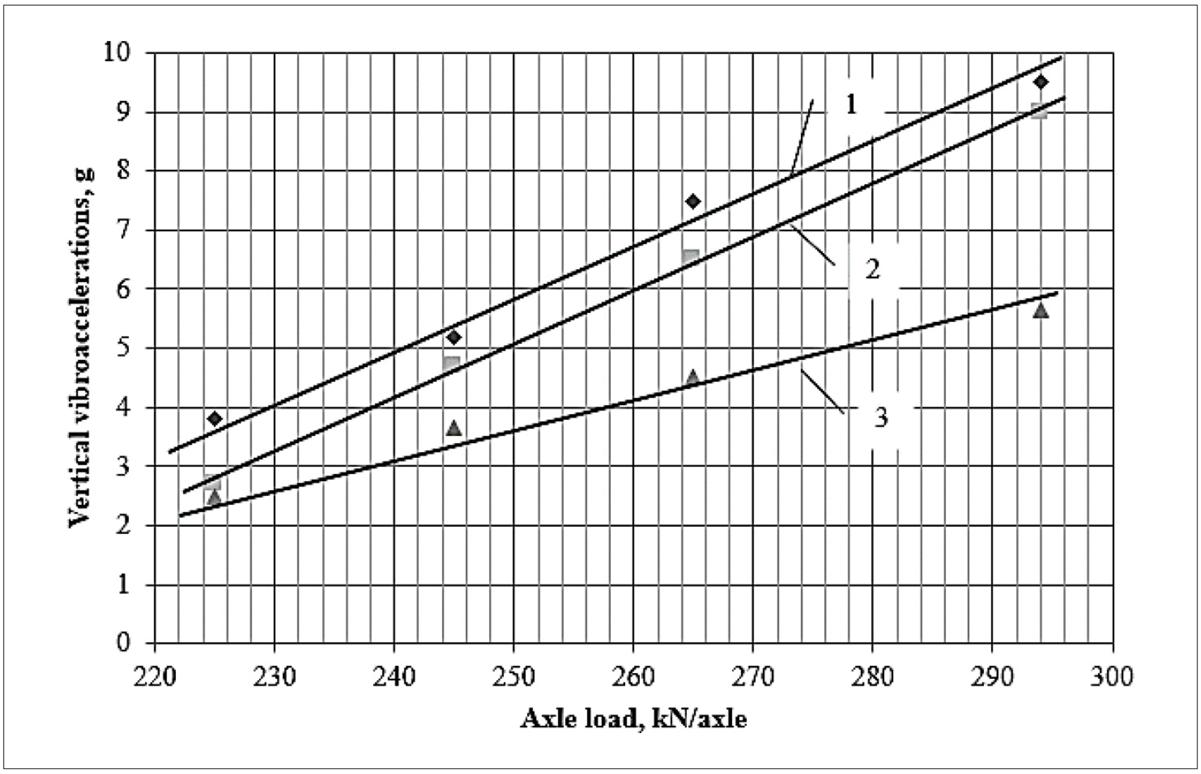

Figure 2 Vertical vibrational acceleration distribution at the level of 10 cm under the sleeper: 1 – at underrail section, 2 – near center line of a track, 3 – at the sleeper end

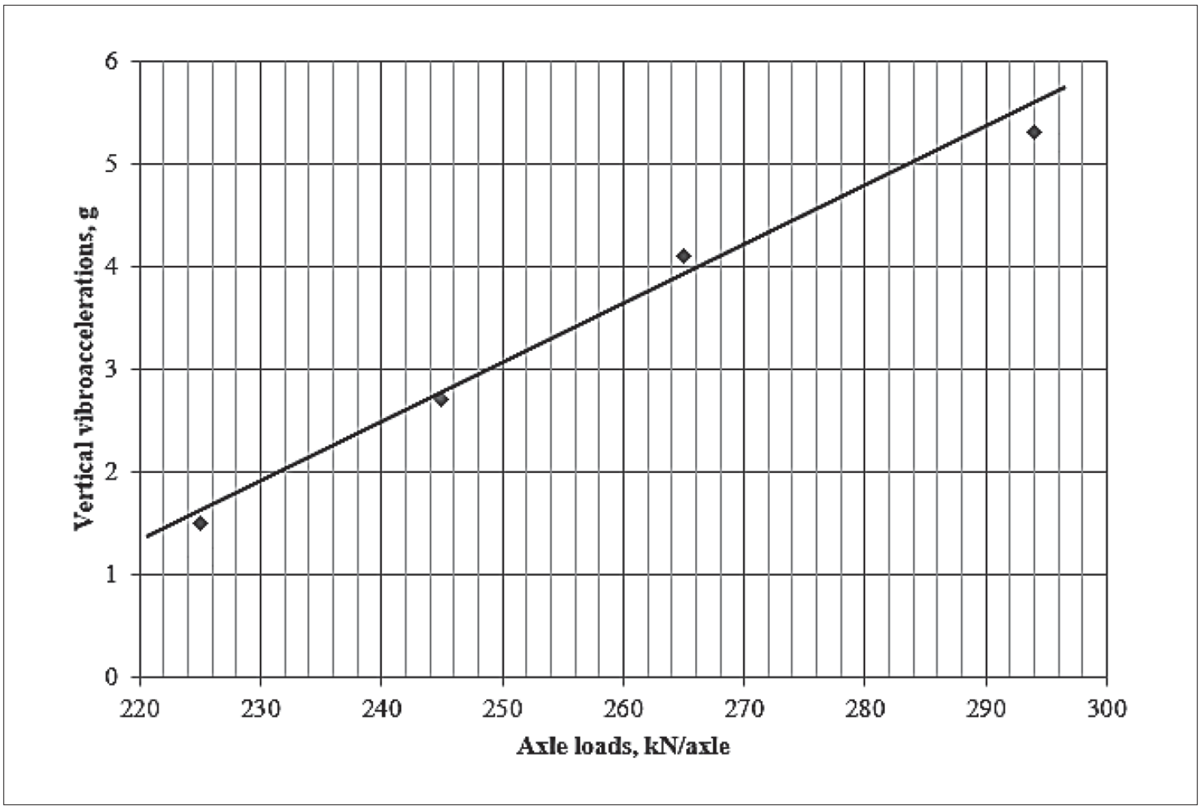

Figure 3 Vertical vibrational acceleration distribution at the level of 55 cm at the sleeper end

Increasing of rolling stock axle loads from 225 to 294 kN/axle causes growth of vertical VA. Maximal values of VA are recorded at the underrail section, reaching from 3.8g to 9.5g and growing for 2.5 times. At the sleeper end vertical VA are about 15 % lower, than at the underrail section and amount from 2,7g to 9g for 225-294 kN axle load at depth of 10 cm under sleeper. At the section near center line of the track vertical VA have the lowest values, which change from 2,5g to 5,7g. Horizontal vibrational acceleration distribution at level of 10 cm under the sleeper is shown in Fig. 4.
Horizontal VA distribution varies from the one for vertical VA. As shown in Fig.4, maximal values of VA are registered at the section near center line of a track. They reach from 8,1g to13,3g for car axle loads from 225 to 294 kN respectively. Minimal horizontal VA are recorded at the sleeper end. They amount from 3,5g to 7g. VA at underrail section are 10 % higher than at the sleeper end and reach from 3,7g to 7,5g for car axle loads from 225 to 294 kN respectively.

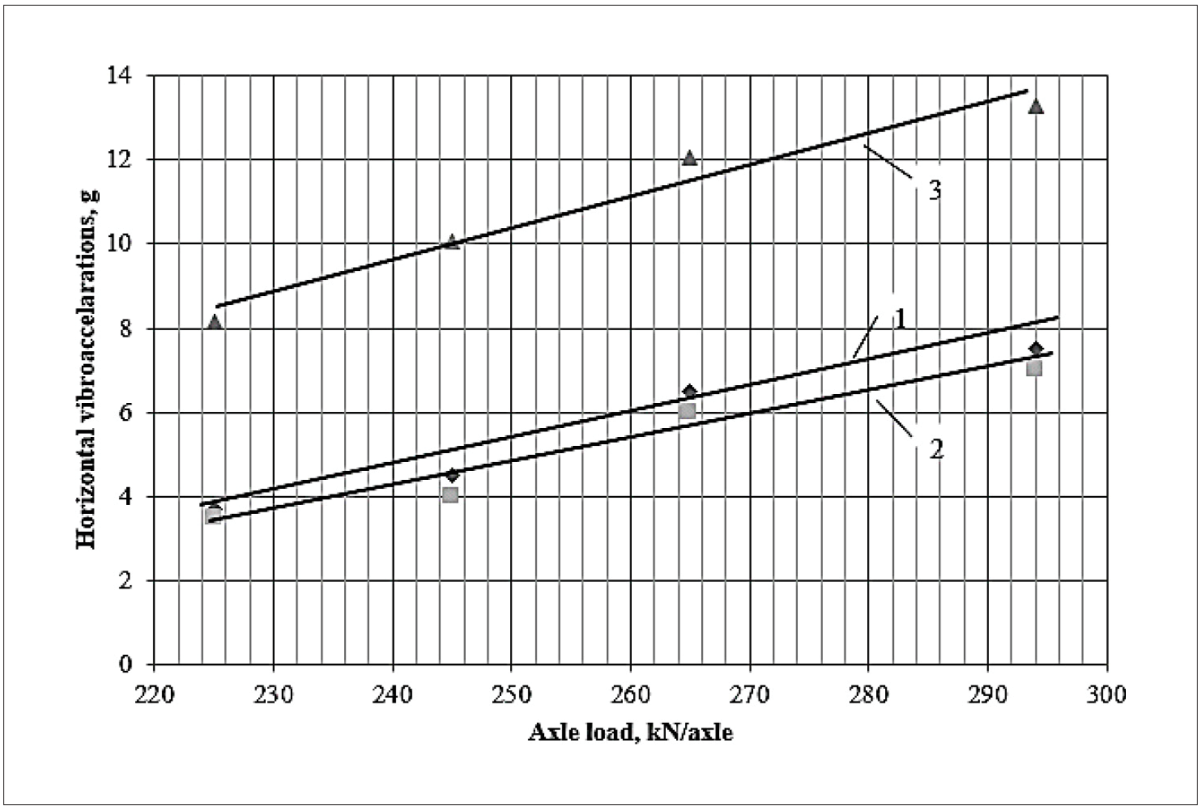

Figure 4 Horizontal vibrational acceleration distribution at the level of 10 cm under the sleeper: 1 – at underrail section, 2 – at the sleeper end, 3 – near center line of a track

Obtained data was represented in analytical form for further use in calculations. Oscillation distribution can be described using damping factors in vertical and horizontal plane. Damping factors were determined as vibrational acceleration value ration to vibrational acceleration under the sleeper. Damping factors as a function of point coordinates were plotted in semilogarithmic frame. Resulting curves were described with following equations:

$$\frac{d^2U}{dt^2} = g_0^v \cdot \exp(-\delta_z^v \cdot z - \delta_y^v \cdot y) \tag{1}$$

$$\frac{d^2V}{dt^2} = g_0^h \cdot \exp\left(-\delta_z^h \cdot z + \delta_y^h \cdot y\right) \tag{2}$$

4 Conclusions and implications

Increasing of rolling stock axly loads leads to rise of vibrational dynamic impact on railway track. Axle load growth from 225 to 294 kN provides increased vibrational acceleration under the sleeper. Vertical VA grow from 3,8g to 9,5g or 2,5 times in terms of axle load increasing from 225 to 294 kN. Horizontal VA enlarge from 3,7g to 7,5g or 2,02 times respectively.

Maximal values of vertical VA are registered at the underrail section. They change from 3,8g to 9,5g for axle loads 225-294 kN. Vertical VA are about 15 % lower at the sleeper end than at the underrail section. Vertical VA at the sleeper end amount from 2,7g to 9g at the level of 10 cm below the sleeper. Section near the center line has the lowest vertical VA values.

Maximal values of horizontal VA are registered at the section near the center line. Horizontal VA in this section are 8,1g for 225 kN axle load and 13,3g for 294 kN axle load. Horizontal VA decrease in the direction of the sleeper end. There are intermediate values registered at the underrail section. Section at the sleeper end has minimal horizontal VA values.

At the level of 55 cm below the sleeper end vertical VA change from 1,5g to 5,3g in terms of axle loads increasing from 225 to 294 kN.

Vertical and horizontal VA distribution in ballast can be described with Eqs. (1) and (2). These equations determine inertial forces, generated in soil media by vibrational dynamic impact. Eqs. (1) and (2) are used in calculations of ballast bearing capacity in terms of rolling stock vibrational dynamic impact [9].

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