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TRAIN-INDUCED VIBRATIONS: MOVING LOAD MODELING

SUMMARY

In this paper numerical modeling of train induced vibration is presented. The wheel force is modeled with assumption that only static component with constant load shape and constant velocity exists. The dynamic and inertial part of loading is neglected. The dynamic response, caused by the calculated moving forces of train “Beovoz”, in the selected points of existing structures at railway station “Belgrade-Center” in Prokop are obtained using the Finite element analysis in the Frequency domain and the Thin layer method. Some of the results are presented.

Key words: Moving load modeling, Thin layer method, frequency domain, SSI

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УПАТСТВА ЗА ПОДГОТОВКА НА ТРУДОТ

РЕЗИМЕ

Клучни зборови: Максимум еден ред

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1. INTRODUCTION

One of the main environmental pollutions today is traffic induced vibrations, which is increasingly being considered as a nuisance. Traffic induced vibrations often occur around the most busy areas of the city, day and night, and thus have the long-term influence on the residents or people working there, and can hardly be avoided. The numerical modeling of train induced vibration consists of 3 main parts:

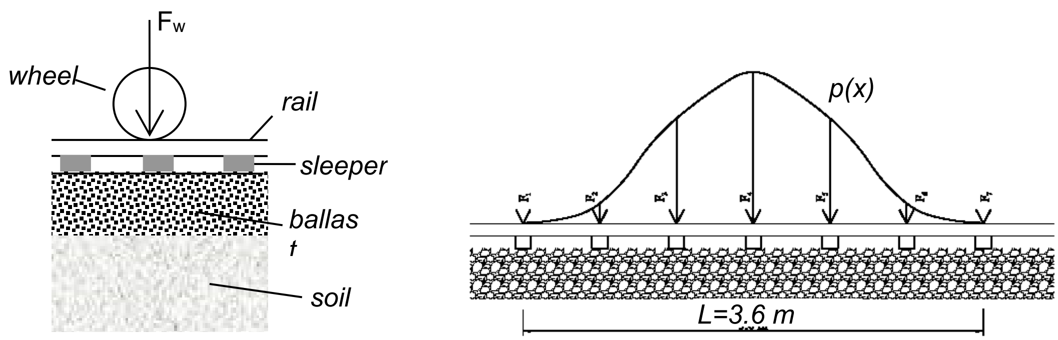
- modeling of a moving load,
- response in the soil domain caused by the passage of a vehicle,
- dynamic response of structure due to free field motion.

In this paper a numerical model for moving load produced by the four cars of “Beovoz” train is presented and dynamic response of the platform of the railway station "Belgrade-Center" and surrounding soil is calculated using the Thin layer method and program SASSI [4]**Error! Reference source not found.**.

2. NUMERICAL MODEL OF A MOVING LOAD

2.1 Wheel force

Numerical simulation of a moving wheel is complex problem due to the interaction between wheel, rail, sleeper, ballast and surrounding soil, *Fig. 1a*. Vertical wheel force consists of static and dynamic components. Static component arises from the weight pressure of the wheel, while dynamic one originates from rail roughness, wheel irregularities and so on. There are a lot of different proposals for modeling of the wheel force in literature [3], [5]. In this paper simple model, concerning only static component with constant load shape and constant velocity is assumed, *Fig. 1b*.



a) *b)*

Fig. 1

The loading function *p(x)* is expressed as:

$$p(x) = p_o \cdot \left[\frac{\sin\left(\frac{2\pi x}{L}\right)}{\frac{2\pi x}{L}} \right]^2 \tag{1}$$

In Eq. (1) *L =3.6 m* is the length of the wheel load transferred to the rail *Fig. 1b* and p_o is the amplitude of wheel force.

$$p_o = \frac{F_w}{A} \tag{2}$$

In Eq. (2) F_w is the wheel force and A is the area under the curve p(x*)* divided by p_o*:*

$$A = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{p(x)}{p_o} = \int_{-\frac{L}{2}}^{\frac{L}{2}} \left[\frac{\sin \frac{2\pi x}{L}}{\frac{2\pi x}{L}} \right]^2 dx \tag{3}$$

The forces F_i acting on each sleeper can be obtained integrating the function p(x) along the belonging distance. The distance between sleepers is 0.60 m, so the integration is performed from -0.30 m to +0.30 m with reference to each sleeper axis:

$$F_i = \int_{x_i - 0.30}^{x_i + 0.30} p(x)\, dx \qquad \text{i=1,...4} \tag{4}$$

For the Beovoz, *Fig 2*, the wheel force is F_w =75 kN. After integration of Eq. (4) the following forces accting uppon sleepers are obtained (see *Fig. 1*b):

$$F_1 = F_7 = 0.159, \quad F_2 = F_6 = 5.20, \quad F_3 = F_5 = 18.70, \quad F_4 = 26.87 \tag{5}$$

2.2 Moving load

The moving load is calculated for the train “Beovoz” consisting of four cars, *Fig. 2*. Each car has two pair of forces F=150 kN, moving with train speed v=50 km/h. Moving load caused by chosen trains, can be easily obtained since the two parameters, constant load shape and the variable *x*, are related by the constant load speed.

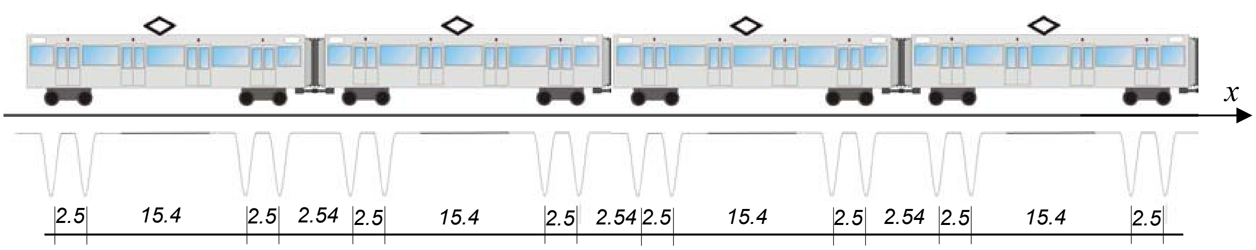


Fig. 2

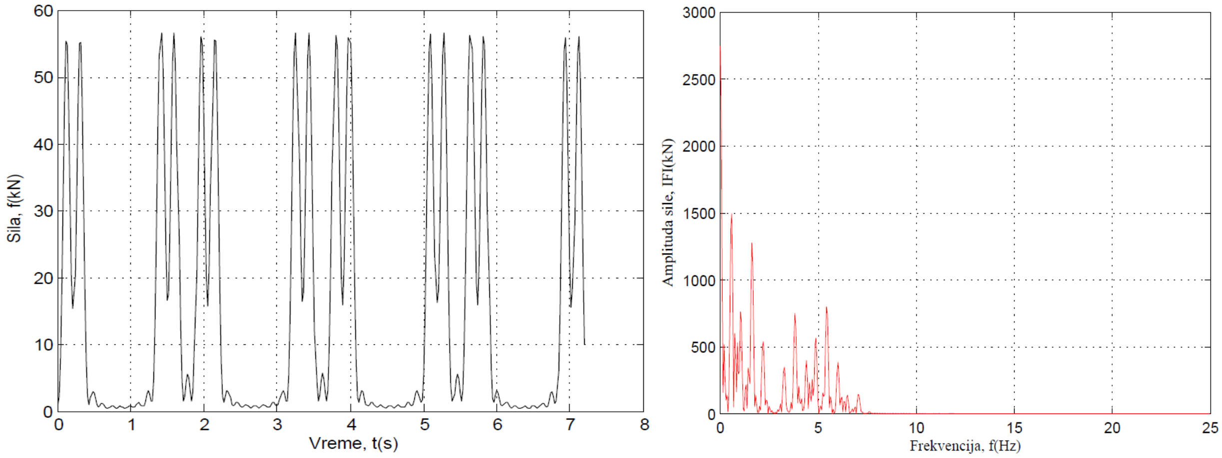
The load function *F(x)* is obtained using MATLAB, taking into account the train speed, wheel forces F_i (5) and wheel forces distribution (*Fig. 2*). *F(x)* is transferred to the time function *F(t)* using well known relation *t=x/v, see Fig. 3a.* The time duration of the train passage is T=7.2 s. The diagram shows peaks at bogie’s passing frequency f_b, wheel passing frequency f_w and sleeper passing frequency f_s:

$$f_b = \frac{v}{3.6 \cdot L_b} = \frac{50}{3.6 \cdot 15.4} = 0.901 \text{ Hz}, \qquad \Delta t_b = 1.10 \text{ s}$$

$$f_w = \frac{v}{3.6 \cdot L_w} = \frac{50}{3.6 \cdot 2.5} = 5.55 \text{ Hz}, \qquad \Delta t_w = 0.18 \text{ s} \tag{6}$$

$$f_s = \frac{v}{3.6 \cdot L_s} = \frac{50}{3.6 \cdot 0.60} = 23.15 \text{ Hz}, \qquad \Delta t_s = 0.04 \text{ s}$$

The moving load is transformed into frequency domain by the Fourier transformation (*Fig. 3 b).*



a) *b)*

Fig. 3

3. NUMERICAL ANALYSIS OF PLATFORM VIBRATION

The influence of train induced vibration in the selected location of the station, called Profile 1 (see *Fig. 4*) is obtained in frequency domain using the program SASSI [4].

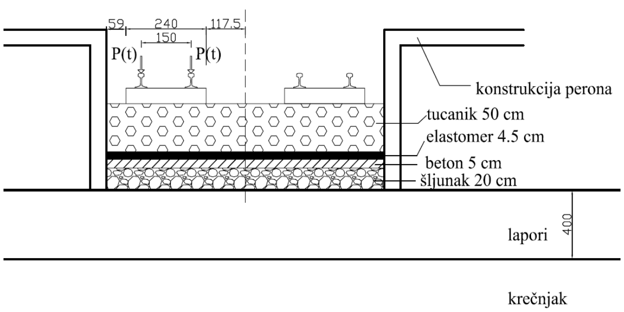


Fig. 4

Sloj	E	G	ρ	ν
	$[kN/m^2]$	$[kN/m^2]$	$[kNm^4s^{-2}]$	-
šljunak	$4\cdot10^5$	$16\cdot10^4$	1.8	0.25
beton	$2.1\cdot10^7$	$1.05\cdot10^7$	2.5	0.16
tucanik	$5\cdot10^5$	$20.83\cdot10^4$	1.6	0.25
lapor	$1\cdot10^5$	$4\cdot10^4$	1.8	0.25
krečnjak	$2\cdot10^6$	$8\cdot10^5$	2.6	0.25

Table 1. Material characteristics

The sleepers, tracks and ballast between the platforms are modeled by finite elements; platforms are modeled by rigid springs, while surrounding soil is modeled by sufficient number of layers, *Fig. 5.* The propagation of waves is calculated using the Thin Layer Method. Moving load is simulated using quasistatic approach. For time interval *Δt* loads move by length *Δy* keeping the same load distribution. This means that it is sufficient to calculate only once displacements in the selected point *k* due to the dynamic force acting in point *i* in frequency domain by SASSI. These displacements are transferred in time domain using Inverse Fourier Transform (IFFT). The final response is obtained by summing the displacements translated in *y* direction along the rail for increment *Δt*:

$$u^k = \sum_{i=1}^{n} u^i\left(\left(n-i+1\right)\Delta t\right) \tag{7}$$

The length of FE model is limited by the maximum number of elements and max length of an element defined by the Lysmer's criteria: $\Delta x = \frac{1}{5}\frac{c_s}{f_{max}} = 0.27$ m (c_s is velocity of shear waves and f_{max} is max frequency). The length and the width of the FE domain are 20m and 8.33 m, *Fig. 5.*

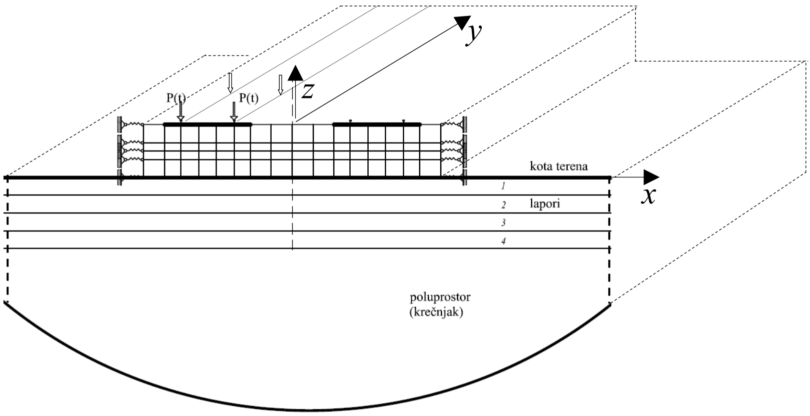


Fig. 5

Existing system:

Sleepers:	Rail:
A=0.0477 m^2	*A=62.29 cm2*
I_x=0.000129 m^4	*γ=49.39 kg/m*
I_y=0.000279 m^4	*I_x=1816 cm^4*
E=2.1 GPa	*I_y=319.1 cm^4*
γ=2.4 t/m^3	

Vanguard fastening system:

K_v = 8 MN/m
K_{pop} = 13 MN/m
K_{long} = 1.5 MN/m

Table 2. Characteristic of systems

The dynamic equation in Frequency domain is:

$$\begin{bmatrix} \mathbf{K}_{SS}^{S} & \mathbf{K}_{SI}^{S} \\ \mathbf{K}_{IS}^{S} & \mathbf{K}_{II}^{S} + \mathbf{K}_{II}^{F} \end{bmatrix} \begin{bmatrix} \mathbf{u}_S \\ \mathbf{u}_I \end{bmatrix} = \begin{bmatrix} \mathbf{P}_S \\ \mathbf{P}_I \end{bmatrix} \tag{8}$$

where $\mathbf{K}^S$ and $\mathbf{K}^F$ are the dynamic stiffness matrices of the sub-structures. Upper index S is for structure (in this case rail+balst+sleepers+gravel), index F is for layered soil.

For model in *Fig. 5* the vertical and transverse vibrations due to moving loads are calculated in selected points: (1) on the rail, (2) on the sleepers, (3) at the edge of platform and (4) on the platform nearby the column, Fig. *6*.

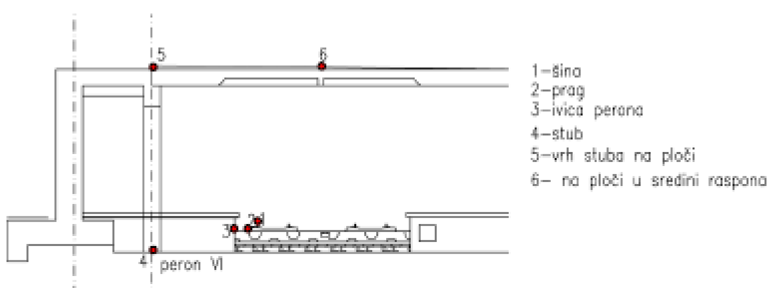


Fig. 6

The analysis was performed for two types of rail systems: standard (existing ones) and new Vanguard fastening system, in order to check the possibility to reduce existing vibrations in the system [1]. The characteristics of existing rail system and Vanguard fastening system is given in *Table 2*.

4. RESULTS

Vertical displacements of the rail (a), sleeper (b), and edge of platform (c) and at the column base (d) are shown in *Fig. 7*, respectively. Vertical vibrations of the rail are much higher for Vanguard case, due to the fastening system which permits rail to move in vertical direction, but displacements at the end edge of the platform as well as at the column base in Vanguard case are smaller than in the case of standard rails. It means that Vanguard system is quite effective in reduction of vibrations on the platform level.

These results were also used to calculate the displacements of the chosen section of the huge RC platform built above the tracks. Some of obtained results are presented in companion paper [2].

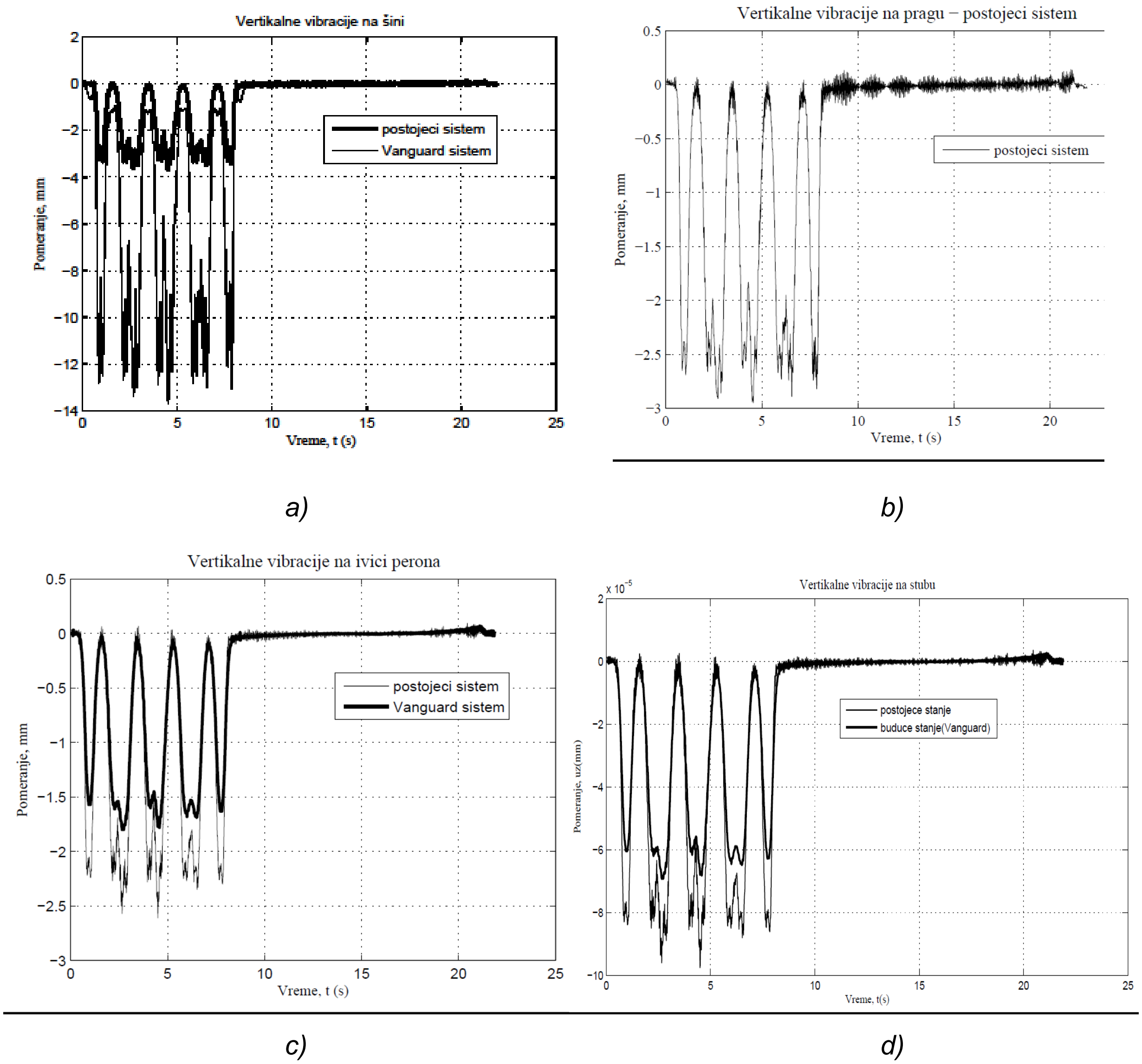


Fig. 7

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