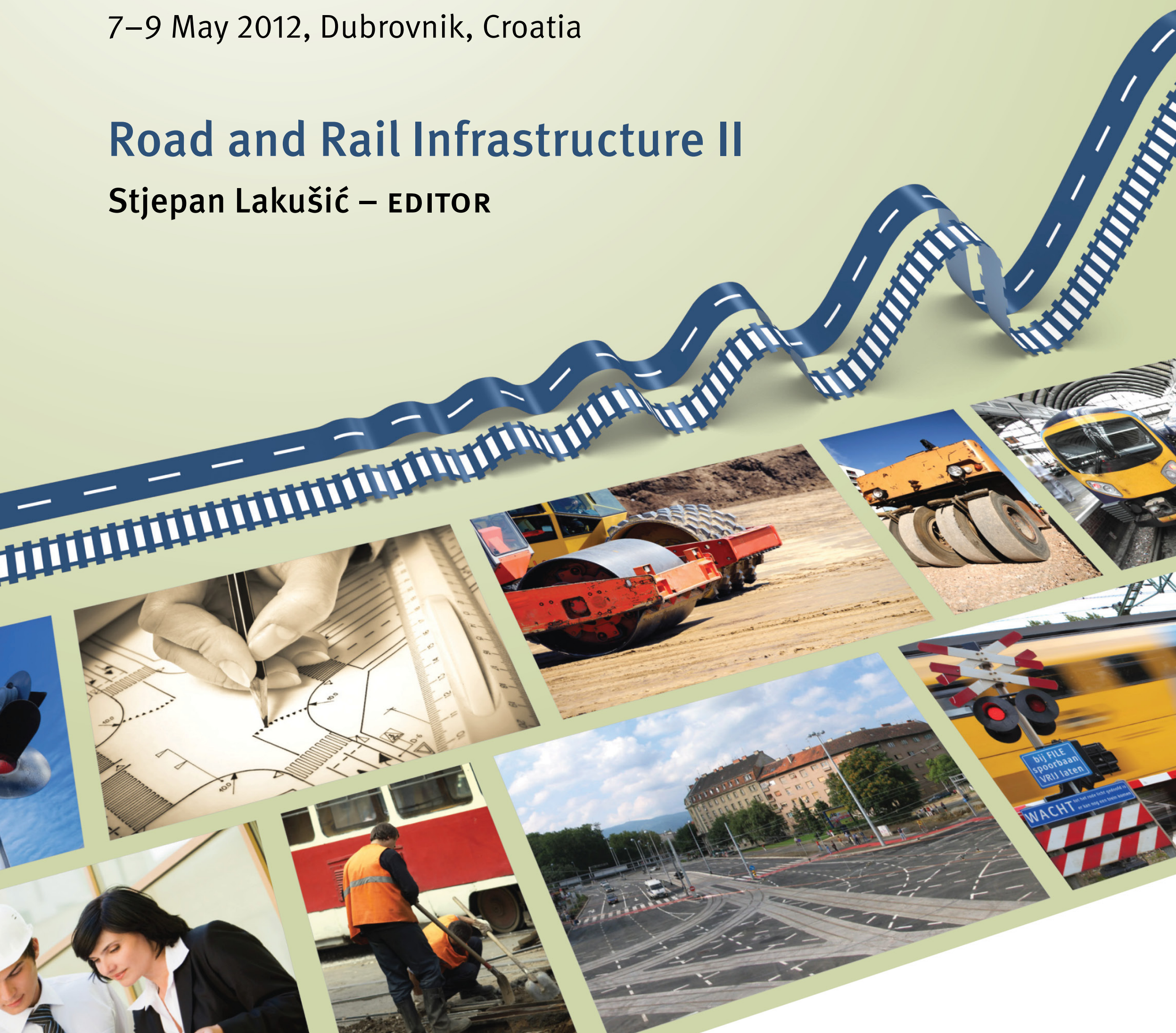
CETRA 2012

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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DYNAMIC EFFECT OF MOVING LOAD ON ASPHALT PAVEMENT

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Abstract

The roads represent the transport structures subjected to intensive dynamic effect of moving vehicles. The knowledge of the development of the strain and stress states in time is needed during the solution of various engineering tasks. One possibility how to obtain such information is to utilize the possibilities of numerical simulation methods of real processes. This advance demands the creation of vehicle computing models and pavement computing models. In this contribution the pavement computing model created on the theory of endless beam on elastic foundation is introduced. The goal of the calculation is to obtain the vertical deflection in one point of the pavement at the passing the vehicle and the time courses of vertical tire forces. The equations of motion are derived in the form of differential equations. The assumption about the shape of deflection curve on the generalization of experimental tests is adopted. It is assumed the validity of Maxwell theorem about mutuality of deflections. The equations of motion are solved numerically in the environment of program system MATLAB. The results following the influence of various parameters (speed of vehicle motion, stiffness of subgrade, modulus of elasticity, road profile) on the pavement vertical deflections and the vertical tire forces are introduced. The outputs from numerical solution in time domain can be transformed into frequency domain and subsequently employ for the solution of another tasks.

Keywords: dynamic, computing models, asphalt pavement, vibration, tire forces

1 Truck computing model

For the purpose of this contribution the plane computing model of the truck TATRA 815 is adopted, Figure 1. The computing model of the truck has 8 degrees of freedom – 5 mass and 3 massless. The massless degrees of freedom correspond to the vertical movements of the contact points of the model with the surface of the roadway. The vibration of the mass objects of the model is described by the 5 functions of time $r_i(t)$, (i = 1, 2, 3, 4, 5). The massless degrees of freedom are coupled by the tire forces $F_i(t)$, (i = 6, 7, 8,) acting at the contact points. The equations of motions and the expressions for tire forcers have the following form:

$$
\begin{aligned}
\ddot{r}_1(t) &= -\left\{+k_1\cdot d_1(t)+b_1\cdot\dot{d}_1(t)+k_2\cdot d_2(t)+b_2\cdot\dot{d}_2(t)+f_2\cdot\dot{d}_2(t)/d_{cv}\right\}/m_1\\
\ddot{r}_2(t) &= -\left\{-a\cdot k_1\cdot d_1(t)-a\cdot b_1\cdot\dot{d}_1(t)+b\cdot k_2\cdot d_2(t)+b\cdot b_2\cdot\dot{d}_2(t)+f_2\cdot\dot{d}_2(t)/d_{cv}\right\}/I_{y_1}\\
\ddot{r}_3(t) &= -\left\{-k_1\cdot d_1(t)+b_1\cdot\dot{d}_1(t)+k_2\cdot d_2(t)+k_3\cdot d_3(t)+b_3\cdot\dot{d}_3(t)\right\}/m_2\\
\ddot{r}_4(t) &= -\left\{-k_2\cdot d_2(t)-b_2\cdot\dot{d}_2(t)-f_2\cdot\dot{d}_2(t)/d_{cv}+k_4\cdot d_4(t)+b_4\cdot\dot{d}_4(t)+k_5\cdot d_5(t)+b_5\cdot\dot{d}_5(t)\right\}/m_3\\
\ddot{r}_5(t) &= -\left\{-c\cdot k_4\cdot d_4(t)-c\cdot b_4\cdot\dot{d}_4(t)+c\cdot k_5\cdot d_5(t)+c\cdot b_5\cdot\dot{d}_5(t)\right\}/I_{y_3}
\end{aligned}
\qquad (1)
$$

$$
\begin{aligned}
F_6(t) &= -G_6 + k_3 \cdot d_3(t) + b_3 \cdot \dot{d}_3(t) \\
F_7(t) &= -G_7 + k_4 \cdot d_4(t) + b_4 \cdot \dot{d}_4(t) \\
F_8(t) &= -G_8 + k_5 \cdot d_5(t) + b_5 \cdot \dot{d}_5(t)
\end{aligned}
\tag{2}
$$

The meaning of the used symbols is as follows: k_i, b_i, f_i are the stiffness, damping and friction characteristics of the model, mi, I_{yi} are the mass and inertia characteristics, a, b, c, s are the length characteristic of the model, $g = 9{,}81\ m.s^{-2}$, Gi are the gravity forces acting at the contact points. The deformations of the spring elements are $d_i(t)$ and the derivation with respect to time is denoted by the dot over the symbol.

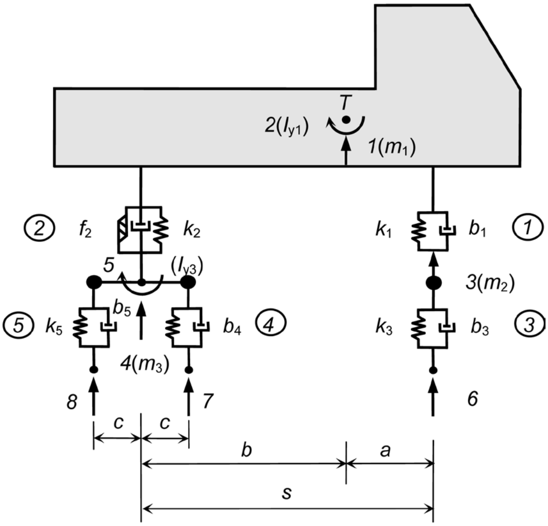

Figure 1 Truck computing model

2 Pavement computing model

The plane computing model of an asphalt pavement is based on theory of endless beam resting on Winkler elastic foundation [1]

$$
EI\frac{\partial^4 v(x,t)}{\partial x^4} + \mu\frac{\partial^2 v(x,t)}{\partial t^2} + 2\mu\omega_b\frac{\partial v(x,t)}{\partial t} + k \cdot v(x,t) = p(x,t) \tag{3}
$$

The wanted function v(x,t) describing the beam vertical deflections will be expressed as the product of two functions

$$
v(x,t) = v_0(x) \cdot q(t) \tag{4}
$$

The function $v_o(x)$ figures as known function and it is dependent on the coordinate x only and the function q(t) figures as unknown function and it is dependent on the time t. The function q(t) has the meaning of generalized Lagrange coordinate. With respect to the goal of the solution and with respect to the results of experimental tests the assumption about the shape of the function $v_o(x)$ was adopted as

$$v_0(x) = \frac{1}{2}\left(1 - \cos\frac{2\pi x}{l}\right) \tag{5}$$

The meaning of the other symbols is as follows: E modulus of elasticity [N.m^{-2}], I cross section moment of inertia [m^4], μ mass intensity [kg.m^{-1}], ωb damping circular frequency [rad.s^{-1}], k modulus of foundation [N.m^{-2}], p(x,t) represents the continuous load in [N.m^{-1}], l the length of the beam on which the deformation due to truck load occurs. With respect to the assumption (5) for plane computing model of the truck and for x=l/2 the equation (3) can be rewritten to the form

$$\ddot{q}(t)\cdot\mu + \dot{q}(t)\cdot 2\mu\omega_b + q(t)\left[k + \frac{1}{2}EI\left(\frac{2\pi}{l}\right)^4\right] = \sum_{j=6,7,8} F_j(t)\frac{1}{l}\left(1 - \cos\frac{2\pi x_j}{l}\right) \tag{6}$$

3 Numerical analysis

3.1 Parameters of the computing model

For the purpose of numerical analysis the following pavement construction was considered, Figure 2. The upper 3 layers of the pavement construction are considered as the beam with the height $h = h_1 + h_2 + h_3 = 40 + 50 + 50 = 140$ mm = 0,14 m and the width b = 1,0 m. For these 3 layers the equivalent modulus of elasticity and moment of inertia of the cross section were calculated

$$E = \frac{E_1\cdot h_1 + E_2\cdot h_2 + E_3\cdot h_3}{h_1 + h_2 + h_3} = \frac{5500\cdot 40 + 6000\cdot 50 + 3050\cdot 50}{40 + 50 + 50} \cong 4800\text{MPa},$$

$$I = \frac{1}{12}b\cdot h^3 = \frac{1}{12}1{,}0\cdot 0{,}14^3 = 2{,}2866667\cdot 10^{-4}\text{m}^4.$$

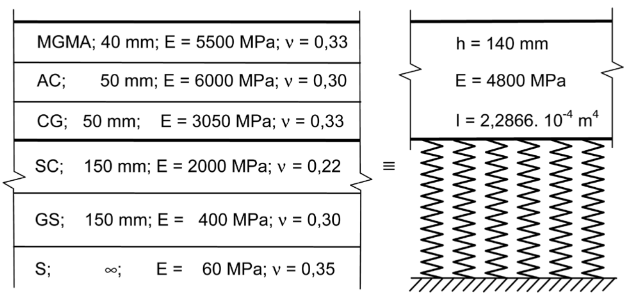

Figure 2 Pavement computing model, MGMA – medium grained mastic asphalt, AC – asphalt concrete, CG – coated gravel, SC – soil cement, GS – gravel sand, S – subgrade

The layers, No. 4 – 6, are taken into calculation as Winkler elastic foundation. The modulus of compressibility K=156,04549 MN.m^{-3} was calculated by the use of the program LAYMED [2]. The modulus of compressibility used at the beam computing model respects the beam width b, k=K.b=156,04549 MN.m^{-3} . 1,0 m=156,04549 MPa. The mass intensity of the beam μ=ρ.b.h=2200. 1,0.0,14 ≅ 310,0 kg.m^{-1}. The damping circular frequency is taken as ωb=0,1 rad.s^{-1}. These numerical data are considered as the base data.

3.2 Influence of the speed of truck motion

For the numerical solution of the mathematical apparatus the computer program in the programming language MATLAB was created. The program enables the calculation of the time courses of all kinematical values of the truck (deflection, speed, acceleration), kinematical values at 1 point of the pavement and tire forces under the individual axles. The illustrations of the form of the obtained results are in Figures 3, 4.

The results of solution are influenced by various parameters of the considered system (speed of truck motion, stiffness of subgrade, modulus of elasticity of the beam, road profile, …). The influence of the speed of vehicle motion was analyzed in the interval of speeds V = 0 – 120 km/h with the step of 5 km/h. The maximums of vertical deflections at the monitored point of the pavement versus speed of the truck motion are plotted in the Figure 5. The results are obtained for the smooth road surface.

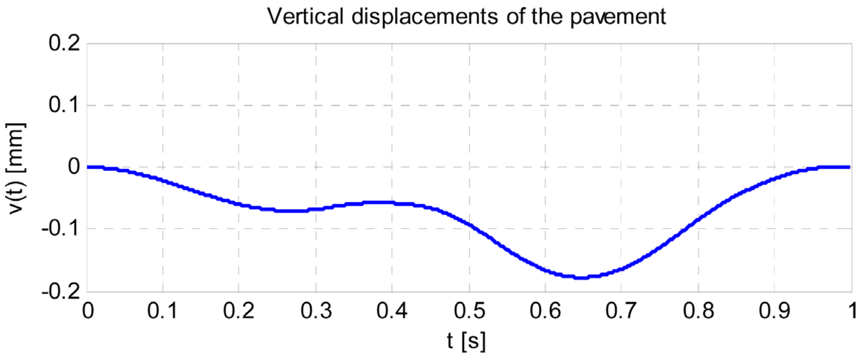

Figure 3 Vertical displacement of the pavement v(t), speed V = 40 km.h^{-1}

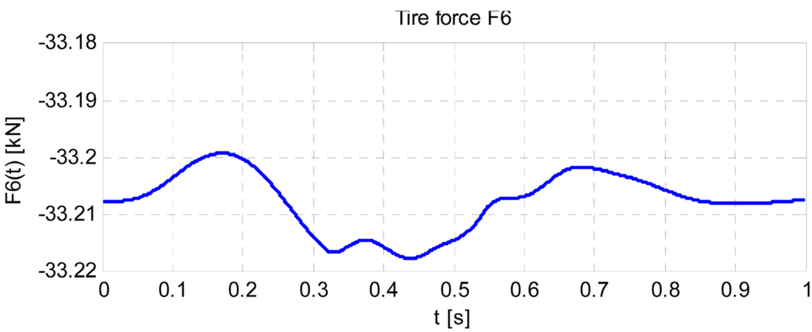

Figure 4 Tire force F_6(t) under front axle, speed V = 40 km.h^{-1}

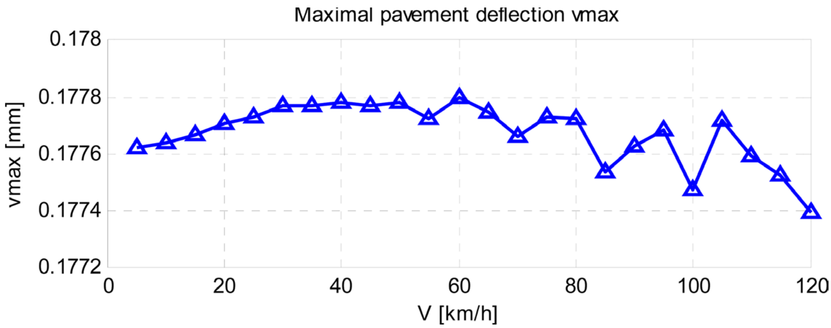

Figure 5 Maximal pavement deflection versus truck speed

3.3 Influence of the subgrade ftiffness

The influence of the modulus of foundation k was analyzed in the interval 50–200 MPa with the step of 25 MPa and in the interval 200–500 MPa with the step of 50 MPa. The speed of vehicle motion was V = 60 km.h^{-1}. The maximums of vertical deflections at the monitored point of the pavement versus modulus of foundation are plotted in the Figure 6. Similarly the extremes (maximum, minimum) of tire force under rear axle versus modulus of foundation are plotted in the Figure 7.

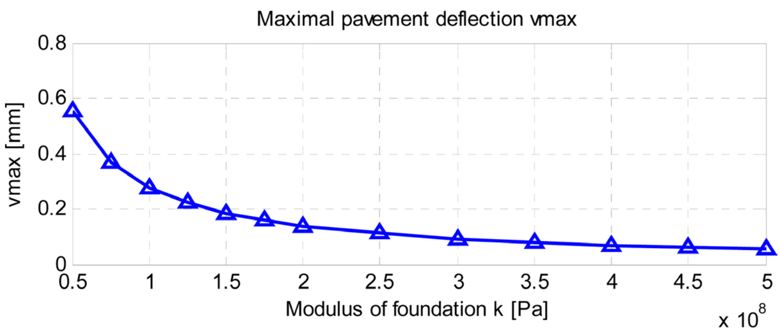

Figure 6 Maximal pavement deflection versus modulus of foundation k

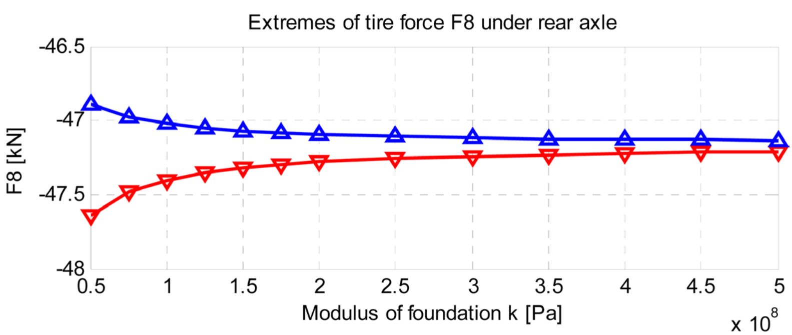

Figure 7 Extremes of tire force F_8(t) versus modulus of foundation k

3.4 Influence of the beam modulus of elasticity

The influence of the beam modulus of elasticity E was analyzed in the interval 2000–7000 MPa with the step of 500 MPa. The speed of truck motion was V = 60 km.h^{-1}. The maximums of vertical deflections at the monitored point of the pavement versus modulus of foundation are plotted in the Figure 8. Similarly the extremes (maximum, minimum) of tire force under rear axle versus modulus of foundation are plotted in the Figure 9.

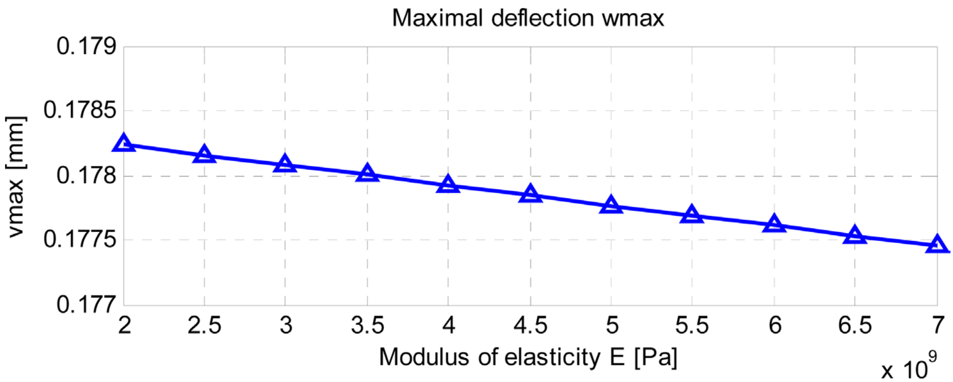

Figure 8 Maximal pavement deflection versus beam modulus of elasticity E

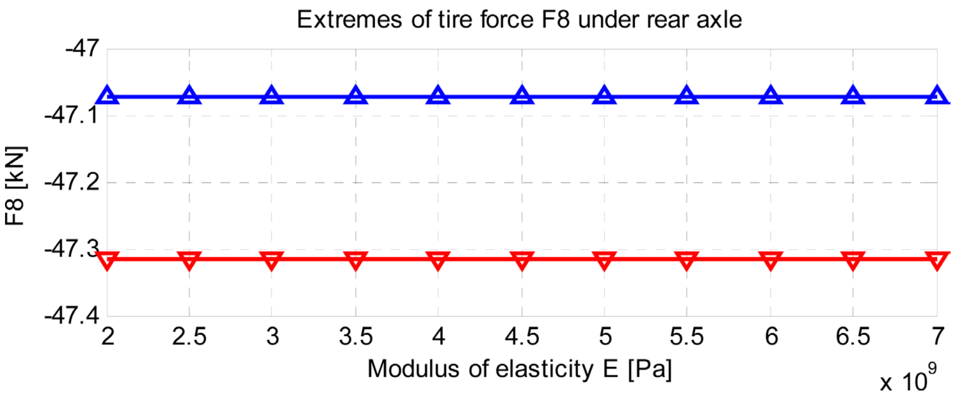

Figure 9 Extremes of tire force $F_8(t)$ versus beam modulus of elasticity E

3.5 Influence of the road profile

The above–mentioned results were obtained for the smooth road profile. The real road profile has stochastic character and it represents the dominant source of kinematical excitation of vehicle. Also the vehicle response has stochastic character. The results of solution can be presented in time or in frequency domain. The influence of quality of the road profile on the tire forces is followed in this paper. As an example the tire forces under front axle $F_6(t)$ and their power spectral densities evaluated for very good profile ($\Phi o = 4.10^{-6}$ m²/(rad/m) [3]) and average profile ($\Phi o = 64.10^{-6}$ m²/(rad/m) [3]) are presented in the Figure 10, 11.

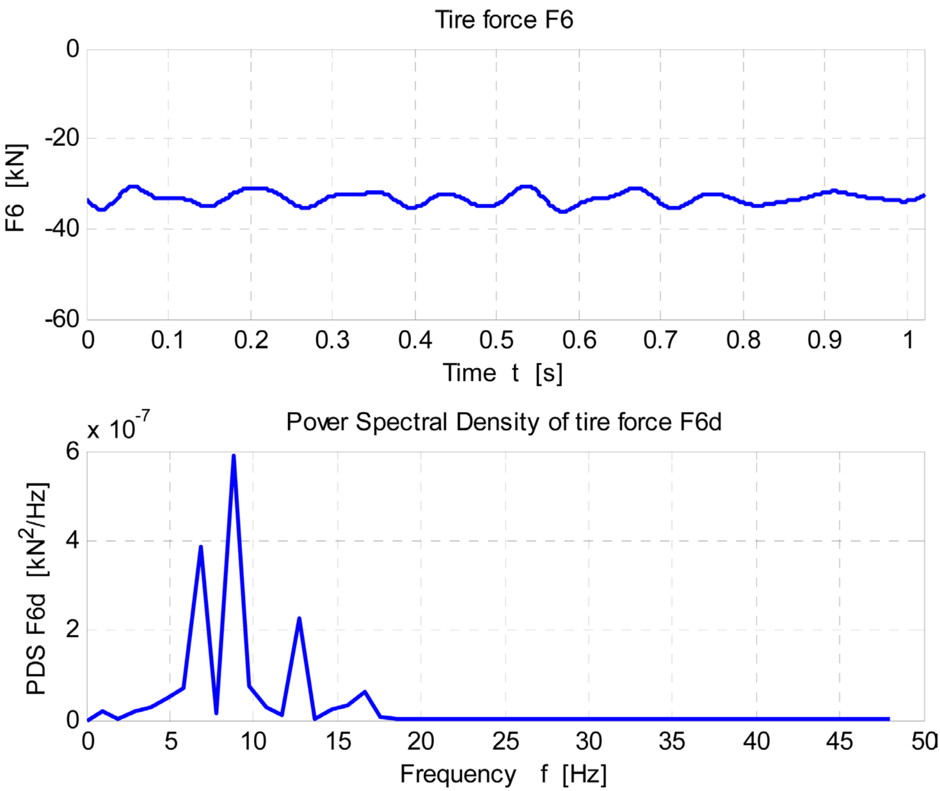

Figure 10 Tire force $F^6(t)$ and its PSD, $\Phi o = 4.10^{-6}$ m²/(rad/m)

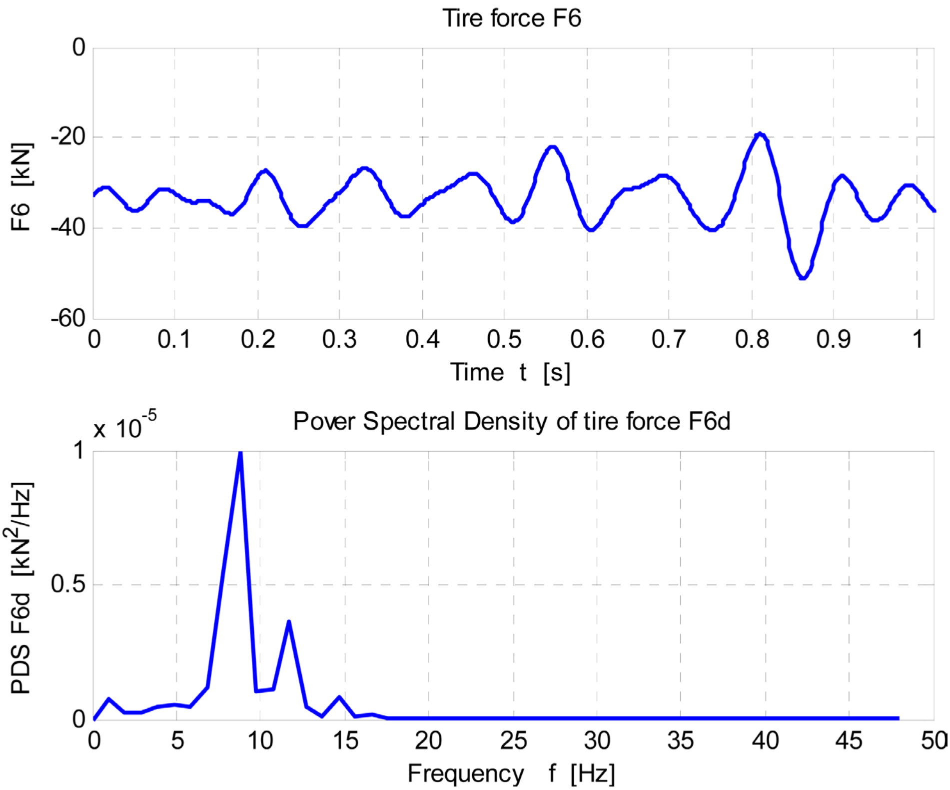

Figure 11 Tire force $F_6(t)$ and its PSD, $\Phi o = 64.10^{-6}\ m^2/(rad/m)$

4 Conclusion

Computing model of the road based on the theory of beam on elastic foundation with adopting the assumption about the shape of bending elastic line provides the effective tool for the solution of many dynamic problems in time domain. Numerical solution can be realised in the environment of the program system MATLAB. The outputs from numerical solution in time domain can be transformed into frequency domain and subsequently employed for the solution of another tasks.

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