УДК 656.071.8

J. Melcer

*University of Žilina, Faculty of Civil Engineering,
Department of Structural mechanics (Slovak Republic)*

THE LOAD FROM CITY TRANSPORT

The information about the load from city transport can be obtained by experimental or by numerical way. The present state of computing technique enables to carry out the numerical simulation of vehicle moving along the roads in real time and to obtain similar results as from experimental test. This process requires creation of vehicle computing models and roads computing models, solution of equations of motion and processing of obtained results in time or in frequency domain. In this paper the space computing model of a lorry is introduced. The road surface is modeled as random profile from the known power spectral density function. The equations of motion are solved by step-by-step Runge-Kutta integration method in the environment of program system MATLAB. The attention is oriented on the fire forces acting on the road. The obtained results are analysed in time and in frequency domain.

Key words: *moving load, city transport, numerical simulation, computing models, road profile, numerical integration, tire forces, frequency spectra.*

Introduction

The roads in urban centers are exposed to intensive road transport. The road load due to road transport represents the main source of kinematical excitation of the surrounding civil engineering structures. The knowledge of this load, its variability in time and frequency composition is needed for assessment of the dynamic effect of moving vehicles on civil engineering structures. The task can be solved by experimental or by numerical way. But the most effective way is the combination of the both mentioned advances. The offered paper is dedicated to the description of facilities how to obtained the required data by numerical way. This process requires creation the computing models of vehicles, the computing models of the roads and to pay attention to the numerical solution of equations of motion and to the analysis of obtained results in time and in frequency domain. The road surface quality plays the important role in this process. The emphasis in this paper will be put on the problem how the quality of the road profile affects the time histories and frequency composition of the tire forces.

Vehicle computing model

The computing models of vehicles can be created on various levels as 1-dimensional, 2-dimensional or 3-dimensional [1]. For the purpose of this contribution the 3-dimensional space computing model of a lorry was adopted, *Fig. 1*. It is discrete computing model with 15 degrees of freedom. The 9 mass degrees of freedom correspond to the vertical displacements $r_i(t)$ of the mass objects m_i. The mass-less degrees of freedom correspond to the vertical movements of the contact point of the model with the road surface. The vibration of the mass objects of the model is described by the 9 functions of time $r_i(t)$, (i = 1÷9). The mass-less degrees of freedom are associated with the tire forces $F_j(t)$, (j = 10÷15) acting at the contact points.

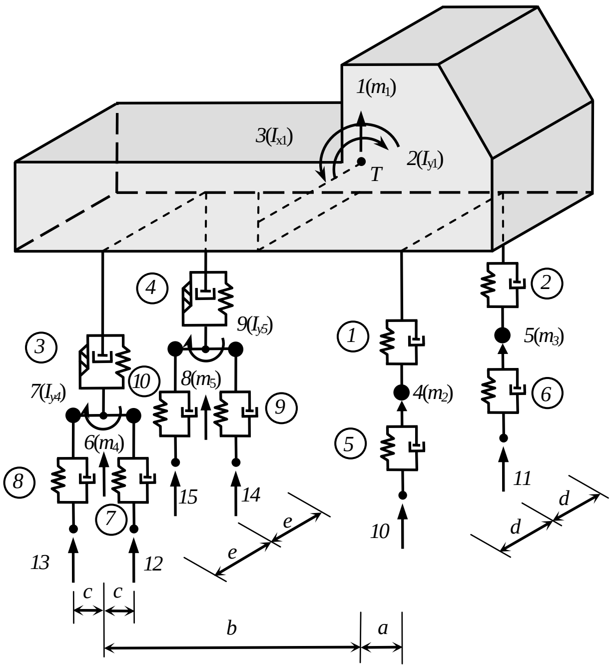

Fig. 1. Vehicle computing model

The equations of motion have the form of ordinary differential equations and with respect on the used method of numerical solution they can be written in the form

$$[m]\cdot\{\ddot{r}\}+[b]\cdot\{\dot{r}\}+[k]\cdot\{r\}=\{F\}\ , \qquad (1)$$

$$[m]\cdot\{\ddot{r}\}=\{F\}-[b]\cdot\{\dot{r}\}-[k]\cdot\{r\}= =\{F\}-\{F_d\}-\{F_{re}\}=\{F_v\}\ . \qquad (2)$$

Solution of equations of motion is realized numerically in the environment of programming system MATLAB.

Road surface unevenness

The rigid pavement with random road profile is assumed for the purpose of numerical solution. The random road profile h(x) is assumed as stationary ergodic function with zero mean value and normal distribution. The properties of the road profile are described by Power Spectral Density function (PSD) in the form

$$S_h(\Omega)=S_h(\Omega_0)\cdot\left(\frac{\Omega}{\Omega_0}\right)^{-k}\ , \qquad (3)$$

where Ω in [rad/m] denotes the wave number, Ω_0 = 1 rad/m is the reference wave number and the waviness k = 2. According to the international directive ISO 8608 [2], typical road profiles can be grouped into classes from A to H. Each class is simply defined by its reference value $S_h(\Omega_0)$, Fig. 2, Table 1.

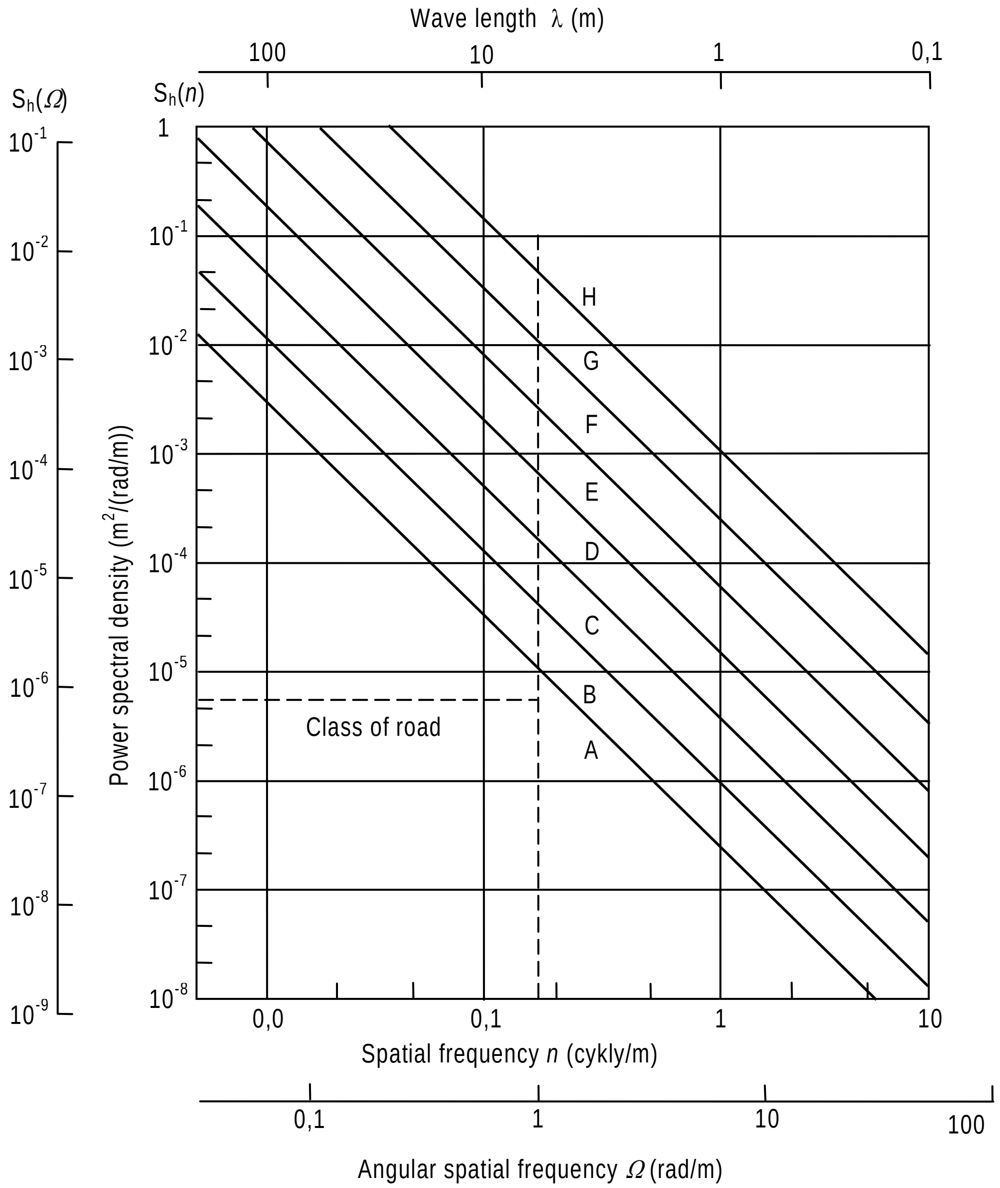

Fig. 2. Power spectral densities of road profiles

Table 1. Classification of pavements according to road unevenness [2]

Class	$S_h(\Omega_0)$ [m²/(rad/m)] at Ω_0 = 1 rad/m		
	lower bound	geometric average	upper bound
A	-	1.10⁻⁶	2.10⁻⁶
B	2.10⁻⁶	4.10⁻⁶	8.10⁻⁶
C	8.10⁻⁶	16.10⁻⁶	32.10⁻⁶
D	32.10⁻⁶	64.10⁻⁶	128.10⁻⁶
E	128.10⁻⁶	256.10⁻⁶	512.10⁻⁶
F	512.10⁻⁶	1024.10⁻⁶	2048.10⁻⁶
G	2048.10⁻⁶	4096.10⁻⁶	8192.10⁻⁶
H	8192.10⁻⁶	16384.10⁻⁶	-

A random profile of a single track can be approximated as

$$h(x) = \sum_{i}^{N} \sqrt{2 \cdot S(\Omega_i) \cdot \Delta\Omega} \cdot \cos(\Omega_i \cdot x + \varphi_i)\,, \qquad (4)$$

where φ_i is the uniformly distributed phase angle.

Results of numerical simulation of the tire forces

Numerical solution was carried out in the environment of the program system MATLAB. The 4st order Runge-Kutta step-by-step integration method was used for the solution of equations of motion [3]. As the result of numerical simulation the movement of vehicle along the road profile with the speed V = 36 km/h was simulated. In the first step the random road profile h on the basis of known power spectral density for the value $S_h(\Omega_0)$ = 4.10^{-6} m^2/(rad/m), category B, was generated. The generated road profile is shown in the (Fig. 3).

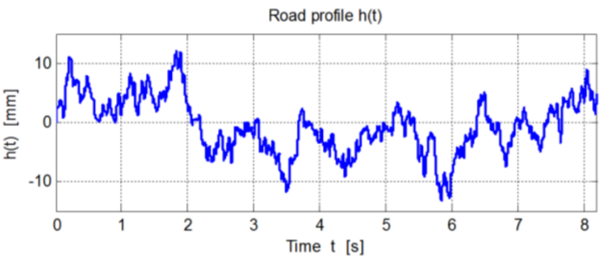

Fig. 3 Random road profile, $S_h(\Omega_0)$ = 4.10^{-6} m^2/(rad/m)

The corresponding tire forces under rear wheel of rear axle of the vehicle computing model are shown in the *Fig. 4*.

Similar results can be obtained for various road profiles, for various speeds of vehicle motion and for various vehicle computing models. Falling of the quality of the road profile has as the result the larger values of tire forces. In the *Table 2* the ranges of road profile $\Delta h = h_{max} - h_{min}$ and corresponding ranges of tire forces $\Delta F = |F_{max}| - |F_{min}|$ are introduces.

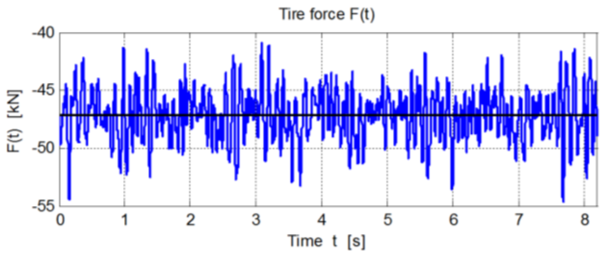

Fig. 4 Tire forces under rear wheel of rear axle

Table 2. Road profile and tire force ranges for various road category

Road category	$S_h(\Omega_0)$ [m²/(rad/m)]	$\Delta h = h_{max}$ - h_{min} [mm]	$\Delta F = \|F_{max}\|$ - $\|F_{min}\|$ [kN]
A	1e-6	12,6190	6,8160
B	4e-6	25,2380	13,6500
C	16e-6	50,4760	27,3749
D	64e-6	100,9519	54,5401
E	256e-6	201,9038	76,9016

The solution can by carried out in the time domain, as it was shown above, or in the frequency domain. In the frequency domain the frequency composition of vibration is interesting. It can be assessed for example through Power Spectral Density functions (PSD). The PSD function of the road profile informs us about the frequency composition of the road profile and the PSD of the tire force informs us about the frequency composition of the pavement load. The PSD of the road profile from the *Fig. 3* is plotted in the *Fig. 6* and the PSD of the dynamic component of tire force from the *Fig. 5* is plotted in the *Fig. 7*. As we can see in the frequency composition of the road profile the low frequencies dominate. In the frequency composition of the tire forces the frequencies in the interval from 6 to 12 Hz dominate. It relates with natural frequencies of the vehicle.

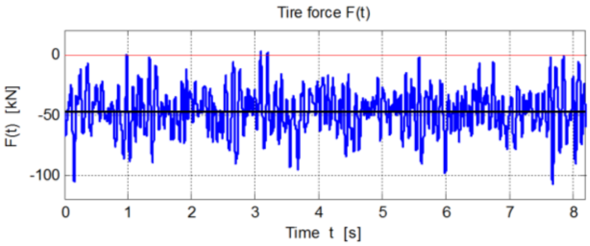

Fig. 5 Time history of tire force at the road category *E*

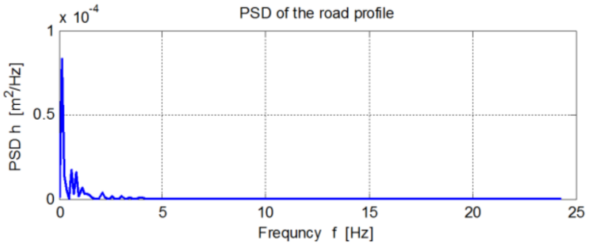

Fig. 6 PSD of the road profile

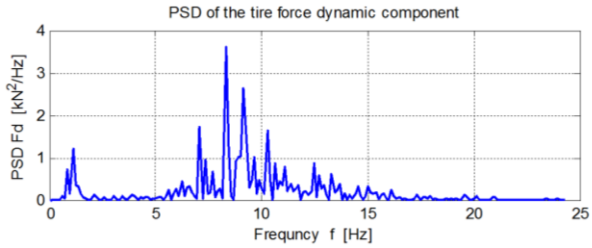

Fig. 7 PSD of tire forces

Conclusion

The knowledge of the moving load on the roads, its variability in time and frequency composition is needed for assessment of the dynamic effect of moving vehicles on civil engineering structures. The required data can be obtained by numerical way. The road surface quality plays the important role in this process. The task can be solved by experimental or by numerical way. But the most effective way is the combination of the both mentioned advances.

Acknowledgements

This work was supported by the Grant National Agency VEGA, project 1/0259/12.

References

1. Melcer, J. – Martinická, I.: Roll effect on the force and kinematical values of vehicle. Civil and Environmental Engineering, Vol. 6, No. 2, 2010, ISSN 1336-5835, p. 128-137.

2. ISO 8608, Mechanical vibration – road surface profiles – reporting of measured data, International standard, 1995.

3. Melcer, J. – Lajčáková, G.: Dynamic effect of moving load on asphalt pavement. Proceedings of the 2nd International Conference on Road and Rail Infrastructure, CETRA 2012, Road and Rail Infrastructure II, Croatia, Dubrovnik, May 7-9, 2012, University of Zagreb, 2012, ISBN 978-953-6272-49-5, p. 719-726.

Автор: MELCER Jozef,
DrSc., Prof. Ing., University of Žilina, Faculty of Civil Engineering, Department of Structural mechanics, Slovak Republic
E-mail - jozef.melcer@fstav.uniza.sk

НАГРУЗКИ ОТ ГОРОДСКОГО ТРАНСПОРТА

Йожеф Мельцер

Информацию о нагрузке от городского транспорта можно получить экспериментально или численными методами. Современная вычислительная техника позволяет осуществлять численное моделирование транспортного средства, двигающегося вдоль дорог в реальном времени, а также получить результаты, как от экспериментальных испытаний. В статье представлена численная модель транспортного средства. Дорожная поверхность моделируется как случайный профиль от известных сил в виде спектральной функции плотности. Выравнивание движения решается пошаговым методом интеграции Runge-Kutta в окружающей среде программной системы MATLAB. Внимание ориентируется на нагрузки, действующие на дорогу. Полученные результаты анализируются во времени и в частотной области.

Ключевые слова: перемещение груза, городской транспорт, численное моделирование, расчетная модель, дорожный профиль, численная интеграция, динамические нагрузки, частотные спектры.

НАВАНТАЖЕННЯ ВІД МІСЬКОГО ТРАНСПОРТУ

Йожеф Мельцер

Інформацію про навантаження від міського транспорту можна отримати експериментально або чисельними методами. Сучасна обчислювальна техніка дозволяє здійснювати чисельне моделювання транспортного засобу, який рухається уздовж доріг у реальному часі, а також отримати результати, як від експериментальних випробувань. У статті представлена чисельна модель транспортного засобу. Дорожня поверхня моделюється як випадковий профіль від відомих сил у вигляді спектральної функції щільності. Вирівнювання руху вирішується покроковим методом інтеграції Runge-Kutta у довкілля програмної системи MATLAB. Увага орієнтується на навантаження, діючі на дорогу. Отримані результати аналізуються у часі і в частотній області.

Ключові слова: *переміщення вантажу, міський транспорт, чисельне моделювання, розрахункова модель, дорожній профіль, чисельна інтеграція, динамічні навантаження, частотні спектри.*