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Full Length Research Paper

Effect of shock vibrations due to speed control humps to the health of city bus drivers

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Speed Control Humps (SCH) are used to slow down the vehicles and improve traffic safety. While passing over the humps, the drivers of public transport buses are exposed to shock vibrations. An analysis of the effects of shock vibrations to the health of a city bus driver, while passing over three types of SCHs, is made by simulation, using an original oscillatory model with five degrees of freedom (DOF). The evaluation is carried out using the method and criteria accepted by ISO 2631-5 standard. The assessment of the effects of shock vibrations to the health of the bus driver on public transport line 26 in Belgrade is also made. While passing over a rounded profile, the driver's health is more affected at lower bus speeds (15 km/h), even as over flat platform, harmful effects are more significant at higher speeds (over 40 km/h). If the bus on the line 26 is driven over humps at 40 km/h, harmful effects to the driver's health occur at the age of 50. By driving at or under 30 km/h, the driver can almost avoid harmful effects at all.

Key words: ISO 2631-5 standard, shock vibrations, city bus, driver's health, simulation.

INTRODUCTION

The vehicle drivers during work are exposed to vibrations, mainly due to ground irregularities. Vibration may provoke sensation of discomfort, reduce work capacity and by longer exposure can jeopardize health (Dedović and Mladenović, 1999). The especially susceptible groups are the drivers of agricultural and civil work machinery, heavy trucks and buses. One of main driver's health problems related to the effect of vibrations is musculoskeletal disorder: pain at shoulders, neck and upper back, as well as acute low back pain (Kompier, 1996; Whitelegg, 1995; Okunribido et al., 2007; Bovenzi and Hulshof, 1999; Milosavljevic et al., 2010). The occurrence of driver's acute low back pain is mostly related to the effect of shock vibrations (Health and Safety Executive, 2001). Shock vibrations occur as a consequence of the wheel bump to humps or potholes on road surface. Strong shocks may induce serious damages and injuries of human spinal column (Bowrey, 1996). The paper of Sandover (1998) estimates that the effect of short shock vibrations to the human health is more dangerous than the effect of random vibrations. Frequent and long exposure to shocks can provoke a degenerative illness which is one of the most common causes of acute low back pain (Jandrić and Antić, 2006). The drivers of urban and suburban buses on routes with speed control humps are exposed to daily and frequent effect of shock vibrations.

The research work (Rosander et al., 2007) mentions that some bus drivers pass over speed control humps up to 300 times per day. The results show that in such situation an important risk to driver's health is present which contributed that Swedish Work Environment Administration close bus transit on some bus lines in Taby area, neighboring Stockholm (Rosander et al., 2007). The drivers of city buses are generally against the application of speed control humps (Bjarnason, 2004; Swedish National Road Administration, 1999; Greater Manchester Passenger Transport Executive, 2009). There are also opinions that the application of SCH should be avoided on the city bus routes (Greater Manchester Passenger Transport Executive, 2009).

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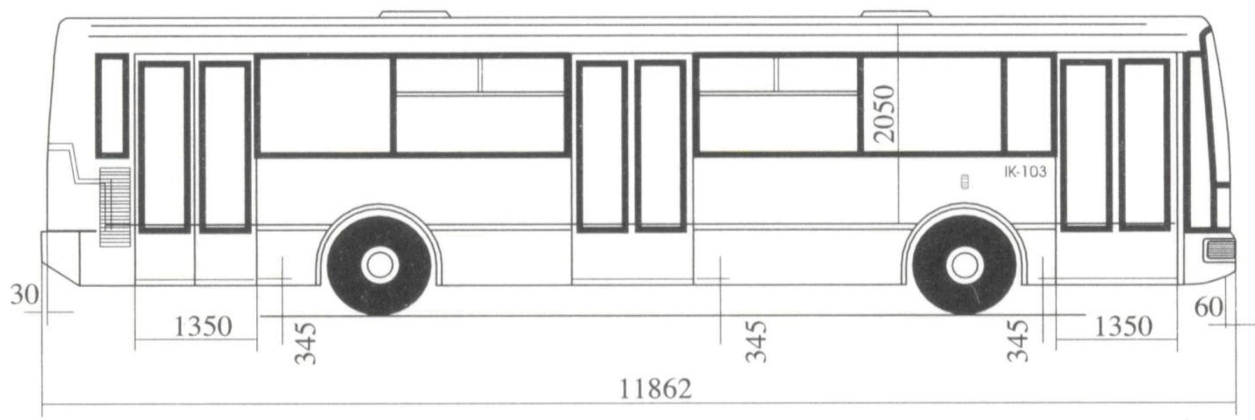


Figure 1. City bus IK-103.

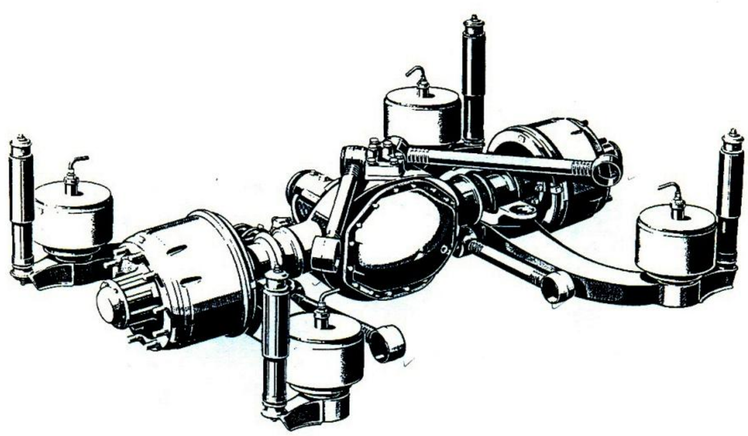


Figure 2. IK-103 bus rear axle.

Anyway, they are widely used as devices to reduce speed and increase safety. This paper considers only the effect of shock vibrations to the driver of the city bus while passing over SCH, by simulation using an original oscillatory model with five degrees of freedom (DOF). The evaluation of the vibration effect to the driver is carried out according to the procedure of the ISO 2631-5 standard, for three profiles of speed control humps: flat platform and two rounded ones, with different heights and at different speeds. These types of SCH profiles are often used on the streets of Belgrade where bus routes go through. Special care in the paper is devoted to the analysis of the effect of shock vibrations to the driver's health on the specific bus line 26 which makes part of mass passenger public transport (MPPT**)** in Belgrade.

BUS OSCILLATORY MODEL

The bus IK-103 (Figure 1) is a typical modern city bus with two rigid axles and pneumatic suspension system (Nijemčević et al., 2001). Front axle has two pneumatic suspension elements and four hydraulic telescopic shock absorbers, and rear one is equipped with four pneumatic suspension elements and four shock absorbers. Front axle is fitted with two wheels and rear one with two twin wheels (four tires). All tires are of the same size. Figure 2 shows the arrangement of the rear axle of the bus considered and Figure 3 presents the scheme of the rear suspension elements with the geometry used for the calculation of equivalent stiffness and equivalent damping. Plane oscillatory model of the bus with five DOF is shown in Figure 4. The independent displacements of the concentrated masses of the considered mechanical oscillatory system are vertical displacements of driver, vehicle center of gravity (T) and front and rear axles, as well as the angular motion of the suspended mass around the (transversal) y-axis. The effect of vibrations transmitted from the road to the driver's body depends also on the characteristics of the

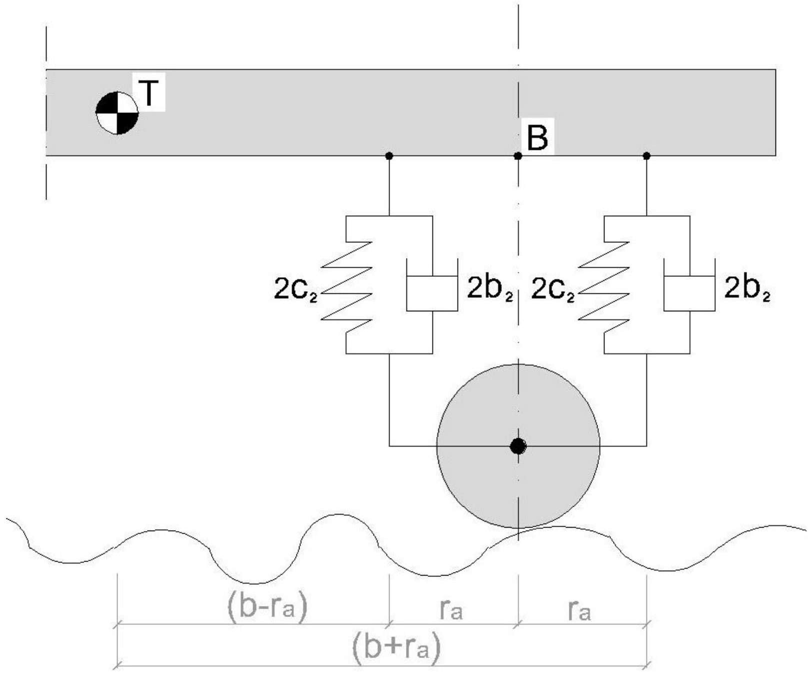


Figure 3. Rear axle suspension elements.

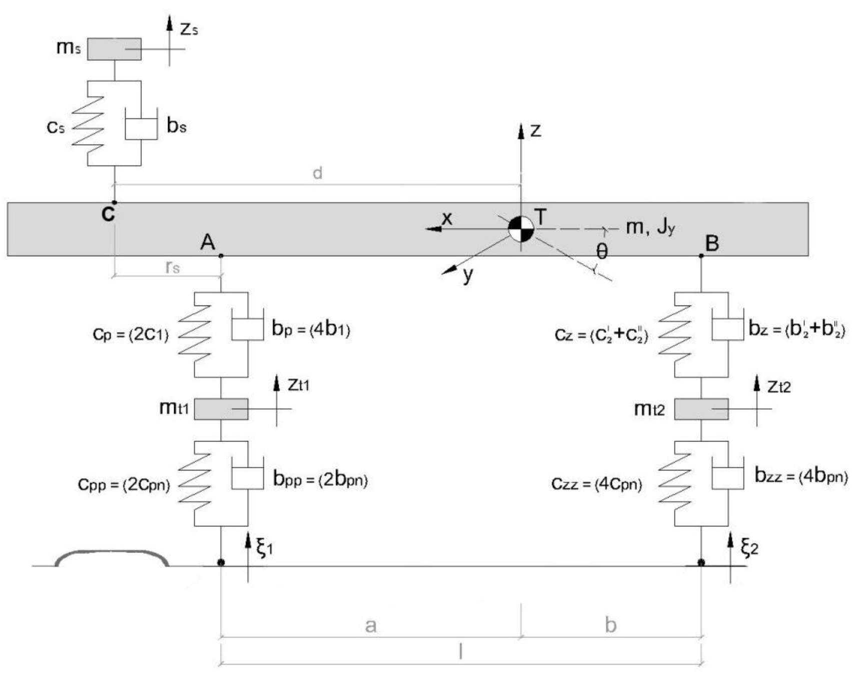


Figure 4. Plane oscillatory model of the bus IK-103.

driver's seat suspension. The seat is equipped with separate pneumatic suspension element and hydraulic damper (Nijemčević et al., 2001). Elastic and damping characteristics of the driver's seat are given in Table 3.

Oscillatory model of the bus has been defined according to the following assumptions:

i) Bus is symmetrical relative to longitudinal (x) axis.

Table 1. Geometry parameters of the IK-103 bus.

Geometry parameters	Values (m)
l - distance between axles	5.65
a - distance from the front axle to CG	3.12
b - distance from the rear axle to CG	2.53
r_s - distance from the driver's seat to the front axle	1.50
d - distance from the driver's seat to CG	4.62
r_a - distance from the rear axle suspension element to the vertical axis of the rear wheel	0.30

Table 2. Masses parameters of the IK-103 bus.

Mass parameters	Values
m_s - mass of the driver and the seat	100 kg
m - suspended mass of the partially loaded bus	11900 Kg
m_{t1} - mass of the front axle	745 kg
m_{t2} - mass of the rear axle	1355 kg
J_y - inertia moment of the suspended mass related to transversal axis	50000 kgm^2

ii) There are no angular movements around *x*-axis.
iii) The excitations on both left and right wheels are the same.
iv) All possible displacements of concentrated masses around the static equilibrium position are small.
v) All elastic and damping characteristics are linear.
vi) The bus wheels are in permanent contact with road surface.
vi) The bus movement is linear and at constant speed.

The meaning of the labels from Figures 3 and 4 is shown in Tables 1, 2 and 3, together with the values of parameters used in simulation. The values are assumed after the relevant literature (Nijemčević et al., 2001; Mladenović, 1997; Simić et al., 1979). According to the data from Fiure 3, the equivalent stiffness and equivalent damping for the rear axle are calculated using expressions 1 and 2:

$$c_z = c_2' + c_2'' = 2c_2 \frac{(b-r_a)^2}{b^2} + 2c_2 \frac{(b+r_a)^2}{b^2} \tag{1}$$

$$b_z = b_2' + b_2'' = 2b_2 \frac{(b-r_a)^2}{b^2} + 2b_2 \frac{(b+r_a)^2}{b^2} \tag{2}$$

To start the analysis of the effect of shock vibrations to driver's health, the differential equations of motion of concentrated masses of the oscillatory model are needed. Using the Lagrange's equations of second order, and considering earlier assumptions, the differential equations of motion of the proposed model are defined by the following expressions:

$$m_s\ddot{z}_s + b_s\dot{z}_s + c_s z_s - b_s\dot{z} - c_s z - b_s d\dot{\theta} - c_s d\theta = 0, \tag{3}$$

$$\begin{gathered} m\ddot{z} + (b_s + b_p + b_z)\dot{z} + (c_s + +c_p + c_z)z + (db_s + ab_p - bb_z)\dot{\theta} + \\ (dc_s + ac_p - bc_z)\theta - b_s\dot{z}_s - c_s z_s - b_p\dot{z}_{t1} - c_p z_{t1} - b_z\dot{z}_{t2} - c_z z_{t2} = 0, \end{gathered} \tag{4}$$

$$\begin{gathered} J_y\ddot{\theta} + (d^2b_s + a^2b_p + b^2b_z)\dot{\theta} + (d^2c_s + a^2c_p + b^2c_z)\theta + (db_s + ab_p - bb_z)\dot{z} + (dc_s + ac_p - bc_z)z - \\ db_s\dot{z}_s - dc_s z_s - ab_p\dot{z}_{t1} - ac_p z_{t1} + bb_z\dot{z}_{t2} + bc_z z_{t2} = 0, \end{gathered} \tag{5}$$

$$m_{t1}\ddot{z}_{t1} + (b_p + b_{pp})\dot{z}_{t1} + (c_p + c_{pp})z_{t1} - b_p\dot{z} - c_p z - ab_p\dot{\theta} - ac_p\theta = b_{pp}\dot{\xi}_1 + c_{pp}\xi_1, \tag{6}$$

$$m_{t2}\ddot{z}_{t2} + (b_z + b_{zz})\dot{z}_{t2} + (c_z + c_{zz})z_{t2} - b_z\dot{z} - c_z z + bb_z\dot{\theta} + bc_z\theta = b_{zz}\dot{\xi}_2 + c_{zz}\xi_2. \tag{7}$$

Numerical solving of the differential equations is realized through the program written in MATLAB® and MATLAB's function 'ode45' was used. Starting conditions defined for all variables were set to zero. According to ISO 2631-5 standard, the signal of vertical acceleration of the driver is sampled at each 1/160 of the second. The time of simulation was limited to 8 s.

BUS EXCITATION

Speed control humps used on routes of city bus lines in MPPT in Belgrade wherever needed to considerably reduce vehicle velocity have two main configurations. Fiure 5 shows a flat platform and Figure 6 shows the type with rounded profile. Characteristic dimensions of the humps are shown in Figures 5 and 6, and values are presented in Tables 4 and 5. The analytic expression describing SCH in form of flat platform is given by Expression 8 and one describing rounded profile by

Table 3. IK-103 bus oscillatory model parameters.

Oscillatory model parameters	Values
c_s - driver's seat spring stiffness	8500 N/m
b_s - driver's seat damping	650 Ns/m
c_1 - one front axle pneumatic suspension element stiffness	175000 N/m
c_p - equivalent stiffness of front axle pneumatic suspension elements	350000 N/m
b_1 - one front axle shock absorber damping	20000 Ns/m
b_p - front axle shock absorbers equivalent damping	800000 Ns/m
c_2 - one rear axle pneumatic suspension element stiffness	200000 N/m
c_z - equivalent stiffness of rear axle pneumatic suspension elements	811250 N/m
b_2 - damping of one rear axle shock absorber	22500 Ns/m
b_z - equivalent damping of rear axle shock absorbers	91265 Ns/m
c_{pn} - front and rear tire stiffness (per tire)	1000000 N/m
c_{pp} - equivalent front axle tires stiffness	2000000 N/m
c_{zz} - equivalent rear axle tires stiffness	4000000 N/m
b_{pn} - front and rear tire damping (per tire)	150 Ns/m
b_{pp} - equivalent front axle tires damping	300 Ns/m
b_{zz} - equivalent rear axle tires damping	600 Ns/m

Figure 5. Speed control hump - flat platform.

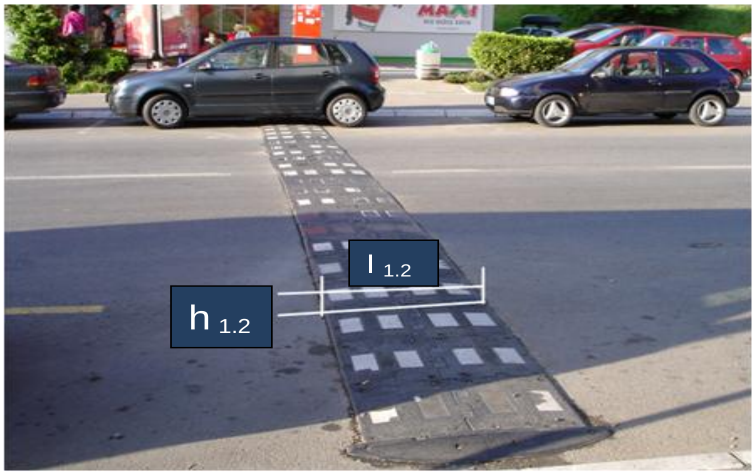


Figure 6. Speed control hump - rounded profile.

Table 4. Dimensions of flat platform.

h - height of flat platform	0.08 m
l_{ru}, l_{rs} - length of ascending and descending ramp	1.00 m
l_{pl} - length of flat platform	10.00 m
l_{uk} - overall length of the platform	12.00 m

Table 5. Dimensions of rounded profile humps.

Rounded profile	Type 1 (m)	Type 2 (m)
$h_{1.2}$ - height of profile	0.03	0.05
$l_{1.2}$ - length of profile	0.83	0.96

Expression 9 (Salau et al., 2004; Oke et al., 2005). Characteristic dimensions are taken from manufacturer's data (technical data for road humps):

$$\xi(t)=\begin{Bmatrix} \frac{h}{l_{ru}}\cdot V\cdot t,\ 0\le t<\frac{l_{ru}}{V} \\ h,\ \frac{l_{ru}}{V}\le t\le\frac{l_{ru}+l_{pl}}{V} \\ -\frac{h}{l_{rs}}\cdot V\cdot t+\frac{h\cdot(l_{ru}+l_{pl})}{l_{rs}}+h,\ \frac{l_{ru}+l_{pl}}{V}<t\le\frac{l_{ru}+l_{pl}+l_{rs}}{V} \\ 0,\ t>\frac{l_{ru}+l_{pl}+l_{rs}}{V} \end{Bmatrix} \tag{8}$$

$$\xi(t)=\begin{Bmatrix} h_{1,2}\cdot\sin(\frac{\pi\cdot V}{l_{1,2}}\cdot t),\ 0\le t\le\frac{l_{1,2}}{V} \\ 0,\ t>\frac{l_{1,2}}{V} \end{Bmatrix} \tag{9}$$

The excitations due to flat platform and to rounded profiles for constant bus speed of 10 km/h are shown in Figures 7 and 8.

ISO 2631-5 STANDARD

The ISO 2631-5 standard defines the method of quantification of shock vibrations acting to the human body in sitting position. It also gives the procedure for the evaluation of vibrations effect to the human health. Based on the method described, the pressure exerted to the lumbar part of spinal column, consequent to shock vibrations can be calculated. By comparison to the evaluation criteria, the risk of getting health problems can be assessed. The evaluation procedure is based on the acceleration response of the lumbar part of human spinal column. With the ISO standard, a linear oscillatory model with a single mass and one DOF is used to calculate responses in horizontal plane (along x- and y-axes). To determine the acceleration in vertical direction (along z-axis), the ISO standard method uses non-linear model based on recurrent neural network. The models are set after the results of the experimental investigation of acceleration and can be applied only for the sitting position of the body.

The ISO standard defines two values through which the effect of shock vibrations can be evaluated – 'daily equivalent static compression dose for lumbar spine - parameter Sed and Factor R', defined for use in the assessment of the adverse health effects related to the human response acceleration dose. The parameter 'Sed' is suitable for the evaluation of the negative effect to health when the exposure to shock vibrations during the whole working life period is considered. Factor R is particularly suitable for evaluation of the negative effect of shock vibrations to health in n-years of human body exposure to shock vibrations.

The procedure for the calculation of the parameter 'Sed' and the Factor R is described in detail in the Annex A of the ISO 2631-5 standard (ISO 2631-5, 2004). For the calculated values of the parameter 'Sed' and the Factor R, one can estimate the effect of vibrations comparing them with the limit values as follows:

a) For the parameter Sed:

i) If Sed<0.5 (MPa), the probability of negative effect to health is low.
ii) If Sed>0.8 (MPa), the probability of negative effect to health is significant.

b) For the Factor R:

i) If R<0.8 (-), the probability of negative effect to health is low.
ii) If R>1.2 (-), the probability of negative effect to health is significant.

The evaluation criteria for the parameter 'Sed' are set

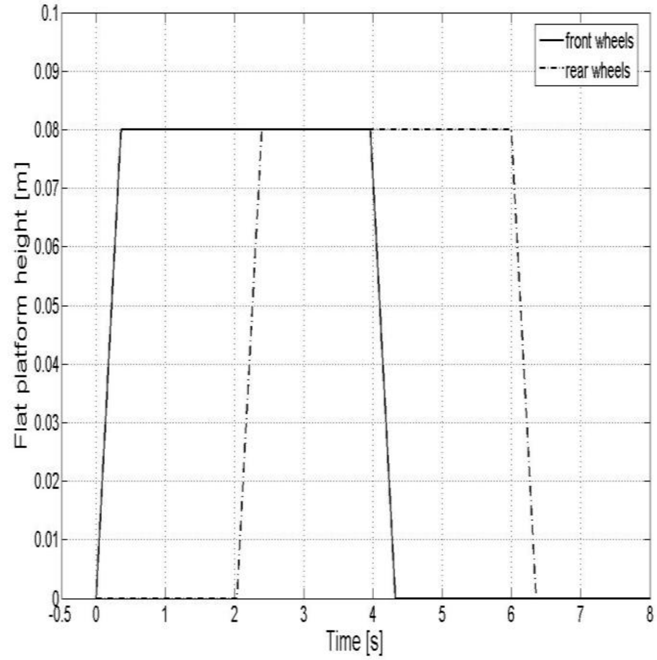


Figure 7. Excitation due to flat platform h = 0.08 m, bus speed 10 km/h.

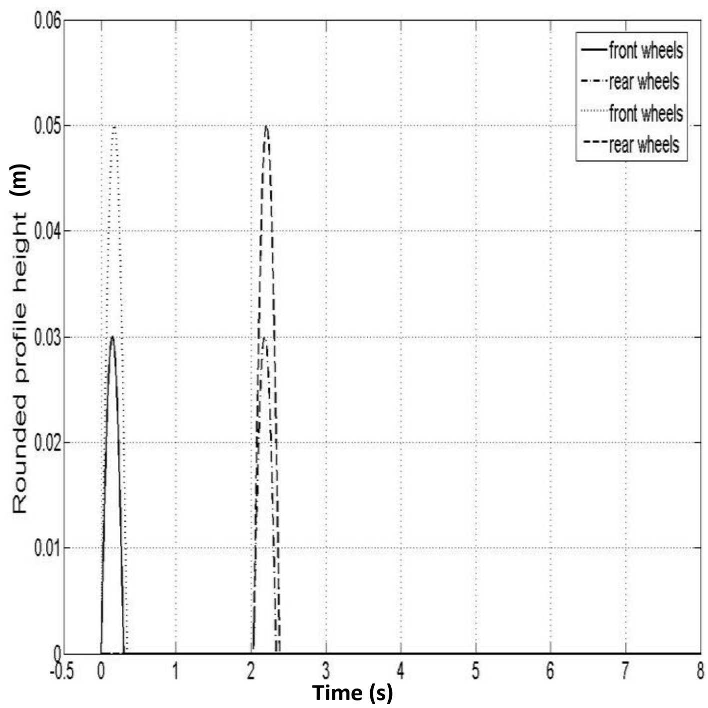


Figure 8. Excitation due to rounded profiles h = 0.03 and 0.05 m, bus speed 10 km/h.

with the assumption that human body is exposed to shock vibrations during 240 days per year which corresponds to the usual number of working days per employee and per year. Within the evaluation of the

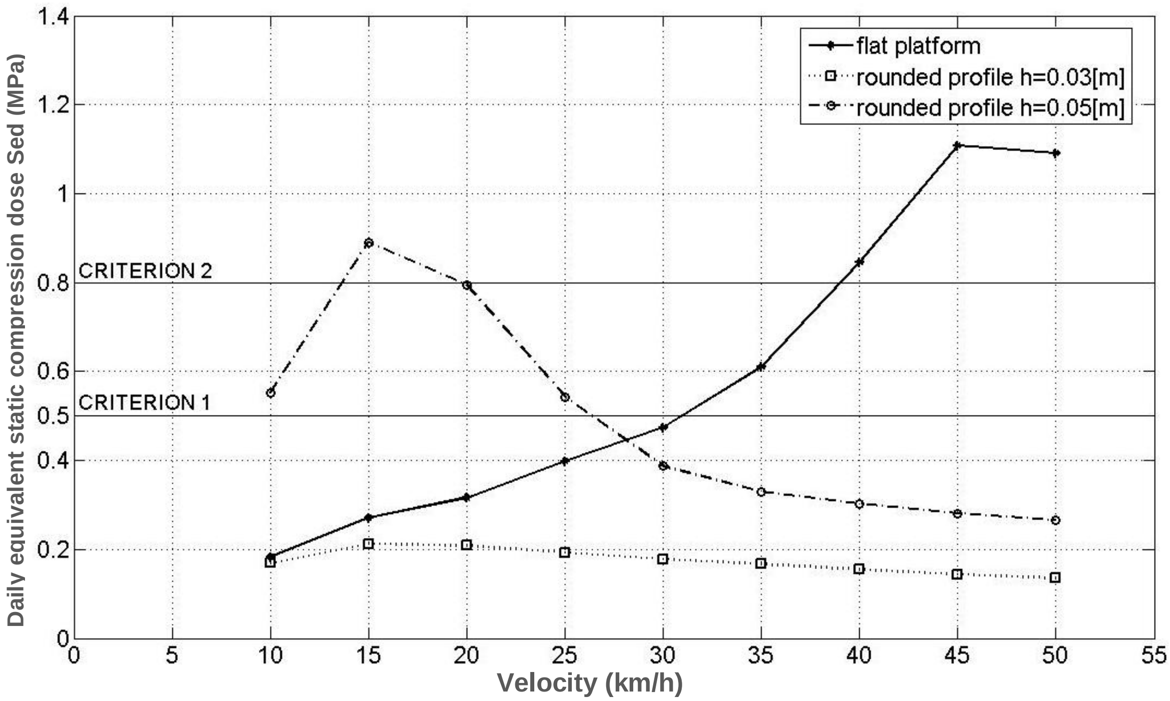


Figure 9. Daily equivalent static compression dose Sed for the driver with 45 passes over per day, for three profiles of SCH and at different speeds.

effect of shock vibration to the driver's body in this paper, only the vertical acceleration on the driver's seat was considered and only the part of the program from Annex D of the ISO 2631-5 standard has been applied. The Annex D considers the seated human body acceleration along all three axes (x, y and z). With this paper, only the part of program analyzing the effect of shock vibrations along the vertical axis on human health is applied. It is sufficient for the analysis, having in mind that vertical acceleration has major intensity and, accordingly, the most important negative effect to driver's body.

RESULTS OF THE SIMULATION

The law administrates the maximum speed of 50 km/h for MPPT bus (Subotić, 2009). The actual bus speed range in Belgrade is 10 to 50 km/h (GSP Beograd, 2005). That is why the range of 10 to 50 km/h is considered for the analysis of the effects of shock vibrations caused by SCH to driver's body.

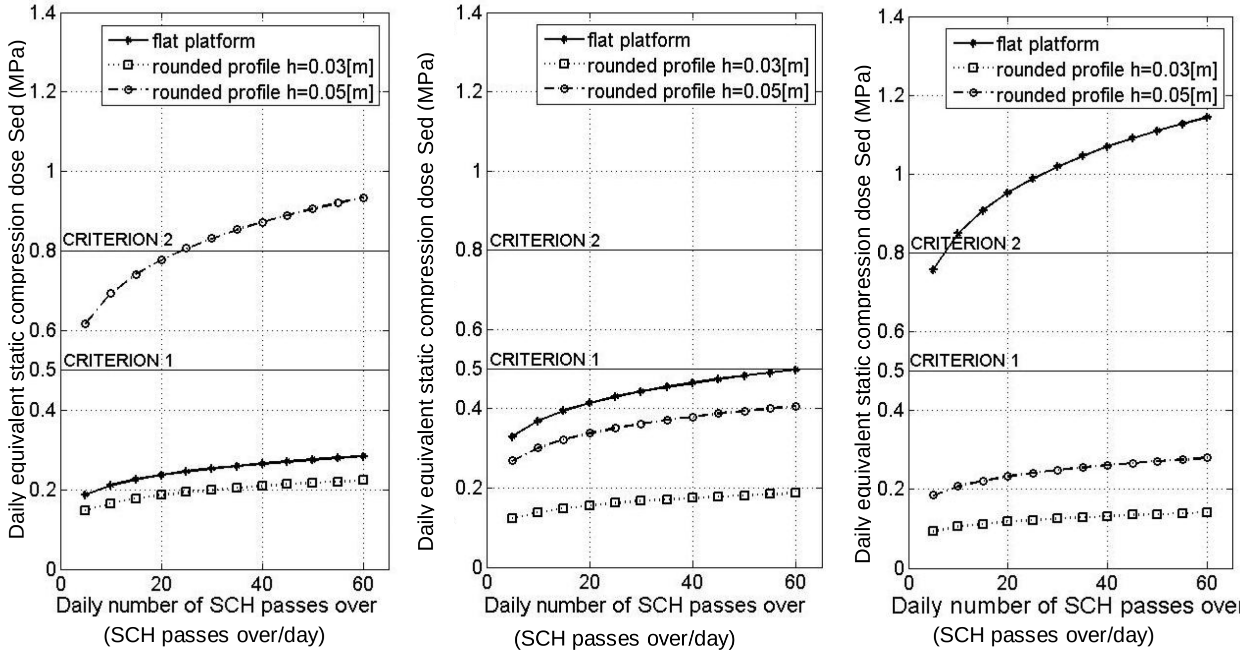
Passing over different types of SCH and at different speeds

Two main issues were analyzed: 1) the influence of shock vibrations due to different SCH at different speeds in range 10 to 50 km/h and for 45 passes over per day, and 2) the influence of shock vibrations due to different number of daily passes over SCH at three constant speeds (15, 30 and 50 km/h).

1) The first analysis is carried out for 45 passes over SCH per day at different speeds. Figure 9 shows the plot of the ‘Sed’ values for the driver in function of bus speed. For the flat platform, the values of Sed’ exceeds the evaluation criterion of 0.8 MPa at speeds over 38 km/h. The highest value of Sed’ is 1.15 MPa at the bus speed of 45 km/h. On the rounded profile, 0.05 m high, the highest value of Sed’ reaches 0.9 MPa at the speed of 15 km/h. For the flat platform, up to the speed of 31 km/h, and for rounded profile 0.05 m high over 26 km/h speed, the value of Sed’ parameter is under 0.5 MPa. The lowest values of Sed’ are for the rounded profile 0.03 m high, far under 0.5 Mpa, at all bus speeds considered.

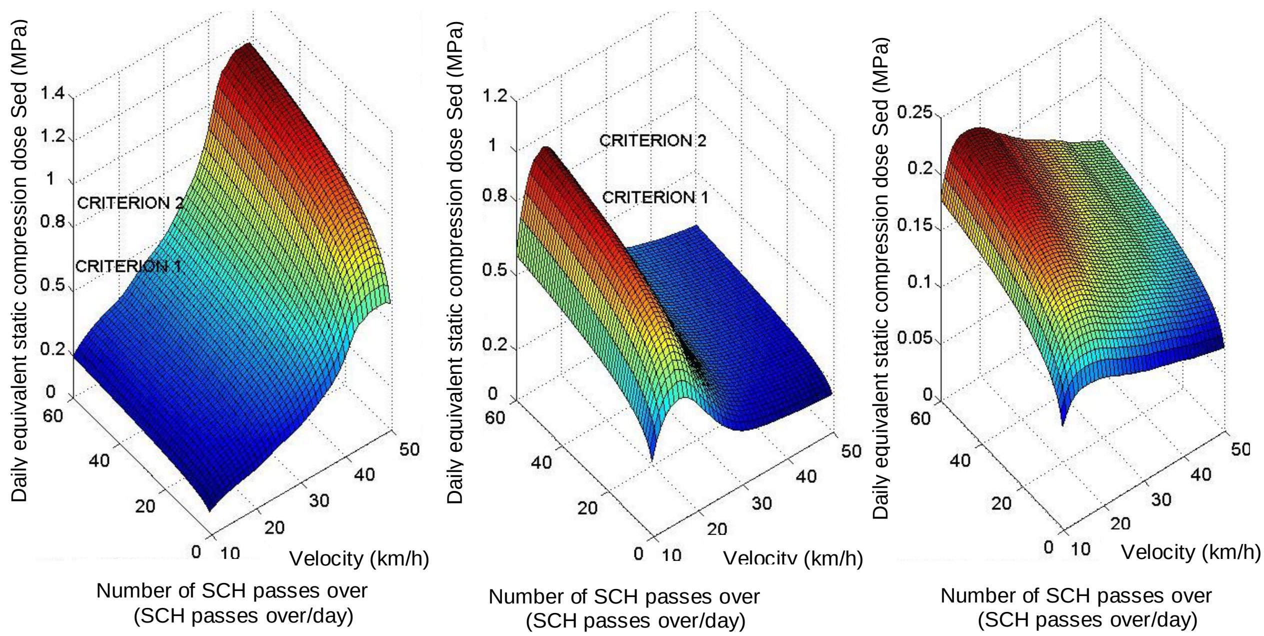
2) The second analysis is carried out at constant speeds and for different number of passes over SCH. At constant bus speed, the effect of shock vibrations to the driver's body depends on the number of passes over SCH per day. Figure 10a, b and c show the change of parameter Sed’ in function of the number of passes over all three types of SCH and for constant bus speeds of 15, 30 and 50 km/h, within the range of 5 to 60 passes over per day.

With the increase of the number of passes over all types of SCH, the value of parameter Sed’ increase for all bus speeds considered. At the constant bus speed of 30 km/h, all values of parameter Sed’, for all SCH types, and



a) Bus speed 15 km/h b) Bus speed 30 km/h c) Bus speed 50 km/h

Figure 10. Daily equivalent static compression dose Sed for the driver as function of number of SCH passes over.



a) Flat platform h = 0.08 m b) Rounded profile h = 0.05 m c) Rounded profile h = 0.03 m

Figure 11. Daily equivalent dose of static compression Sed for the driver as function of number of SCH passes over and bus speed.

in the whole range considered are under the value of the moderate negative effect criterion (0.5 MPa). Only the shock vibrations due to the flat platform at 60 passes over per day reach the level of moderate negative effect to the driver's health (Figure 10b). Three dimensional plots of functions considered are shown in Figure 11a, b and c where the changes of the driver's parameter Sed' value against the bus speeds and number of passes over

Figure 12. Route of the Belgrade bus line 26 with SCH positions.

three types of SCH profiles are presented.

Cumulative effect of shock vibrations on the bus line 26 in Belgrade

The Belgrade MPPT bus line 26 connects the downtown (Dorćol) with the community Braće Jerković (Figure 12). This line is about 10 km long and is one of the Belgrade bus subsystem with the highest passenger flow (Subotić, 2009). On the route of the bus line 26, there are two speed control humps in form of flat platform, two with rounded profile of 0.03 m and one with rounded profile of 0.05 m (Figure 12). During one working day the driver makes 4.5 turns (Subotić, 2009). That means he makes 18 passes over flat platform, 18 over rounded profile of 0.03 m and 9 over rounded profile of 0.05 m. Figure 13 shows the change of Sed' parameter in function of bus speed for total of daily passes over all SCHs on the bus line 26 acquired through the application of ISO 2631-5 standard methodology.

DISCUSSION

Passing over different types of SCH and at different speeds

After the ISO 2631-5 standard criteria, passing over the SCH in form of the flat platform, at the speed of 45 km/h, the driver may be exposed to 'high risk of negative effect' of shock vibrations to his health. For the SCH in form of the rounded profile 0.05 m high, and at the speeds between 13 and 20 km/h, shock vibrations may have 'significant negative effect' to the driver's health. Both for flat platform and rounded profile 0.05 m high, up to the

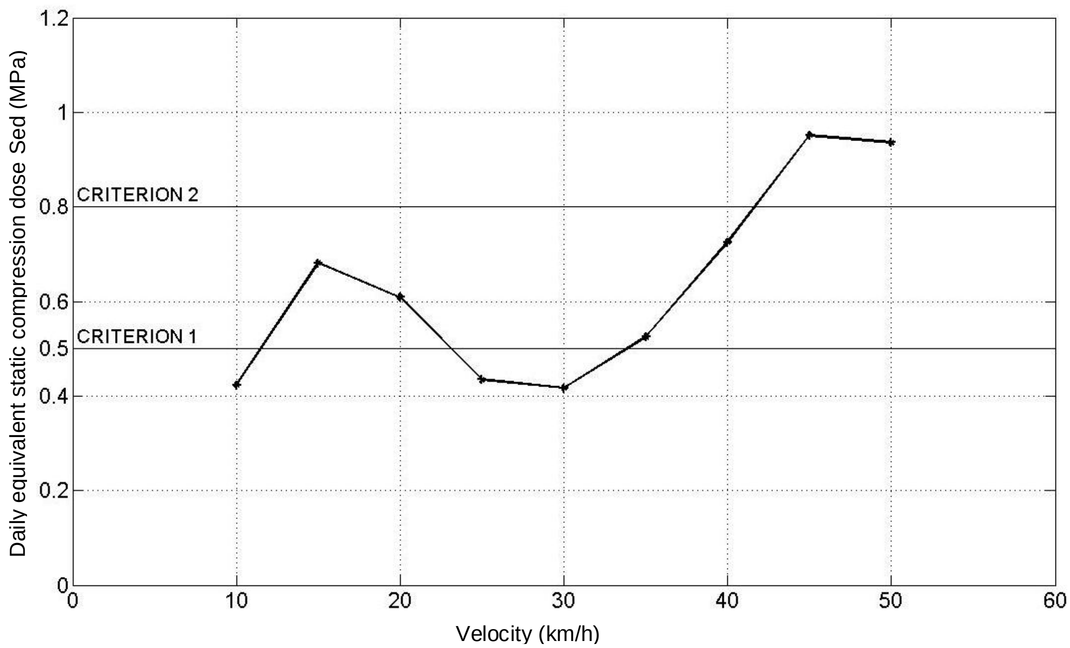


Figure 13. Parameter Sed for the bus driver on the line 26 in Belgrade.

speed of 31 km/h and over 26 km/h respectively, as well as for the rounded profile 0.03 m high at all speeds considered, the driver's health is susceptible to the 'low risk of negative effect' of shock vibrations. Based on the analysis of the results of simulation, it follows:

a) At higher speeds, major negative effect to the driver's health comes from shock vibrations due to the pass over the flat platform. For this type of SCH, the highest values of the parameter 'Sed' correspond to highest speeds and largest number of passes over (Figure 11a). With the increase of the number of passes over, the raise of Sed value is more significant with higher bus speeds.
b) At lower speeds, major negative effect to the driver's health comes from shock vibrations due to the pass over the rounded profile 0.05 m high. The highest values of Sed parameter for the rounded profile of 0.05 m correspond to low bus speeds and large number of passes over (Figure 11b). With the decrease of the bus speeds, the raise of Sed value is more significant with higher number of passes over SCH.
c) Maximum values of Sed parameter for the rounded profile 0.03 m high occur also for large number of passes over and low bus speeds, but those values of Sed parameter, after the ISO 2631 standard have insignificant effect to the driver and indicate low risk to the driver's health.
d) The height of the rounded profile significantly influences the effect of shock vibrations to the driver's body (Figures 11b and 1c).

The analysis for constant speeds and different number of passes over SCH shows that at the constant bus speed of 15 km/h and for whole considered range of the number of daily passes over the flat platform, as well as over the rounded profile 0.03 m high, shock vibrations have a 'low risk' effect to the driver's health. At the same speed, passing over the rounded profile 0.05 m high, shock vibrations have the 'moderate' effect to the driver's health, even for only five passes over per day. For more than 25 passes over per day, the parameter Sed gets the values larger than 0.8 MPa (Figure 10a) which is the criterion of 'significant risk' to the driver's health. Above 45 passes over per day, Sed value is in excess of 0.9 MPa. At the constant bus speed of 50 km/h and for rounded profile 0.05 m high, the values of Sed exceed the criterion of 'significant risk' to the driver's health at only 7 passes over. For 60 passes over per day, Sed reaches the very high value of 1.18 MPa (Figure 10c).

Cumulative effect of shock vibrations on the bus line 26 in Belgrade

Two obvious peaks (at 15 and 45 km/h) can be explained considering the results of the simulation previously exposed. At lower speeds, the main effect to the driver's health comes from the shock vibrations due to passing over the rounded profile of 0.05 m. The high 0.7 MPa value of the parameter Sed for the speed of 15 km/h can be emphasized. Over 35 km/h, the vibrations due to passing over the flat platform have major effect to the driver's health. At speeds over 42 km/h, the driver is exposed to 'significant risk' of consequences to health and the greatest value of Sed parameter is 0.95 MPa while bus speed is 45 km/h. At speeds up to 12 km/h and in range 23 to 34 km/h, the negative effect of shock

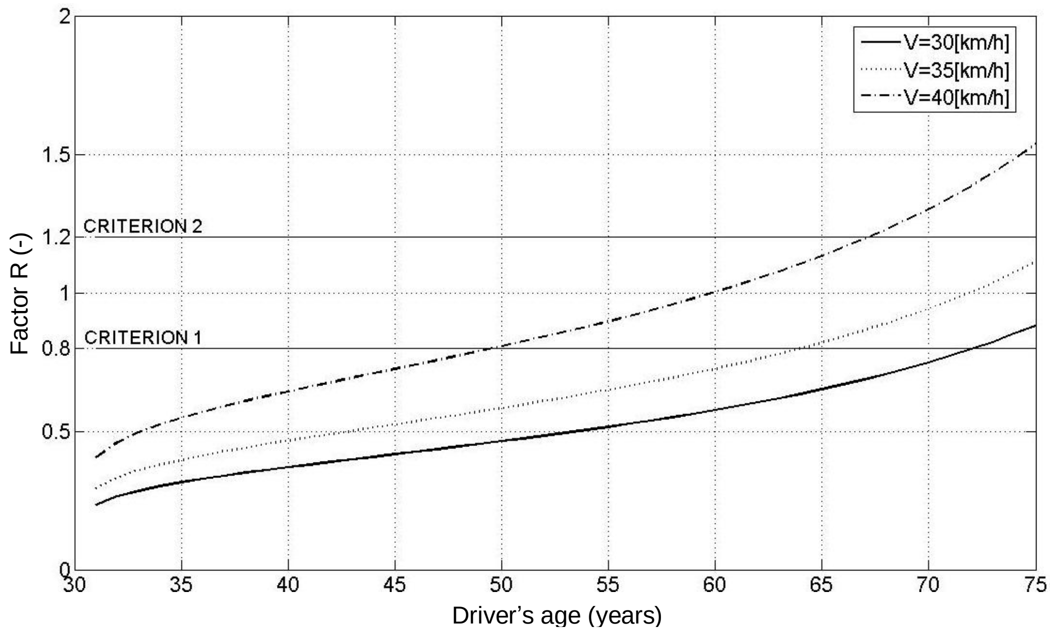


Figure 14. Factor R for the bus driver on line 26.

vibrations to the driver's health after the ISO 2631-5 standard is low. At speeds from 12 to 23 km/h, the driver's health is exposed to moderate risk from shock vibrations, while at speeds over 42 km/h ISO 2631-5 standard, the driver is exposed to significant risk of lumbar spine illness. Figure 14 shows the change of the Factor R for the driver on the line 26 for bus speeds of 30, 35 and 40 km/h. The Factor R is calculated with the assumption that the city bus driver starts his working life when 30 years old and works 240 days per year.

According to Figure 14, at low speeds (30 km/h), harmful effect of shock vibrations to the driver's health may occur in later period of his life only. A moderate negative effect to the driver's health at speed of 40 km/h may appear around the age of 50 which is important having in mind that in average, drivers work actively until age of 55 (GSP Beograd, 2005). The effect of shock vibrations due to passing over SCH to the driver's health in service, considering his working life and average route depends mainly on the speed applied to pass over the obstacles. Even relatively small speed differences can make distinction between categories "insignificant - low risk", "moderate" and "harmful - significant risk" of negative effect to the driver's health.

Conclusions

Speed control humps (SCH) are widely used as means to reduce vehicle speed and improve safety in some urban areas. The bus drivers are generally exposed to shock vibrations which are particularly intensive when passing over SCH. Repeated and long-term exposure of driver to shock vibrations during his working life produces musculoskeletal disorders, the acute low back pain being one of the most important. The simulation analysis of the effects of shock vibrations to the health of the driver of a typical modern city bus is performed in this paper through simulation, by means of an original oscillatory model with five degrees of freedom and using evaluation method and criteria approved by ISO 2631-5 standard. Shock vibrations due to three typical SCHs at different speeds were analyzed, as well the cumulative effect of different SCH on an actual public transport bus line in Belgrade. The results show that the effect of shock vibrations resultant to passing over SCH to the specific bus driver's health depends on the bus speed, geometry of the hump and daily number of passes over. The influence of the SCH with rounded profile 0.03 m high to driver's health, for all bus speeds considered is low or negligible. The rounded profile 0.05 m high has major harmful effect to driver's health at low speeds, being the most significant at 15 km/h. Over 26 km/h, the risk of health disorders caused by harmful effect of shock vibrations for this SCH profile considerably decrease. The flat platform has major harmful effect to driver's health at higher speeds, particularly at 45 km/h.

Below 31 km/h, the risk of health disorders caused by harmful effect of shock vibrations for the flat platform decreases. During one working day on the bus line 26 in Belgrade, the driver makes 4.5 turns and 18 passes over rounded profile of 0.03 m, 9 over rounded profile of 0.05 m and 18 over flat platform. Harmful effect of shock vibrations to the driver's health, passing over SCHs at lower speed (30 km/h), may occur in later period of his life only. At speed of 40 km/h, a moderate negative effect to the driver's health may appear around his fifties, which is important considering that drivers work actively until age of 55. The effect of shock vibrations to the given city bus driver's health in service depends mainly on the speed applied to pass over speed control humps. Even relatively small speed differences, on long term, can make distinction between categories "insignificant - low risk", "moderate" and "significant risk" of negative effect to the driver's health.

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