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VEHICLE SPEED INFLUENCE ON GROUND-BORNE VIBRATIONS CAUSED BY ROAD TRANSPORT WHEN PASSING VERTICAL TRAFFIC CALMING MEASURES

ABSTRACT

Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorized street users. Vibration measurements were performed by the authors of this paper near the roads with traffic calming devices. The measurements were taken throughout two seasons: in the winter and in the summer in order to evaluate the influence of soil freezing on traffic-induced vibrations. The only car measured was Fiat Doblo (weight 1,405 kg), and its driving speed when passing a speed bump or a speed table was controlled (20 km/h; 30 km/h; 40 km/h). The results show that the Peak Particle Acceleration (PPA) values were higher in the winter season compared with the summer. The vehicles passing over the speed tables induce lower PPA values than those passing over the speed bumps.

KEY WORDS

ground-borne vibrations; traffic calming measures; traffic-induced vibrations; seasonality;

1. INTRODUCTION

Road transport-induced vibrations are a common concern in cities worldwide. House owners may complain about the annoyance and building damage. There is a concern about the possibility of negative effects of vibrations on historical buildings, especially if they are in poor condition. Vibrations may also interfere with sensitive processes, such as those in hospitals, scientific research laboratories, and high-tech industries [1-4].

Traffic calming is a combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour, and improve conditions for non-motorized street users [5]. Vertical Speed Control Measures are the vertical elevated segments of roadway that slow down the vehicle traffic. Typical vertical speed control measures include speed bumps, speed tables, raised sidewalks, and raised intersections [6-8]

A speed table is a raised flat-topped device, which is placed across the roadway. Speed tables usually have a height from 76 to 101 millimetres. The flat top has a length of approximately 3 widths in the direction of travel and each ramp has a length of 1.8 metres. The design speed for a speed table is approximately 30 kmph, which is a safe and comfortable speed for passenger vehicles. Even though it is agreed that the speed tables reduce vehicle speed effectively, there are concerns about noise and vibration emissions. The main disadvantage of such a device is that emergency vehicles must also reduce their speed [8, 9].

A speed bump is generally designed as a rounded, raised pavement structure which usually has a height from 0.05 to 0.15 m. It is usually designed with a length from 0.3 to 0.9 m. A width of a speed bump may be e.g. 0.3 m or even 3 m, depending on the intent of the device and the nature of the road on which it was constructed. The design of speed bumps generally enforces a comfortable crossing speed under 8 kilometres per hour or lower; therefore, the speed bumps are usually appropriate only for use at parking lots, private roads and on some residential streets, where the vehicle speed is typically the lowest [8, 10].

Ground-borne vibrations are produced when vehicles pass over the profiles mentioned before and, in some cases, they can reach perceptible levels in adjacent buildings. G. R. Watts and V. V. Krylov took measurements of peak particle velocity alongside a selection of speed bump and speed cushion using a range of vehicles under controlled driving conditions. Ground-borne vibrations are generally perceptible in situations where the road surface is uneven and the buildings are situated close to the road [11]. Vertical traffic calming measures can be a potential source of vibrations. Both compression and shear waves are produced in the ground and their amplitudes and attenuation with distance depend critically on the soil composition. These short-duration or impulsive ground-borne vibrations, rather than those produced by airborne sound waves, often produce the highest peak particle velocities (PPVs) in the hard structure of the buildings [12].

The propagation of traffic-induced vibrations from the source depends on the distance from the receiver, frequency of vibrations, topography between the source and the receiver, and on the soil and geotechnical characteristics of the ground. Vibrations propagate through the ground in the form of body waves (compression and shear waves), and in the form of surface or Rayleigh waves. The Rayleigh waves are the most important form for the propagation of traffic-induced vibrations because at the ground level the amplitude of the Rayleigh waves decreases (due to geometric spreading) as the inverse of the square root of the distance from the source, while the amplitude of body waves decreases as the inverse of the square of the distance from the source [13-15].

According to the studies by other researchers, the soil freezing mainly influences the dynamic modulus and damping ratio of soil which are the most important parameters in the ground-borne vibrations spread [16-19].

The aim of this paper is to evaluate the differences between ground-borne vibration values throughout the warm and cold seasons.

2. METHOD

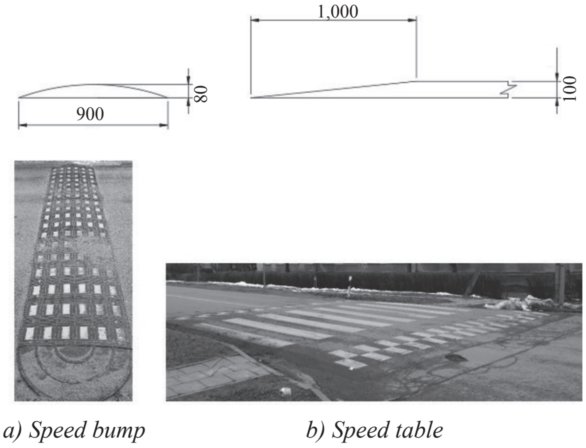
Vibration measurements were taken near roads where traffic calming devices have been built. Measurements were taken throughout two seasons: in the winter and in the summer, according to the same methodology, to assess the impact of the season on traffic vibrations.

The only car measured was Fiat Doblo (weight 1,405 kg), the driving speed of which when passing over speed bumps or speed tables was controlled (20 km/h; 30 km/h; 40 km/h). The speed limit on the tested road sections is 50 km/h; however, it would not have been meaningful to go faster than 40 km/h because the real traffic conditions would not be simulated. The traffic-induced vibration depends on three variables at the source: surface condition (random surface roughness, cracks, and junctions), vehicle parameters (weight, axle stiffness) and vehicle speed (Hajek et al. 2006, [13]). The decision to control speed and measure the same car eliminates two controllable variables at the vibration source. The road surface condition might slightly change due to freezing and warming, but such changes were not noticed in this research.

Two different vertical traffic calming measures were picked for testing. Principal schemes of both measures are shown in *Figure 1*. The speed bump is made of rubber, and the speed table is made of asphalt. The whole length of the speed table is 6 metres.

To measure the traffic-induced vibrations, a vibration meter was used. In the set of equipment, an accelerometer and signal amplifier were also used. The set of equipment used to measure vibrations is shown in *Figure 2*.

Acceleration of the vibration was measured in all three axes (X, Y, Z). After the check, the later measurements were taken in that axis in which acceleration of the vibrations was measured as the



a) Speed bump *b) Speed table*

Figure 1 – Cross sections and photos of tested traffic calming measures

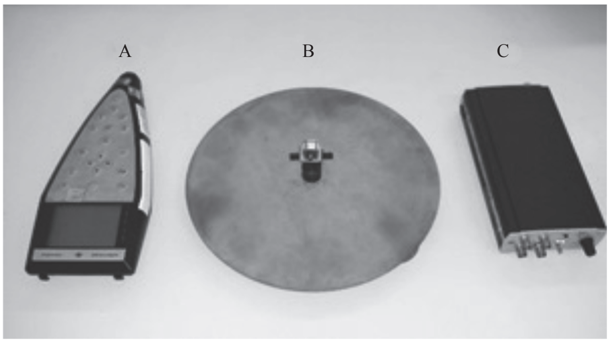


Figure 2 – Set of equipment used to measure vibrations A –Vibration meter; B – Steel plate with accelerometer; C – amplifier

highest. Z-axis is a vertical axis, X-axis is parallel to the road, Y-axis is crossing the road. The measuring parameter is the acceleration of vibrations (mm/s^2).

Two measurement points were selected on the road section near the speed bump or table where the distance from the road was 1 and 5 m perpendicularly. Two reference measurement points were chosen within the same distances from the road, where the influence of the speed bump was unnoticeable. The reference points were chosen in the distance of 100 m to the traffic calming device on the selected road section for the study. The principal measurement set up is given in *Figure 3*.

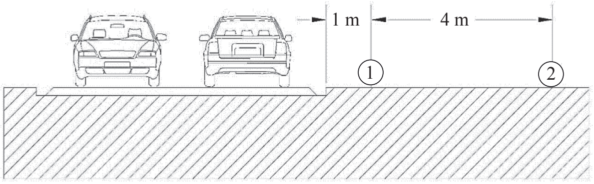


Figure 3 – Principal scheme of measurement points

Every passing by of the test vehicle was measured separately. For the tests, two measurement systems were used. The measurements were done simultaneously near the speed calming device and at the reference point within the same distance from the road. In every measurement point 30 passes were recorded. The measured parameter is the peak particle acceleration (PPA, mm/s^2).

3. RESULTS

Ground-borne vibration tests near the traffic calming measures were performed throughout different seasons. The test results near the bump show that in the winter the PPA values were higher. During the measurement in the winter the air temperature was –5°C. It is important to notice that the air temperature during the 30 days before the test were constantly below 0°C and the lowest negative values in that month reached –20°C, and this temperature was maintained for a week before testing. In the summer, at the moment of testing, the temperature was 22°C, and 30 days before the testing the temperature never dropped below 15°C. When the vehicle increases speed, the PPA values increase more throughout the cold season. During both seasons, there is a gap between the values. This shows that when the vehicle runs on different sides of the tested road, the PPA reduction is noticeable.

Test results near the speed bump are shown in *Figure 4*. The highest PPA values were recorded when the vehicle crossed the speed bump at a speed of 40 km/h. The highest PPA value was recorded in the winter and it reached 25 mm/s^2. The lowest values were recorded when the vehicle crossed the speed bump at a speed of 20 km/h.

At the reference measurement point (*Figure 5*), higher PPA values were also recorded during the cold season. When the vehicle increased speed, at the reference measurement point, the PPA values did not increase so significantly as at the measurement point near the speed bump (*Figure 4*). On the road section near the reference measurement point the asphalt was in good condition, and no cracks or bumps were visible. When the road pavement is even, the PPA values are similar to those when the vehicle runs at a speed of 30 km/h or 40 km/h.

At the reference measurement point, the highest PPA values were recorded when the vehicle was running at a speed of 30 km/h; the highest PPA value was recorded in the winter and reached 16.1 mm/s^2. The lowest values were recorded when the vehicle was driving at a speed of 20 km/h. It is noticeable that a speed bump increases the traffic-induced vibrations compared with the same street section where such a device is absent. On average, when the vehicle was driving at a speed of 40 km/h, the speed bump increased the PPA values by 7.6 mm/s^2.

The measurements near the speed table were taken in the second part of the test. The results show that vehicle driving at different speeds does not induce such an increase of PPA values as it was noticed during the measurements near the speed bump, which means that when vehicle crosses a "smoother" traffic calming device, the impact force does not increase significantly when driving at different speeds.

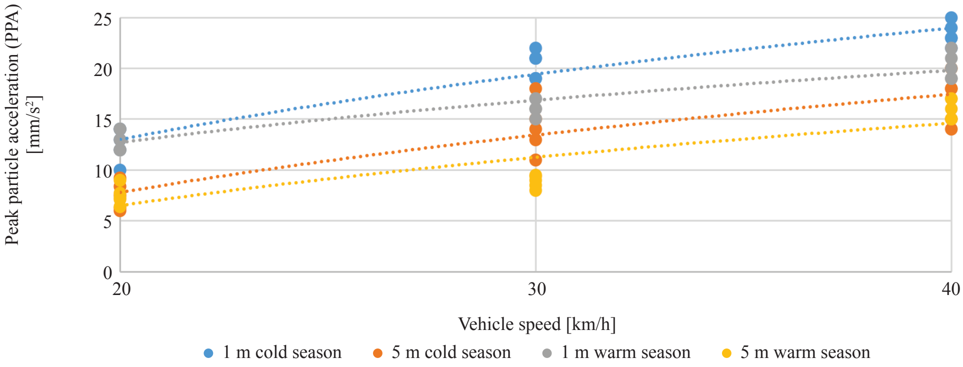


Figure 4 – PPA values at measurement points, near the speed bump

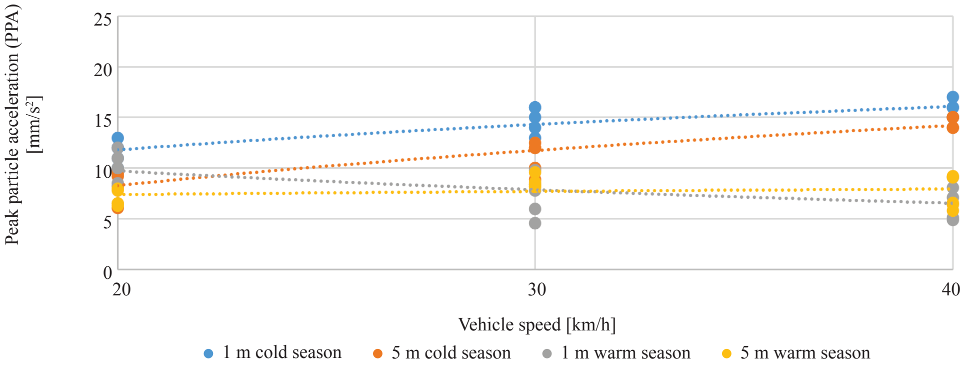


Figure 5 – Peak particle acceleration values at speed bump reference measurement point

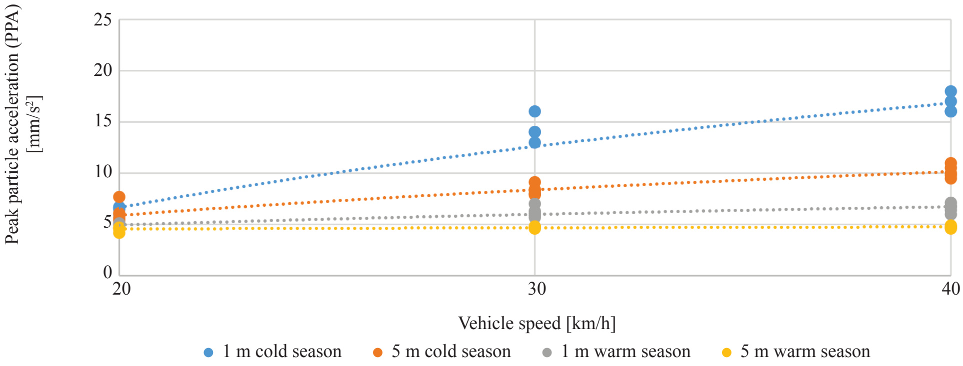


Figure 6 – Peak particle acceleration values at measurement point, near the speed table

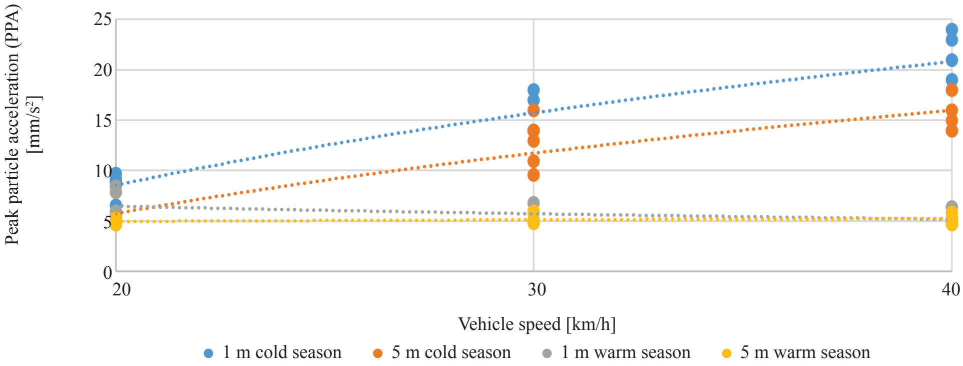


Figure 7 – Peak particle acceleration values at speed table reference measurement point

The test results near the speed table are shown in *Figure 6*. The highest PPA values were recorded when the vehicle was crossing the speed table at a speed of 40 km/h, the highest PPA value was recorded in the winter and reached 18 mm/s^2.

At the reference measurement point, the results show that the obtained PPA values were higher than those near the speed table. On this street, the asphalt was not new and there were some cracks on the road surface. Such condition of the road pavement causes an increase of PPA values even higher than those near the traffic calming device.

The test results obtained at the reference measurement point are shown in *Figure 7*. The highest PPA values were recorded when the vehicle was driving at a speed of 40 km/h. The highest PPA value was recorded during the cold season and it reached up to 24.1 mm/s^2. The lowest values were recorded in the summer, and the PPA values were similar even if the vehicle was driving at different speeds. The PPA values in the summer were approximately 5 mm/s^2.

The difference of PPA values was noticeable when the test vehicles were passing the measurement area on different sides of the road (*Table 1*). The comparison of the results indicated that shifting the source farther away reduces the PPA values by 26% during the winter and by 17.2% during the summer.

In *Table 1* the average values of the test results are shown when the vehicle was driving closer to the line of the measurement point. The results show that the PPA values were higher in the winter than in the summer. A speed table induces lower PPA values than a speed bump.

The average values of test results obtained at the measurement point when the vehicle was driving on the other side of the road are shown. The results show that the PPA values were higher in the winter than in the summer. A speed table induces lower PPA values than a speed bump.

The results of experimental study indicate that the changes of temperature in different seasons influence the values of ground-borne vibrations.

4. DISCUSSION

In this study the authors have measured traffic-induced ground-borne vibrations near two different traffic calming devices (speed tables and speed bumps) in the summer and in the winter. These traffic calming devices were built on the city streets. During the test, the vehicle was driving at the speeds of 20 km/h; 30 km/h and 40 km/h. After measurements and data analysis it was identified that ground-borne vibrations increased in the winter.

In most recent studies, the authors have found similar trends. However, in this study the difference of cold and warm seasons is considered. In addition to other similar studies, the authors have found the same tendency in vehicle speed correlation with the induced ground-borne vibrations [12]. Most of the studies testing the source of ground-borne vibrations use heavy transport. In this study the residential areas where heavy transport is forbidden were chosen; therefore, in this study, the absolute PPA values are on the average 50% lower compared with the results obtained by other authors [1, 3, 12, 20].

The properties of soil were not tested in this study. Therefore, the comparison between speed bump and speed table reference points is not possible. This limitation did not allow making the conclusions on the road patching effect on the ground-borne vibrations.

During the study, it was indicated that on the patched road section the PPA values for ground-borne vibrations were similar or higher compared

Table 1 – Average values of test results, when the vehicle runs on different sides of the road, the measuring distance being 1 m to the road

Type of traffic calming measure Season		Average PPA value [mm/s^2]					
		20 km/h		30 km/h		40 km/h	
		Closer side of road	Farther away side of road	Closer side of road	Farther away side of road	Closer side of road	Farther away side of road
Near the speed bump	Winter	12.6	7.5	20.4	14.2	23.4	17.0
	Summer	13.0	7.5	16.2	8.9	20.2	16.0
Near the speed table	Winter	6.5	5.9	13.0	8.34	16.6	10.2
	Summer	4.9	4.5	6.2	4.7	6.6	4.7
Speed bump reference point	Winter	11.6	8.6	14.8	11.8	15.8	14.6
	Summer	9.9	7.0	7.3	8.6	6.9	7.4
Speed table reference point	Winter	8.7	5.3	15.4	12.7	21.0	15.4
	Summer	6.6	4.9	5.4	5.3	5.4	5.1

with the values obtained at the speed table. The ground-borne vibrations measured on the repaired (patched) roads need further investigation.

5. CONCLUSION

Traffic calming measures increase the ground-borne vibrations caused by the road transport. The PPA values near the speed bump were 10% higher than at the reference point, when the vehicle was driving at a speed of 20 km/h. When vehicle speed was 30 km/h and 40 km/h, the PPA values were 21% and 28% higher, respectively.

When road pavement has been repaired several times, the road surface is cracked and bumpy, and the PPA values are higher on such roads compared with vibrations near the vertical traffic calming measure. Such condition of the road surface increased the vehicle-induced ground-borne vibrations more than the newly built speed table itself. Such phenomenon was found on the measurement site near the speed table. On the average, the PPA values were higher at the reference point by 7% when the vehicle was driving at a speed of 20 km/h. When the vehicle was driving at the speeds of 30 km/h and 40 km/h, higher PPA values were recorded at the reference point by 24% and 27%, respectively.

When the vehicle increased the speed, the PPA values increased. The PPA value was 22% higher when the vehicle was driving at a speed of 30 km/h comparing with the vehicle driving at a speed of 20 km/h. In comparison to the speed of 30 km/h and 40 km/h – the PPA value is higher by 11% at the speed of 40 km/h.

Vibrations caused by traffic were higher throughout the cold season (in the winter). Near the speed bump in the winter, the PPA values were on average 12% higher than in the summer. Near the speed table in the winter, the PPA values were on average 43% higher than in the summer.

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AUTOMOBILIO VAŽIAVIMO GREIČIO ĮTAKA ŽEME SKLINDANČIOMS VIBRACIJOMS, KAI AUTOMOBILIS VAŽIUOJA PER VERTIKALIĄSIAS GREIČIO MAŽINIMO PRIEMONES

SANTRAUKA

Įvarios, daugiausiai fizinės priemonės kurios sumažina negatyvius transporto naudojimo efektus (keičiami vairavimo ypatumai, gerinamos sąlygos pėstiesiems) vadinamos greičio mažinimo priemonės. Šio straipsnio autoriai atliko vibracijos tyrimus prie kelių kuriuose sumontuotos greičio mažinimo priemonės. Tyrimai truko du sezonus: žiemos ir vasaros sezonais, tam, kad įvertinti dirvožemio įšalo įtaką transporto sukeliamoms vibracijoms. Vienintelis automobilis, kuris buvo naudojamas tyrimų metu: Fiat Doblo (Svoris 1405 kg), kurio greitis važiuojant per greičio mažinimo kalnelius buvo kontroliuojamas (20 km/h; 30 km/h; 40 km/h). Rezultatai parodė, kad didžiausias dalelių pagreitis (DDP) buvo didesnis žiemos sezono metu palyginus su vasaros. Automobiliui važiuojant per trapecijos formos greičio mažinimo kalnelį sukeliamos didesnės DDP vertės palyginus su apskritiminės formos greičio mažinimo kalneliu.

REIKŠMINIAI ŽODŽIAI

žeme sklindanti vibracija; greičio mažinimo priemonės; transport sukeliama vibracija; sezoniškumas;

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