THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

ISSN 1822-427X / eISSN 1822-4288
2015 Volume 10(2): 191–199

SPEED BUMPS IMPACT ON MOTOR TRANSPORT NOISE

Tomas Januševičius[1]✉, **Rasa Akelaitytė**[2]

Dept of Environmental Protection Institute, Vilnius Gediminas Technical University,
Saulėtekio al. 11, 10223 Vilnius, Lithuania
E-mails: [1] *tomas.janusevicius@vgtu.lt;* [2] *rasa.akelaityte@stud.vgtu.lt*

Abstract. Most accidents are caused by excessive speed or aggressive driver behavior. One of the most popular speed regulation implement is speed bumps. However, there are some problems with speed bumps as well – it has been noticed that speed bumps increase motor vehicle-induced noise. This article presents investigation on how speed bumps increase motor vehicle-induced noise. The investigations were carried out on Klaipėda and Vilnius streets during different time of the day and year. Brüel&Kjær sound level meters type 2260 and 2270 were used to investigate how much noise is caused by vehicles passing different types of speed bumps.

Keywords: speed bumps, noise, traffic, noise level limit, noise barrier, speed reduction, speed cushion, speed table.

1. Introduction and problem

With increase of automation of the manufacturing industry and agriculture, traffic flows in towns and residential areas as well as with household appliances becoming more modern, the number of acoustical discomfort zones is rapidly growing. The level of noise in a workplace or home environment is one of the main factors predetermining the indicator of comfort, therefore, an increasing attention is devoted to the analysis of noise processes (Grubliauskas, Butkus 2009).

Noise is defined as an unpleasant sound that causes discomfort. Most of the noise that one hears originate from human activities. The main sources of noise are: transport sector, industrial and construction machinery and special events. Noise pollution is increasing in the industrial societies and cities (Jadhav 2011). Traffic-generated noise accounts for 60–80% of the noise prevailing in towns and during the last 10 years noise levels in towns have increased by approximately 0.5–1 dB per year. Therefore, all over the world, in order to reduce noise pollution in the environment, shields and walls protecting from noise and pollution are built near streets with intensive traffic, highways and noisy factories (Grubliauskas, Butkus 2009).

It is well known that noise brings many negative physiological and psychological effects for people and many residents suffer from traffic-generated noise – constant noise acts as a factor causing nervous strain and stress (Lipfert, Wyzga 2008). Urban noise has become a major environmental problem, mainly due to intense road and air traffic, while many technologies have been developed to reduce industrial noise. Sleep disturbance is among the most important health effects of urban noise (Stosić *et al.* 2009). The problem of traffic noise due to crossroads with traffic lights and roundabouts is almost 30 years old (Makarewicz, Kokowski 2007). The origins of environmental noise are human activities especially associated with the process of urbanization and the development of transport (Jagniatinskis *et al.* 2011).

A few most common approaches for reducing environmental noise levels are as follows (Lorenzen 2009):

- reducing noise at source – from machines, engines, tires and surface;
- reducing speeds and traffic volume;
- limiting the transmission of noise by placing sound barriers between the source and people affected;
- reducing noise at the reception point, such as noise insulation of buildings.

The level of vehicle-induced noise depends on the amount of elements: driving speed, technical condition of vehicles, traffic intensity, tires, road paving, etc. Traffic noise compose of two components: the sound wave generated directly from the noise source which includes mechanical sourced noise – engine and electric fan noise and noise generated by the interaction between tire and pavement. The second component is the noise reflected by the pavement surface (Baltrėnas *et al.* 2009)

Speed reductions are a way of reducing traffic noise, providing that the necessary measures do not lead to an

doi:10.3846/bjrbe.2015.24

increase in accelerations and decelerations. Drivers know by experience that, at high crossing speeds, humps cause large vehicle body pitching motion, large suspension travel, and may further result in wheels losing contact with the road surface. Speed control bumps, on the other hand, offer a harsh effect on rides at low crossing speeds and may lose their effectiveness at higher crossing speeds (Başlamişli, Ünlüsoy 2009). A speed bump, speed hump or ramp is a traffic calming measure of road design used to slow traffic or to reduce through traffic via vertical deflection. Humps are placed across the road to slow traffic and are often installed in a series of several humps in order to prevent cars from speeding before and after the hump. A warning sign notifies motorists before humps. Humps generally have pavement markings to enhance visibility and a taper edge near the curb to allow a gap for drainage. Speed humps are used in locations where very low speeds are desired and reasonable. Speed humps are typically placed on residential roads and are not used on major roads, bus routes, or primary emergency response routes. Placement is generally mid-block between intersections. Typical speeds resulting from speed humps are 15–30 km/h. Studies show an average 18% reduction in traffic volume and an average 13% reduction in collisions. Although speed bumps are very effective in keeping vehicle speed down, their use is sometimes controversial as they are cause noise and possibly vehicle damage if taken at too great a speed. Poorly designed speed bumps often found in private car parks (too tall, too sharp an angle for the expected speed) is hard to negotiate in vehicles with low ground clearance, such as sports cars, even at very slow speeds. Speed bumps also pose serious hazards to motorcyclists and bicyclists if not easily noticed, though in some cases a small cut in the bump allows those vehicles to pass through without impedance (Blažys *et al.* 2009).

An optimal hump shape is expected to cause maximum discomfort to the driver exceeding the speed limit while minimizing discomfort below reference speed. Fig. 1 shows schematics of light car moving over speed hump and bump. Common speed hump shapes are parabolic, circular, and sinusoidal (Liu *et al.* 2014).

While similar to speed bumps, humps are less aggressive than speed bumps at low speeds and are used on actual streets, as opposed to bumps which are primarily placed in parking lots. While speed bumps generally slow cars to 8–15 km/h, the humps slow cars to 15–30 km/h). The narrow nature of speed bumps often allows vehicles to pass over them at high speed while only perturbing the wheels and suspension, hardly affecting the vehicle cab and its occupants. The relatively long slopes of speed humps

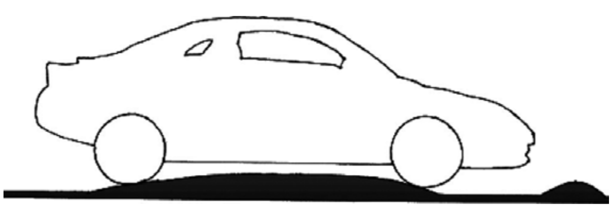

Fig. 1. Speed humps and bumps (Başlamişli, Ünlüsoy 2009)

gradually accelerate the entire vehicle in vertical direction causing the perturbation of the cab to become progressively more severe at higher speeds (Brambilla, Maffei 2010).

Speed cushions are traffic calming devices designed as several small speed humps installed across the width of the road with spaces between them. They are generally installed in a series across a roadway resembling a split speed hump. The design of speed cushions forces cars to slow down as they ride with one or both wheels on the hump. However, the wider axle of fire engines (and all other large vehicles) allows them to straddle the cushions without slowing down (Arana 2010).

Drivers slow down before and after the bump accelerate and at sites, where the device does not extend over the whole street, perform diversion maneuvers by traveling short distances in bus lanes, bus stops, or in lanes with oncoming traffic (Pau 2002). This kind of behavior causes increased traffic noise – clatter driving over the speed bump, acceleration after it. That also depends on vehicle type – heavy vehicles generate more noise driving over the speed bump than passenger cars and length of speed bump – as can be seen in picture above, if speed bump is long, going through is always smoother and the drivers experience less inconvenience. But if speed bump is short, then vehicle trembles more and that increases noise and drivers feel more uncomfortable.

There are some disadvantages using speed bumps:

- the city of Modesto in California, U.S. produced a fact sheet which contains the following disadvantages (City of Modesto...2009):
  - slow response time of emergency vehicles;
  - may divert traffic to parallel residential streets;
  - there is a possibility of increased noise and pollution for residents living immediately adjacent to the speed bumps.
- the English town of Eastleigh states the following as disadvantages (Brown *et al.* 2011):
  - can cause damage to some vehicles;
  - can increase traffic noise, especially when large goods vehicles pass by;
  - signs, street lighting and white lines are all required and may be visually intrusive;
  - can cause discomfort for drivers and passengers;
  - can cause problems for emergency services and buses.

Other sources argue that speed bumps increase pollution as traffic travels in a lower gear using significantly more fuel per mile are a substitute for active enforcement increase noise by both traversing over the bumps and by using more engine revs than normal.

The downside of speed humps is their effect on emergency vehicles. The response time is slowed by 3–5 s per hump for fire trucks and fire engines and up to 10 s for ambulances with patients on-board (Institute of Transportation...). Speed humps are thus usually not placed on primary response routes. Speed cushions may be placed on these routes instead. Occasionally, there is an increase in traffic noise from braking and acceleration of vehicles on streets with speed humps, particularly from buses and trucks (Paožalytė *et al.* 2012).

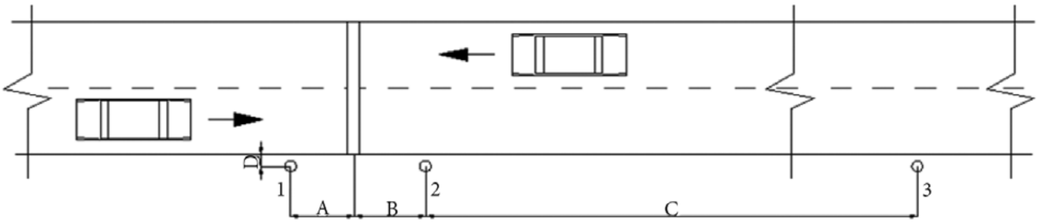

Fig. 2. The principal of traffic noise measurement: 1 and 2 – sound level meter position near the speed bump; 3 – sound level meter position about 100 m from speed bump; A, B – the distance between sound level meter and speed bump when sound level is measured near the speed bump; C – the distance between 2nd and 3rd sound level meter positions

Other effects include increased vehicle fuel consumption and emissions – as most fuel injection systems in modern internal combustion engines operate in open-loop mode (fuel rich) when accelerating – as well as increased wear and tear on brakes, engine and suspension components. Also heavy sedans, trucks, and S.U.V.'s (a large car with an engine that supplies power to all four wheels that is usually used for ordinary driving) are less affected by speed humps, and may not have to slow down as dramatically (Dai *et al.* 2008).

2. Object and methodology of investigation

The purpose of the study is to determine vehicle-induced traffic noise from driving over the speed bumps and to perform equivalent and maximum noise measurements. Measurements were carried out at 7 chosen streets in Vilnius and Klaipėda, where different kind of speed bumps and humps were installed. In all selected places a continuous car flow was ensured.

Two measuring points were selected near the speed hump in places where peak noise emission occurs and the third – the control measurement location – was selected away from speed bump, where the traveling cars do not affect noise emission (Petraitis *et al.* 2011).

The measurement results near the speed bump are compared to the results of the control point where noise levels are not influenced by speed bump. The principal of measurement is illustrated in Fig. 2. Noise is measured at 1.5 m from the edge of the street and a microphone is raised to 1.5 m height from ground level, at least 0.5 m away from the person performing the measurements.

The measurement equipment was:

- Brüel&Kjær sound level meter – type 2260. 2260 sound level meter is a precision sound analyzer platform. Three of the applications available are for full octave analysis, for full and 1/3-octave analysis and for extended range, 8 Hz–20 kHz, full and 1/3-octave analysis;
- Brüel&Kjær sound level meter – type 2270. An advanced, dual-channel, hand-held analyzer and sound level meter that has everything needed to perform high-precision, Class 1 measurement tasks in environmental, occupational and industrial application areas.

Before the noise level measurements weather conditions must be determined: relative humidity, air temperature and wind speed. This is necessary to decide whether to make measurements or not.

Fig. 3. Brüel&Kjær sound level meters 2260 and 2270

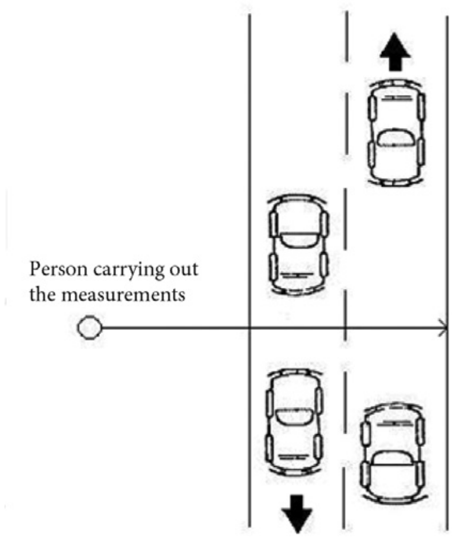

Fig. 4. The principal of traffic flow measurement

The aim of traffic flow calculations is to evaluate road flows and their impact on noise levels. Traffic flow is calculated during measurement of noise levels in all directions. The principal of measurement is illustrated in Fig. 4.

During calculations traffic flow is divided into passenger cars (cars with less than 3.5 t carrying capacity) and heavy vehicles (cars with more than 3.5 t carrying capacity) for more accurate evaluation of motor vehicle-induced noise.

In this investigation three types of speed bumps were selected – long and narrow, square shape and the raised crossing. These three types were selected to be able to compare the effect on noise from different type of speed bumps and to perform complete analysis of the noise generated near the speed bump.

The first measurement point was selected at Mogiliovas street where there are two 7200×420×60 mm speed bumps. This street is located in residential area, near schools, kindergartens and residential houses. In this particular area speed bumps are necessary to prevent accidents when pupils are crossing the street after school or after-school activities. Fig. 5 illustrates the area and shows the principle of speed bumps installment. From both sides of the street there are residential houses.

The second measurement point was selected at Debrecenas street. Around this point there are 4 schools and speed bumps (9000×420×45 mm) are installed near pedestrian crossing which is always full of pupils. The area from one side of the street is planted with trees and scrubs and on the other side of the street there are schools and dormitories. Fig. 6 illustrates situation of the area.

The third measurement point was selected at Tiltai street. This point is near the old town of Klaipėda and street is always full of townspeople, tourists and motor vehicles. To ensure safety of pedestrians there was installed 12000×800×50 mm speed bump. This area is open from both sides of the street. Fig. 7 shows situation at Tiltai street.

The fourth measurement point was selected at Sukilėliai street in Vilnius where 6000×800×60 mm speed bump is installed. Although this particular street is narrow and there are always a lot of heavy vehicles which induce a lot of noise. Near this measurement point there are residential houses, cemetery. Fig. 8 illustrates this area.

The next measurement point was selected at Šilutė avenue. As Fig. 9 shows, there are three square shape (2500×2500×70 mm) speed cushions. Šilutė avenue is one of the main streets in Klaipėda and is always full of traffic.

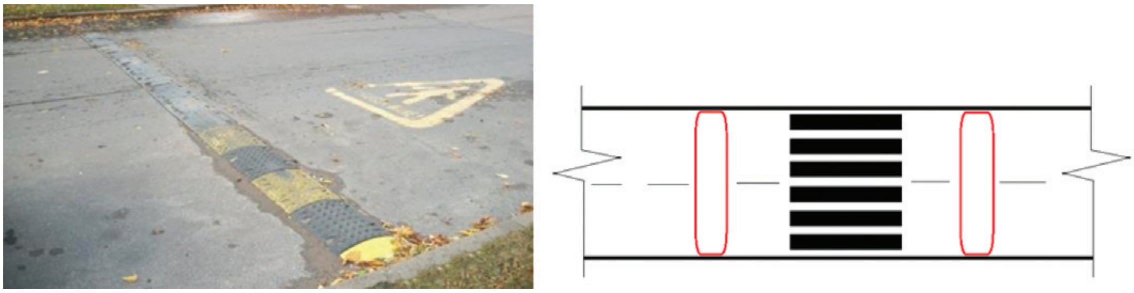

Fig. 5. Situation in Mogiliovas street and the principal scheme of speed bumps placing

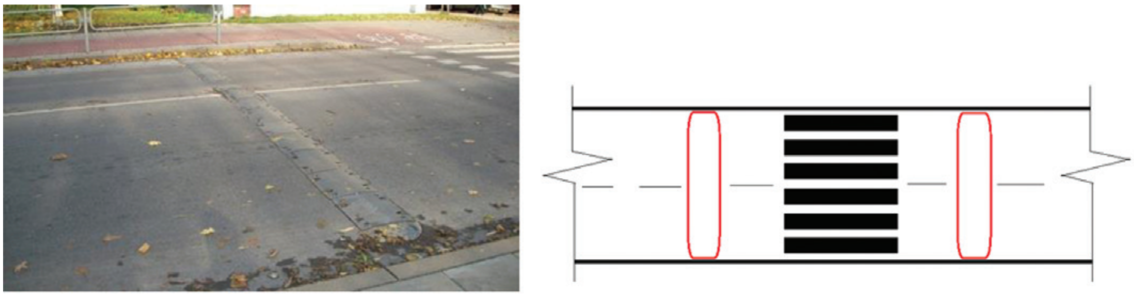

Fig. 6. Situation in Debrecenas street and the principal scheme of speed bumps placing

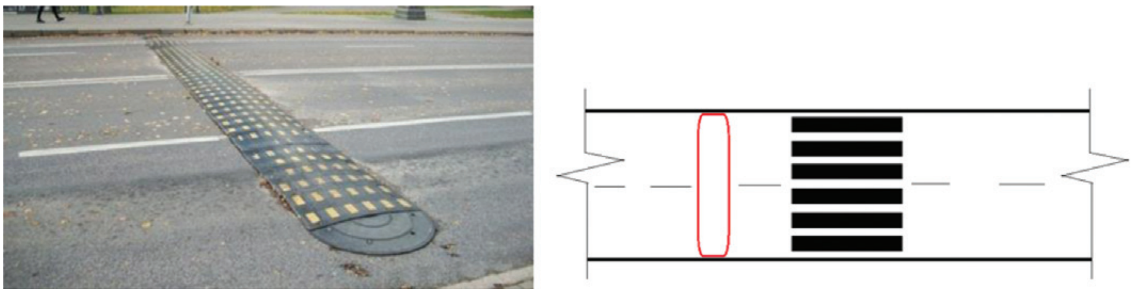

Fig. 7. Situation in Tiltai street and the principal scheme of speed bump placing

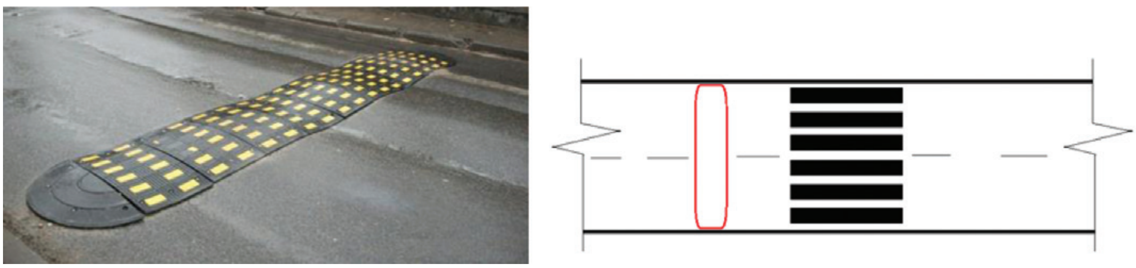

Fig. 8. Situation in Sukilėliai street and the principal scheme of speed bump placing

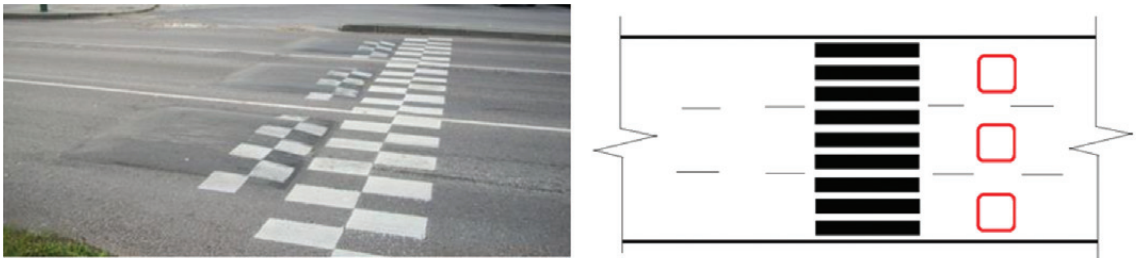

Fig. 9. Situation in Šilutė avenue and the principal scheme of speed bumps placing

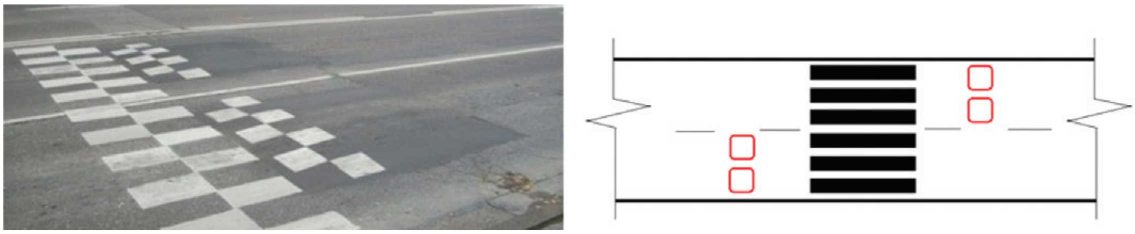

Fig. 10. Situation in Smiltelė street and the principal scheme of speed bumps placing

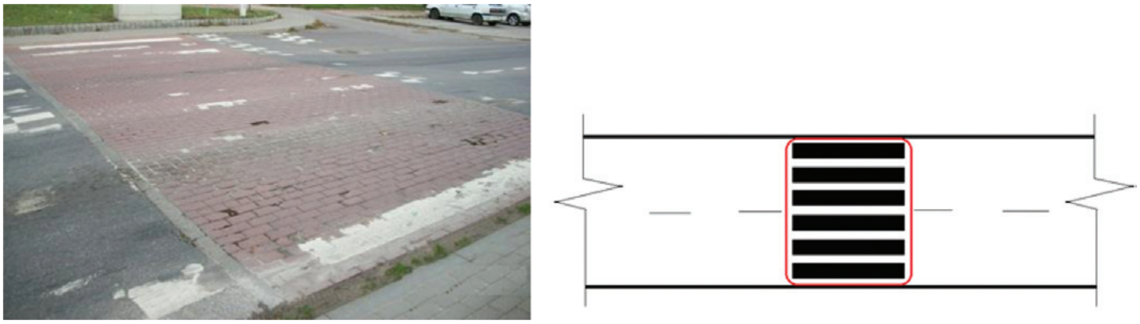

Fig. 11. Situation in Rimkai street and principal scheme of speed hump placing

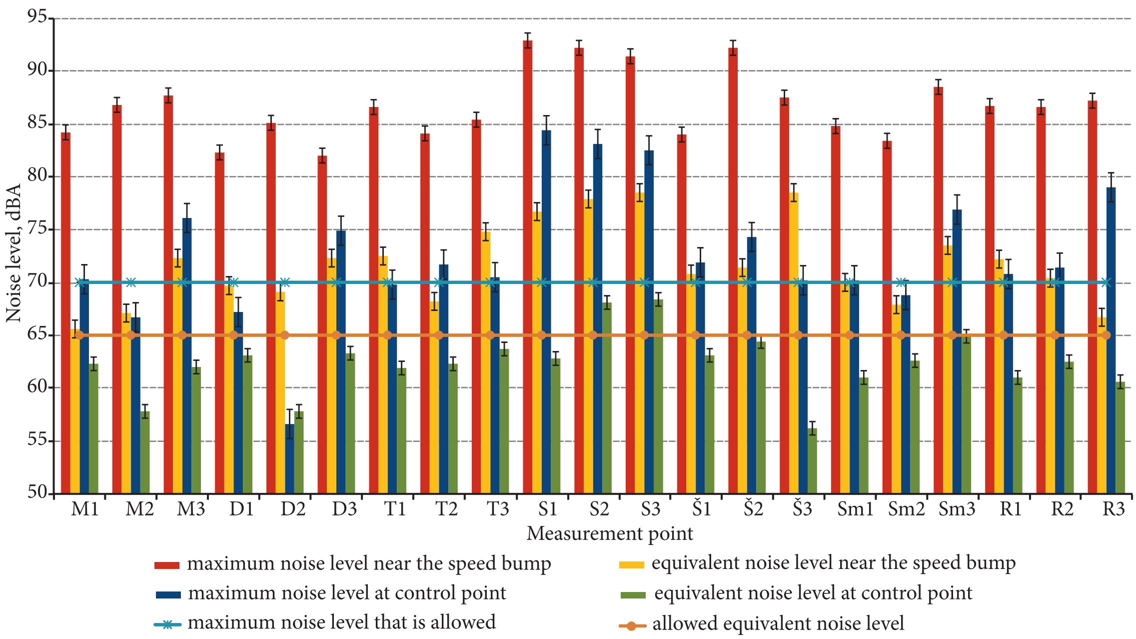

Fig. 12. Average level of noise in different stations: M – measurement point at Mogiliovas street; D – measurement point at Debrecenas street; T – measurement point at Tiltai street; S – measurement point at Sukilėliai street; Š – measurement point at Šilutė avenue; Sm – measurement point at Smiltelė street; R – measurement point at Rimkai street; 1, 2, 3 – the first, second and third measurement at the same point

The pedestrian crossway near those speed cushions is often used to get to the bus station. This area is open from one side of the street, but on the other side – there are residential houses and schools.

The same type of speed cushions (2500×2500×90 mm) is at Smiltelė street where the sixth measure point was selected. This area is open from one side of the street, but the other is by residential houses build-up. Fig. 10 illustrates the situation at the measurement point.

The last measurement point was selected in Rimkai street. Fig. 11 shows that in this area, there is a raised crossing (7000×4600×50 mm) which is used as speed hump or speed table. This street always full of goods traffic from the port and cargo from the port and railway station to the industrial area, suburbs and other towns. This raised crossing forces all the traffic to lower their speed to ensure safety of local residents.

3. Investigation results

Atmospheric conditions have effect on the spread of noise. During measurements the air humidity varied from 52 to 75%, the atmospheric temperature reached 7–10 °C and the wind speed in the daytime and in the evening was around 3–4 m/s. The prevailing winds were of the western direction.

The measurements of traffic noise were repeated three times thus making an overall test time of 12 h; a total of more than 7000 vehicles were observed during the measurements. Noise levels were measured in 7 different streets (Mogiliovas street, Debrecenas street, Tiltai street, Sukilėliai street, Smiltelė street, Šilutė avenue, Rimkai street) where different types of speed calming devices have been installed. Fig. 12 shows the noise levels in different measurement stations.

In order to determine how much influence speed bumps have on traffic noise, noise levels at different locations at different times were measured but at all times continuous car flow was ensured. The average noise levels are shown in Fig. 12. From Fig. 12 it is observed that the maximum noise levels remained similar during all three measurements in some locations. For example, in Sukilėliai and Rimkai streets near the speed calming device – varies for less than 1 dBA. The results in other streets vary more. This is explained by different traffic composition – although during the whole measurement there was constant traffic flow, but the number of light weight and heavy vehicles was different, thus giving us different results. The total number of traffic in all locations is shown in Table 1.

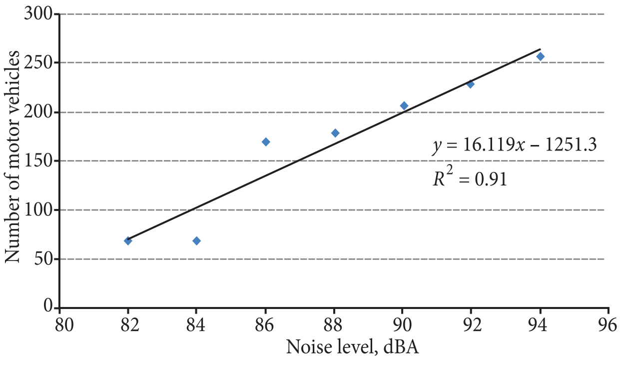

Fig. 13. Variation of noise level with traffic

From Fig. 11 seems the measured equivalent noise levels at speed bump come to 77–78 dBA and at control point the equivalent noise level reaches an average of 62 dBA what is 15 dB lower. The highest maximum noise levels at the speed bumps are as high as 92 dBA and only 74 dBA at the control points, what is 18 dB less than at the speed bump. Comparing these results it is seen that more motor vehicle-induced noise was generated by crossing speed bumps. Although measurements were carried out near different type of speed bumps, at all locations near speed bumps the difference of 10–20 dB from control point are recommended to be observed.

Most vehicle-induced noise was observed at Sukilėliai street measurement point. Probably, the wall which was built on one side of the street, affects these results. Noise, emitted from passing vehicles, was reflected from the wall, thus increasing results by few decibels. Noise measured at the control point in Sukilėliai street reaches the highest values of all results at control point. These results are caused by wider section of the street at which the control point was selected – increased capacity of motor vehicles resulted in higher levels of registered noise.

The biggest difference between maximum noise level near the speed bump and maximum noise level at control point was registered at Mogiliovas street measurement point. The average difference between three measurements reaches 14.6 dB. Equivalent sound pressure level (Leq) is defined as the average noise level on an equal-energy basis for a stated period of time and is commonly used to measure steady-state sound or noise that is usually dominant. The biggest difference between equivalent noise level neat the speed bump and equivalent noise at control point was registered at Sukilėliai street. The average difference between measurements is 11.3 dB.

The permitted equivalent noise level was exceeded at all locations where measurements were made. The maximum permissible noise level also exceeded at all stations. Measurements of control point show that the maximum permissible noise level was exceeded at only 5 situations out of 21. Fig. 13 depicts the relationship between traffic volume and noise level.

The maximum levels of noise were generated by heavy vehicles. Because of a different design compared to passenger cars, heavy vehicles cause considerable noise when passing road obstacles. Since most of speed humps are installed in the streets in residential area the noise affects people, especially during the summer, when the ambient temperature is high and windows are open for ventilation.

Fig. 14 shows percentage distribution of maximum noise level at different measurement locations. Percentage distribution of noise levels helps to determine which part of registered noise was induced by heavy vehicles. The highest values of noise levels were registered at Sukilėliai street. Most of motor vehicles induced noise a level (95%)

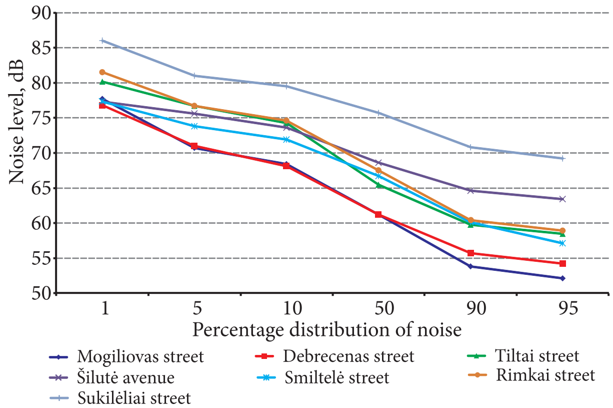

Fig. 14. Percentage distribution of maximum noise level

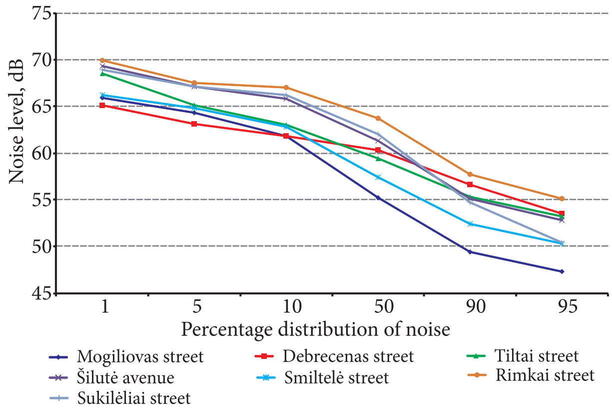

Fig. 15. Percentage distribution of equivalent noise level

Table 1. Summarized results

Speed-bump cross section	Noise levels, dBA				Number of motor vehicles			
	Max		Eq		Near speed bump		At control point	
	Near speed bump	At control point	Near speed bump	At control point	Light weight	Heavy	Light weight	Heavy
	Mogiliovas street							
	84.2	70.3	65.6	62.3	57	20	55	17
	86.8	66.7	67.1	57.8	63	18	71	18
	87.7	76.1	72.3	62.0	79	13	76	10
	Debrecenas street							
	82.3	67.2	69.7	63.1	192	25	11	13
	85.1	65.6	69.1	57.8	173	14	194	15
	82.2	74.9	72.3	63.3	176	8	194	6
	Tiltai street							
	86.6	69.8	72.5	61.9	25	25	30	22
	84.1	71.7	68.2	62.3	26	19	27	27
	85.4	70.5	74.8	63.7	30	10	22	7
	Sukilėliai street							
	92.9	84.4	76.7	62.8	313	18	281	32
	92.2	83.1	77.9	68.1	262	23	277	16
	91.4	82.5	78.5	68.4	175	8	168	12
	Šilutė avenue							
	84.0	71.9	70.8	63.1	257	30	265	28
	92.2	74.3	71.4	64.4	263	28	272	25
	87.5	70.2	73.7	65.2	150	17	167	19
	Smiltelė street							
	84.8	70.2	70.0	61.0	231	15	208	22
	83.4	68.8	67.9	62.6	222	15	227	20
	88.5	76.9	73.5	64.9	227	15	233	15
	Rimkai street							
	86.7	70.8	72.2	61.0	181	27	245	19
	86.6	71.4	70.4	62.5	241	26	195	24
	87.2	79.0	66.7	60.6	190	23	168	22

varies from 53 dB to almost 70 dB. But 1% of all traffic flow at that point induced noise levels over 85 dB. Those 1% motor vehicles caused such high measurement results shown in Fig. 11. 95% of traffic flow consists of passenger cars which induce lower noise levels. But if the traffic flow very high, noise level from passenger cars can add up and this will cause higher noise levels. That can be observed in Fig. 14 at sukilėliai street and Šilutė avenue – traffic flow there is really heavy any time of day.

Fig. 15 shows percentage distribution of equivalent noise level at different measurement locations. AIf percentage distribution of maximum noise levels (Fig. 14) is compared to percentage distribution of equivalent noise levels it could be seen that equivalent noise levels are spread more evenly. That is because equivalent noise level shows steady sound level of a noise energy-averaged over time, therefore the average noise level at different locations differs by only 5–7 dB.

Table 1 shows that in five locations (Debrecenas street, Sukilėliai street, Šilutė avenue, Smiltelė street, Rimkai street) traffic flow is really heavy even during working hours. In other two (Mogiliovas and Tiltai streets) heavy vehicles accounted for half of the traffic flow. When comparing noise level results at those two locations and the rest of them there are observed that for amount of traffic passed the average noise levels were higher compared to the results at locations where light-weight vehicles accounted for most of the traffic flow. From these results are seen heavy vehicles play a key role in the maximum levels of traffic noise.

4. Discussion

The relation between the speed of vehicles and the noise levels emitted when comparing various road surfaces is well known – up to 50 km/h the engine noise dominates and above 50 km/h the tire noise becomes the dominant noise source. To decrease the speed of vehicles in urban conditions, various types of road bumps can be used. These measures require the vehicle to slow before the bump and usually its speed increases after the bump, adding an accelerating engine to the noise sources. To evaluate the consequences of different types of speed bumps in terms of road traffic noise emission, a similar vehicle noise measurements were carried out in the city of Volos in Greece where 2 bumps (of different size and type) were installed and were subjected to multiple passes of a passenger car a S.U.V vehicle with simultaneous noise measurements and at Adam Mickiewicz University in Poland where not only noise levels near speed bumps were measured but also the driving style (normal or aggressive) was considered (Preis *et al*. 2008).

The vehicles conducted passages over the experimental sets with steady speed. Three passages were made by type and by speed. The passing speeds varied from 40 km/h to 60 km/h. As the vehicles conducted the passages, the microphones recorded and analyzed simultaneously the noise signals (Elioy, Vogiatzis 2013).

Results of these studies show similar results to the results of the authors of this article – noise levels near speed bump increase significantly – by 5–7 dBA, and in case the driving style is aggressive – by additional 5 dBA.

5. Conclusions

1. The noise levels on the main road near residential area or educational area are above the recommended level (65 dBA). This is mainly caused by heavy vehicles which generate more noise in engine crossing road obstacle.

2. Comparing vehicle-induced noise results at different type speed reducing device, most noise was emitted when driving through speed bump (Mogiliovas, Debrecenas, Tiltai, Sukileliai streets). That is because speed bumps are poorly designed (too tall, too sharp an angle for the expected speed) whereas speed cushions or humps are flat and low.

3. Most of registered traffic noise was induced by passenger cars (95%). The remaining 5% belongs to heavy vehicles which induced highest noise levels.

4. All speed reducing devices must be constantly renewed – where speed bumps are broken over time, noise levels are significantly lower but also the vehicles speed is higher and a speed control device is no longer affective and loses its purpose.

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Received 1 February 2013; accepted 3 January 2014