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Research into the impact of speed bumps on particulate matter air pollution

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ABSTRACT

Most traffic accidents occurs when a vehicle collides with another vehicle, pedestrian, animal, road debris or other stationary obstruction, such as a tree or utility pole. One of the most popular speed regulation implement is speed bumps. Speed bumps are installed in residential areas and towns to regulate the speed of traffic. When vehicles pass through them air pollution with particulate matter increases due to emissions from vehicles during braking and particulate matter dispersion. Transport is one of the particulate matter emission sources of the size of 10 μm (PM10) and less that are harmful to humans and nature in general, have been studied. Air pollution with particulate matter at speed bumps was assessed analysing speed bumps structures of different types installed in Lithuania's different residential areas. According to the research it was found particulate pollution at different car number and relative humidity. As determined according to the results of the performed research, air pollution with particulate matter increases by 2–5 times. Pollution near the trapezium-shaped pedestrian crossings increased 55.7% and near the plastic circular speed bumps – 58.6%.

1. Introduction

Road vehicle emissions account for about 70–80% of the pollutants getting into the air. Basing on research results, pollution with small particulates, not larger than 10 μm in diameter (PM10, PM2.5), is some of the most serious air quality problems in towns [21,22,25,26]. Their daily average concentrations in urban areas exceed the standards every year [3,7,14,17].

Basing on air pollution studies, nearly 34% of fine particulates get into the atmosphere from non-asphalt roads and roads untreated with any materials [18]; however, a fair amount of pollution is caused by particulate matter from vehicles travelling along asphalt roads [6,20,27]. Atmospheric pollution caused by the use of speed bumps (SBs) is particularly responsible for increased pollution [2,4,11,13].

Installation of traffic calming signs rarely solves the problem of traffic safety on dangerous road sections [28]. Therefore, use of SBs has proved to be an efficient method for regulating vehicle speed on roads [9,10,23]. Due to sharp braking of the vehicles travelling towards SBs wear of the tyres increases and larger emissions of particulate matter in exhaust gas and other pollutants generate. Changing velocity causes additional ambient air turbulence [1,5,8,12,15,16,19,24].

The aim of this research is to evaluate ambient air pollution with particulate matter resulting from the use of SBs. The actual and caused air pollution was compared with the limit values established in accordance with the requirements laid down in Directive 2008/50/EC of the European Union.

2. Methodology

SB measurements are selected so as not to interrupt the work of special services. The materials and the whole structure of SB are resistant to heavy vehicles load and can be used in the places of communal and goods vehicle traffic. SBs are universal because they can be installed on a lane of any width; temporary SBs can be used in the places where temporary speed reduction is necessary. They are installed into asphalt with metal spikes. In the case of concrete surface, they are infixed with bolts. They are particularly durable and stable, and distinguished by 'hard' operation. A SB reduces vehicle speed by up to 3–8 km/h (Fig. 1a).

Tests for air quality at traffic calming devices were performed at ten sites in Lithuania. To evaluate the influence of these devices on an increase in air pollution, they were divided into two groups:

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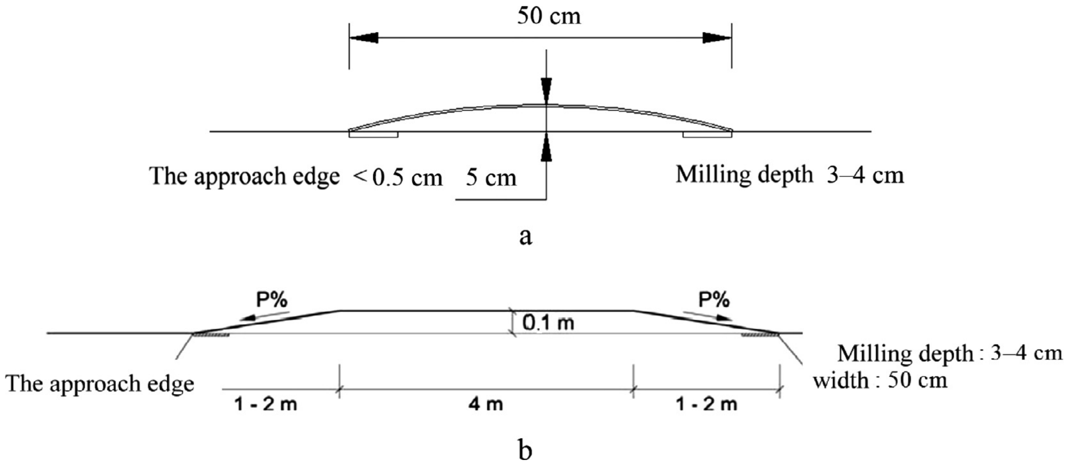

Fig. 1. Structure of prefabricated plastic speed bump (a) and raised trapezium-shaped crosswalk (b).

(1) trapezium-shaped SBs, 3 m long and 10 cm ± 1 cm high, length of the raised area – 4 m ± 0.20 m (also known as a raised pedestrian crossings) (Fig. 1b);
(2) the longitudinal section of the trapezium-shaped SB consists of one elevated section and two sloping areas called ramps (altogether forming a trapezium) (Fig. 1b);
(3) length of ramps – from 1 to 2 m: 1 m – in a 30 km/h speed zone; 1.40 m – where the permitted speed is 40 km/h; 2 m – where the permitted speed is limited to 50 km/h;
(4) prefabricated plastic (circular) SBs, approximately 0.5 m long and 5 cm high (Fig. 1b).

Two types of different SB structures – raised trapezium-shaped and prefabricated plastic bumps – were analysed in this research (Fig. 2).

Raised trapezium-shaped asphalt or prefabricated pedestrian crossings and a raised pedestrian crossing (RPC) were used in seven measurement sites. In the remaining three sites measurements were performed at circular plastic prefabricated bumps. The site for dust concentration research is selected according to the direction of the wind. The research site has to be downwind. The wind parameters and PM concentration measured using half–hourly averaging time. The data measured at constant weather conditions. Mismatches on the wind direction and strength, or precipitation (rain) or other factors research for the time being terminated, thus, it was to avoid inconsistencies. Concentration determination studies has not been made at wind gusts or variable direction strong wind, it has been done to minimize the impact on the results. The analyser of PM_{10} concentration (a β sensor) was calibrated each time with a known concentration of PM_{10} standard, thus the impact of moisture parameters on the measurement results was avoiding.

During measurements the concentration of dust (particulate matter) was measured with the analyser having two β sensor together in the control site and in the research site at SB. At the same time it was visually identified and calculated the number of light and heavy vehicles. Measurements were made in the range of particulate matter less than 10 μm in diameter (PM_{10}) of 0–10,000 $\mu g/m^3$. The research was carried out at a height of 0.5 m and at a distance of 1.5 m from the roadside. During research dust concentration in ambient air was measured simultaneously in two research sites: sites 1 and 2 (Fig. 3). Measurement site 1 was selected at the SB where speed on the road is calmed. Measurement site 2 was selected at a distance of 150–400 m from the place where speed on the road is calmed, i.e. in the control site where vehicles can travel without any hindrances (Table 1).

Based on the studies it was determined PM_{10} concentrations in the control sites and at different types SB by comparing with the standard of the ambient air. It was found a correlation between the vehicles having passed through SB and the emission of PM_{10}. It was estimated the relative humidity in each area, and according to the PM_{10} in the control and at SB point were composed their dependences.

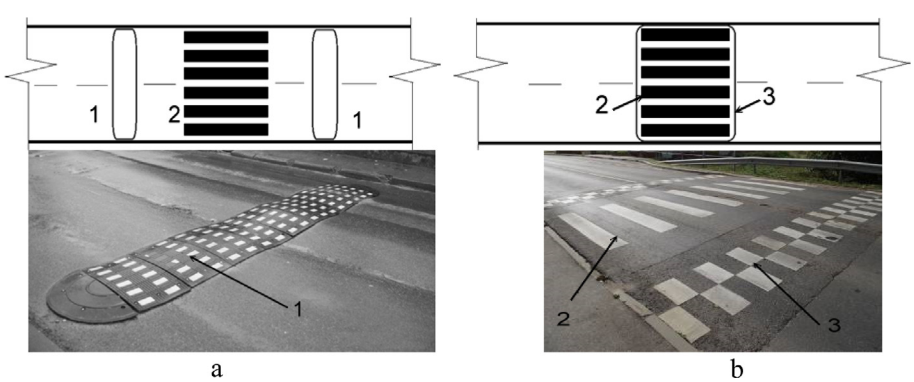

Fig. 2. Basic diagrams and the samples of use of speed bumps: a – prefabricated plastic speed bump, b – raised trapezium-shaped SB, 1 – speed bump plastic element, 2 – pedestrian crossing, 3 – speed bump asphalt element.

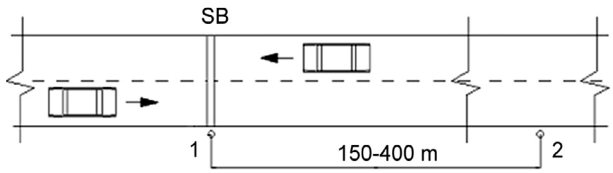

Fig. 3. Diagram of particulate matter research sites: SB – speed bump, 1 – research site at SB, 2 – research site in the control site.

3. Results and discussion

The influence of SBs was evaluated according to the main typical factors – traffic in the site analysed, meteorological conditions, SB arrangement on the road section – which were responsible for the level of caused particulate matter pollution. A complex relationship between all these factors and caused pollution was also analysed.

The main factor determining an increase in pollution with particulate matter at SBs was vehicles having passed during research. This indicator can be related to road traffic, e.g. during the peak period, and the maximum level of caused pollution. It has been determined that particulate matter concentration increases at SBs in all research sites compared to the concentrations determined in the control sites. Also, heavy vehicles passing through SBs cause much greater pollution compared to pollution produced by light vehicles. However, meteorological conditions, particularly increased humidity, reduce the dispersion of pollution caused at SBs. During deceleration and acceleration at SBs in dry weather conditions particulate matter is raised from road paving due to air turbulence and pollution spreads in the surrounding area. When relative air humidity is high, vortexes caused by deceleration at SBs are unable to raise particulate matter from the road surface and therefore the concentrations are by several times lower than in the case of a dry road surface. An important case was determined in research site 6. The traffic recorded there was one of the heaviest (476 vehicles per hour), but relative air humidity reached 80%. At that time in research site 4 traffic was more than twice lower (214 vehicles per day) and relative air humidity was by 2% lower reaching 78%. In the latter research site particulate matter concentration at the SB increased by 3.7 times compared to the control site where it stood at 18.28 μg/m^3. At that time in research site 6 a concentration of 91.69 μg/m^3 was determined by the SB being by 1.11 times above the level determined in research site 4. These results lead to the assumption that one of the main factors having an influence on particulate matter concentration is relative air humidity. When air humidity is below 70% pollution caused by the SB is equated to the level of pollution caused by the SB on the road with traffic of double intensity. One of possible methods of solution to the problem of cutting the level of pollution with particulate matter at a SB is selecting SB structures according to local conditions (Fig. 4).

The comparison of two different types of SB structures under conditionally equal weather conditions has shown that particulate matter concentrations are higher when a plastic prefabricated SB is installed. An obvious difference was seen while analysing research sites 4 and 9. During pollution measurement these research sites were dominated by quite stable weather: relative air humidity was 50–80%, atmospheric pressure was close to 1000 mbar, the wind was western of 4 m/s on the average, and air temperature was stable reaching 17° in research site 4 and 15°in research site 9. Since weather conditions are very similar in both sites, it is possible to evaluate pollution caused by SBs. Traffic of 163 vehicles per hour, light vehicles mainly, was determined in research site 9 (Fig. 5). In both cases the exceedances of concentration standards were determined due to possible dry weather conditions, the wind of average strength and its direction towards SBs. However, in research site 4 concentration reached 82.69 μg/m^3, which represented an exceedance of 32.69 μg/m^3. Taking into account the concentration of 18.28 μg/m^3 determined in the control site it can be stated that the existing SB causes atmospheric pollution with particulate matter which is nearly 5 times above the background level.

Analysis of the results obtained in research site 9 with a prefabricated plastic SB installed has shown that the concentrations measured there were higher than those obtained in research site 4.

First, it has to be noted that the background concentration at a SB in research site 9 was high, more than twice above the standards. This has also possibly resulted from dry weather conditions and considerable wind speeds. However, the exceedance of standard concentrations is considerably bigger in research site 9 where the measured particulate matter concentration reached 248.65 μg/m^3, whereas the concentration at a SB in research site 4 was by 3.01 times lower and stood at 82.69 μg/m^3 (Fig. 5). Considering that the other factors responsible for pollution are very similar to each other, it can be stated that different structures of SBs determine different levels of particulate matter pollution. Due to the structural peculiarities of prefabricated plastic SBs motor vehicle drivers have to slow down more at them compared to trapezium-shaped traffic calming devices. At the same time pollutants are more intensely dispersed from the road paving and vehicle parts due to the turbulence caused by tyre wear and changing speed. A particulate matter concentration of 248.65 μg/m^3 was measured in research site 9 which exceeded the permitted standard by 198.65 μg/m^3, i.e. was more than 4 times above it (Fig. 5). Therefore, it can be stated that pollution caused by SBs is higher when prefabricated plastic traffic calming devices are installed.

Table 1
Research sites for speed bumps of different types and traffic during research.

Type of speed bump structure	Research site	Number of vehicles having passed during research		The distance between speed bump and reference point, m
		Light vehicles	Heavy vehicles	
Raised trapezium-shaped crosswalk	No 1	257	32	300
	No 2	75	15	300
	No 3	36	4	300
	No 4	187	27	200
	No 5	148	15	200
	No 6	462	14	150
	No 7	325	14	300
Prefabricated plastic speed bump	No 8	52	28	400
	No 9	148	15	200
	No 10	45	15	300

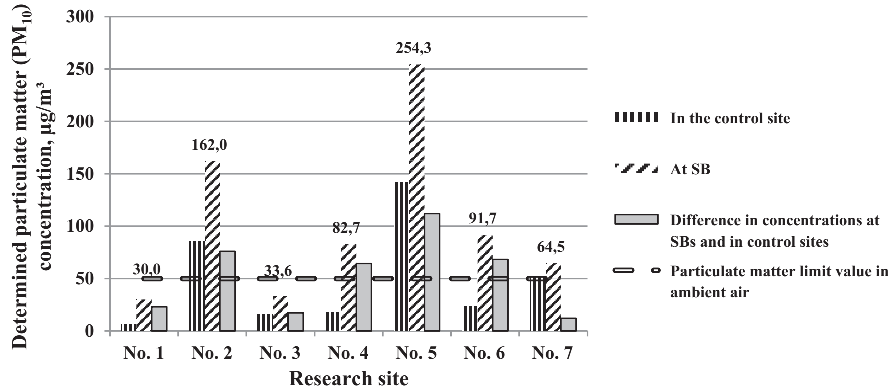

Fig. 4. Determined particulate matter (PM_{10}) concentrations in the control sites of residential areas and at trapezium-shaped speed bumps.

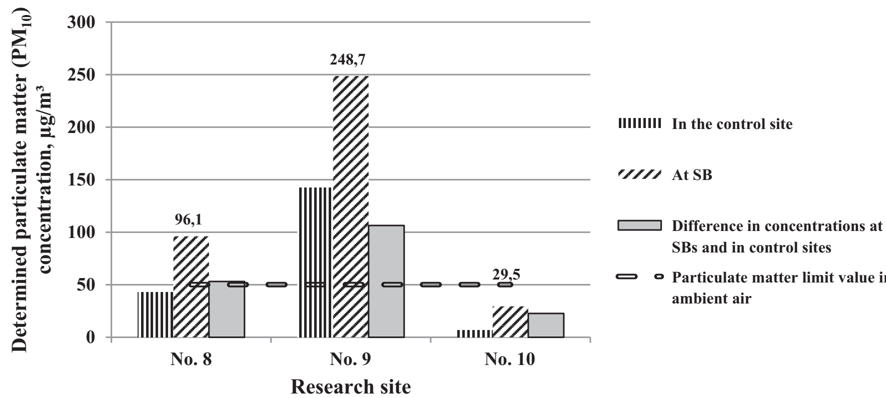

Fig. 5. Determined particulate matter (PM_{10}) concentrations in the control sites of residential areas and at prefabricated plastic speed bumps.

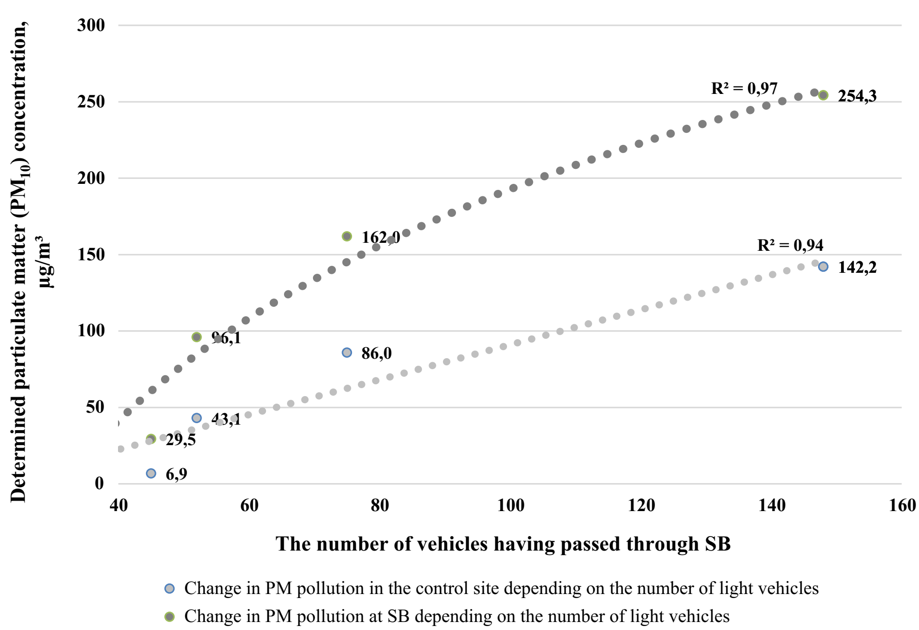

Fig. 6. Dependence of the determined particulate matter (PM) concentration on the number of light vehicles in the control site and at SB.

Fig. 6 shows the change of particulate matter concentrations depending on passing traffic. It is evident from these dependences that the PM concentration at SBs remains higher and increases faster than in the control site. When the number of passing vehicles is above 100, pollution at SB remains approximately more than twice above pollution in the control site.

No significant relationships to meteorological conditions were identified at raised trapezium-shaped pedestrian crossings in

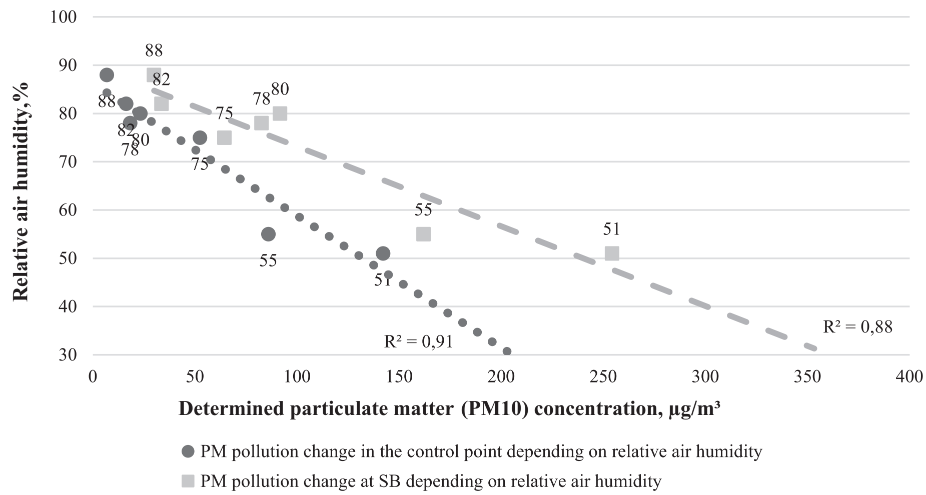

Fig. 7. Determined particulate matter concentrations in the control site and at the raised trapezium-shaped pedestrian crossing at different relative air humidity.

research sites 1, 2, 3 and 7. Since trapezium-shaped SBs of the same type are installed at these sites, it can be stated basing on the obtained exceedances of pollution levels that the impact on environmental pollution is evident. At SB in research site 1 particulate matter pollution increases 77%. This has mainly resulted from motor traffic of 289 vehicles in total. The results obtained in research sites 2 and 3 can be analysed jointly. As Table 1 shows, when traffic increased by around two times, the levels of pollution increased, on the average, by 5 times in both the control site and the research site at SB. In such a case the pollution level at SBs in research sites 2 and 3 was twice above the level in the control sites. This leads to the conclusion that vehicles passing SBs cause particulate matter pollution which is twice and more above the concentrations measured in the control sites. In research site 7 the level of pollution at SB increased 19%. Although traffic was heavy, 339 vehicles, relative air humidity reached 75–85% during research. In such a case the road paving was not dry as particulate matter was taken away from SB only in short distances. As Fig. 7 shows, basing on research results a relationship is identified between the measured concentrations in research sites at different relative air humidity.

The correlation coefficients, approximately equal to 0.9, show a strong relationship between the values. A stronger relationship was determined with regard to concentrations in the control site than at SBs (Fig. 7). We arrived at the conclusion that the determined PM concentration increased when relative air humidity decreased.

A big influence on the results was also done by SB arrangement aimed at reducing the speed of passing traffic. One applied method of arrangement – installation of SBs at different points of traffic in both directions. In the case of such arrangement vehicles having passed through a SB on a lane of one direction travel further accelerating, while vehicles travelling along the other lane decelerate at the same point while passing through the SB. Since traffic is quite heavy, additional turbulence forms between traffic moving in opposite directions and particulate matter raised during deceleration is additionally dispersed due to friction by the vehicles accelerating on the other lane. Such arrangement is possible only by installing plastic prefabricated bumps. The devices of such type were analysed in research sites 9 and 10.

Another method of SB application – installation of two plastic prefabricated bumps in both directions from a pedestrian crossing. That was the case only in one research site – site 8. However, as the research results show, when traffic was low an increase in particulate matter concentration of 55% was measured at SB compared to the control site and the determined concentration stood at 96.13 $\mu g/m^3$. The increase of particulate matter pollution at the SB of research site 8 can be related to bigger impediments to motor vehicles to pass obstacles (SBs). On the road section between the structures of two prefabricated bumps motor vehicles have to decelerate additionally, while afterwards they accelerate emitting the biggest particulate matter emissions and motor fuel combustion product emissions. In spite of that, two-way SB installation is a rational solution to the problem of particulate matter pollution in an urbanised area. Due to such installation of SBs the motor vehicle drivers have to reduce speed. Having passed through the first SB the driver will have no motive for accelerating because of another obstacle on the road ahead. For these reasons low speed will be maintained on the road section between two SBs. However, this speed is not sufficient for raising particulate matter from the road paving.

4. Conclusions

1. After analysing the impact of traffic calming trapezium-shaped pedestrian crossings on particulate matter concentrations it has been determined that particulate matter concentration at speed calming crossings increases from 18 to 80%. An average increase in particulate matter concentration reaches 55.7%.
2. Compared to the control site, the determined increase in particulate matter concentration at plastic circular speed bumps varied from 45 to 75%. An average increase in particulate matter concentration reached 58.6%.
3. Speed bumps and raised pedestrian crossings undoubtedly increase particulate matter pollution and are often installed near objects sensitive to pollution, such as schools; therefore, it is recommended to install two speed bumps rather than one bump that the drivers would not be motivated to accelerate after having passed through one bump and would not increase particulate matter concentration.

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