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INFLUENCE OF ROAD PAVEMENT MACROTEXTURE ON TYRE/ROAD NOISE OF VEHICLES

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Abstract. Noise level in the surroundings of traffic routes mainly depends from traffic volume, flow composition, speed of the vehicles as well as from the cross-section and road longitudinal gradient. Under higher speeds significant influence on the noise level has also tyre/road noise. Tyre/road noise depends on type and pavement condition state, specifically from the surface macrotexture. The influence of macrotexture is varying and strictly connected with the type of vehicles, tyres characteristics, frequencies of emitted noise. On the base of investigations of the rolling noise applying Statistical Pass-By method along the Polish roads the paper presents elaborated dependences and fixed values of differences between maximum noise levels under passing multiple-axle heavy vehicle and passenger car on the asphalt concrete surface, stone mastic asphalt and the surface dressing. The functional dependences between maximum rolling noise levels in the range of complete level and in the octave band spectra: 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz and between the surface macrotexture described by mean profile depth, and logarithm of vehicle speed and adequate nomograms were evaluated in the paper. On this base the values of differences in the levels of emitted noise from passing heavy vehicle and passenger car in function of speed and surface macrotexture were computed. The manuscript also presents how surface macrotexture and traffic flow composition have influence on equivalent noise level in the road vicinity under equal traffic volume.

Keywords: macrotexture, tyre/road noise, passenger car, multiple-axle heavy vehicle.

1. Introduction

Traffic noise is one of the most important problems in the frame of environmental protection. Evaluation of traffic noise and its prognosis in the vicinity of roads remains complex problem. Various aspects of this problem are considered in the bibliography where traffic analysis, methods of evaluation of noise, modeling of the traffic systems and vicinity of roads (Bazaras *et al.* 2007; Jagniatinskis *et al.* 2011) remain the main topics. Reduction of excessive noise is feasible through decrease of traffic volume, elimination of heavy vehicle and diminishing of the vehicle speed, decrease of vehicle rolling noise, installation of the sound barriers and insulation of buildings.

Rolling noise reduction at the source is in most cases cost effective reduction measure and has a high priority in many countries. It is imperative to design the road surface standard that lowers sound level emitted from the tyre/road system. Research projects, e.g. *HARMONOISE*, *SILVIA*, *IMAGINE*, *PERS*, dedicated to that problem have been conducted in many research centres (Descornet, Goubert 2006; Sandberg, Goubert 2011). The project *HARMONOISE* dealt with improving of noise prognosis methods from road traffic and railway system as a result of detailed description of noise sources specifically considering influence of road surface characteristic. The *SILVIA* project indicates the most rational undertakings limiting noise from traffic including construction of the "quiet road surfaces".

Within period of last years the attention is paid to searching the so called low-noise road surface (Sandberg, Goubert 2011). Among the low-noise road surfaces already in use the single-layer porous asphalt, twin-layer porous asphalt and thin asphalt layers shall be specified. The use of these surfaces decrease the noise level significantly from 3–5 dB(A) on the single-layer to 10–12 dB(A) on the twin layers. The use of the thin asphalt may cause decrease of noise at 3–5 dB(A). Some countries worked out a system for specification and documentation of noise reducing asphalt pavement (Kragh *et al.* 2012)

The studies showed that the mixtures with rubberized asphalt reduce noise from 2 dB(A) to 10 dB(A) (Freitas 2012;

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Paje *et al.* 2013) In the frame of the *PERS* project realized in Sweden and in Japan the investigation on reduction of noise level through the use of poroelastic road surfaces was conducted (Fujiwara *et at.* 2005). The *PERSUADE* project remains the continuation of the *PERS* project where 7 countries are contributing and its aim is a further development of the poroelastic road surface (Sandberg, Goubert 2011).

There are also works conducted from the point of view of decrease of the rolling noise on cement concrete surfaces. The method of the surface texturing (e.g. exposed aggregate) influence on emitted noise from passing cars and behavior of porous cement concrete surface are analysed.

The paper (Leipus *et al.* 2010) presents results of noise test under traffic in vicinity to the roads of gravel and asphalt surface in winter and summer time. It comes from the test results that gravel surface emits noise level higher from 2 dB(A) to 5 dB(A) than the asphalt surface, and it depends on car speed, physical properties of tyres and time of the year.

Some countries admitted the use of studded tyres (e.g. Belgium, Denmark, Estonia, Finland, France, Latvia, Lithuania, Great Britain, etc.). The use of studded tyres has negative influence on noise level from passing vehicles. Results of conducted tests indicate that the noise level is higher even up to 6 dB(A) in these cases (Vaiškūnaitė *et al.* 2009).

Significant influence under higher speeds on noise level in the vicinity of roads has noise emitted in the tyre/road contact surface. The surface texture significantly decides this noise level. The surface texture determined in the form of geometric description of irregularities plays a decisive role in creating and protecting safe traffic. It has also significant influence on fuel consumption, wearing of tires and emission of noise in the tyre/road contact surface.

According to *ISO 13473-1:1997 Characterisation of Pavement Texture by Use of Surface Profiles – Part 1: Determination of Mean Profile Depth* irregularities of texture are classified into microtexture (texture wavelengths: < 0.5 mm; amplitudes: 0.001–0.5 mm), macrotexture (texture wavelengths: 0.5–50 mm; amplitudes: 0.1–20 mm) and megatexture (texture wavelengths: 50–500 mm; amplitudes: 0.1–50 mm) as a function of wavelengths.

Investigations of surface texture influence on the level of rolling noise of vehicles have been conducted in many countries. The works of Sandberg, Descornet (1980), Sandberg, Ejsmont are to be specified and underlined (2002). As it comes to France investigations (Bar, Delanne 1993) on the surface of fine texture (according to the sand patch test: *MTD* (Mean Texture Depth) = 0.37–0.60 mm) the noise level was fairly 3 dB(A) higher than on the surface of very fine texture (*MTD* = 0.30–0.34 mm) and it was close to 3 dB(A) lower comparing with the noisiness on very coarse surface (*MTD* = 2.50–3.00 mm). Sandberg and Descornet (1980) indicate increase of the noise level under low frequencies of sound (below 1000 Hz), with increase of the texture amplitude in the range of waves irregularities of 10–500 mm length, while the level of noise for high frequencies (above 1000 Hz) decreases with the increase of texture amplitude in the range of waves irregularities of 0.5–10 mm length.

Investigations on influence of surface texture on noisiness level of vehicles have been conducted in Bialystok University of Technology. The paper presents results of investigations on the pavements of the dense asphalt concrete surface (asphalt concrete, stone mastic asphalt and surface dressing) comparing to noise level in the range of complete level as well as in the third-octave band spectra (1/3 octave) and in the octave band spectra.

The differences in the emitted sound pressure levels under rolling statistic multiple-axle heavy vehicle and passenger car in the aspect of macrotexture and vehicle speed were observed and underlined.

2. Road pavement macrotexture – indicators of evaluation

According to *ISO 13473-1:1997* the most often used parameters evaluating macrostructure based on profiles surface unevenness are mean profile depth (*MPD*), mean arithmetic profile deviation (R_a), profile root mean square (R_{ms}), asymmetry profile (R_{sk} – skewness), depth of texture in three dimensional system *TD* – texture depth.

Spectroanalyses, which are adopted on wide scale in acoustic in vibration analysis and electrotechnics, are used in macrotexture investigations. Decibel (dB) is the unit of the irregularity level of the road pavement as a result of logarithmic conversion of ratio of amplitude of curve describing road texture profile (in the value of R_{ms}) and datum level (10^{-6} m). The texture amplitude of asphalt concrete pavement and standard cement concrete pavement are in the range of 10^{-5} m to 10^{-2} m being referred to the level of texture profile from 20 dB to 80 dB.

The road macrotexture profiles are determined on the basis of irregularities profiles and they are corresponding to the ranges:

– macrotexture (L_{ma} – level in the third-octave band spectra determined for irregularity waves from 2 mm to 50 mm);

– megatexture (L_{me} – level in the third-octave band spectra determined for irregularity waves from 63 mm to 500 mm);

– waves of 5 mm length (L_5 – the level of 5 mm octave band – the length of irregularities waves from 4 mm to 6.3 mm (octave 5 mm)), significant parameter due to noise level in the range of high frequencies – above 1000 Hz;

– waves of 80 mm length (L_{80} – the level of 80 mm octave band – the length of irregularities waves from 63 mm to 100 mm (octave 80 mm)), significant parameter due to the noise level in the range of low frequencies – below 1000 Hz.

The macrotexture descriptor *MTD* is measured with a laser profilometer nowadays. Values of *MPD* evaluated in the investigations conducted by the team of Bialystok University of Technology along the tested sections of national roads are between 0.20 mm and 1.30 mm.

3. Pavement noisiness – general remarks

Road pavement noisiness investigations are conducted using CPX method *(ISO 11819-2:2000 Acoustics – Method* *for Measuring the Influence of Road Surfaces on Traffic Noise – Part 2: the Close Proximity Method)* where the level of noise emitted in the tyre/road contact surface is measured with a set of test tyres or applying SPB method (*ISO 11819-1:1997 Acoustics – Method for Measuring the Influence of Road Surfaces on Traffic Noise – Part 1: the Statistical Pass-By Method*) where the rolling noise levels under passing of vehicles category "1" (passenger cars), category "2*A*" (dual-axle heavy vehicles) and category "2*B*" (multiple-axle heavy vehicles) are measured.

CPX method of measurements uses special type of trailers or microphones installed on the vehicle wheel (Meunier *et al.* 2010). SPB method of measurements is conducted fixing the vehicle speeds and the maximum *A*-weighted sound level emitted under statistic significant number of singly passing three categories of vehicles. Also, the method of CPB method (*NF S 31-119-2: 2001 Acoustics – in Situ Characterization of the Acoustic Qualities of Road Surfaces – Pass-By Acoustic Measurement. Part 2: Controlled Pass-By Method*) where the noise level under singly rolling test vehicle is used in identification of pavement noisiness.

The Close Proximity Index *(CPXI)* as a result of measurements in CPX method is computed as the mean arithmetic of maximum value of noise level for set of test tyres. In SPB and CPB methods results come from noise level rolling statistic single vehicle of specified category ("1", "2*A*" and "2*B*") for adopted speed determined from the equation:

$$L(V) = A + B\log V, \qquad (1)$$

where *A*, *B* – regression factors; *V* – speed, km/h.

The paper does not present specified method of measurements of tyre/road noise and rolling noise of vehicles as well as obtained results because they are specified in literature (Ejsmont 2002; Ejsmont, Mioduszewski 2009; Paje *et al.* 2009; Sandberg, Mun *et al.* 2007).

Investigation team of Bialystok University of Technology has been conducting investigations of the rolling noise level applying SPB method for more than 15 years and these investigations covered more than 40 sections of roads of varying surfaces, mainly on the pavements of asphalt concrete and SMA (pavements that are very often used on Polish roads). Tests on paving stones, concrete pavements, surface dressing, very thin bituminous concrete (BBTM) and porous asphalt were also carried out.

Results of investigations conducted by the author of this research were the roots of elaborated classification of pavements on out–of–town roads in respect of their noisiness. Value of *CPXI* (80 km/h) index and maximum noise level under rolling statistic car with a speed of 80 km/h (L_1(80)), according to SPB method, were taken as a criterion of classification. Distribution of road pavements into five classes has been proposed (Gardziejczyk 2011):

– LN (Low noise): *CPXI*(80) < 93.5 dB(A), L_1(80) < 73.0 dB(A);

– RN (Reduced noise): *CPXI*(80) = 93.5–96.4 dB(A), L_1(80) = 73.0–75.9 dB(A);

– NN (Normal noise): *CPXI*(80) = 96.5–99.4 dB(A), L_1(80) = 76.0–78.9 dB(A);

– IN (Increased noise): *CPXI*(80) = 99.5–102.4 dB(A), L_1(80) = 79.0–81.9 dB(A);

– HN (High noise): *CPXI*(80) ≥ 102.5 dB(A), L_1 ≥ 82.0 dB(A).

Classifications of pavements have been already worked out or are being in progress of their adaptation in many countries (Paulo *et al.* 2010; Sandberg, Ejsmont 2002). The paper (Descornet, Goubert 2006) presents classification of road pavements in respect of noisiness elaborated in 17 countries. There are usually classification of 3–5 classes, however, in some countries some correction factors are given due to technology of wearing course (kind, granulation of aggregate, texture, age of surface) as well as taking into account characteristics of traffic (speed of vehicles, participation of multiple-axle heavy vehicles in the traffic flow).

4. Results of tests and their analysis

Results of tests conducted in different research centres indicate that the tyre/road noise level depends on technology of the wearing coarse construction. Results presented in Fig. 1 indicates the need for independent investigations of texture influence on noisiness level of

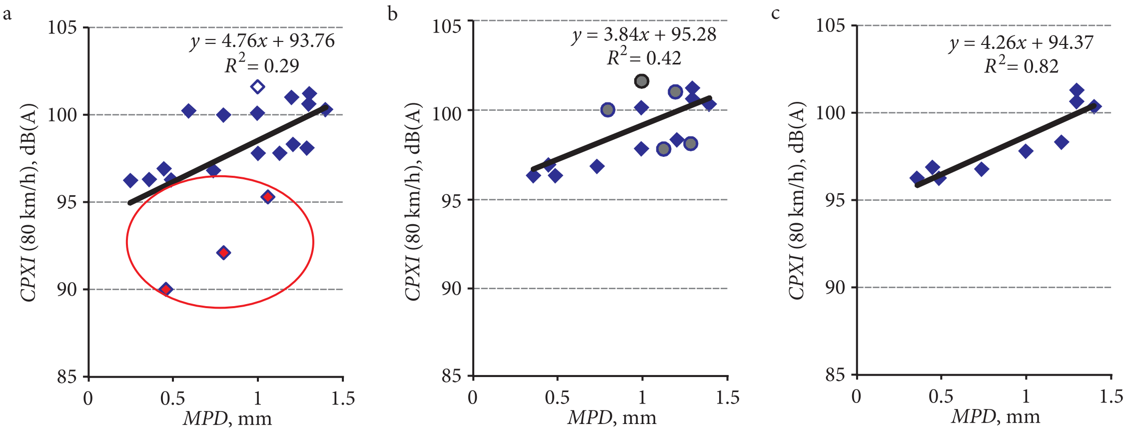


Fig. 1. Noise level as a function of macrotexture: a – tested pavements (porous pavements distinguished); b – tested pavements without porous asphalt pavements; c – dense asphalt concrete pavements

the dense asphalt concrete surface (types of asphalt concrete, stone mastic asphalt, surface dressing), on surface of cement concrete (in result of various surface texture character like brushing, grooving, gouging) and on the porous surfaces (large number and voids content). Considering varying road pavements (dense asphalt concrete, cement concrete pavements, porous asphalt concrete), determination coefficient R^2 has value 0.29 (Fig. 1a) and $R^2 = 0.42$ (Fig. 1b) in case excluding porous asphalt surfaces as well as $R^2 = 0.82$ (Fig. 1c) if dense asphalt concrete surfaces are evaluated.

Detailed tests were conducted taking into account the above notes investigating influence of macrotexture on the level of rolling noise from vehicles on three sections with pavements:

– asphalt concrete (AC12): *MPD* = 0.35 mm (section BW6);

– stone mastic asphalt (SMA12): *MPD* = 0.75 mm (section BW8);

– surface dressing (SD): *MPD* = 1.15 mm (section BW11).

Fig. 2 presents profiles of surface irregularities on the investigated sections elaborated using a needle profilometer built in Bialystok University of Technology.

Noise level (total, the third-octave band spectra and octave band spectra) was measured along each section of road under 120 singly passing cars and 80 multiple-axle heavy vehicles (according to the Statistical Pass-By method). Low share in the traffic stream on tested sections and poor technical state of dual-axle heavy vehicles eliminate these vehicles from the conducted tests and investigations. Fig. 3a presents values of maximum noise level under passing statistic passenger car (L_1) and multiple-axle heavy vehicle (L_{2B}), and noise spectra in third-octave band spectra on specified pavements are presented in Fig. 3b.

The presented values indicate that noise level emitted from statistic vehicle, passenger car as well as from multiple-axle heavy vehicle is similar in value on the asphalt concrete and SMA pavements. The noise level from passing passenger car on the surface dressing is 3 dB(A) higher than along two remaining pavements, and is lower by 1.2 dB(A) than from heavy vehicle. As it comes to spectral analysis in case of passenger car in the range of frequencies the third-octave band spectra from 250 Hz to 1250 Hz differences in noise level reach 5–6 dB(A). Values

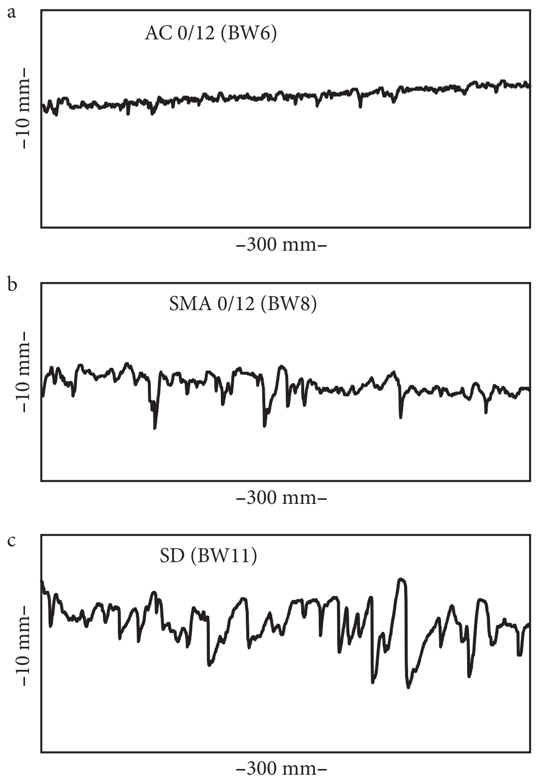


Fig. 2. Profiles of irregularities of pavements on tested sections: a – asphalt concrete: *MPD* = 0.35 mm; b – stone mastic asphalt (SMA): *MPD* = 0.75 mm; c – surface dressing (SD): *MPD* = 1.15 mm

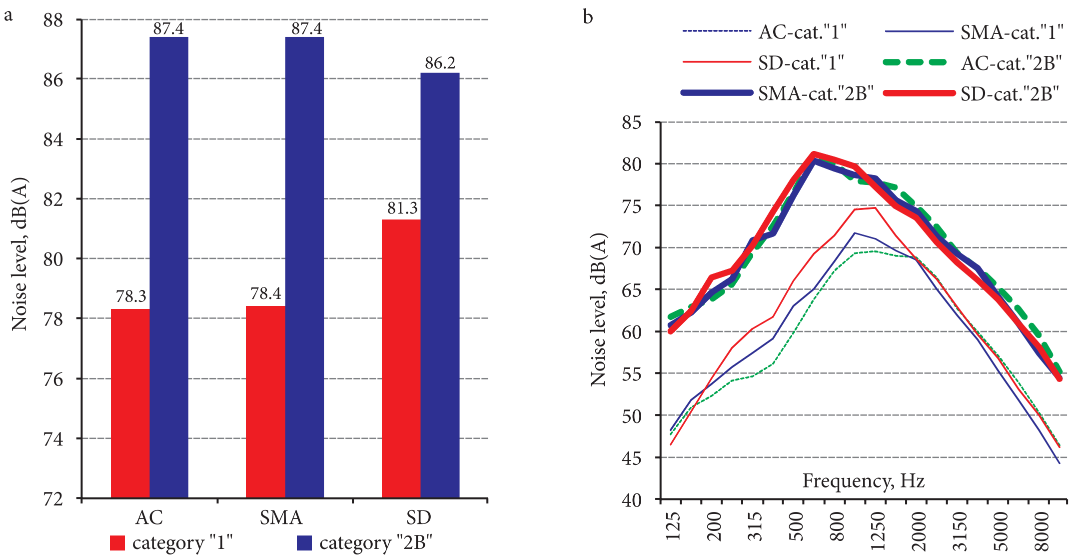


Fig. 3. Noise level (a) and tyre/road spectrum (b) obtained for statistic passenger car (cat."1") and multiple-axle heavy vehicle (cat."2*B*") on tested three pavements (speed $V_1 = V_{2B}$ = 80 km/h)

of differences in relation to statistic multiple-axle heavy vehicle are decidedly lower on tested pavements. The levels of noise and emitted spectra are similar to the values obtained in the works of the other scientists on surfaces with similar characteristics in the other countries. An example, in case of multiple-axle heavy vehicle the maximum value of the noise level in the range of frequencies 630–800 Hz were obtained and for passenger car are in the range of 1000–1250 Hz. Fixed values of noise level for heavy vehicle are lower on surface of coarse texture than on fine and medium texture.

Elaborated dependence on the base of test results and analysis describes differences in noise levels in the third-octave band spectra emitted from the rolling statistic passenger car (category "1") in function of the logarithm of frequencies (log*f*) relating to the technology of wearing course (asphalt concrete, surface dressing, stone, mastic asphalt):

$$\Delta L_1^{f(SD-AC)} = -4.26(\log f)^4 + 65.68(\log f)^3 - 366.23(\log f)^2 + 875.57\log f - 754.26,\ R^2 = 0.93, \quad (2)$$

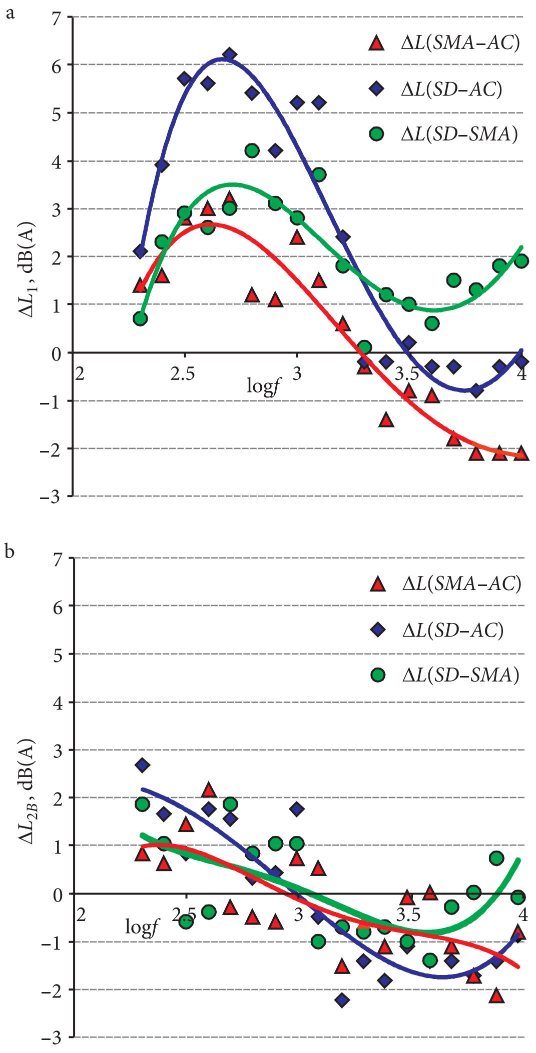


Fig. 4. Values of differences between levels of rolling passenger car noise (a) and heavy vehicle category 2B (b) in the third-octave band spectra on three tested pavements

$$\Delta L_1^{f(SD-SMA)} = -2.28(\log f)^4 + 36.02(\log f)^3 - 203.99(\log f)^2 + 493.51\log f - 429.76,\ R^2 = 0.73, \quad (3)$$

$$\Delta L_1^{f(SMA-AC)} = -1.98(\log f)^4 + 29.66(\log f)^3 - 162.24(\log f)^2 + 382.06\log f - 324.49,\ R^2 = 0.92, \quad (4)$$

and multiple-axle heavy vehicle (category „2B"):

$$\Delta L_{2B}^{f(SD-AC)} = 0.55(\log f)^4 - 4.31(\log f)^3 + 9.39(\log f)^2 - 3.08\log f - 3.43,\ R^2 = 0.81, \quad (5)$$

$$\Delta L_{2B}^{f(SD-SMA)} = 2.46(\log f)^4 - 28.68(\log f)^3 + 124.27(\log f)^2 - 238.78\log f + 173.10,\ R^2 = 0.42, \quad (6)$$

$$\Delta L_{2B}^{f(SMA-AC)} = -1.91(\log f)^4 + 2438.00(\log f)^3 - 114.87(\log f)^2 + 235.71\log f - 176.54,\ R^2 = 0.54. \quad (7)$$

Values of computed differences between noise levels in the third-octave band spectra in relation to two categories of vehicles and approximation of results are presented in Fig. 4. The presented results explicitly indicate that decidedly higher is influence of pavement characteristic on emitted noise from passenger car in relation to heavy vehicle and it depends on frequencies of emitted sounds.

Values of computed differences between maximum levels of noise levels emitted from multiple-axle heavy vehicle (category "2*B*') and passenger car (category "1") on similar pavements are examined in the next stage of investigations. These dependences were described in formulae 8–10 and the results of tests and analyses are presented in Fig. 5.

$$\Delta L_{BA}^{f(2B-1)} = -27.67(\log f)^4 + 366.44(\log f)^3 - 1794.10(\log f)^2 + 3840.80\log f - 3017.50,\ R^2 = 0.89, \quad (8)$$

$$\Delta L_{SMA}^{f(2B-1)} = -27.60(\log f)^4 + 361.16(\log f)^3 - 1746.80(\log f)^2 + 3694.80\log f - 2869.60,\ R^2 = 0.83, \quad (9)$$

$$\Delta L_{PU}^{f(2B-1)} = -22.85(\log f)^4 + 296.45(\log f)^3 - 1418.50(\log f)^2 + 2962.10\log f - 2266.70,\ R^2 = 0.76. \quad (10)$$

The most differences of about 16 dB(A) in the range of frequencies 400–630 Hz appear in case of asphalt concrete pavements. Much lower differences were observed in the range of frequencies 1000–3150 Hz.

5. Pavement macrotexture and noise level of passing vehicle

Relations in the form of polynomial between emitted noise level under singly passing passenger car (L_1) or multiple-axle heavy vehicle (L_{2B}) in octave band spectra and macrotexture (*MPD*) and logarithm of speed were elaborated on a base of conducted tests results:

$$Y_i = b_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1^2 + b_{22}X_2^2, \quad (11)$$

where Y_i – noise level from statistic vehicle category „1" (L_1) and category „2*B*" (L_{2B}); X_1 – mean profile depth (*MPD*); X_2 – logarithm of vehicle speed ($\log V$); b_0, b_1, ..., b_{22} – coefficients of approximating polynomial.

The worked out models have the following form having checked the significance of coefficients b_i of polynomial from formula (11) and the adequacy:

– for passenger car:

$$L_1 = 31.36 - 5.17MPD + 25.06\log V + 6.00MPD^2, \quad (12)$$

– for multiple-axle heavy vehicle:

$$L_{2B} = 27.76 + 8.36MPD + 30.13\log V - 6.69MPD^2. \quad (13)$$

The sequent stages of analysis in details are presented in (Gardziejczyk 2005). Fig. 6 shows in a graphic form the dependence between the noise level in function of *MPD* and the speed of statistic passenger car or multiple-axle heavy vehicle. In case of passenger car, increase of *MPD* value causes increase of noise level. This increase is decidedly higher in case of *MPD* value > 0.7 mm. Noise emitted under rolling heavy vehicle on pavement of *MPD* < 0.9 mm does not significantly differ, and the higher values of *MPD* cause decrease of level of emitted noise.

Similar analysis was conducted in relation to noise level in the octave band spectra 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Values of L_1 and L_{2B} in octave band spectra in relations to *MPD* and vehicle speed are presented in Fig. 7 (Gardziejczyk 2005), while Table 1 gives the values of approximating polynomial coefficients (according to formula (11)) in relation to noise levels in octave band spectra. It ought to be underlined a big difference of noise levels in case of multiple-axle heavy vehicle in relation to frequency of noise. For 250 Hz frequency increase of *MPD* value influences increase of noise level, while under 500 Hz frequency has not been noticed influence of value of *MPD* variation on level of noise, and at the same time in the range of frequencies 1000 Hz, 2000 Hz and 4000 Hz, increase *MPD* generates decrease of level of emitted noises. Under lower frequencies of 250 Hz, 500 Hz and 1000 Hz increase of *MPD* significantly produces increase of noise level while under frequencies of 2000 Hz and 4000 Hz the changes are not so decided for the passing passenger car.

Values of differences between the levels of emitted noise from statistic heavy vehicle (category "2*B*") and statistic passenger car (category "1") is described by the formula:

$$\Delta L_{2B-1} = -3.60 + 13.53MPD + 5.07\log V - 12.69MPD^2. \quad (14)$$

Values of differences between the levels of emitted noise in the function of *MPD* and vehicle speeds are presented in Fig. 8, while Table 1 presents a set of values of approximating

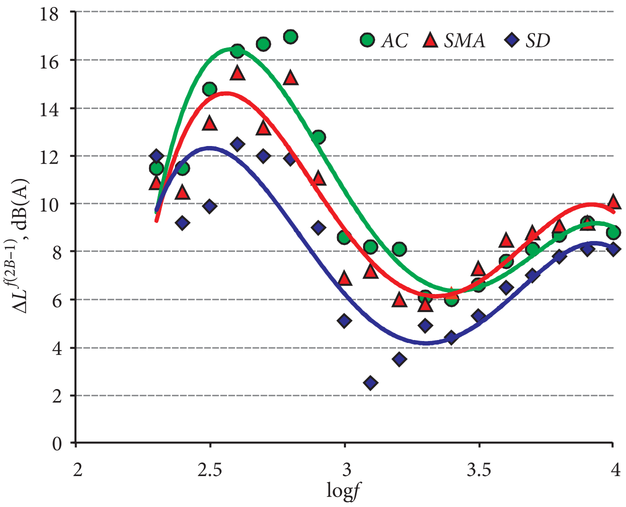


Fig. 5. Values of differences between noise levels from multiple-axle heavy vehicle and passenger car on three tested pavements in the third-octave band spectra

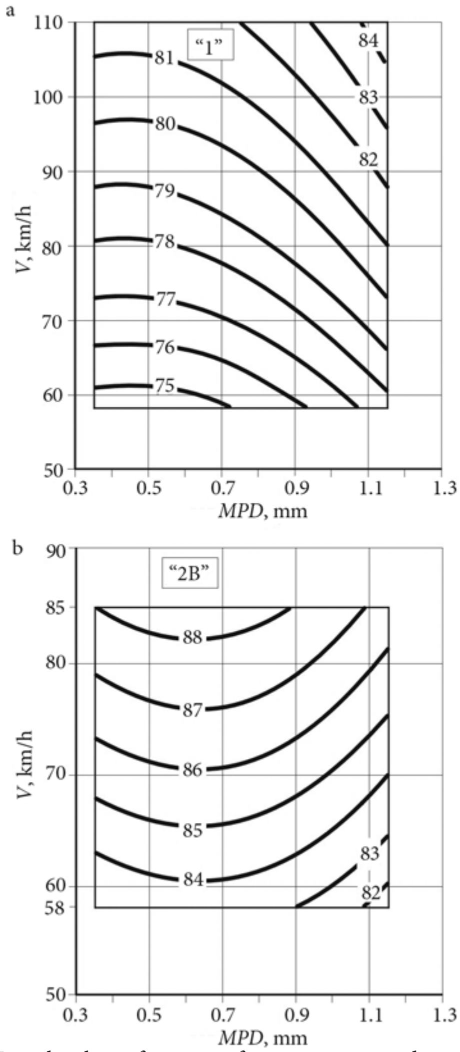
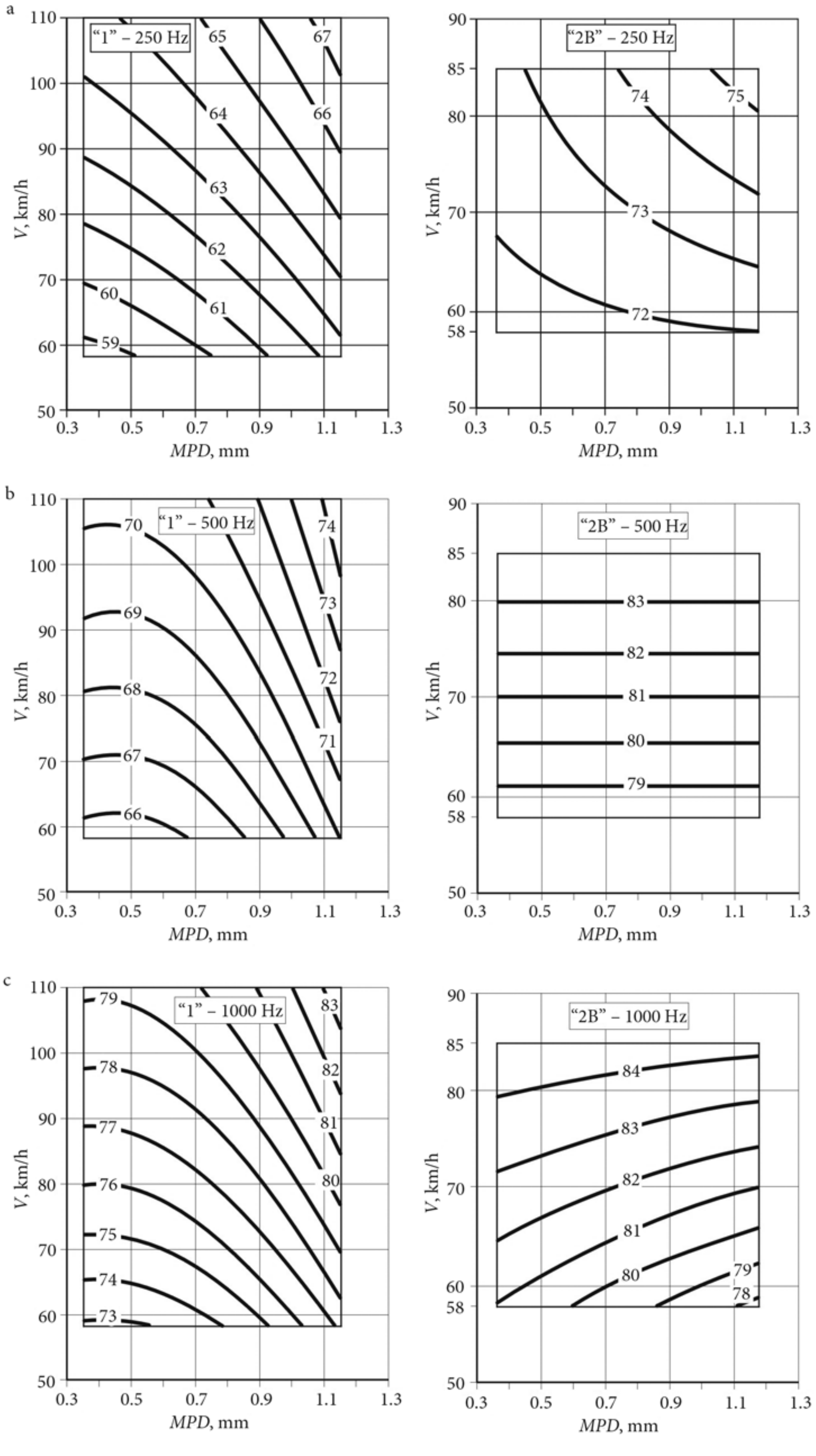


Fig. 6. Noise level as a function of macrotexture and speed of vehicle: a – passenger car (category "1"); b – multiple-axle heavy vehicle (category "2*B*")


a
"1" – 250 Hz
"2B" – 250 Hz
b
"1" – 500 Hz
"2B" – 500 Hz
c
"1" – 1000 Hz
"2B" – 1000 Hz
V, km/h
MPD, mm

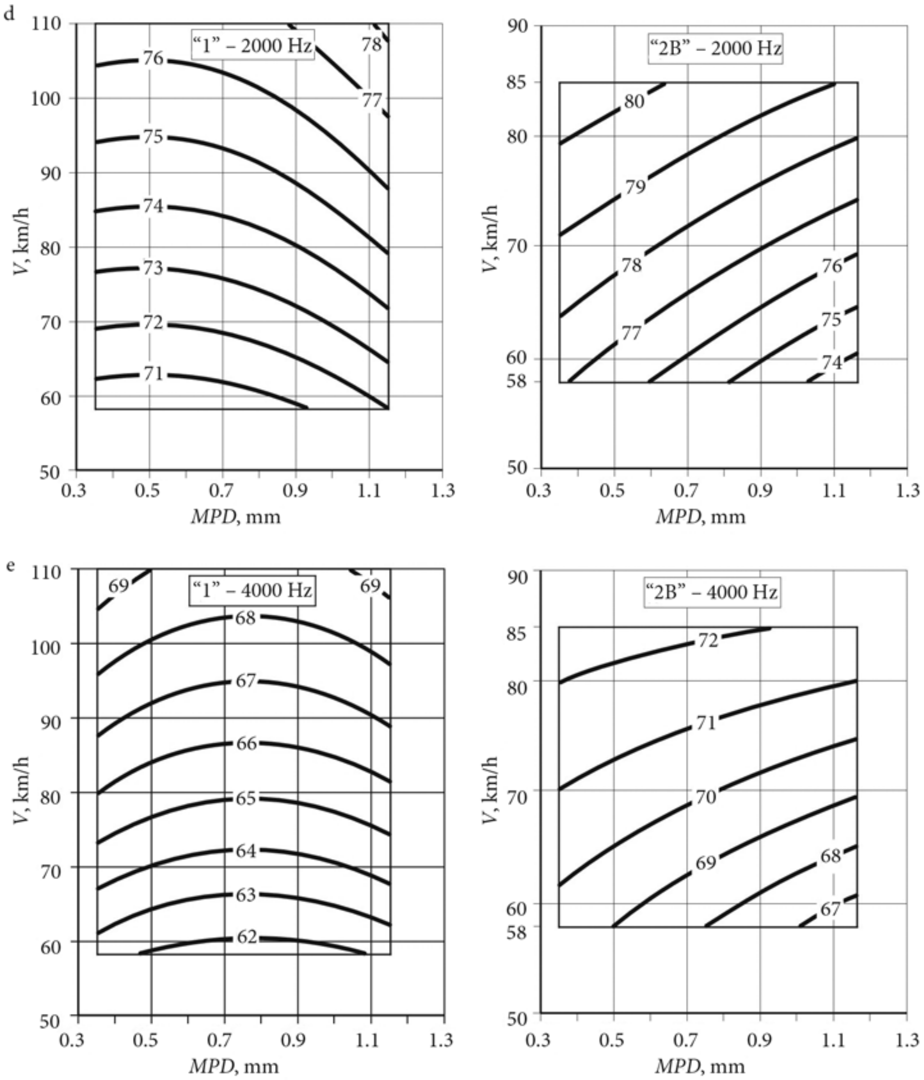


Fig. 7. Noise level in the octave band spectra as a function of *MPD* and speed of passenger car (category „1") and heavy vehicle (category „2*B*"): a – frequency 250 Hz; b – frequency 500 Hz; c – frequency 1000 Hz; d – frequency 2000 Hz; e – frequency 4000 Hz

polynomial coefficients. Table 2 gives the determined from formula 14 values of differences in relation to the speed of 80 km/h. Significantly high values of differences even up to 15 dB(A) for frequencies 500 Hz are to be underlined.

The elaborated formulae were verified by additional tests conducted along selected sections of road with the surface of asphalt concrete, stone mastics asphalt SMA and surface Ruflex type in different regions of Poland. Mean profile depth *MPD* of irregularities on tested pavements were in the range of 0.37 mm to 1.06 mm, and the noticed values of maximum differences between rolling noise in results of tests and analysis did not exceed 1.5 dB(A) for statistic passenger car and 2.0 dB(A) under statistic multiple-axle heavy vehicle.

6. Pavement macrotexture and equivalent noise level in the vicinity of road

Taking into consideration varying influence of pavement macrotexture on the level of emitted noise under specified categories of passing vehicles it has to be assumed that decisions undertaken while selecting the type of pavement shall include a kind and structure of traffic along the designed road.

The values of noise level under passing statistic passenger car L_1 and heavy vehicle category "2B" (L_{2B}) are obtained from information on pavement macrotexture and speed of traffic, and they are further utilized as the basic data determining the equivalent noise level L_{Aeq} in the vicinity of roads. Results of exemplifying computations of L_{Aeq} at the distance of 7.5 m from the road in the function of pavement macrotexture and traffic flow composition are presented below. Assuming the surface of pavement is described by the value of MPD = 0.4 mm, 0.7 mm and 1.1 mm the road was loaded with traffic of 1000 vph where the heavy vehicles participation is varying from to 0% to 50% and the average speed of passenger cars is 90 km/h and of heavy vehicles is 70 km/h. The algorithm described in the French *Prevision des Niveaux Sonores – Guide Du Bruit des Transports Terrestres* in 1980 has been used in the analysis.

Table 1. Values of approximating polynomial coefficients

Frequencies *f*, Hz		Values of coefficients					
		b_0	b_1	b_2	b_{12}	b_{11}	b_{22}
250	L_{2B}	70.71	–30.23	0.36	17.47	–	–
	L_1	25.59	–0.10	18.48	–	3.38	–
	ΔL_{2B-1}	45.12	–30.13	–18.12	17.47	–3.38	–
500	L_{2B}	18.35	–	33.98	–	–	–
	L_1	37.40	–8.50	17.04	–	9.38	–
	ΔL_{2B-1}	–19.05	8.50	16.94	–	–9.38	–
1000	L_{2B}	55.55	–39.47	15.19	20.18	–	–
	L_1	33.32	–6.25	22.58	–	7.81	–
	ΔL_{2B-1}	22.23	–33.22	–7.39	20.18	–7.81	–
2000	L_{2B}	51.36	–31.19	15.54	15.06	–	–
	L_1	32.49	–4.03	22.00	–	4.06	–
	ΔL_{2B-1}	18.87	–27.16	–6.46	15.06	-4.06	–
4000	L_{2B}	51.54	–36.79	11.01	18.68	–	–
	L_1	18.38	–4.93	25.67	–	3.13	–
	ΔL_{2B-1}	33.16	–31.86	–14.66	18.68	–3.18	–

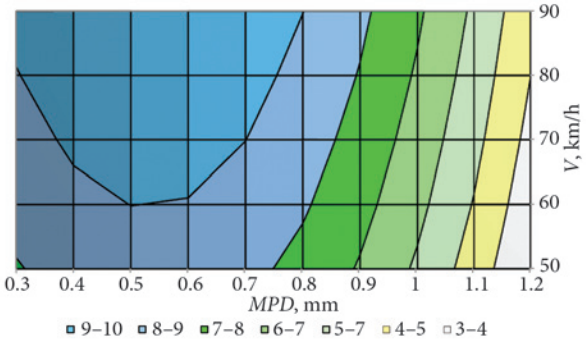


Fig. 8. Influence of pavement macrotexture and speed of vehicle on difference between noise level of heavy vehicle and noise level of passenger car (in dB(A))

The values of equivalent noise level $L_{eq1(2B)}$ under passing of single passenger car (L_1) and heavy vehicle (L_{2B}) is determined from the formula:

$$L_{Aeq1(2B)}(1h) = L_{1(2B)} + 10\log\frac{d}{V} - 30, \qquad (15)$$

where d – the distance of vehicle from point of reception of noise, m; V – speed of vehicle, m/s; and values of equivalent noise level under N_i passing vehicles category "1" and "2*B*" is computed from formula:

$$L_{Aeq}\left(N_{1(2B)}\right) = L_{Aeq1(2B)} + 10\log N_{1(2B)}. \qquad (16)$$

Table 2. Values of differences of maximum noise level of statistic heavy vehicle and passenger car in relation to pavement macrotexture ($V_1 = V_{2B} = 80$ km/h)

MPD, mm	Δ*L*, dB(A)	Δ*L* in frequencies bands, dB(A)				
		f = 250 Hz	*f* = 500 Hz	*f* = 1000 Hz	*f* = 2000 Hz	*f* = 4000 Hz
0.3	9.2	11.3	14.9	9.0	6.7	6.1
0.4	9.7	11.3	15.1	9.0	6.5	6.2
0.5	9.9	11.3	15.1	8.8	6.3	6.3
0.6	9.9	11.3	14.9	8.5	6.0	6.3
0.7	9.6	11.2	14.5	8.0	5.6	6.3
0.8	9.0	11.0	14.0	7.3	5.2	6.2
0.9	8.2	10.7	13.2	6.5	4.6	6.0
1.0	7.1	10.4	12.3	5.5	4.0	5.8
1.1	5.8	10.0	11.2	4.4	3.3	5.5
1.2	4.3	9.5	9.9	3.1	2.5	5.2

Total equivalent noise level for N ($N = N_1 + N_{2B}$) vehicles in the vicinity of road is determined from the formula:

$$L_{Aeq}(N) = 10\log\left[10^{\frac{L_{Aeq(1)}}{10}} + 10^{\frac{L_{Aeq(2B)}}{10}}\right]. \quad (17)$$

The values of L_{Aeq} presented in Fig. 9 confirm that selection of construction technology of wearing coarse and its surface macrotexture shall consider foreseen aspects of traffic along the designed road. Higher contribution of multiple-axle heavy vehicles in traffic volume favourable solution requires a wearing course of coarse macrotexture. On pavement of finer texture (*MPD* = 0.4 mm) the equivalent level of noise in the vicinity of road increases from 74.9 dB(A) to 79.2 dB(A) (increase of 4.3 dB(A)) including higher participation of heavy vehicles from 5% to 50%. On pavement of very coarse texture (*MPD* = 1.1 mm) the value of L_{Aeq} is varying from 77.0 dB(A) to 78.9 dB(A) (increase of 1.9 dB(A)). At the sometime significant differences between the values of L_{Aeq} on the asphalt concrete pavement and SMA pavement have not been observed.

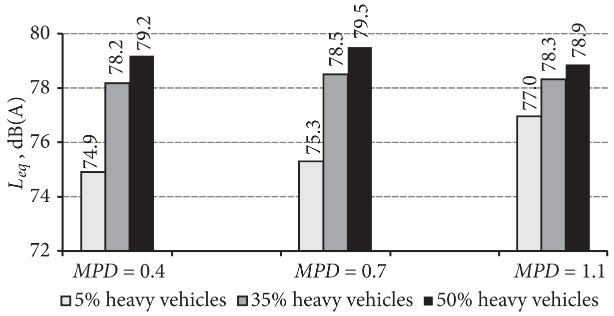


Fig. 9. Equivalent noise level at a distance of 7.50 m for different macrotexture of pavements and different traffic flow composition (traffic volume N = 1000 vph; V_1= 90 km/h; V_{2B} = 70 km/h)

7. Conclusions

Based on the conducted tests and analysis the following conclusions can be drawn:

1. Pavement macrotexture has decidedly higher influence on maximum noise level from passenger car than from multiple-axle heavy vehicle. On surface dressing the noise level of passenger car is 3 dB(A) higher than on asphalt concrete and stone mastic asphalt. In case of heavy vehicle the noise level on surface dressing is 1.2 dB(A) lower than on asphalt concrete and stone mastic asphalt. On the surface of fine and medium macrotexture the maximum rolling noise level of statistic heavy vehicle track is 9 dB(A) higher compared to the noise level while statistic passenger car is passing. On the surface of coarse macrotexture this difference is much lower and is close to 5 dB(A).

2. Technology of construction of dense asphalt pavements has no significant influence on noise spectrum from passing multiple-axle heavy vehicle. In case of passing passenger car, in the range of frequencies 250–1250 Hz, the differences between noise levels reach 5–6 dB(A) on surface dressing and on asphalt concrete and stone mastic asphalt. In the range of frequencies 2000–8000 Hz no significant influence of macrotexture on the level of emitted noises has been admitted.

3. Mean profile depth of dense asphalt pavements and logarithm of speed of the passing vehicle allow to calculate the maximum level of emitted noise from passing vehicles.

4. Influence of macrotexture on emitted the noise level by passing passenger car in the range of frequencies 250 Hz, 500 Hz and 1000 Hz is decidedly higher than in the range of higher frequencies (2000 Hz, 4000 Hz). In case of heavy vehicle the lowest noise levels become at values of *MPD* equal 0.6–0.8 mm. In range of lower frequencies 250 Hz the noise level raises with the increase of macrotexture while for frequencies 1000 Hz, 2000 Hz and 4000 Hz it decreases with the increase of macrotexture within the investigated range, and for frequencies of 500 Hz macrotexture has no influence on the noise level.

5. Speed of the vehicles has significant influence on maximum level of emitted noise and increase of speed by 20 km/h causes increase of noise level of 3–4 dB(A).

6. Evaluated dependences describing rolling noise in function of surface macrotexture and speed of vehicles enable computation of equivalent noise values in the vicinity of constructed roads. This indicates that at the stage of the surface construction technology acceptance and selection of macrotexture can be influenced on creation of acoustic climate in the vicinity of roads.

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