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Influence of surface textures of road markings on tyre/road marking noise

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ABSTRACT

Road markings are an essential component of a safe road. In particular, the optical guidance at night and under wet conditions rates high. Special surface textures of road markings can enhance the nighttime visibility during wetness, but they can lead on the other hand to noise emission during passages of vehicles and thus annoy residents. In the present study the tyre/road marking noise is analysed based on two different measurement methods for traffic noise: Several different road markings with increased nighttime visibility during wetness were overrun and the noise was determined by controlled coast-by measurements as well as close-proximity measurements. For both measuring methods the averaged A-weighted sound pressure levels were determined and an analysis of the third octave spectra was performed in order to identify annoying tonal components. The results of both measurement methods were compared with each other. Limitations of the individual measurement methods were overcome by combining the data. Properties of road marking noise depending on the texture of the marking are discussed in relation to those of road surface noise. The results will help specifying road marking texture types that ensure less annoyance and at the same time good visibility at wetness and night-time.

Keywords: tyre/road noise, road markings, sound pressure level, frequency domain, spectral analysis
I-INCE Classification of Subjects Number(s): 52.3, 72.1, 74.8

1. INTRODUCTION

Road markings can be designed as flat markings or as markings with a structured surface. A good visibility at night and rain can be ensured if flat markings are equipped with relatively big glass beads that enhance the retroreflection of the light of vehicle head lamps. Road markings having a structured surface show also a good visibility at night time and rain because not all glass beads at the slopes of the structures are covered with a water film during rain and hence light of vehicles can be retroreflected.

Structured road markings can also be used as an acoustic warning device in order to prevent lane departures because of their noise production during vehicle passages.

In Germany there is a broad range of application of road markings with increased night time visibility during wetness. They are intended for example for highways and other multi-lane roads and for critical zones such as accident black spots. The use of structured road markings as acoustic warning device is not so prevalent in Germany than in other countries. It is limited in the main to the use of ribbed road markings in tunnels and the intended use in some areas where an acoustic warning has to be realised by a road marking.

The special surface textures of structured road markings that enhance the night time visibility during wetness can lead to noise emission during passages of vehicles and this can annoy residents. Since there are recent problems with the annoyance of residents and there are up to now no regulations in Germany for tyre/road marking noise a project of the Federal Highway Research Institute (BASt) has been initiated. The aim of this project was to analyse tyre/road marking noise in terms of sound pressure levels, annoyance due to tonal effects, developing measurement methods and to develop quieter structured road markings having a good night time visibility during wetness as well.

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2. MEASUREMENT OF TYRE/ROAD MARKING NOISE

2.1 Composition of the study

This study was based on a previous study of the Federal Highway Research Institute on tyre/road marking noise (1). In that study six different structured and non structured road markings were analysed with respect to sound pressure levels and the properties of the frequency spectra using Coast-By measurements. The present study is taking into account further road marking structures that could not been analysed in the first study. Furthermore the Coast-By method as well as the Close-Proximity (CPX) method were used in order to determine road traffic noise. Comparing the two measurement methods with each other will help to build a bridge to existing data and regulations on tyre/road noise. A part of the measurement results of this study is provided for a working group of the European Committee of Standardisation (CEN) that is dealing with horizontal signalisation and in particular with developing a standardised measurement method for the noise production of road markings overrun by vehicles (CEN/TC 226/WG 2/EP 5).

2.2 Experimental setup

For the present study of noise emission of road markings overrun by vehicle tyres 7 different agglomerate road markings were applied on a landing runway at an airfield. In order to prepare the landing runway for the study the surface had to be reconditioned with a layer of stone mastic asphalt of the aggregate size 0/8 which has been used as a reference pavement during the study. Since the test site is closed to public traffic the SMA 0/8 has a lower grade of gritting and compacting than usual stone mastic asphalts.

The analysed road markings consisting of a cold plastic material with embedded drop-on glass beads (see Figure 1) were all applied at the same day. All road marking stripes had a length of 100 m and a width of 0.3 m. The width of 0.3 m was chosen to ensure that the tyres of the test cars and the CPX trailer respectively can overrun the road marking completely. The width of 0.3 m is used in Germany mainly for right edge lines on highways.

The following agglomerate road markings and a reference pavement were analysed (see Figure 1):

1. irregular scattered dots
2. irregular dense structure
3. irregular lengthwise structure
4. regular broad drops
5. regular dense dots
6. regular narrow drops
7. irregular perforate plate structure
8. stone mastic asphalt 0/8 (SMA 0/8) with lower grade of gritting and compacting as a reference

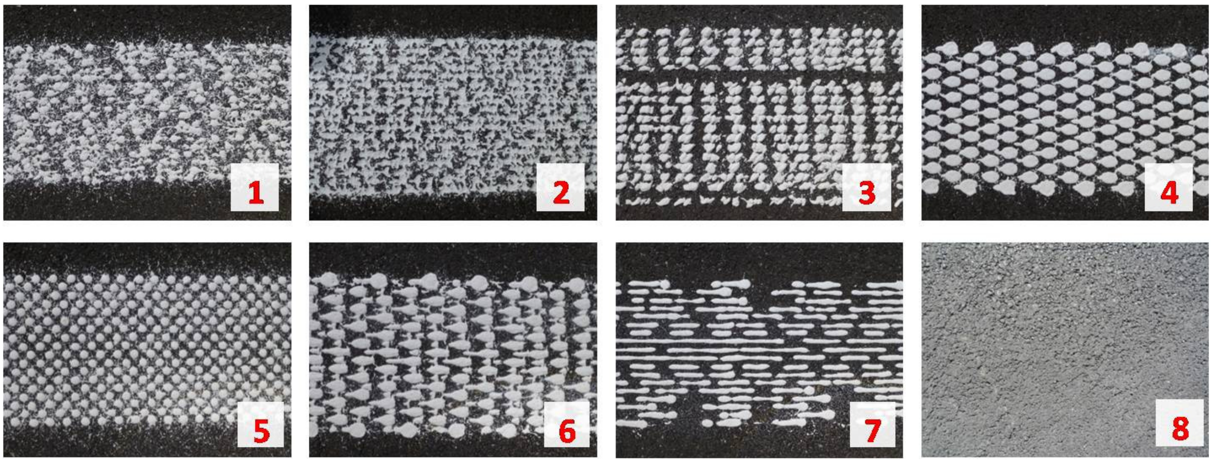

Figure 1 – Analysed road markings and reference pavement (no. 8).

2.3 Coast-By measurements

One of the two methods for measuring the influence of road surfaces on traffic noise described in the ISO standard 11819-1 is the Statistical Pass-By (SPB) method (2). This method is used for the determination of traffic and vehicle noise on different pavements and under different traffic conditions. For a statistically significant number of vehicles the A-weighted sound pressure levels and the appendant vehicle speeds are measured. From this an average maximum A-weighted sound pressure level at a certain reference speed and for a certain vehicle category or for a mixed vehicle collective can be calculated according to ISO 11819-1.

Since the measurements were carried out at a test site that is closed to public traffic a variant of the SPB method had to be used, the so called Coast-By (CB) method that is described in ISO 13325 (3). In the present study the Coast-By measurements were carried out with the following frame conditions.

- Use of passenger cars for overrunning the road markings.
- Use of the Standard Reference Test Tyre (SRTT) of ASTM F2493-08 (4) that is representing a passenger car tyre.
- Overrun of the road markings in coast-by mode in order to prevent engine noise.
- Measurement speeds of 30, 50, 70, 100 and 120 km/h in order to carry out a regression analysis and thus calculate sound pressure levels for speeds in between.
- Microphones in a height of 1.2 m and additionally of 2.4 m. A distance of the microphones to the center line of the vehicle of 7.5 m.
- Using the time weighting "FAST".
- Only evaluate measurements with car tyre being hundred per cent on the road marking.
- Meteorological conditions according to ISO 11819-1.
- Conditions for road area under observance, surrounding area and the background noise according to ISO 11819-1 and ISO 13325.

The Coast-By measurements were performed with two test vehicles that were equipped with SRTT tyres in order to have consistent tyres for Coast-By and Close-Proximity measurements. The first part of the Coast-By measurements were carried out with a minibus because this car had sufficiently large wheel arches for the SRTT tyres. During the measurements a change of the test car was necessary by reason of a limited acceleration track length. The minibus could not reach the maximum speed of 120 km/h within this track. A passenger car with suitable wheelarches and wheels was used for the pending measurements with higher speeds (see Figure 2).

Figure 2 – Coast-By measurements. Left: Measurement with minibus.
Middle: Measurement with passenger car. Right: Microphones, speed indicator and devices for meteorological measurements.

For comparison reasons a number of conjunction measurements on the reference pavement were performed with speeds of 50, 70 and 100 km/h. On the road marking with regular broad drops conjunction measurements with speeds of 50 and 100 km/h have been performed as well. Furthermore the tyre loads and inflation pressures were arranged consistently according to ISO 13325 for the minibus and the passenger car.

For each road marking at least 4 valid Coast-By runs per measurement speed were performed. The number of Coast-By runs per measurement speed on the reference pavement was much higher due to conjunction measurements at the beginning and the end of each measurement day.

2.4 Close-Proximity measurements

A second method of measuring traffic road noise is the "Close-Proximity Method" (CPX). The CPX measurements on road markings and the reference pavement were performed according to the requirements of ISO/DIS 11819-2 (5). For the CPX measurements an enclosed single-axle trailer towed by a separate vehicle was used (Figure 3, left). The tyres of the trailer create the tyre/road noise that was recorded by two microphones in front and at the rear of the tyre (Figure 3, middle). Special reference tyres according to ISO/DIS 11819-2 have to be used for the measurement. Depending on the purpose of the measurement, this are reference tyres representing passenger cars (tyre P1) and/or heavy vehicles (tyre H1). In the present study a P1 tyre was used.

Since the ISO/DIS 11819-2 does not contain specific measurement instructions for CPX measurements on road markings, the European standardisation group CEN/TC 226/WG 2/EP 5 (Positive and negative noise of structured road markings) developed a draft protocol for CPX measurements on road markings that was taken into account for the measurements. The main additional points and enclosures respectively of this draft protocol compared to ISO/DIS 11819-2 are:

- Use of a standard reference test tyre (SRTT) according to ASTM F2493-08 (4) (see Figure 3, right).
- Choice of the measurement speed of 80 km/h ± 4 km/h.
- At least two measurement runs have to be carried out for each type of road marking. During repetition the same measurement section has to be used.
- Measurement of sound pressure levels with A-weighting and time weighting "FAST" (0.125 s).
- Measurement of the A-weighted sound pressure level L_{CPX} of the tyre/road noise according to ISO/DIS 11819-2 and determination of the third-octave band spectra.

Figure 3 – Left: Enclosed CPX trailer with towing vehicle. Middle: SRTT with microphones on mandatory positions. Right: Open trailer box with SRTT.

The CPX measurements were conducted close to the reference speed of 80 km/h. In addition to the above mentioned drafted measurement protocol CPX measurements at a reference speed of 50 km/h were carried out. The measurement speed was regulated by a speed control with a deviation of approximately ± 0.2 km/h. In addition a yellow sticker has been fixed to the enclosure of the trailer and has been centred to the tyre contact area. The driver could control the position of the trailer via the right rear mirror. The tested road markings were overrun only with the right tyre-wheel assembly of the trailer. Parallel to the overrun a video recording was performed with a camera inside of the enclosement of the trailer. During evaluation of the data this helped to identify the road segments where the tyre did not run completely on the road marking. Those segments were dropped.

A temperature correction according to ISO/DIS 11819-2 has not been applied because the air temperature was in the range of 21 to 22°C for all test runs. A possible temperature correction to the reference temperature of 20°C would be extremely low (≤ +0.1 dB(A)) and was therefore not carried out.

On each agglomerate road marking and the reference pavement several runs with the CPX trailer were performed and have been averaged arithmetically according to the calculation procedure described in ISO/DIS 11819-2. At the reference speed of 80 km/h 6 - 8 runs per sample were carried out for the agglomerate road markings and 5 runs for the SMA 0/8 reference. For the reference speed of 50 km/h 3 runs in each case were taken into account for the evaluation of the data.

The CPX measurements at 80 km/h were also contributed to a Belgian-German CPX measurement campaign in the frame of the European standardisation activities on “Horizontal Signalisation”. The results of these measurements are described in detail in (6).

3. RESULTS

3.1 Results of Coast-By measurements

For each vehicle passed by the speed and the A-weighted maximum sound pressure level with time weighting "FAST" L_{AFmax} were measured. For all speeds v in the range of the measured speeds an estimated averaged sound level $L_{ave}(v)$ was calculated according to ISO 11819-1 respectively ISO 13325 (3). The averaged sound levels $L_{ave}(v)$ for the analysed road markings at a microphone height of 1.2 m are shown in Figure 4.

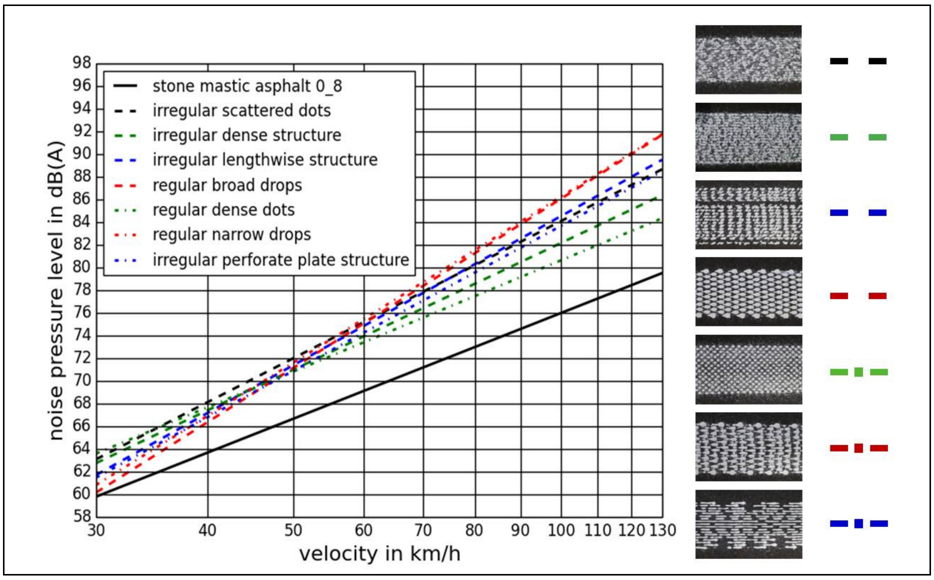

Figure 4 – Averaged sound levels $L_{ave}(v)$ of analysed road markings obtained from Coast-By measurements.

3.1.1 Conclusions of the measurement of the averaged sound level

- The reference pavement at the test site shows the lowest slope of averaged sound pressure levels with increasing measurement speed. It has a L_{ave} of 73 dB(A) at 80 km/h and 78.4 dB(A) at 120 km/h. Since the SMA 0/8 at the test site is not intended for traffic it was not gritted and not compacted sufficiently and hence the voids content is higher. Therefore we refer to additional data given in the draft of the future German guidelines for noise protection on roads (7). Therein the maximum averaged sound levels obtained from Statistical Pass-By measurements of light traffic are listed. For passenger cars driving on stone mastic asphalts 0/8 and 0/11 the maximum averaged sound levels have a value of 78.1 dB(A) for a speed of 80 km/h and 83.4 dB(A) for a measurement speed of 120 km/h. The comparison shows that the reference SMA 0/8 has averaged sound levels that are 5 dB(A) lower than those of common stone mastic asphalts in Germany used by traffic. A comparison study of Coast-By measurements with SRTT tyres and Statistical-Pass-By measurements in the United States (8) has shown that Coast-By measurements with SRTT tyres produce sound pressure levels that are approximately 2.7 dB(A) lower than Statistical-Pass-By measurements at the same site. It might be the case that therefore the difference of 5 dB(A) between the test site and common stone mastic asphalts is not only based on the lower grade of gritting and compacting but also on the choice of SRTT tyres.
- The two regular drop-shaped road markings show the strongest slope with increasing measurement speed. At a speed of 80 km/h they show a L_{ave} of approximately 81 dB(A) and at 120 km a L_{ave} of 90 dB(A). This is about +3 dB(A) at 80 km/h and +6.6 dB(A) at 120 km/h above the commonly used SMA 0/8.

- At higher speeds the irregular lengthwise structure, the perforate plate structure and the irregular scattered dots form a group with averaged sound levels of approximately 80 dB(A) at a speed of 80 km/h and between 87 and 88 dB(A) at a speed of 120 km/h. This is approximately +2 dB(A) at 80 km/h and 3.6 - 4.6 dB(A) at 120 km/h above the commonly used SMA 0/8.
- The regular dense dots show averaged sound levels of 77.5 dB(A) at 80 km/h and 83.2 dB(A) at 120 km/h. Compared to commonly used SMA 0/8 this is -0.6 dB(A) at 80 km/h and -0.2 dB(A) at 120 km/h below.
- The irregular dense structure has an L_{ave} of 78.6 dB(A) at a speed of 80 km/h and 85.1 dB(A) at 120 km/h. Compared to commonly used SMA 0/8 this is +0.5 dB(A) at 80 km/h and +1.7 dB(A) at 120 km/h.

3.1.2 Analysis of third octave spectra

The third octave spectra for a speed of 80 km/h (Figure 5) (calculated by regression analysis per each third octave for this speed so that it can at a later stage be directly compared with CPX measurements) show that the road markings have elevated levels below 1 kHz and almost equal levels above 1 kHz compared to the reference pavement. The highest sound pressure levels are found at a value of about 800 Hz with strong slopes at both sides for all road markings. In contrast the reference pavement has a plateau of maximum values in the range of 800 – 1000 Hz. Since tonal components in tyre/road marking noise can annoy residents the third octave spectra were calculated for all measurement speeds. Some of the analysed road markings show beside the maximum at 800 Hz another maximum at about 400 Hz which is more or less pronounced. Especially such side lobes can be responsible for tonal effects that are audible. For the two drop-shaped agglomerates the speed dependent analysis of the third-octave spectrum is given in Figure 6 showing tonal effects at certain frequencies and at certain speeds.

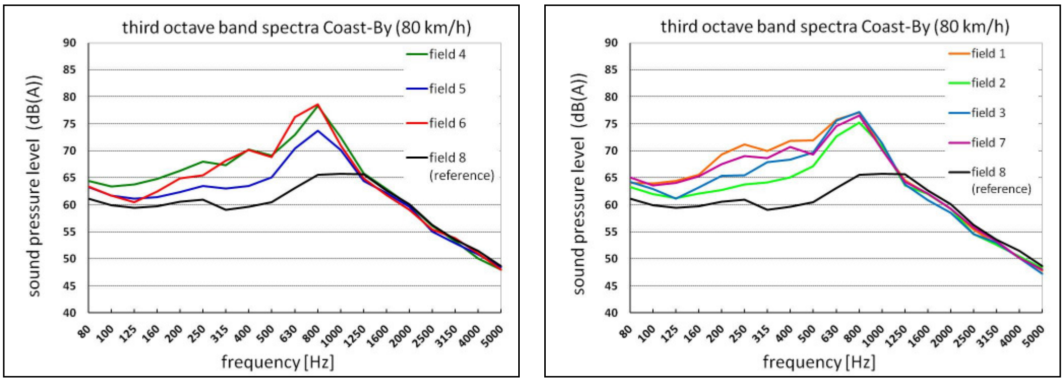

Figure 5 – Third octave spectra for Coast-By measurements at 80 km/h, obtained from regression per each third octave. Left: Spectra of regular structures and reference pavement. Right: Spectra of irregular structures and reference pavement.

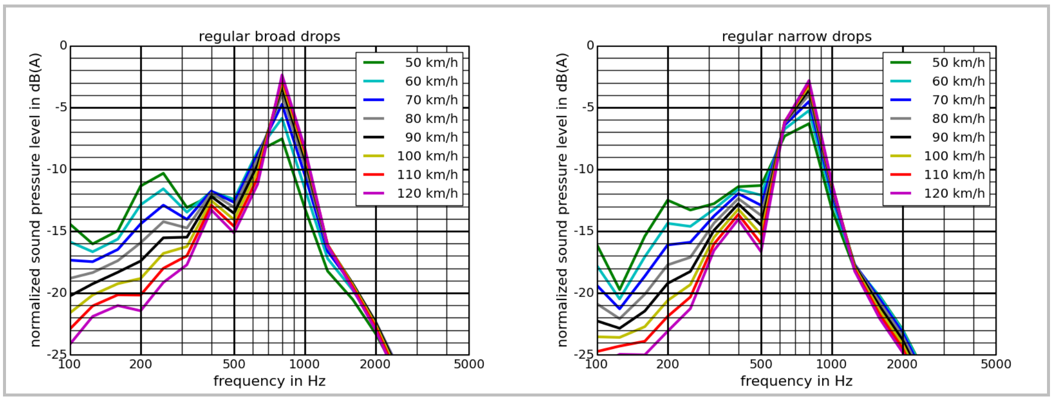

Figure 6 – Normalised third octave spectra for Coast-By measurements in dependence on the speed (regression per each third octave). Left: Regular broad drops. Right: Regular narrow drops.

3.2 Results of Close-Proximity measurements

The "Close-Proximity level for light vehicles" (CPXP) according to ISO/DIS 11819-2 was determined. This is an index for comparison of road surfaces, which is based on the tyre/road sound pressure levels of - in this case - one tyre representative of a passenger car tyre (denoted by P1). The measured CPXP values are shown in Figure 7.

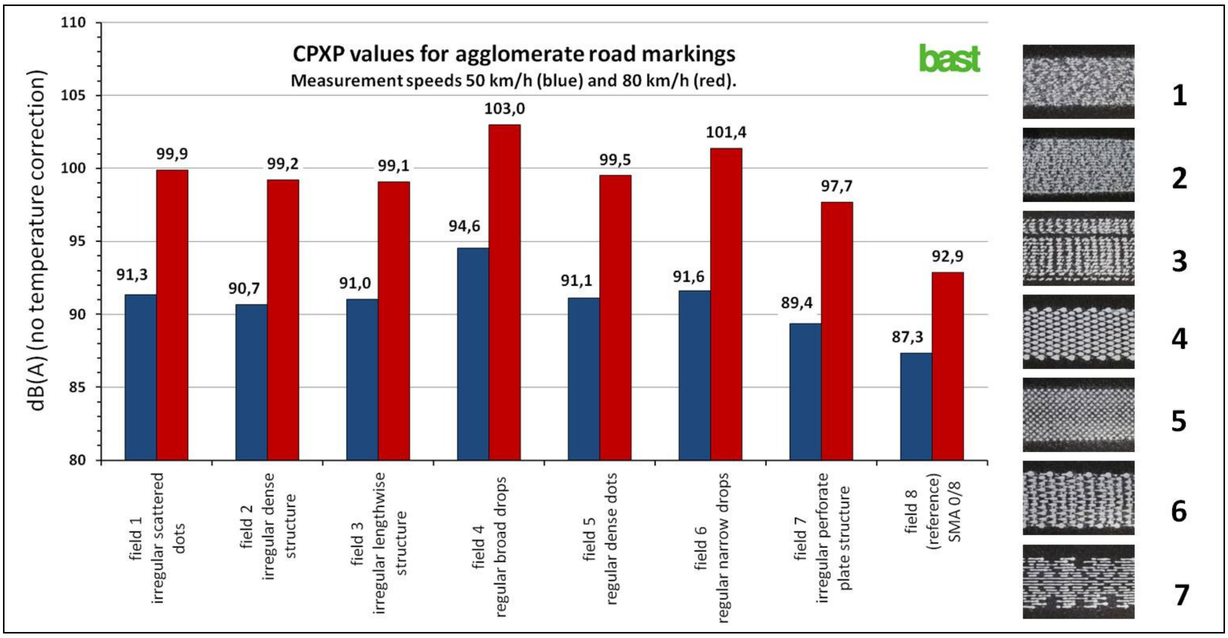

Figure 7 – CPXP values for analysed road markings.

3.2.1 Conclusions of CPX measurements at a speed of 80 km/h

- The stone mastic asphalt 0/8 at the test site shows with a value of approximately 93 dB(A) a low sound pressure level compared to usual SMA 0/8. Since the SMA 0/8 at the test site is not intended for traffic it was not gritted and not compacted sufficiently and hence the voids content is higher. Therefore it is necessary to refer to additional data. An evaluation of a series of CPX measurements on stone mastic asphalts in Germany has shown that SMA 0/8 pavements have on average a CPXP value of about 97.5 dB(A) for measurements with a P1 tyre and a measurement speed of 80 km/h. SMA 0/11 pavements measured with a P1 tyre show on average values of about 97 dB(A) for a measurement speed of 80 km/h (9, 10).
- In comparison to the reference pavement at the test site with a CPXP value of 92.9 dB(A) the sound pressure levels of the tested agglomerate road markings show significantly increased values in the range of 4.8 to 10.1 dB(A).
- Compared to commonly used SMA 0/8 pavements there is an increase of 3.9 dB(A) for regular narrow drops and 5.5 dB(A) for regular broad drops. In the German measurement campaign the two regular drop-shaped road markings show the highest CPXP values with 101.4 dB(A) for narrow drops and 103 dB(A) for broad drops.
- The regular dense dots have a CPXP value of 99.5 dB(A) and are less noisy than the regular drop-shaped structures. Compared to commonly used SMA 0/8 pavements their CPXP value is 2 dB(A) higher.
- The three irregular structures with lengthwise pattern, a dense structure and scattered dots have all comparable CPXP values in a range of approximately 99 - 100 dB(A). This is around 1.5 - 2.5 dB(A) higher than the CPXP values of commonly used SMA 0/8.
- The irregular perforate plate structure shows with 97.7 dB(A) the lowest CPXP value of all agglomerates and is hence comparable with CPXP values of commonly used SMA 0/8. It has to be taken into account that this structure is thinned out compared to all other analysed road markings. It has a considerably lower pavement coverage than the other agglomerates.

3.2.2 Conclusions of CPX measurements at a speed of 50 km/h

The CPXP values of the analysed road markings at a measurement speed of 50 km/h are approximately 8 - 10 dB(A) lower than the corresponding values at a measurement speed of 80 km/h. Concerning the reference pavement at the test site the CPXP value at 50 km/h is 5.6 dB(A) lower than the value at 80 km/h. For the measurement speed of 50 km/h the CPXP values of the road markings are approximately 2 to 7 dB(A) above the reference pavement (Figure 7). The order of the analysed road markings with respect to the height of CPXP values is almost the same for 80 and 50 km/h, only the irregular dense and the irregular lengthwise structure change their places. Since the differences of sound pressure levels for these two road markings are very low this effect can be neglected.

3.2.3 Analysis of frequency spectra

The third octave band spectra for the P1 tyre on the tested road markings are shown in Figure 8. The frequency spectra show the following distinctive features. The highest sound pressure levels for the tested road markings are found in the frequency region of 800 to 1000 Hz that is characteristic for tyre/ road noise. For road markings the 800 Hz sound pressure levels predominate however concerning the maximum levels. In contrast to stone mastic asphalts 0/8 road markings show a strong increase of sound pressure levels in the range of low frequencies. In the range of higher frequencies (1250 – 1600 Hz) there is on the other hand a decrease of sound pressure levels.

In case of the broad and narrow regular drops (road markings 4 and 6, Figure 8 upper row, left picture) a second maximum exists at low frequencies for a speed of 80 km/h. Due to their structure a long-wave texture content is generated that leads to a low-frequency contribution at 500 Hz for regular narrow drops (road marking 6) and at 315 Hz for regular broad drops (road marking 4).

At a measurement speed of 50 km/h the frequency range between 400 and 500 Hz has side lobes for regular broad drops and regular dense dots and a pronounced contribution for the regular narrow drops exists at 315 Hz.

Another possible explanation for the features of the frequency spectra is that during overrun of the regular and coarse structures there could be a mechanical stimulation transferred via the axle and the chassis of the trailer towards the microphone holders.

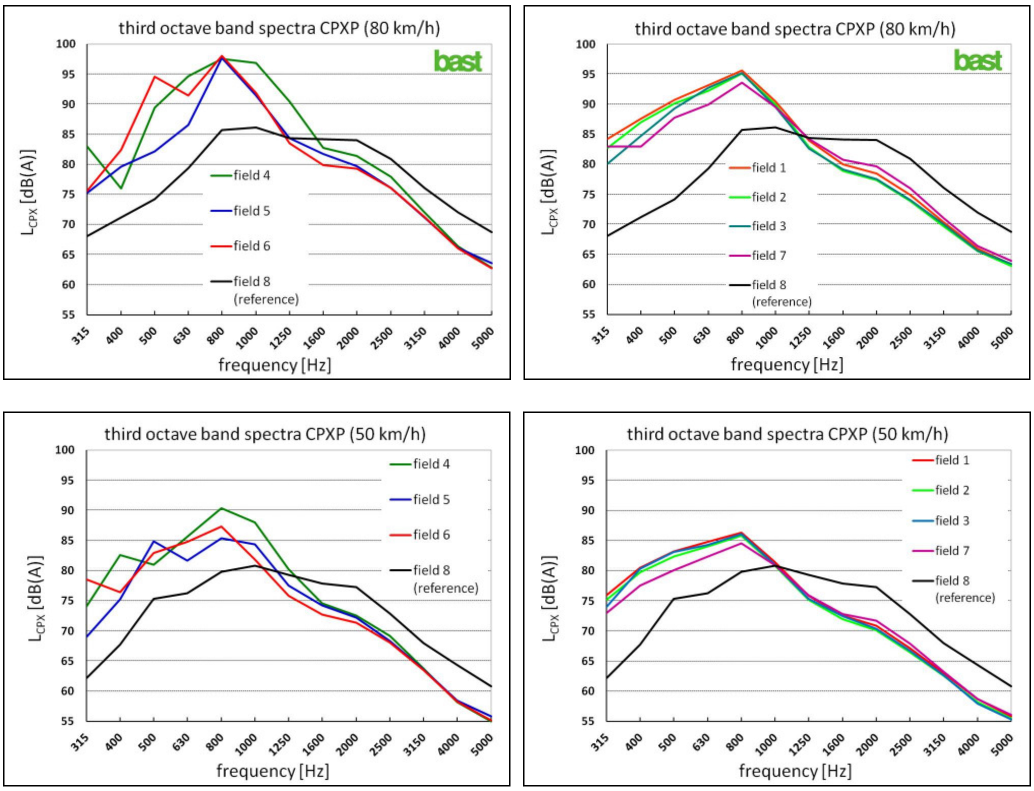

Figure 8 – Third octave band spectra for CPX measurements in comparison with reference pavement. Left: Spectra for regular structures (reference speeds 80 and 50 km/h). Right: Spectra for irregular structures (reference speeds 80 and 50 km/h).

3.3 Comparison of Coast-By and Close-Proximity measurement results

Coast-By and Close-Proximity measurements in this study are compared in the following – as far as this is possible for different measurement methods. In order to obtain a better comparability the Standard Reference Test Tyre SRTT according to ASTM F2493-08 (4) has been used for both measurements. Further on the Coast-By measurements were carried out in the coast-mode in order to exclude engine noise. The measurements show the differences in the measured sound pressure levels between the near field that is recorded with CPX measurements and the listening situation of a person standing at the roadside (far field) represented by the Coast-By measurements. At the compared speeds of 50 and 80 km/h there is a difference of approximately 20 dB(A). A direct comparison for the speed of 80 km/h is shown in Figure 9 (Coast-By values calculated by regression analysis). The levels are shown in descending order of the CPXP values. The comparison shows that the order of CPXP values does not correspond one-to-one to the order of averaged sound pressure levels obtained from Coast-By measurements. The CPXP values of fields 1, 5, 2 and 3 are lying for example in a range of 99 – 100 dB(A) whereas the L_{ave} of the corresponding Coast-By measurements spread in a range of 2.8 dB(A).

The frequency spectra at the speed 80 km/h show some smaller variations between CPX and Coast-By but in principle the same features of the analysed road markings and the reference are depicted.

Both measurement methods identified a discontinuity in road marking 4 (regular broad drops) by showing a higher standard deviation than the average.

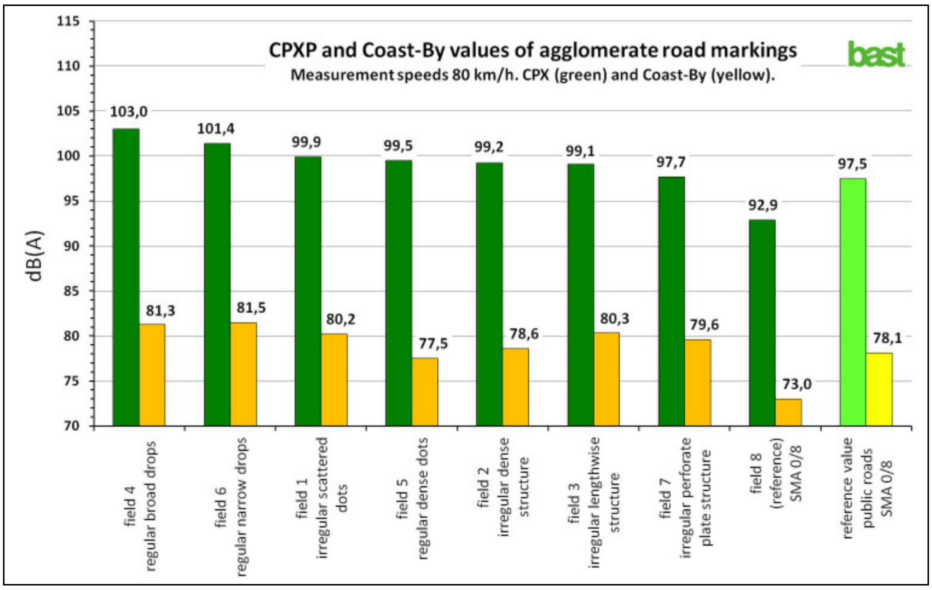

Figure 9 – Comparison of CPXP and Coast-By values at a speed of 80 km/h.
The levels are shown in descending order of the CPXP values.

In the following some advantages and disadvantages of the two measurement methods that turned out during the study are given:

Advantages CPX method:

- Measurements on road markings on public roads are also possible.
- A longer, continous road marking section can be measured.
- The method is cost-effective and time-saving.

Disadvantages CPX method:

- At higher measurement speeds lanekeeping on road markings is difficult to realise. Speeds less or equal to 80 km/h are uncomplicated. On public roads it is difficult to keep the lane on the road marking and to oberserve similarly the traffic. For safety reasons it is recommended to use an accompanying safeguard vehicle and a co-driver for the CPX measurement system.
- For the measurements a longer road marking section of about 100 - 200 m is necessary.

Advantages Coast-By method:

- Measurements within a broad speed range can be realised.
- The speed-dependent evaluation of the frequency spectrum can be analysed.
- For the measurements a short road marking section of about 20 m is sufficient.

Disadvantages Coast-By method:

- Measurements are only possible at special test sites as a rule since road markings are not overrun permanently.
- The tyre/road marking noise is measured only at a special spot.
- The measurements would have to be interrupted if wind speeds were too high.

4. CONCLUSIONS

The analysis of agglomerate road markings with Coast-By and CPX measurements has shown that these types of road markings have in most of the cases elevated sound pressure levels compared to reference pavements (see both references in Figure 9). In comparison with commonly used stone mastic asphalts in Germany and at a speed of 80 km/h the road markings show maximum sound pressure levels of about +5.5 dB(A) for CPX measurements and +3.4 dB(A) for Coast-By measurements. But there are agglomerate structures that have CPXP and averaged sound levels that are comparable with corresponding values of reference pavements for public roads.

Although both measurement methods can in principal be used in order to determine tyre/road marking noise they deliver partially different results in ranking road markings based on sound pressure levels. It is therefore necessary to also assess the tonal components of the noise to identify road marking structures with increased annoyance.

A further project that is currently under work is dealing with psycho acoustical properties of road markings (11). With the help of these additional results suggestions for national requirements for the use of agglomerate road markings can be drafted. In addition the long-term properties of agglomerate road markings with regard to on the one hand tyre/road noise and on the other hand performances for road users like night time visibility have to be analysed and have to be taken into account for the intended use. In addition further research is necessary in order to develop a measurement method for assessing tyre/road marking noise in the framework of the European standardisation activities of CEN.

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