Assessing the acoustic properties of audio-tactile road markings

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ABSTRACT

Structured road markings are becoming popular as edge line on high speed roads, ensuring night time visibility (retroreflection) during rain. These markings are often also “audio-tactile”: vehicles (un)intentionally driving over it may produce much more tyre/road sound, which may be observed in the vehicle but also in the vicinity. The sound increase inside the car can be considered as a positive side effect, as it alarms the driver and may be very helpful for the prevention of "doze off" traffic accidents. The sound increase perceived outside the car however, may have a positive aspect as it can warn people on the emergency lane about the approaching vehicle, but it may as well annoy people living around. A method for the assessment of the acoustic properties of audio-tactile markings has been developed. It is mainly based on the "Close Proximity" (CPX) method, an ISO method intended for the acoustic assessment of pavements. The results of measurement campaigns with CPX trailers in Belgium and Germany according to a specially designed procedure are presented. The feasibility of the method is discussed. The research has been carried out in the frame of the standardization activities of the CEN working group CEN/TC226/WG2 “Horizontal signalization”.

Keywords: audio-tactile marking, close proximity, traffic safety I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION

Structured road markings are becoming more and more popular as edge line on high speed roads, as they are effective to enhance the night time visibility (retroreflection) during rain. Vehicles intentionally or unintentionally driving over it may produce much more tyre/road sound than the ones that don’t; therefore these markings can also be referred to as “audio-tactile”. The increased sound production may be observed in the vehicle but also in the vicinity of the road. The sound increase inside the car can be considered as a positive side effect, as it alarms the driver that he/she is deviating from the lane and may be very helpful for the prevention of “doze off” traffic accidents. The effect of the interior sound may be increased by the vibration of the car body induced by the road marking, shaking the driver and awakening him. The sound increase perceived outside the car however, may have a positive aspect as it can warn people (e.g. road workers or people with car breakdown) on the emergency lane about the approaching vehicle, but it may as well annoy people living in dwellings nearby the road.

The growing popularity of structured road markings makes it desirable that there exists a measurement method to assess the noise production of such markings during wheel passages. The

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method should be representative, reproducible, generally applicable throughout Europe and as practical and as little cumbersome as possible.

The CEN working group "road markings" (CEN/TC226/WG2) formed on its meeting on 20 and 21 October 2011 in Leuven (Belgium) an "expert panel" (called EP5 "noise", convened by the main author) for the development of such a measurement method. A method, mainly based on the "Close Proximity" method, an ISO method, primarily intended for the acoustic assessment of pavements, has been drafted and discussed in this EP. In this paper the results of measurement campaigns with the CPX trailer of the Flemish Agency for Roads and Traffic on a selection of commonly applied structured road markings in Flanders and with the German Federal Highway Research Institute CPX trailer on especially for this purpose applied stretches of audio-tactile markings on a discarded airstrip on a German airbase are presented.

2. THE MEASUREMENT METHOD

2.1 The Close Proximity method

The Close Proximity method is a standardized and quite commonly used method for the evaluation of the noisiness of pavements. The method is currently under revision, after having been described in an ISO/TS. The revised method is believed to be more robust and reproducible. Although the revised method is not published yet as an ISO standard, it is already available as an ISO/DIS (1). The method consists basically in letting a standard tyre roll over the pavement and measuring the tyre/road noise with two microphones at two standard positions. Five microphone positions are described, but only two are "mandatory" (Figure 1).

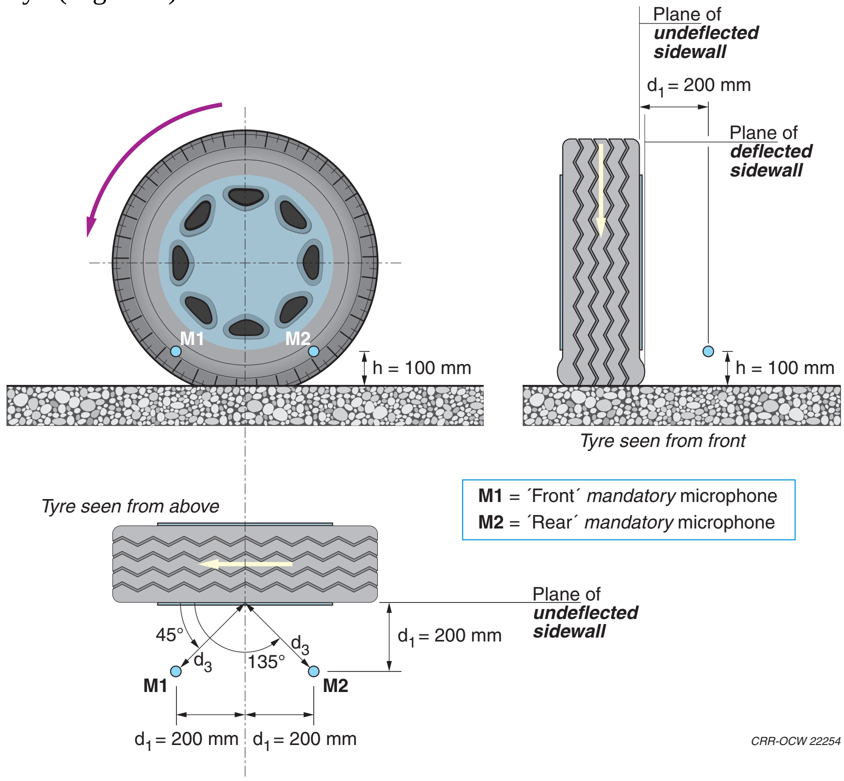

Figure 1 – Microphone positions for the CPX method

Figure 2 shows some images from the CPX trailers from the Flemish Agency for Roads and Traffic and from the German Federal Highway Research Institute. The inside of the hood is covered with a sound absorptive material (see middle pictures). The two microphones on positions M1 and M2 are placed at the inner side of the tyre and can be seen as the two black spheres (wind screens) just above the floor at the left hand pictures.

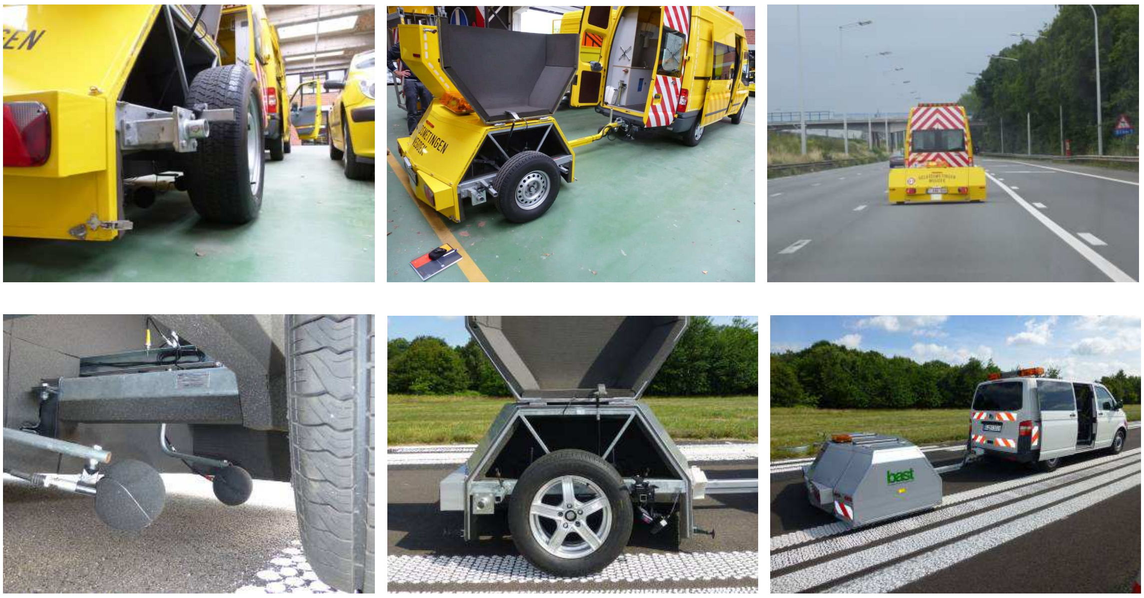

Figure 2 – The CPX trailers (closed type) of the Flemish Agency for Roads and Traffic (upper row) and the German Federal Highway Research Institute (lower row).

2.2 Adaptation of the method to measure on audio-tactile road markings

Although intended for the assessment of pavements, the CPX method can be used to measure the noisiness of structured markings as well, only with a few minor adaptations. The following modifications have been done and instructions for the measurement campaigns are given:

- only use of the Standard Reference Test Tyre (SRTT) P1 of ASTM (2) that is representing a passenger car tyre.
- measurement at a constant speed of 80 km/h ± 4 km/h.
- the test section should not have any curves.
- the operator should ensure that the test tyre rolls 100% on the marking; to ensure this, one can equip the vehicle with an auxiliary device, such as a camera filming the rolling test tyre and - in case of a closed CPX trailer - an appropriate illumination under the trailer cover is needed. Another possibility is that the trailer (“two-tyred” system) vehicle is equipped with an eye-catching coloured plastic sheet as auxiliary device. This plastic sheet with a width just like the width of the road marking can be mounted on the front of the right half of the enclosure and has to be centred with the tyre track. Via the right mirror of the towing vehicle the position of the trailer and with it the position of the rolling test tyre inside the enclosure can be easily aligned with the road marking. For non-enclosed trailers (“two-tyred” systems) this can be done by aligning the tyre with the road marking directly. For a “single-tyred” system (with and without enclosure) the camera mentioned should be used.
- at least two runs on the same test section
- starts/stops the measurement on the same spots.
- the “Close-Proximity Sound Index for passenger cars and light traffic” (CPXP) has to be determined according to ISO/DIS 11819-2. 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). One should measure in each run the sound pressure level (SPL) with the A-frequency weighting and the “FAST” time weighting.
- one should measure as well the 1/3rd octave band spectrum.

The upper row of Figure 3 shows the modifications carried out on the CPX trailer of the Flemish Agency for Roads and Traffic. A CCD camera with integrated LED illumination has been fixed above the trailing edge of the measurement tyre. The camera signal is transmitted via a video cable to a flat screen television which is placed in front of the wind screen, making it easy to the driver and the co-driver to monitor the position of the test tyre with respect to the road marking. The CPX trailer of the German Federal Highway Research Institute (Figure 3, lower row) has also been equipped with a camera for video recording and a torch for illumination. In addition an orange sticker has been fixed to the enclosure of the trailer in order to control the position of the test tyre via the right rear mirror (see

Figure 3, lower row, middle). The driver concentrated on driving the vehicle safely while the co-driver started/stopped the measurement on the right moment and monitored the position of the test tyre on the screen instructing the driver to adapt the lateral position of the vehicle when needed. After some practicing this went quite well and the driver managed to keep the measurement tyre on the road marking, a line of 30 cm wide, without problem.

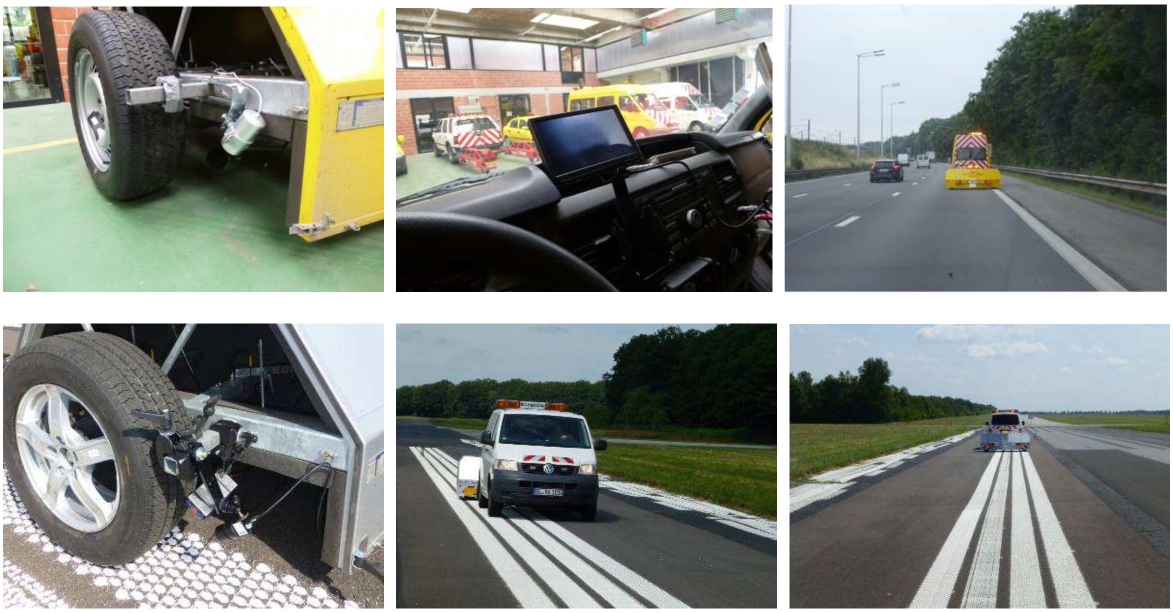

Figure 3 – The CPX trailers with modifications for measuring on audio-tactile road markings (left and middle) and such measurements (right hand side). Upper row: CPX trailer of the Flemish Agency for Roads and Traffic. Lower row: CPX trailer of the German Federal Highway Research Institute.

3. MEASUREMENT CAMPAIGN in Flanders/Belgium

3.1 Tested audio-tactile road markings

A selection of 23 sections of road markings has been made; including dotted (with dots with different sizes and shapes) and ribbed thermo- and cold plastic and structured tape. A selection of the measured road markings are shown in Figure 4. All sections are uninterrupted lines with a width of 30 cm (edge lines on highways). The length of the test sections varies between 40 m and 380 m and on each one two or three passes have been done. Some samples have been chosen on the same edge line in the vicinity of each other and where the same product has been applied. One can expect these results to be similar.

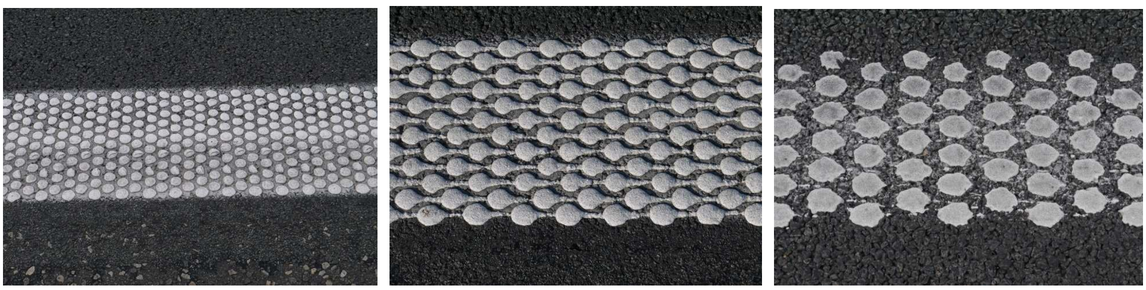

Figure 4 – Some tested audio-tactile road markings with dots (upper row) and ribs (lower row, left and middle) and tape with diamond pattern (lower row, right hand side)

For comparison four sections with common type asphalt pavements have been measured as well. Two sections with SMA 0/10 and two with dense asphalt concrete (unknown stone grading).

3.2 Belgian measurement results

The measured CPXP levels are shown in Figure 5 (3).

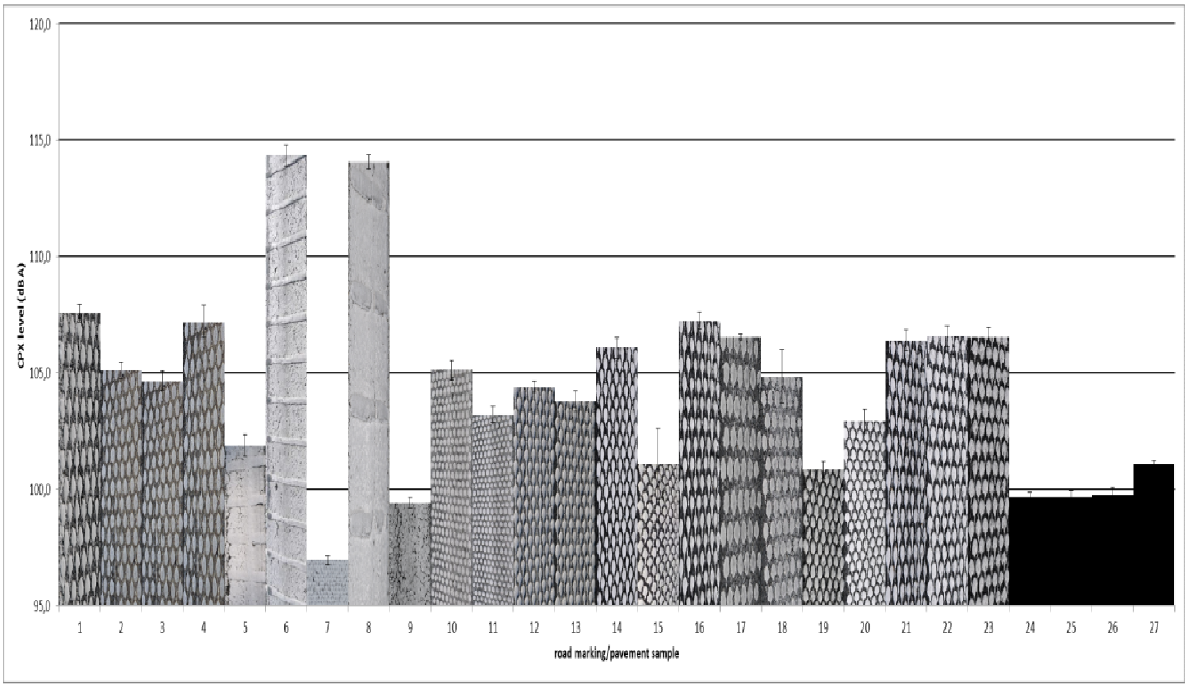

Figure 5 – CPXP levels measured on Belgian audio-tactile (and some other) markings and on common highway pavements (samples 24-27)

The following conclusions can be drawn from the Belgian results:

- Ribbed markings are the noisiest measured (sample 6 and 8), at least for the samples where the ribs were quite pronounced and not flattened by wear. These worn ribbed markings were on the contrary among the quietest. This is not a surprise as pronounced ribs represent texture in the megatexture range which efficiently induces tyre vibrations. The two samples with pronounced ribs yields, although measured on a different location, about the same CPXP level, which is about 14 dB(A) higher than the CPXP level on the reference surfaces (samples 24 – 27).
- Tape (sample 7) is the quietest marking measured and is even quieter than the reference surface.
- Paint (sample 9) does reflect the same texture as the road surface and that is the logical explanation why it exhibits the same noise level as the reference pavements (samples 24 – 27)

- Dotted markings yield levels which roughly vary between 101 and 107 dB(A), corresponding with a noise increase between 1 and 7 dB(A). Round dots are not more silent than droplet shaped dots, nor seems the size of the dots to play a role.
- Measurement results on markings belonging to the same batch, like samples 2 and 3; 10 and 11; 12 and 13; 14, 15 and 16; 17 and 18; 21, 22 and 23, differ up to 2 dB(A), but often less. An exception is sample 15 which is much quieter than 14 and 16, but this is due to a local inhomogeneity which was noticed by the operator and which led to a higher standard deviation. This was also the case, to a lesser extent, for sample 18.
- The standard deviation within one sample ranges from 0,20 to 0,70 dB(A) if the inhomogeneous samples 15 and 18 are left out of consideration. This is very low and indicates that the method is valid and robust.
- The standard deviation is plotted as a function of the length of the sample, is shown in Figure 6. There appears to be no correlation whatsoever and there is hence no need to impose long sample lengths. A sample length of 40 m with two measurement runs will do.

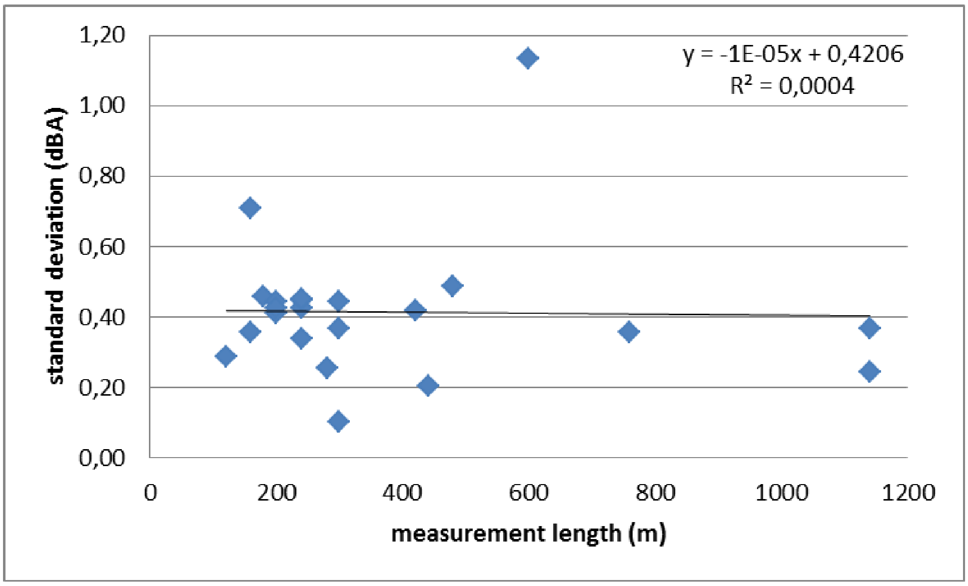

Figure 6– Standard deviation as a function of the measurement length, showing no correlation at all

4. GERMAN MEASUREMENT CAMPAIGN

4.1 Tested agglomerate road markings

In a study of the German Federal Highway Research Institute dealing with noise emission of road markings overrun by vehicle tyres, 7 different agglomerate road markings were analyzed. The road markings were applied on a runway at an airfield. In order to prepare the runway for the study, the surface had to be reconditioned and was equipped with a layer of stone mastic asphalt with aggregate size 0/8 (SMA 0/8) which has been used as a reference pavement in the study. Since the test site is closed for public traffic, the SMA 0/8 has a lower grade of gritting and compacting than usual stone mastic asphalts.

The analyzed road markings consisting of a cold plastic material and equipped with drop-on glass beads were all applied on the same day. All road marking samples 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 test tyre 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 analyzed (Figure 6):

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. reference pavement: stone mastic asphalt 0/8 (SMA 0/8) with lower grade of gritting and compacting

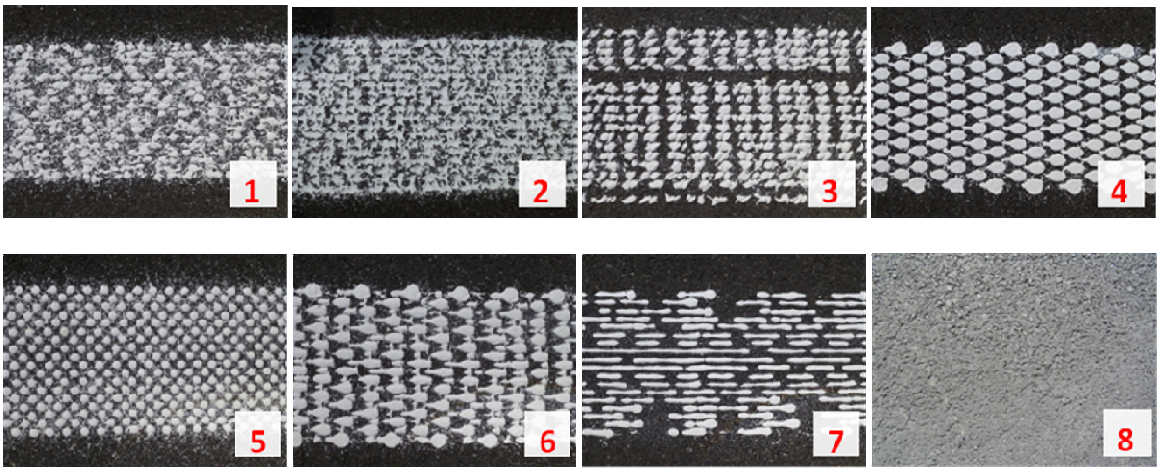

Figure 6 – Analyzed road markings and pavement in the German measurement campaign.

4.2 German measurement results

The CPX measurements were carried out in the framework of the above mentioned research project of the Federal Highway Research Institute on tyre/road marking noise. The CPX measurements for the reference speed of 80 km/h are contributed to the Belgian-German measurement campaign in the frame of the European standardization activities on “Horizontal Signalization” and the results are presented in the following. Further results on CPX measurements at 50 km/h and results of Coast-By measurements within the speed range between 30 and 120 km/h can be found in (4).

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. For the agglomerate road markings 6-8 runs per sample were carried out, for the SMA 0/8 reference 5 runs.

The CPX measurements were conducted close to the reference speed of 80 km/h. The measurement speed was regulated by a speed control with a deviation of approximately ± 0.2 km/h. 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 applied.

The measured CPXP values are shown in Figure 7.

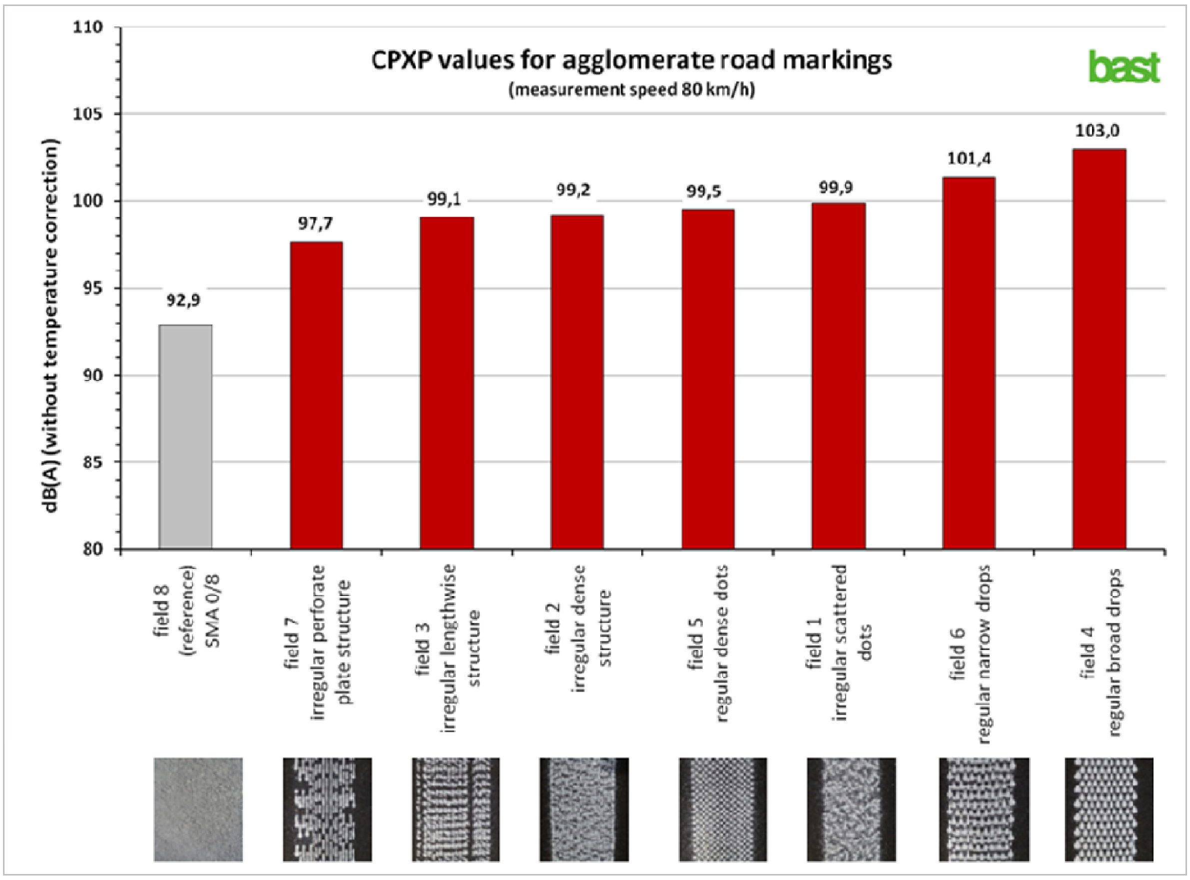

Figure 7 – CPXP values for measurements in German measurement campaign.

From the measurements the following conclusions can be drawn:

- The stone mastic asphalt 0/8 at the test site shows with a value of approximately 93 dB(A) a lower 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. SMA 0/11 pavements measured with a P1 tyre show on average values of about 97 dB(A) (5),(6).
- In comparison to the reference pavement at the test site with a CPXP level 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 nearly 10 dB(A).
- The regular drop-shaped road markings show an increase of 3.9 dB(A) for narrow drops and 5.5 dB(A) for broad drops compared to usual SMA 0/8 pavements. In the German measurement campaign these two 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 usual 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 about 1.5-2.5 dB(A) higher than the CPXP values of usual SMA 0/8.
- The irregular perforate plate structure shows with 97.7 dB(A) the lowest CPXP value of all agglomerate road markings and is hence comparable with CPXP values of usual SMA 0/8. Further it has to be taken into account that this structure is thinned out compared to all other analyzed road markings.

By means of the standard deviation it is possible to describe the homogeneity of road surfaces. The standard deviations for the CPX measurements are shown in Figure 8. The values lie within a range of 0.1 and 0.7 dB(A). Except the regular broad drops with a standard deviation of 0.7 dB(A) because of a discontinuity due to a machine break during application all other road markings and the reference pavement have a sufficiently homogeneous structure.

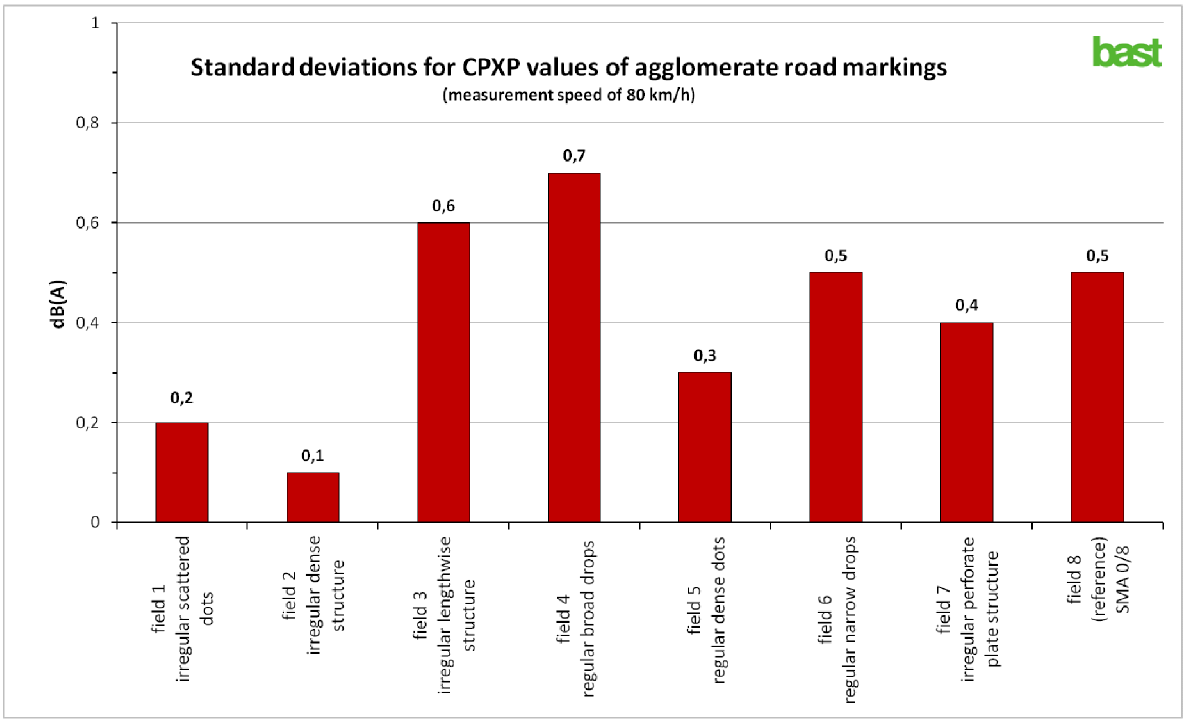

Figure 8 – Standard deviations for CPXP values in German measurement campaign.

The third octave band spectra for the P1 tyre on the tested road markings are shown in Figure 9. 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, which can be attributed to the induction of tyre vibrations by the intrinsic megatexture of the audio-tactile road markings. In the range of higher frequencies (1250 – 1600 Hz) there is on the other hand a decrease of sound pressure levels, due to the efficient suppression of the air pumping. In case of the broad and narrow regular drops (road markings 4 and 6, figure 9 left picture) a second maximum exists at low frequencies. 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). 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 axis and the chassis of the trailer towards the microphone holders.

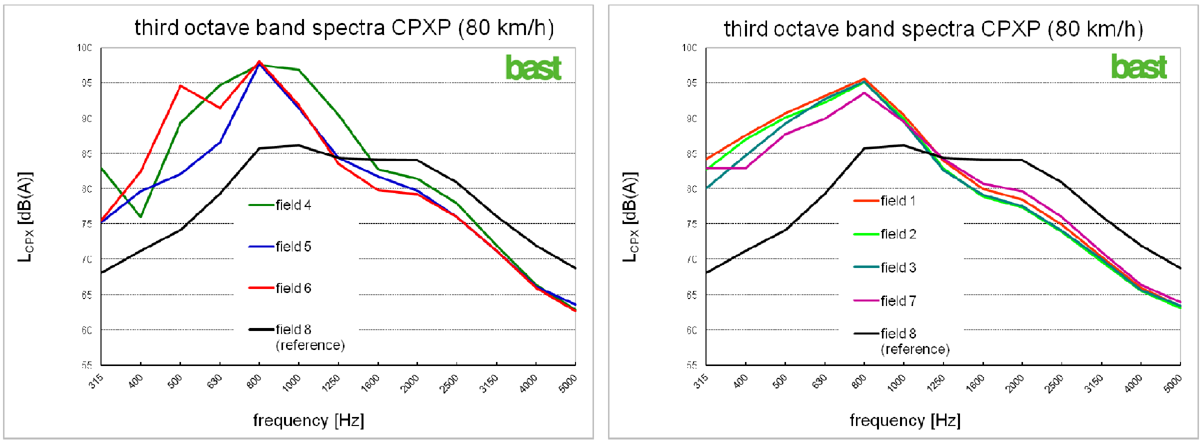

Figure 9 – Third octave band spectra for CPX measurements in comparison with the Geman reference pavement. Left: Spectra for regular structures. Right: Spectra for irregular structures.

5. CONCLUSIONS

The measurement campaigns in Belgium and in Germany have shown that the Close Proximity method (CPX) and especially the proposed adaptations to audio-tactile road markings are working very well. It turned out that a measured road marking length of 40 m and two runs are sufficient. The measurements have further shown that a road marking width of at least 0.3 m is needed in order to keep the lane during CPX measurements.

The CPX measurements in Belgium and Germany are not directly comparable because they were carried out on different road markings that show variations in structure, degree of wear and material. Concerning the tested reference pavements and additional comparative data of reference pavements there are differences as well. They are caused very likely by different aggregate sizes due to national requirements and differences with regard to the age of these pavements.

The measurements in Germany have shown that the CPXP level of regular agglomerate road markings depends on the specific pattern. The dense dots at the German test site have a CPXP value that is about 2 dB(A) higher than the one of usual SMA 0/8 pavements. With regard to regular drop-shaped agglomerate road marking the increase of CPXP values compared to usual SMA 0/8 pavements is even higher. In this case there is an increase of approximately 4 dB(A) for narrow drops and 5.5 dB(A) for broad drops. Also for the analyzed irregular agglomerate road markings an influence of the geometrical pattern on the CPXP values could be observed. The irregular perforate plate structure has lower CPXP values than the other irregular agglomerate markings in this study.

The evaluation of the measurement data has also indicated that the method is robust and that it is possible to detect inhomogeneities in the structure of road markings.

The next step within this project is to perform a Round Robin Test for CPX measurements on road markings. Those tests are carried out regularly for CPX measurements on various pavements but for road markings this has not been done before. After this, a proposal for a CPX measurement method for assessing tyre/road marking noise will be elaborated for the European standardization activities of CEN.

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