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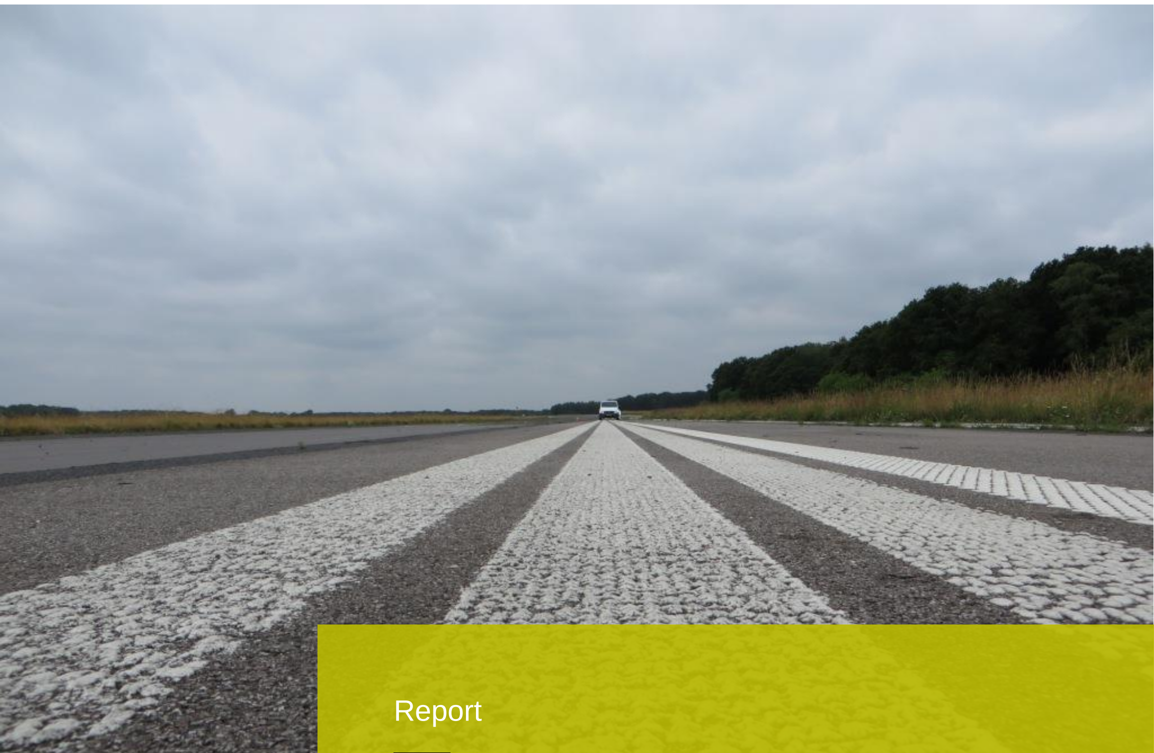

Report

Acoustic properties of road markings

M+P.RGPO.15.02.1 | May 2nd, 2016

Colophon

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Summary

The Dutch Public Roads Administration (Rijkswaterstaat) noticed that the knowledge of the acoustic properties of road markings applied on open/porous road surface is limited. Especially the annoyance the noise can cause for people living nearby the road. Therefore Rijkswaterstaat initiated a research project. M+P conducted this project.

Literature
In literature a relatively small number of reports and publications was found concerning the noise of road markings. Most of the documents concern research projects from Germany and Belgium, but there are alsoa few projects from Austria and the Netherlands. The early documents focused primarily on I visibility, luminance, and skid resistance and less to noise.

Most of the measurements described in literature are Controlled Pass-By (CPB) measurements with the engine switched off (so-called Coast-By measurements). To determine an appropriate measuring method for noise measurements on road markings, BASt in Germany did a comparison between the Coast-By and CPX-method. BASt concluded that the CPX-method was the preferable measurement method to investigate the sound emission of road markings.

To develop a meaurement method for determining the acoustic properties of road markings, the CEN working group *Road markings* (CEN/TC226/WG2) formed a task group *Noise* in October 2011. Goal of this task group is to develop a new measurement method which is mainly based on the CPX-method and must be representative, reproducible and widely applicable throughout Europe.

Measurement and verification method
In 2015 the task group *Noise* had a detailed proposal for a measurement method. This proposal was mainly based on experiences with CPX-measurements on road markings in Belgium and Germany. Within the framework of the current research project some additions have been made to be able to perform measurements on the Dutch road markings, the most important one being the standard width of road markings. In the Netherlands the standard width is 200 mm, while in Belgium and Germany 300 mm is more common. The width of the tyre /road marking contact patch (for the SRTT tyre) is somewhat less than 200 mm. By analyzing measurement results, BASt concluded that the tyre should roll on the marking for at least 85% in order to have a valid measurement run. Furthermore no air temperature correction was applied, because the temperature influence for these kind of measurements is currently unknown. The height of the road marking seemed important for the tyre/road marking noise, therefore the height profile of each marking was measured using a mobile laser texture measurement system.

CPX Round Robin Test
Within the framework of CEN/TC226/WG2/EP5 a CPX Round Robin Test (RRT) on road markings has been performed. The measurements took place in June 2015 on test sections with road markings on an airbase in Geilenkirchen (Germany). M+P together with BRRC participated in this test. BASt already performed CPX-measurements on the same road markings. The M+P results and the preliminary BRRC results showed small differences. However the BASt results differ by approximately 2 dB(A). This difference seems to be systematic. The task group *Noise* will investigate this further.

CPX test sections
For this project CPX-measurements were performed on 9 locations on Dutch highways with in total 22 road marking sections. These sections use different types of road markings. The road markings are applied on dense asphalt concrete (DAC), stone mastic asphalt (SMA), porous asphalt concrete (PAC) or double layered porous asphalt concrete (DLPAC). On all sections CPX-measurements and height measurements have been performed. The CPX-measurements showed difference in CPXP-level of 11 dB(A). If not taking the “zaagtand” and “rammelstrook” marking into account the difference is approximately 5 dB(A). Within a road marking type differences have been found up to 3 dB(A).

Loudness
Based on the raw CPX-measurement signal, the loudness of the markings and asphalt were determined according to DIN 45631. In 2002 an Austrian research project focussed on loudness effects of road markings, trying to better understand possible annoyance for people living nearby. This project showed that different road markings with the same Coast-By levels had differences in loudness between 10 and 20%.

For the measured Dutch road markings the maximum difference in loudness between all measured road markings is around 60%. The maximum difference in loudness between the asphalt on which those road markings are applied, is 35%. For several sections there is no significant difference in loudness between the road marking and the asphalt on which the road marking is applied.

Height measurements
Height measurements have been performed on all road markings using a mobile laser texture measuring system. The height of the road markings above the road surface varies between 2 and 11 mm. Also within a road marking type significant differences have been found. In general, an increase of the height of the road marking results in an increase of the CPXP-level.

SPERoN / AOT calculations
The SPERoN / AOT model was used to predict the noise levels while driving on the markings. A representative part of the height profile was used as an input parameter. For the other input parameters sound absorption, flow resistance and mechanical impedance, assumptions were made which were not representative for all road markings. The calculations showed that most of the predicted CPXP-levels by the SPERoN/AOT model are within ± 2 dB(A) of the measured CPXP-levels.

Recommendations for applying a functional requirement
A functional requirement was proposed based on the maximum allowed increase of CPXP-level when driving on the road marking versus driving on the asphalt. For the CPXP-levels on asphalt, reference CPXP-levels were proposed for the road surface types DAC, SMA, PAC and DLPAC. Calculations have been made using a limit value of 5 dB(A). With this limit value almost all measured road markings can be applied on PAC and approximately half of the markings can be applied on DLPAC.

Contents

1 Introduction

Road markings are not only used as a visual guidance, but are also a key component for road safety. When driving over the markings, the driver is alerted by higher noise and vibration levels. While these properties serve as good safety measures, they also have an impact on the noise levels in the vicinity of the road.

The Dutch Public Roads Administration (Rijkswaterstaat) maintains the highway network in the Netherlands. On the highways various types of road markings are applied. Most important properties of the road markings are visibility (day, night and during wet conditions), skid resistance and durability. Road markings with these properties and an improved reflection during wet conditions are the so-called *Type II profiled road markings*. On more and more roads in the Netherlands these profiled road markings will be applied. This not only concerns locations with no highway lighting or where the highway lighting is switched off during the night period but also on locations where one-sided accidents occur more often than average.
Rijkswaterstaat noticed that the knowledge of the acoustic properties of road markings nowadays applied on open/porous road surfaces, is limited. Especially the annoyance the noise can cause on people living nearby the road. Meanwhile Rijkswaterstaat received some complaints about the noise of road markings.

The main goals of the current research study are:

- To determine a uniform measuring and verification method for noise measurements on road markings;
- To gain more insight and knowledge of the acoustic properties of the different road markings applied on the Dutch highways;
- Recommendations for applying a functional requirement for the sound emission of profiled road markings in future.

2 Literature study

In literature several reports and publications can be found concerning noise of road markings. Most of these European documents concerns research from Germany and Belgium. There are also some documents from Austria and the Netherlands. In the early documents most attention was paid to visibility, luminance (colour) and skid resistance combined with durability. Often there is only a small paragraph concerning noise.

In this chapter a short overview in time is given to focus on an appropriate noise measuring and verification method for road markings.

2.1 The Netherlands

More than 20 years ago Rijkswaterstaat Dienst Weg en Waterbouwkunde (DWW) published a document [1] which stated that applying highly profiled road markings on highways, results in an increase of the sound emission of more than 6 dB(A). Applying less profiled road markings results in an increase of the sound emission of 6 dB(A) or less. The use of highly profiled road marking was also restricted, because of high noise levels. When applying this kind of road marking the nearest houses should be located at a distance of at least 1000 m.

In 1995 DWW published a report [2] which mentioned that in general the sound emission of the less profiled road markings is comparable to the sound emission when driving on a dense asphalt concrete. However the new developments concerning noise reducing pavements, such as single and double layered porous asphalt combined with a highly profiled road marking, could result in an increase of 15 dB(A). At one location a highly profiled road marking had been partly removed due to severe annoyance experienced by people living close to the road.

All measuring data so far was based on the Statistical Pass-By (SPB) method [3]. However the performed measurements were actually Controlled Pass-By (CPB) measurements with the engine switched off: so-called Coast-By measurements. Often one or two passenger cars were used to perform the measurements. Standard measuring distances were 7,5 m and sometimes also 20 m. Since 2001 measurements according to the Close Proximity Method (CPX) [4] became more common. In [5] till [7] results of CPX-measurements on several types of road markings can be found.

2.2 CPB versus CPX

To determine an appropriate measuring method for noise measurements on road markings BASt in Germany did a comparison [8] between the CPB (engine switched off) and CPX-method. On a German airbase measurements were performed on 8 test sections with different road markings using both measurement methods (see figure 1) and the Standard Reference Test Tyre (SRTT) [9] as measurement tyre. Evaluation of the measurement results, showed the following:

Advantages CPX-method:
- Measurements on road markings on public roads are possible;
- A longer continuous road marking section can be measured;
- The method is cost-effective and time-saving.

Disadvantages CPX-method:
- At higher speeds lane keeping on roads markings is difficult to realize. On public roads the maximum width of road markings is 300 mm (in Germany);
- A road marking section should have at least a length of 100 to 200 m.

Advantages Coast-By method:
- Measurements within a broad speed range can be realized in a short span of time;
- A short road marking section of about 20 m is sufficient.

Disadvantages Coast-By method:
- Measurements are only possible at special test sites or on closed public roads;
- The tyre/road marking noise is only measured at a specific spot.

figure 1 *Controlled Pass-By measurement (left) and Close Proximity measurement (right) [8]*

From the advantages and disadvantages as mentioned above the conclusion can be drawn that for measurements of road markings on public roads the CPX-method is the preferable measuring method. With the CPX-method a wide variety of different types of road markings on public roads can easily be measured in a short period of time .

BASt also looked in more detail at the comparability of the noise results obtained with both measurement methods. In figure 2 the results are shown in descending order of the CPXP-values. Figure 2 shows that the order of CPXP-values does not correspond one-to-one to the order of averaged sound pressure levels obtain from the Coast-By measurements. There are partially different results in ranking. The averaged difference between both is approximately 20 dB(A).

Besides difference in ranking order it was remarked that concerning annoyance it is important to not only look at the overall levels. Spectral results are valuable for the detection of tonal components.

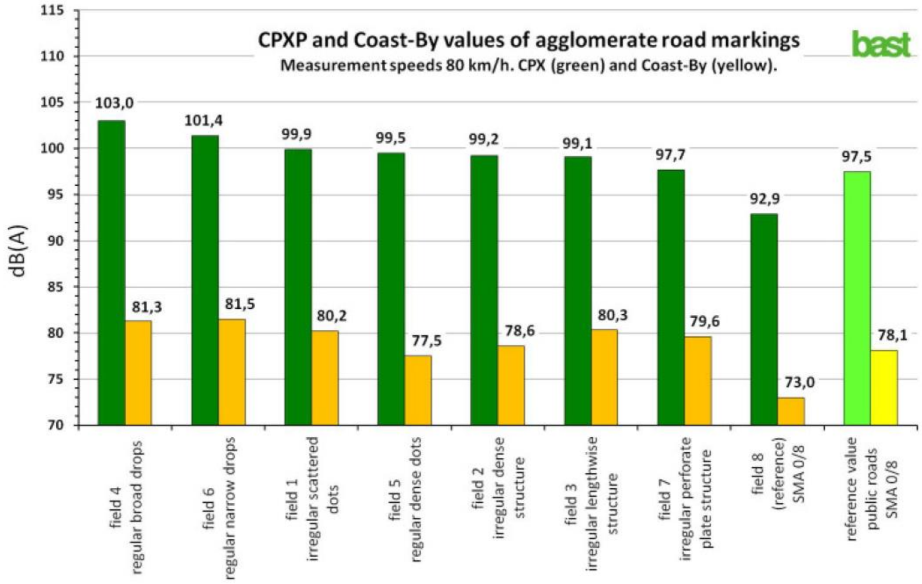


figure 2 *Comparison of CPXP and Coast-By values at 80 km/h [8]*

In figure 3 the results of the regression analysis of the Coast-By values versus CPXP-values is shown. The results show a moderate / poor correlation.

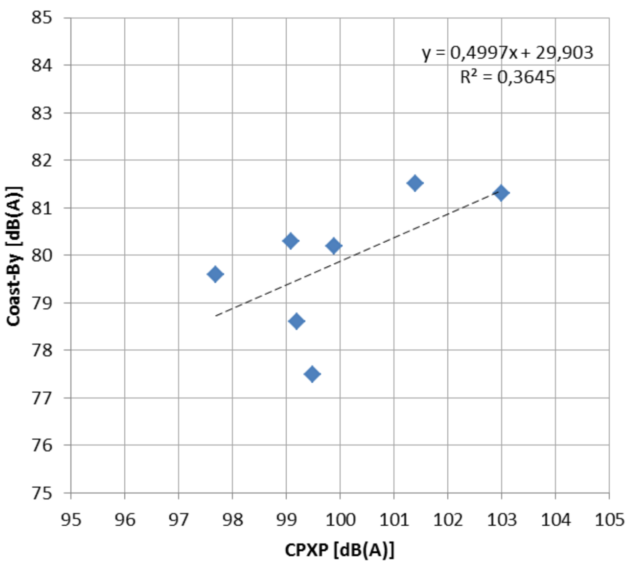


figure 3 *Scatter plot of Coast-By values versus CPXP values at 80 km/h*

2.3 CEN working group *Road markings*

To develop a measuring method for determining the acoustic properties of road markings, the CEN working group *Road markings* (CEN/TC226/WG2) formed a task group *Noise* in October 2011. The new measurement method is mainly based on the CPX-method and will be representative, reproducible and widely applicable throughout Europe.

Within the task group the Belgian Road Research Centre (BRRC) in cooperation with the Flemish Agency of Roads and Traffic did more research on the feasibility of a slightly adjusted CPX-method to measure the acoustic properties of road markings [10]. The adjustments of the CPX-method are:

- Only use the Standard Reference Test Tyre (SRTT);
- Perform measurements at a constant speed (e.g. 80 ± 4 km/h);
- Test section shall be located within a road section without any curves;
- Operator should ensure that the test tyre rolls 100% on the marking. For CPX-trailers with an enclosure this can be achieved by using a camera system (see figure 4);
- Repeat measurements, at least two runs on the same test section;

figure 4 *CPX-trailer of the Flemish Agency for Roads and Traffic equipped with a camera system [10]*

BRCC performed measurements on 23 road markings (width 300 mm). They concluded that the CPX-method is a feasible measurement method for noise measurements on road markings; the results were found to be repeatable and robust. A minimum measurement length of 40 m and two runs were found to be sufficient to determine the average noise level. Furthermore they concluded that the SRTT tyre can be used to assess the acoustic properties of road markings. Important to remark is that all measurements have been performed with the SRTT tyre mounted on the right side of the CPX-trailer.

The paper [10] also suggested to add a sound emission classification to the road markings material standard EN 1436 [11]. As an example the following sound emission classes were proposed:

- SE0: no performance required
- SE1: CPXP < 100 dB(A) quiet
- SE2: 100 dB(A) < CPXP < 105 dB(A) moderate
- SE3: 105 dB(A) < CPXP < 110 dB(A) loud
- SE4: > 110 dB(A) very loud

In the above mentioned classes 100 dB(A) was considered as a typical sound emission on reference pavements.

Mid 2016 the task group *Noise* will present a final document regarding a measurement method to determine the acoustic properties of road markings. It is expected that there will be no significant changes to the current proposed measurement method; the task group already agreed on the adjustments.

3 Measurement and verification method

Most of the measurements within the task group *Noise* have been performed on road markings in Belgium and Germany. Although many types of road markings are the same as in the Netherlands, there are also some differences.

3.1 Road marking width

The standard road marking width in Belgium and Germany is 300 mm (see figure 5). In the Netherlands the width of road markings on highways is 200 mm, so much smaller. The width of the contact patch between tyre and road marking is almost the same. From a practical point of view this makes the requirement of rolling 100 % on the marking somewhat difficult. This will probably mean that measurements have to be repeated several times to have at least two valid measurement runs.

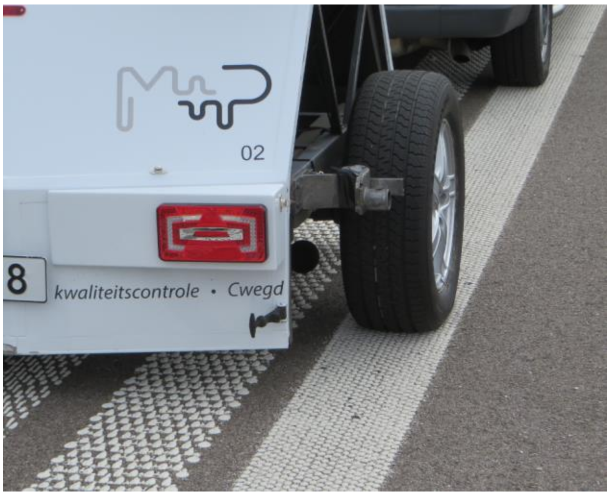


figure 5 *SRTT tyre on road marking with a width of 300 mm*

BASt in Germany analyzed several CPX-measurements concerning different lateral positions of the SRTT tyre on road markings during measurements [12]. The results showed that no differences can be expected when the tyre is not rolling exactly in the middle of the road marking but somewhat more to the left or to the right.

With the Dutch width of the road markings there is the possibility of driving partially (e.g. 90%) on the marking. According to the proposal of the task group *Noise* this means an invalid measurement. By analyzing several measurements in which the tyre was not rolling 100% on the marking, BASt noticed that the measured noise level was not significantly impacted as long as they were driving 80% or more on the marking. BASt expects significant differences to occur when driving less than 80% on the marking. However, further research is necessary to determine these effects more precisely.

→ To reduce the effects of not driving sufficiently on the marking - for this research – it has been decided that the SRTT tyre shall roll on the markings for at least 85%, but preferably 100%.

3.2 Temperature correction

To be able to compare the results of CPX-measurements, CPX-values are usually corrected for air temperature to the reference temperature of 20 °C. To apply the right temperature coefficients the CPX ISO-standard [4] refers to the technical specification ISO/TS 11819-3 which is under preparation at the moment. However in [13] a proposal of the different temperature coefficients can be found. The proposed temperature coefficient depends on the type of road surface and differs significantly (dense -0,10 dB/°C and porous -0,05 dB/°C).

Most of the road markings on highways in the Netherlands are applied on porous asphalt. When using a dense road marking (e.g. thermoplast) on a porous asphalt the question raises which temperature coefficient should be applied.

→ For the measurements on the Dutch road markings it has been decided not to apply any air temperature correction on the CPX-values. Most of the measurements have been performed in a relatively small temperature range around the reference temperature of 20 °C.

3.3 Road marking height

An important parameter of the tyre/road marking noise is the height of the marking above the road surface. Previous research in the Netherlands [5] showed that differences in height can result in significant differences in CPX-value. For most road markings an increase in height results in an increase in CPX-value. The height is not only important to understand possible differences within the same type of road marking (e.g. dots) but also between different road marking types.

In the Netherlands road markings are applied on several types of road surfaces. Applying the same type of road marking with the same equipment on a dense or porous asphalt can result in different heights of the road marking. The differences in height on dense road surfaces such as dense asphalt concrete (DAC) and cement concrete are normally small but can be significant on stone mastic asphalt (see figure 6) and porous asphalt.

figure 6 *Example of a dot marking on SMA with different dot heights*

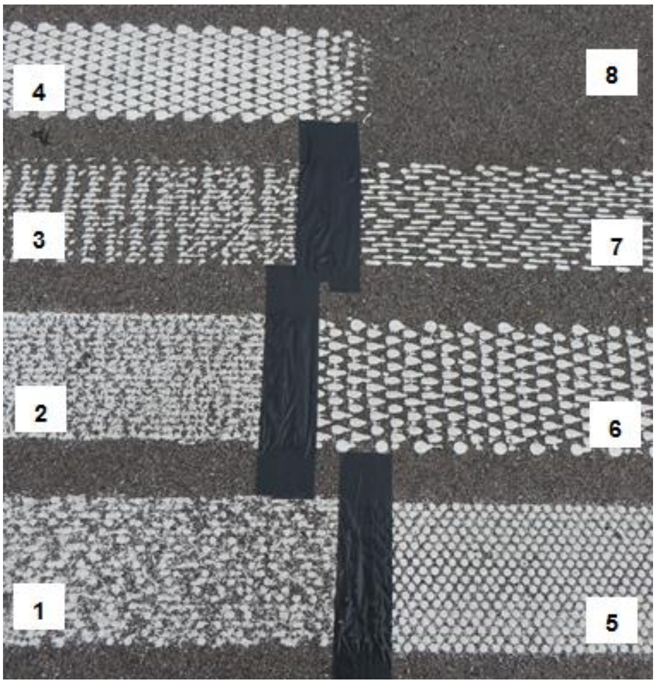
→ For the measurements on the Dutch road markings it has been decided to measure the height of the road markings with a mobile laser texture meter simultaneously with the CPX-measurements.

4 CPX Round Robin Test

Within the framework of CEN/TC226/WG2/EP5 a CPX Round Robin Test (RRT) on road markings has been performed. The measurements took place on June 24th, 2015. M+P together with BRRC participated in this test. BASt already performed CPX-measurements on the same road markings. Goal of this CPX RRT on road markings is to know more about the reproducibility of the proposed measurement method. After the CPX RRT, the task group *Noise* will elaborate a proposal for a CPX measurement method for assessing tyre/road marking noise, for the European standardization activities of CEN.

4.1 Test site

The road markings are applied on a former landing runway at the airbase Geilenkirchen in Germany. It concerns a total of 7 different road markings applied on a SMA 8 (see figure 7) surface. The SMA 8 without road marking will be used as a reference pavement. All road markings have a length of 100 m and a width of 300 mm.



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: SMA 8

figure 7 *Road markings at the German airbase Geilenkirchen*

4.2 CPX measurements

The CPX-systems of M+P and BRRC participated in the Round Robin Test. In figure 8 a picture of both CPX-systems is shown. The CPX-measurements on the road markings have been performed according to ISO/DIS 11819-2 with the adjustments as described in paragraph 2.3. Both CPX-systems are equipped with a camera system (see figure 9). Measurement speeds were 50 and 80 km/h.

In addition to the standard reference test tyre (SRTT) of each participant, there was also a 'reference' SRTT. This was the SRTT of BASt which they used during their earlier measurements on the road markings. Each participant performed measurements with both tyres.

figure 8 *CPX-trailer of M+P (left) and BRRC (right)*

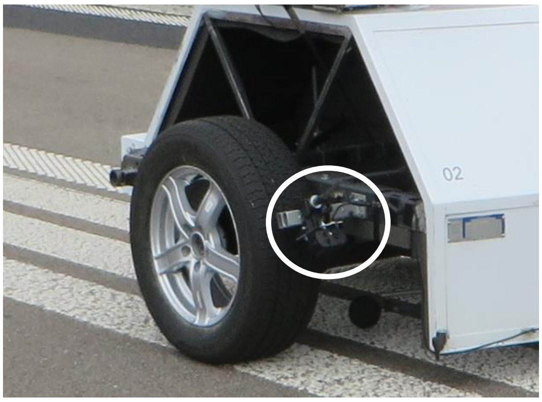


figure 9 *CPX-trailer of M+P equipped with a camera system*

4.3 Measurement results

The Round Robin Test took place on June 24th, 2015 with air temperatures between 15 and 19 °C. M+P started the measurements with BASt reference SRTT. M+P as well as BRRC performed four valid measurement runs per speed and road marking type.

In a separate document belonging to this report the measurement data sheets with results of the M+P CPX-measurements can be found. On all CPXP levels no temperature correction was applied. Therefore the air temperature on all measurement data sheets was set to 20 °C. It must be emphasized that this is not the real air temperature during the measurements. The real air temperature varies somewhere between 15 and 19 °C. In figure 10 and figure 11 an overview of the results of the CPX measurements at 50 and 80 km/h is shown. The error bars in the figures indicate the standard deviation of the 20 m results. On all results no temperature correction has been applied. The results of BASt are also shown.

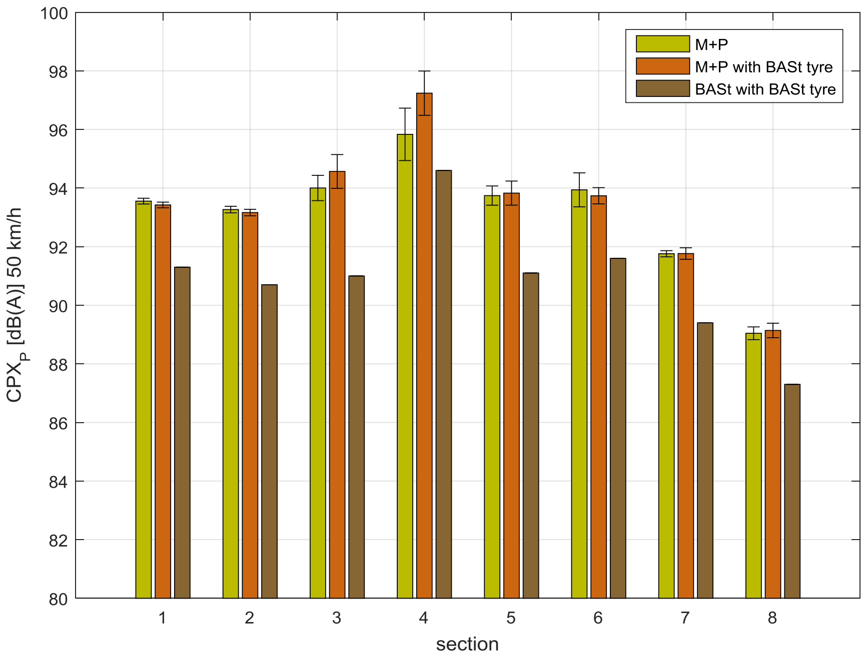


figure 10 *CPXP levels at 50 km/h, measured on the test sections with road marking in Geilenkirchen (no temperature correction applied)*

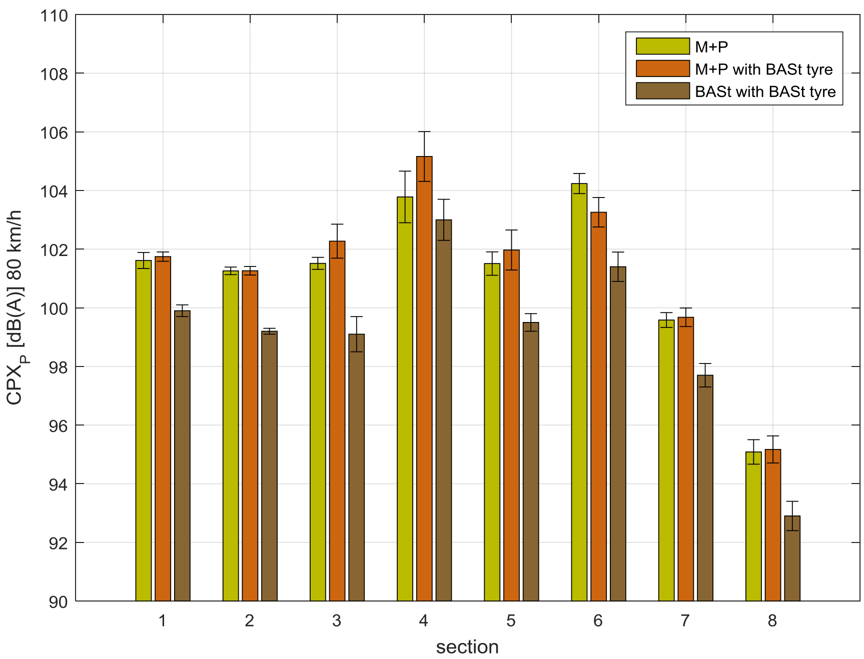


figure 11 *CPXP values at 80 km/h, measured on the test sections with road marking in Geilenkirchen (no temperature correction applied)*

The following conclusions can be drawn from these results:

- The CPXP-levels measured with the M+P trailer using the M+P SRTT tyre are almost the same as the levels measured with the M+P trailer using BASt SRTT tyre. Except for section 4 (both speeds). At 50 km/h differences can be found between 0,1 and 0,6 dB(A) and at 80 km/h between 0,1 and 0,9 dB(A). The standard deviation varies between 0,1 and 0,7 dB(A). These standard deviations are in the same range as found from measurements in Belgium [10];
- The CPXP-levels for section 4 show more differences between both SRTT tyres. At 50 and 80 km/h the difference is 1,4 dB(A). This difference can be explained by irregularities / inhomogeneities in the pattern of the road marking caused during construction (see figure 12);
- Comparing the results of the M+P trailer with the results of BASt trailer shows significant differences. Although the trend of the results is almost the same, all CPXP-results of BASt are significantly lower than the CPXP-results of M+P. There seems to be a systematic difference of approximately 2 dB(A).

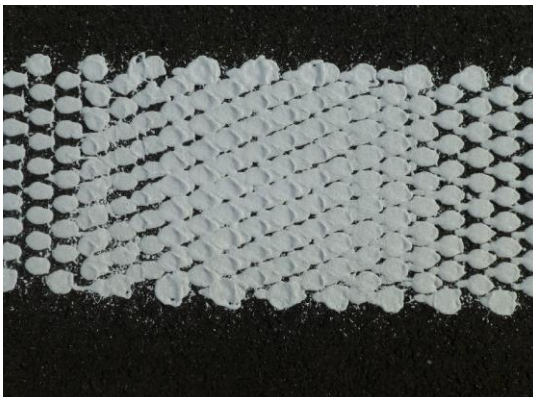


figure 12 *Irregularities in the pattern of road marking section 4 caused during construction*

In figure 13 scatter plots of the CPXP-values are given for 50 and 80 km/h. On the y-axis the CPXP-value measured by M+P with the M+P SRTT tyre and the CPXP value measured by M+P with the BASt SRTT tyre is shown. On the x-axis the CPXP-value of the BASt SRTT tyre measured by BASt. A regression line is given for the M+P results.

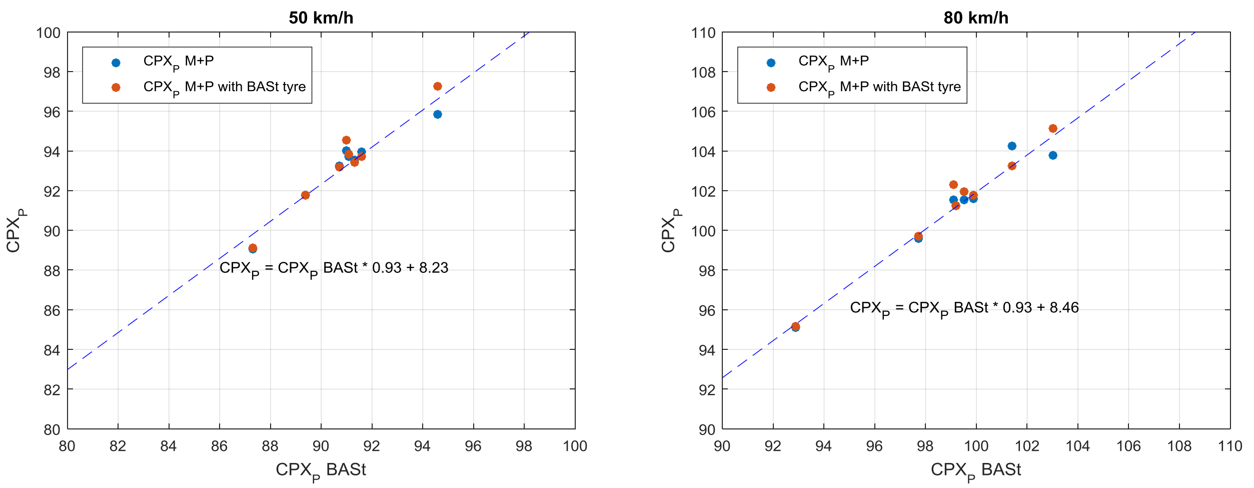


figure 13 *Scatter plot of CPXP-results measured by M+P and BASt*

To investigate the differences in CPXP-level measured by BASt and M+P, the third octave spectrum for section 1 is shown in figure 14. Differences are occurring for frequencies higher than 800 Hz. M+P and BASt have already investigated the results in more detail. However at the moment it is still unknown what causes the differences. It is unlikely that the time difference of approximately 8 or 9 months between the M+P and BASt measurements causes such a significant and systematic difference. The first preliminary results of BRRC show small differences with the M+P results. Within the task group *Noise*, BRRC and BASt will perform further research to find an explanation for the measured differences.

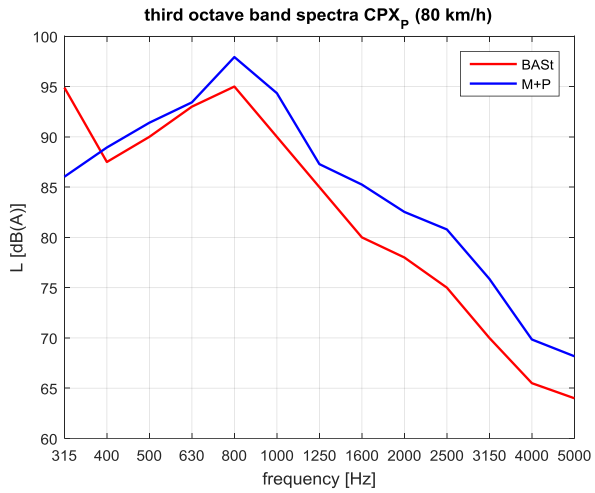


figure 14 *Differences in CPXP-spectrum for section 1, measured by M+P with M+P SRTT tyre (blue) and measured by BASt with BASt SRTT tyre (red)*

5 CPX test sections road markings in the Netherlands

One of the goals of the research project is to get to know more about the acoustic properties of the different road markings applied on the Dutch highways. Therefore noise measurements have been performed on a wide variety of road markings.

5.1 Test sites

Rijkswaterstaat compiled a list of test sections with different types of road markings. This list can be found in Appendix A. In total it concerns 10 locations with 24 road marking sections. After inspection of the locations to check if CPX-measurements were possible, the location *A10 2e Coentunnel* was skipped from the list. Part of the road marking was inside a tunnel and the distance between the road marking and the sidewall of the tunnel was too small to be able to perform CPX-measurements safely. What remains are 9 locations and 22 road marking sections. In table I pictures of the different road markings are shown.

As can be seen in Appendix A all road marking sections have a length of 400 m. The average width of the road markings is 200 mm. The type of road markings concern:

- geprofileerde kantstrepen
- multidot A
- multidot B
- rammelstrook
- spetterplast
- spetterplast op thermo
- tape
- thermo met gootjes
- zaagtandmarkering

The road markings are applied on dense asphalt concrete (DAC), stone mastic asphalt (SMA), porous asphalt concrete (PAC) or double layered porous asphalt concrete (DLPAC).

table I *Pictures of the different road markings*

A6 Bant (rammelstrook)

A28/N34 de Punt (spetterplast)

A28/N34 de Punt (thermo met gootjes)

A33 Appingedam (multidot A)

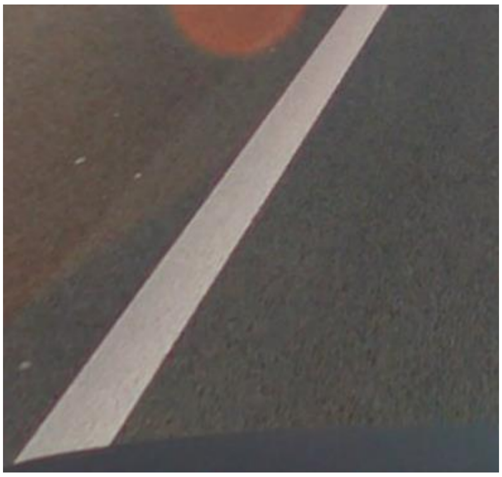
A33 Appingedam (spetterplast)

N36 Rheezerveen (geprofileerde kantstrepen)

N65 Vught (zaagtandmarkering)

A2 Best (thermo met gootjes)

A2 Best (thermo met gootjes)



A2/A67 Eindhoven (tape)

A2/A67 Eindhoven (thermo met gootjes)

A50 Nijnsel (thermo met gootjes)

A50 Nijnsel (tape)

A4 Steenbergen (multidot B)

A4 Steenbergen (spetterplast op thermo)

5.2 CPX measurements

The CPX-measurements on the road markings have been performed according to ISO/DIS 11819-2 with the adjustments as described in paragraph 2.3, 3.1 and 3.2. Measurement speed was 80 km/h and per measurement run at least 200 m should be valid. Each measurement was repeated once. All measurements have been performed with the SRTT tyre mounted on the right side of the CPX-trailer.

Additional to the CPX measurements on the road markings, also CPX measurements have been performed on the road surface (asphalt) on which the road marking was applied. So for each section the difference in CPXP level between driving on the road marking and not driving on the road marking can be determined. With this data it is possible to look in more detail at the possible annoyance for people living nearby.

5.3 Measurement results

The CPX-measurements took place in the period from April till September 2015. In a separate document belonging to this report the measurement data sheets with the results of the CPX-measurements can be found. On all CPXP levels no temperature correction was applied. Therefore the air temperature on all measurement data sheets was set to 20 °C. In Appendix B a summary can be found, showing the CPXP levels per 20 m for each road marking section.

In figure 15 an overview of the CPXP levels per road section of the marking and asphalt is shown. The error bars in the figure indicates the standard deviation of the 20 m results. The results are presented in order of increasing CPXP-value of the road marking. Due to their pattern both “zaagtand” and “rammelstrook” road markings are presented in a lighter shade color because these results are influenced by the road surface properties on which they have been applied. The results from the measurements of the road markings on the airbase Geilenkirchen are also presented (black color)

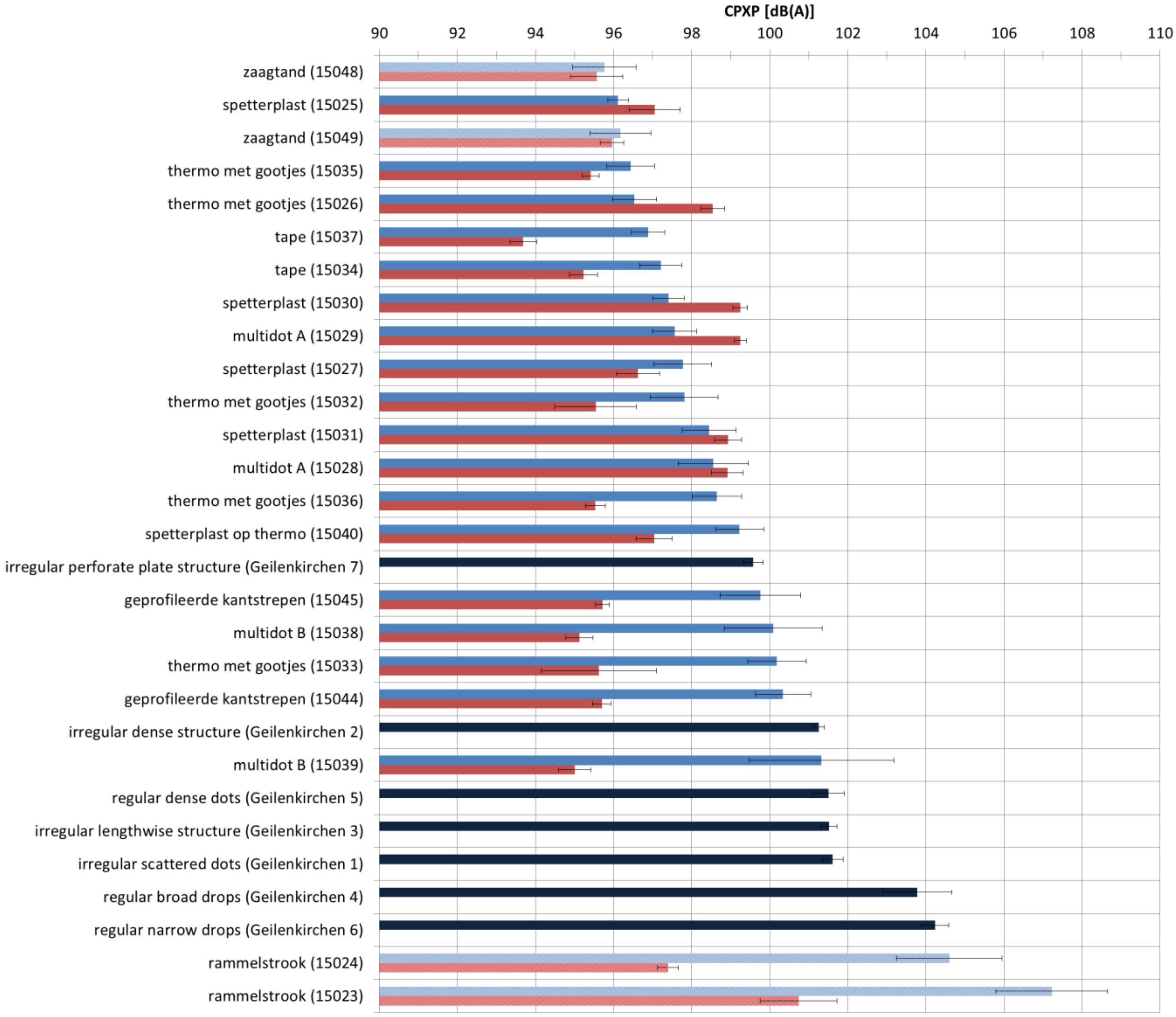


figure 15 *CPXP levels on the Dutch road markings (blue) and asphalt (red) and on the airbase in Geilenkirchen (black). The error bars are the standard deviation of 20 m results. The numbers between brackets refer to the section numbers (see Appendix A).*

The following conclusions can be drawn:

- Rammelstrook markings (A6 Bant, section 15023 and 15024) are the noisiest measured. The most silent marking measured is the “zaagtand” marking (N65 Vught, section 15048). The difference between both CPXP levels is about 11 dB(A). As mentioned those results are influenced by the road surface properties on which they have been applied;
- The maximum difference for the asphalt is 7 dB(A). Lowest CPXP level is found on the DLPAC at the A50 Nijnsel and the highest CPXP level is found on the PAC at the A6 Bant;
- Most of the road markings measured on the airbase Geilenkirchen have higher CPXP levels compared to the road markings measured on the Dutch highways.

5.4 Analysis

5.4.1 Influence of asphalt type

As mentioned in paragraph 5.3 the results of the “zaagtand” and “rammelstrook” marking are influenced by the acoustic properties of the road surface on which they have been applied. Looking to the pictures of those road markings (see paragraph 5.1, table I), it shows that driving on the road markings means also driving a significant part on the road surface.

For the other road markings it is expected that the influence of the acoustic properties of the road surface are small or not significant. Almost all road markings can be considered as dense and have such specific textures which are not influenced by the texture of the road surface underneath it. One exception could be the “spetterplast” depending on the degree of filling. In figure 16 a scatterplot is shown with the CPX-results when driving on the road markings and driving on the asphalt. The symbols indicate the different marking types.

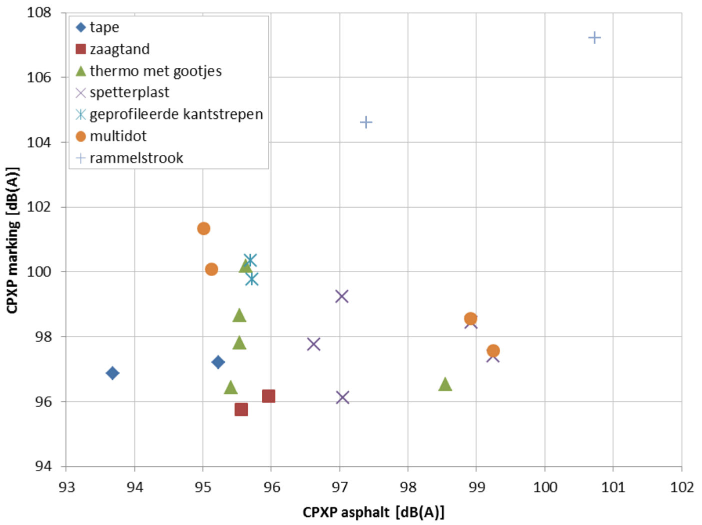


figure 16 *Scatterplot of CPXP-levels of the marking versus CPXP-levels of the asphalt*

The following conclusions can be drawn from these results:

- Although not all road markings have been measured on different road surface types, there is no trend visible that an increase of CPXP-levels of the asphalt results in an increase of CPXP-levels of the road marking (not taken into account the “zaagtand” and “rammelstrook” marking);
- At some locations for the “thermo met gootjes”, “spetterplast” and multidot marking the CPXP-levels of the road marking are lower than the CPXP-level of the road surface on which they have been applied.

5.4.2 Road marking type

As mentioned in paragraph 5.1 the measured road markings can be divided in different types of road marking. In figure 17 the CPXP results per road marking type are shown including the results of the road markings on the airbase Geilenkirchen.

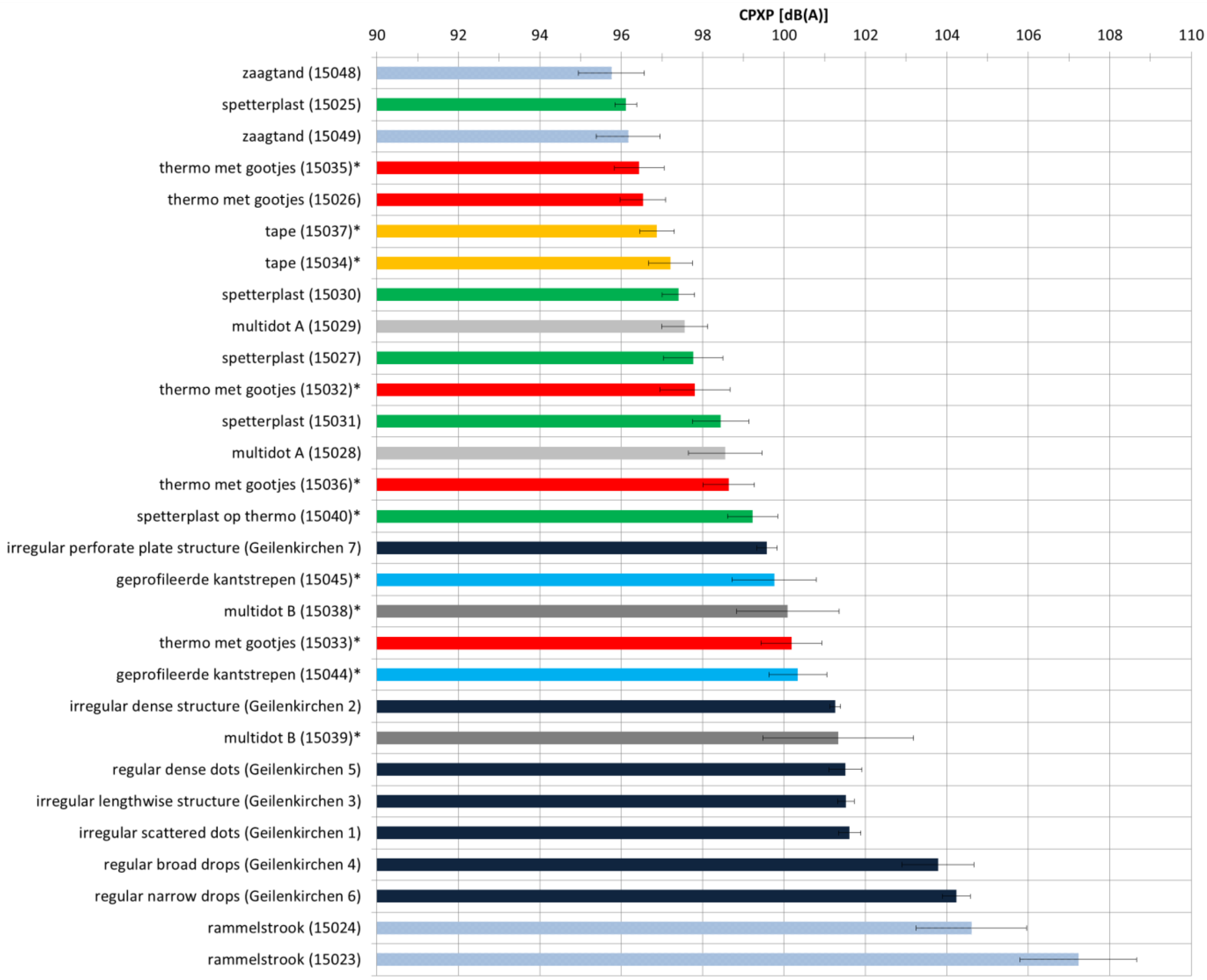


figure 17 *CPXP level differences between road marking and asphalt. The colors indicate the marking type and the error bars indicate the standard deviation between the 20m sections. Ranked by ascending CPXP-level. The with * marked road markings are applied on DLPAC*

The following conclusions can be drawn from these results:

- The maximum measured difference in CPXP-level is approximately 5 dB(A) if not taking into account the “zaagtand” and “rammelstrook” marking and Geilenkirchen markings;
- Within the types “spetterplast” and “thermos met gootjes” differences up to 3 dB(A) can be found;
- The difference between the two tape marking sections is with 0,3 dB(A) very small. Both prefabricated tape markings are of the same type.

5.4.3 Spectral analysis

As mentioned in the previous paragraph within the road marking types “spetterplast” and “thermos met gootjes” there are significant differences in CPXP-level. To investigate what causes these differences it is necessary to look at the one third octave band spectra. In figure 18 the one third octave band CPXP spectra per road marking types are shown.

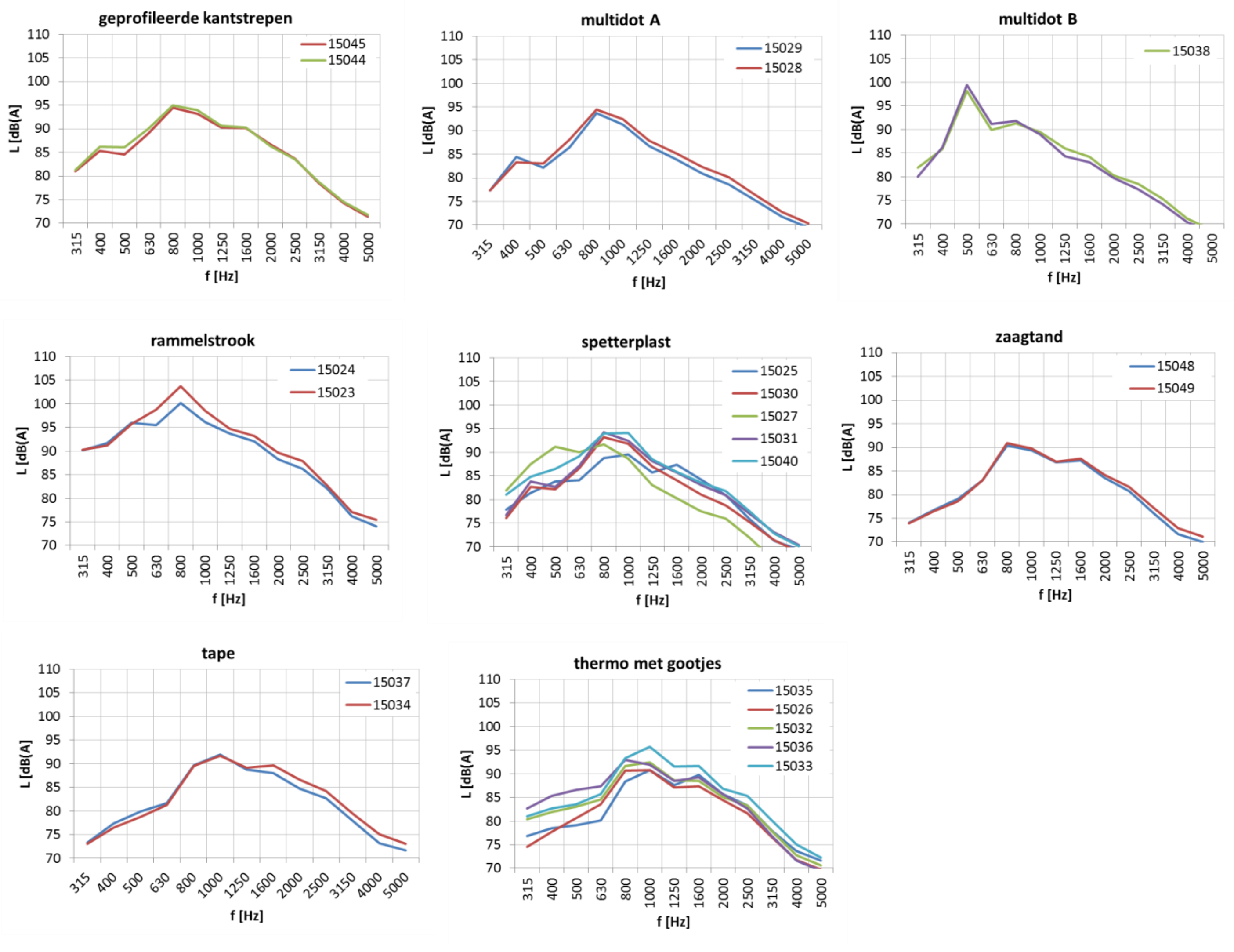


figure 18 *CPXP spectra of all measured road markings (one third octave band)*

The following conclusions can be drawn from these results:

- The highest levels are mostly found in the frequency range of 800 till 1000 Hz which is characteristic for tyre/road noise;
- Within the types “thermo met gootjes” the differences can be found in the frequency range from 315 till 800 Hz. There is one exception (no. 15033) which shows at the higher frequencies also a difference;

- Within the type "spetterplast" there is one section (no. 15027) which shows significant differences at the lower and higher frequencies. This could be caused by the degree of filling of the spetterplast;
- At the lower frequencies the lowest levels are found for the tape road marking. This is due to the smoother texture of the tape road markings compared to the other markings.

5.5 Comparison with results of Flemish Agency for Roads and Traffic

The Flemish Agency for Roads and Traffic performed several CPX measurements on road markings in Belgium [10]. An overview of the result and types of road markings is given in figure 19. It concerns CPXP levels at 80 km/h which are corrected for air temperature (-0,05 dB/°C). Most of the measured road markings concern dot markings.

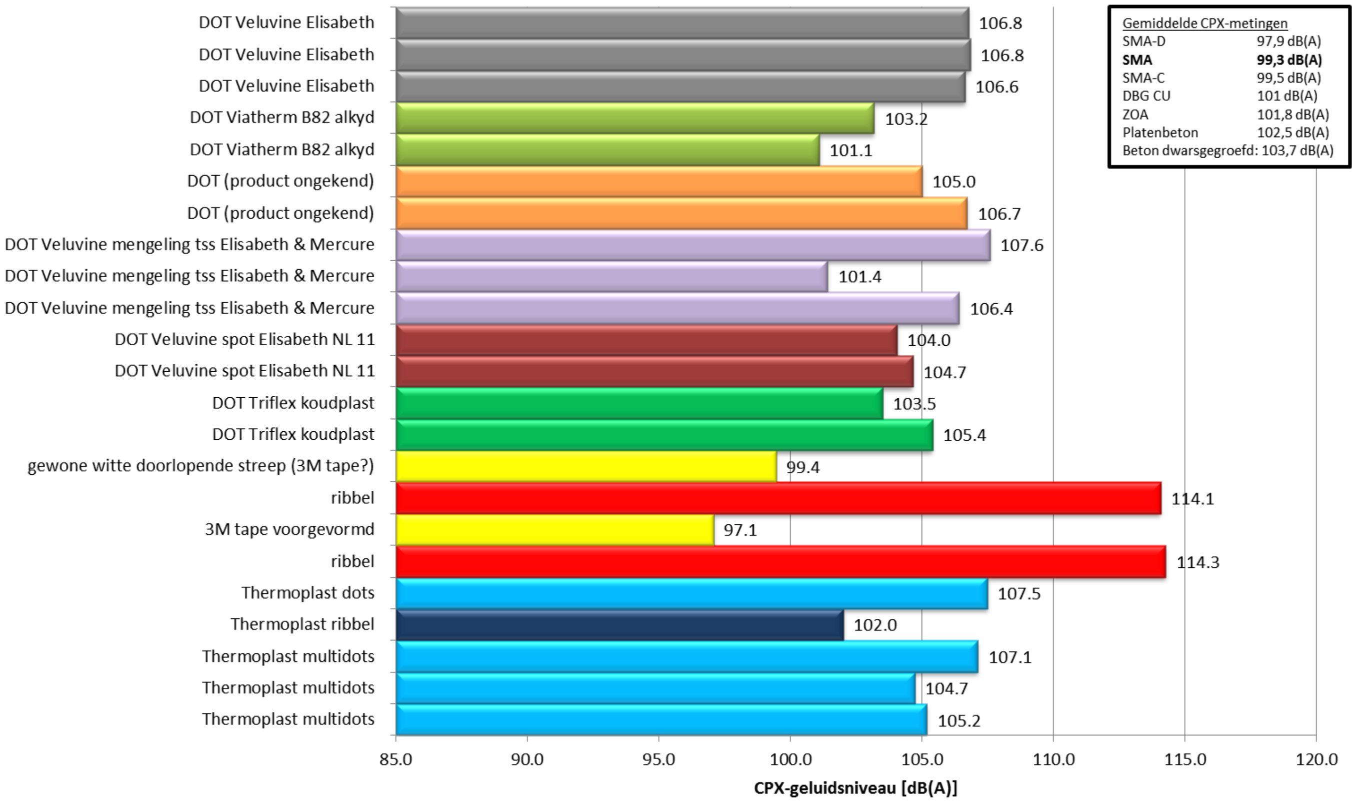


figure 19 CPXP levels (air temperature corrected) at 80 km/h for different types of road marking measured in Belgium by the Flemish Agency for Roads and Traffic

The following conclusions can be drawn from these results:

- The CPXP-levels within the type (multi)dot are significantly higher compared to results measured on the Dutch multidot markings. The average difference is approximately 7 dB(A). These differences are mainly caused by different configurations / pattern and probably also differences in height of the dot marking;
- The result of the tape marking is the same as in the Netherlands. The measured tape marking product is in both cases from the same manufacturer and is also of the same type.

6 Loudness

Sound is often described by physical parameters like pressure, intensity or energy. However, these parameters are not directly related to the perception of the human ear. Therefore the A-weighting filter was introduced. The A-weighting filter describes the frequency response of the human ear more closely.

Wideband noise has a different subjective loudness than a pure tone. However, the A-weighting does not take into account effects like masking. To describe these effects more closely, a more detailed model of human hearing was made by Zwicker. This model describes the loudness of a sound signal in sone. The sone is a linear parameter, e.g. a sound signal with a loudness of 100 sone is perceived twice as loud as a signal with a loudness of 50 sone. The procedure of calculating the loudness according to Zwicker is described in DIN 45631 [14].

6.1 Road markings

In 2002 an Austrian research project [15] paid attention to loudness, trying to better understand possible annoyance of road marking noise for people living nearby. This project showed that different road markings with the same Coast-By levels had differences in loudness between 10 and 20%.

Looking at the possible annoyance of road marking noise it is important to check for tonal components. Tonal components can be extra annoying. Several road markings have a regular and repeated pattern. Especially the noise of these road markings can have a tonal component. In [10] it was stated that one would expect that all road markings with a regular periodic structure will have tonal noise. However, measurements of BRRC showed that only a few of these road markings did indeed have noise with a tonal component.

6.2 Results

From all performed CPX measurements on the Dutch road marking sections, the loudness has been calculated according to DIN 45631. For each road section this means that the loudness of the road marking as well as the loudness of the asphalt on which the road marking is applied, has been calculated. In figure 20 the results of the loudness levels are shown. In figure 21 the difference in loudness for each section expressed as a percentage between road marking and asphalt, is shown.

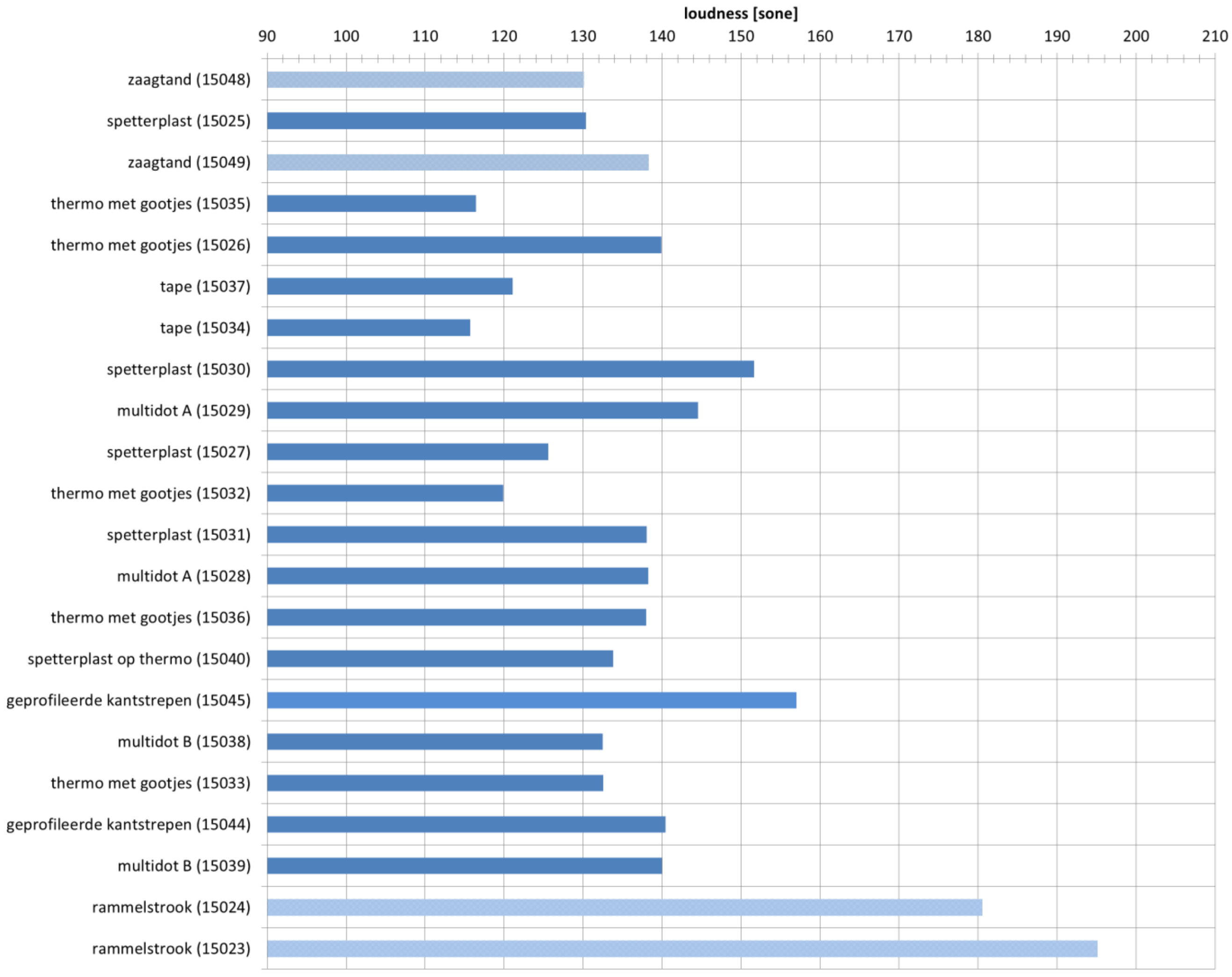


figure 20 *Loudness levels of the measured Dutch road markings and asphalt, ranked by ascending CPXP-level*

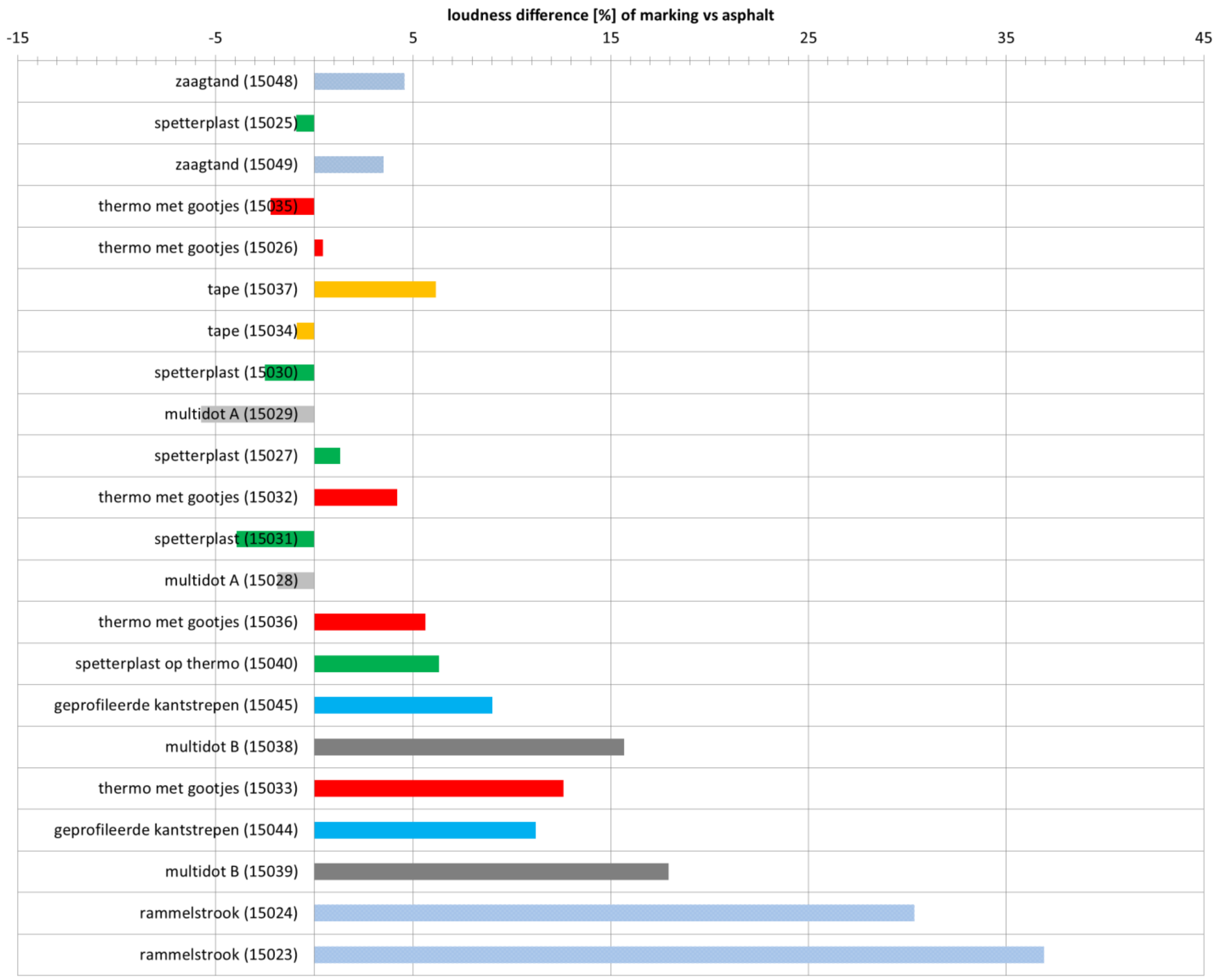


figure 21 *Difference [%] in loudness of road marking and asphalt. The colors indicate the road marking types*

The following conclusions can be drawn from these results:

- The maximum difference in loudness between all measured road markings is around 60%. The maximum difference in loudness between the asphalt on which those road markings are applied, is 35%;
- The “rammelstrook” road markings show increases in loudness of approximately 35%. Both “multidot B” road markings show increases of approximately 15%;
- On several sections there is no significant difference in loudness between the road marking and the asphalt on which the road marking is applied.

7 Height measurements

7.1 Measurement method

The height measurements have been performed with the M+P laser texture system. This system is not bound to a fixed vehicle or set-up. Measurements can be made both stationary or mobile (80 km/h). The system meets the requirements of ISO 13473-3 class D for vertical resolution (i.e. better then 0,03 mm) and class E for wavelength range (i.e. larger than 200 mm). For this project the mobile system has been used (see figure 22).

figure 22 Mobile laser texture meter used for height measurements of road markings

For each road section the average profile height was calculated per 20 m road section. This is the same section length that is used in the CPX-method. It must be emphasized that the CPX and height measurements were not performed simultaneously.

7.2 Results

The results of the height measurements are shown in Appendix B. In Appendix B for each road marking section a representative part of the height profile and the average height of each 20 m section is shown. The average height of the marking per road marking section is shown in figure 23.

In figure 24 a scatterplot of the CPXP level versus average height of each road marking section is shown.

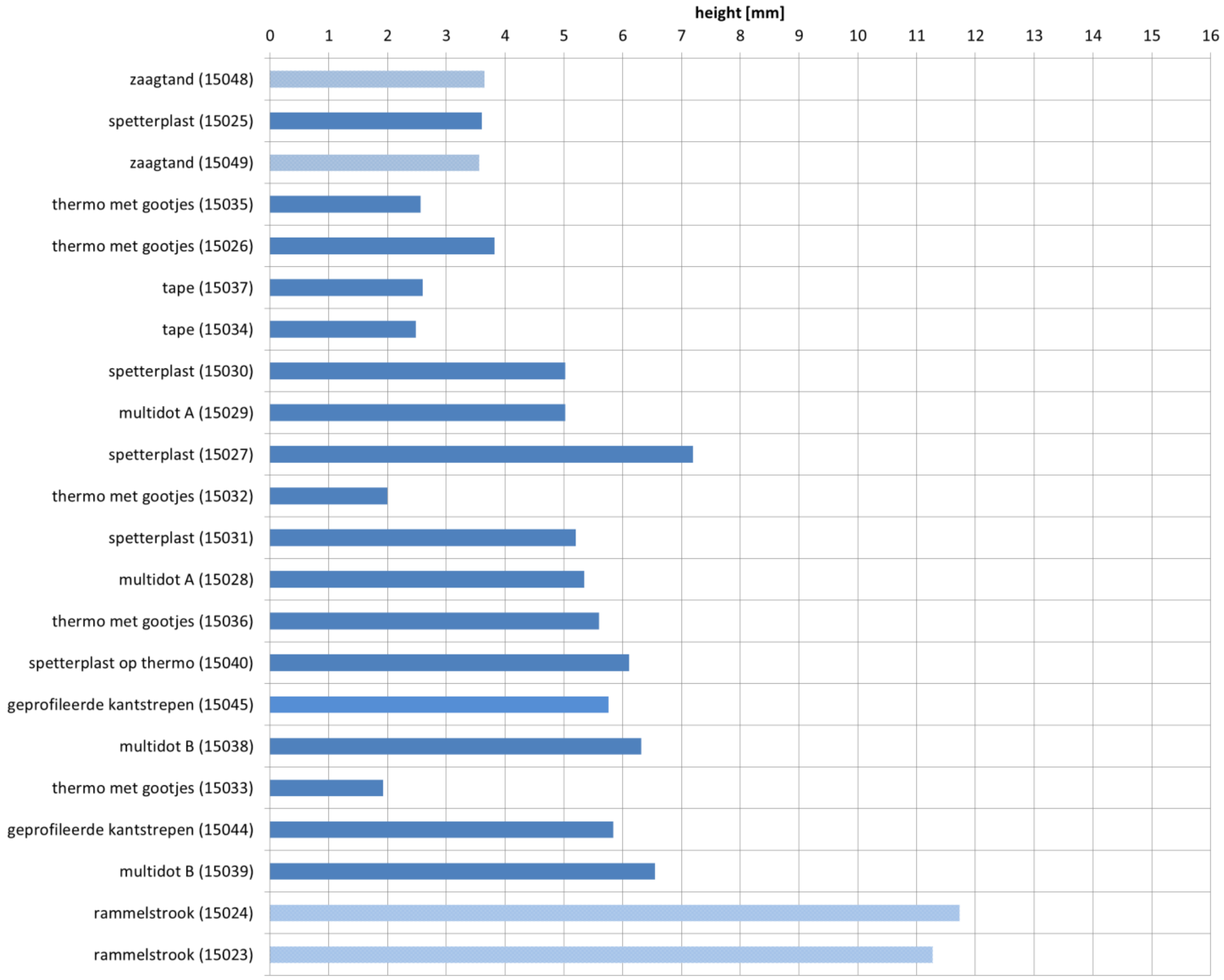


figure 23 *Average height of the marking for each section. Ordered by ascending CPXP-level*

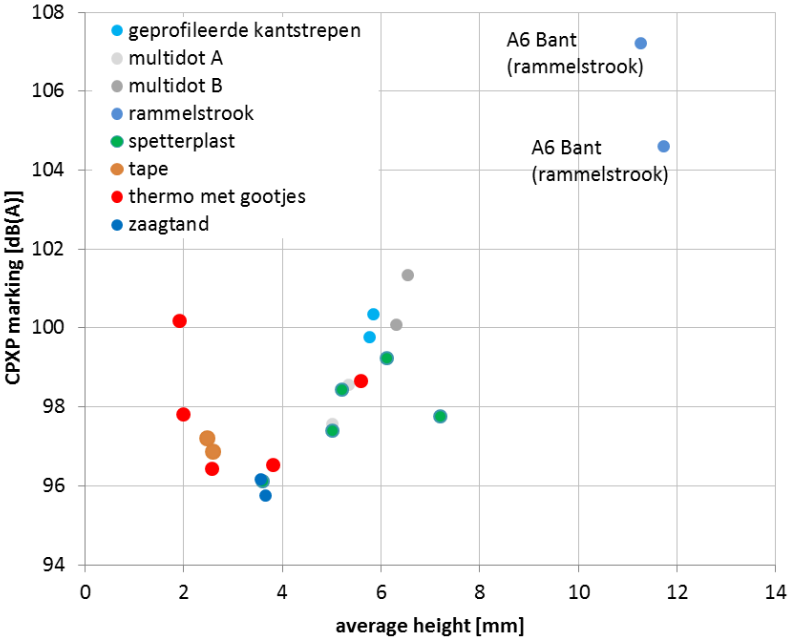


figure 24 *CPXP-levels versus average height of the road marking*

The following conclusions can be drawn from these results:

- The differences in height between the different road marking types are significant. The smallest average height (2 - 3 mm) can be found for the tape and a “thermo met gootjes” and the highest (11 mm) for the “rammelstrook” markings. The multidot markings have an average height of 6 mm;
- Within the road marking type “thermo met gootjes” the largest differences in average height can be found. The average height is between 2 and 6 mm;
- An increase of the height of a road marking often results in an increase of the CPXP-level.

The average height of both tape road markings is 2,5 mm. As mentioned in paragraph 5.4.2 both tape markings are the same product and type. According to specification of the manufacturer the height is 2,8 mm.

8 SPERoN / AOT calculations

8.1 Tyre/road noise

For modern passenger cars, at constant vehicle speeds of 40 km/h and faster, the rolling tyres are the main source of noise. The noise of the vehicle itself (propulsion line, motor, exhaust system) is negligible in the overall noise emission. For trucks this tipping point is at approximately 70 km/h. The dominant source of noise for suburban roads and motorways is therefore the interaction between the tyres and the road surface.

The road surface has a great impact on the rolling noise production. Four important parameters can be distinguished for the road surface:

- *surface texture*, or the roughness of the road. Variations in the road surface height cause the tyres to vibrate and radiate noise. If the road surface is more smooth, the rolling noise is reduced. For very smooth road surfaces, other mechanisms (micro slippage and aerodynamic processes) may come into play;
- *sound absorption*: part of the noise radiated by the tyre can be absorbed by the road surface. This only happens for porous road surfaces, where the noise is lost in the air voids between the stones. For a high sound absorption, the road surface should have a high void content. The air channels between the stones should optimally be narrow, to maximize the contact between the moving air and the road material. Also, it is important to choose the layer thickness such that sound is absorbed for the frequencies at which the noise levels are high;
- *flow resistance*, of the resistance against air escaping the tyre/road contact. A high flow resistance can lead to a higher contribution of airflow related processes. At the same time, for porous road surfaces, a higher flow resistance is good for sound absorption. The flow resistance depends on the void content and the shape of the voids, but for dense road surfaces it strongly depends on the surface texture. The flow resistance is a parameter that is difficult to control and to optimize in the road surface design, but it is important to know;
- *mechanical impedance*, or the resistance of the road surface against (vertical) motion. A regular asphalt surface has a mechanical impedance that is much higher than that of the tyres: the surface is stiff and hard. When the mechanical impedance of the road is lowered, by adding rubber or other flexible components, then part of the tyre vibrations is moderated by the road surface. The tyre will vibrate less, which causes the rolling noise to decrease.

8.2 Acoustic optimization

The four road surface parameters mentioned above all have an influence on the rolling noise at the same time. Also, these four parameters are mutually dependent. The void content has an influence on the flow resistance and on the sound absorption. The choice of stone size influences the surface texture and the flow resistance. The mechanical impedance may also be influenced by void content. Lowering the mechanical impedance makes the surface texture less important. Furthermore, the different parameters have an influence on different parts of the noise spectrum, at higher of lower sound frequency ranges that partly overlap.

For each of these four parameters, M+P has measurement methods available. Using these measurement methods, the texture, absorption, flow resistance and mechanical impedance on test samples in the laboratory, or outside on a real road section (in-situ) can be determined. By comparing the results of these measurement with results for other road surfaces or test samples, M+P can determine the influence of each parameter on the rolling noise.

To come to an optimal combination of road surface design parameters, M+P has the Acoustic Optimization Tool (AOT) available. The measurement data for each parameter are put into the AOT model to predict the CPX and SPB rolling noise levels. By comparing the rolling noise levels to those of a known, existing road surface (for instance, single or double layered porous asphalt concrete), the expected noise reduction can be predicted based on test sample measurements. The road surface parameters can be varied independent of each other and combined with measurement results from a database of existing road surfaces. For the AOT, a large database with road surface measurements of 40 different pavement types is available from the measurements M+P has performed on the Rijkswaterstaat test sections in Kloosterzande (2007-2008).

8.3 Predicting noise levels for road markings

In the current project the AOT model is used to investigate in which extent the tyre/road noise while driving on the markings can be predicted. Therefore the texture profile of a representative part of each road marking section was used as an input parameter. Normally the AOT expects multiple parallel texture profiles, to take into account height differences perpendicular to the driving direction. However of each road marking section only one parallel texture profile was available. It was assumed that the other parallel profiles are the same. This is not representative for all marking types.

The following assumptions were made for the other parameters:
- No sound absorption;
- Airflow resistance is 10.000 Pa.s/m (typical value for a dense road surface);
- Mechanical impedance very high.

In figure 25 per road marking section the CPXP-level predicted by SPERoN/AOT is compared to the measured CPXP level.

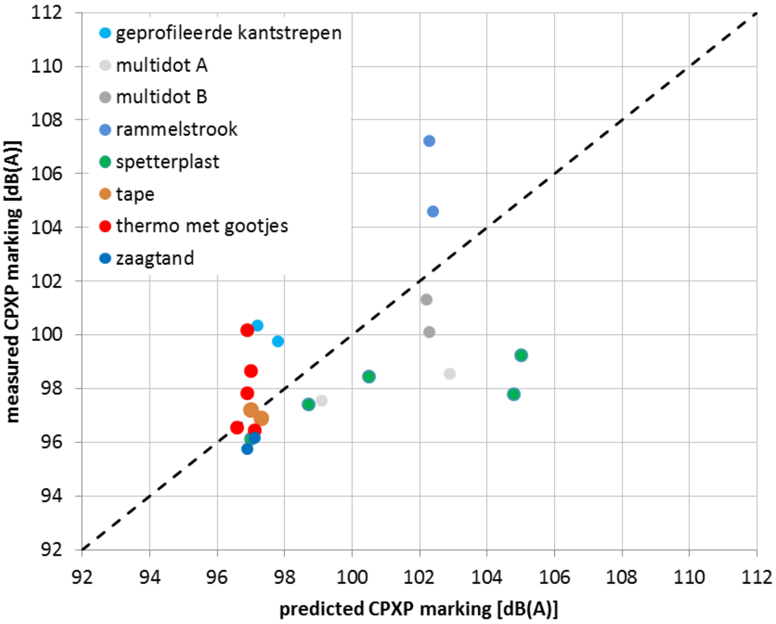


figure 25 Measured CPXP levels versus predicted CPXP-levels of the road marking

The following conclusions can be drawn from these results:

- Most of the predicted CPXP-levels by the SPERoN/AOT model are within ± 2 dB(A) of the measured CPXP-levels;
- Some road marking sections show differences of more than 4 dB(A). This concerns two of the five sections with spetterplast marking, one of “rammelstrook” markings and one of the multidot markings.

As mentioned, for the calculations with the SPERoN/AOT model assumption have been made which are not representative for all road marking. One could consider to measure the input parameters for the SPERon/AOT model and then do the calculations. The measurements could for example be done on the road markings on the airbase in Geilenkirchen.

9 Recommendations for applying a functional requirement

In the measurement program that was conducted for this project, both noise and height measurements were performed on different road marking types. Road markings are not only applied for visual guidance, but also function as a safety measure. When driving on the markings, the driver is alerted by higher noise levels inside the vehicle. However, outside the vehicle the noise of driving on the road marking can cause annoyance for people living nearby. In most situations the noise levels for vehicles driving on the asphalt are significantly lower than the noise levels driving on the road marking. In some cases people already complained about noise of road markings.

To minimize the possible annoyance for people living nearby the road, the Dutch Public Roads Administration (Rijkswaterstaat) is looking for a functional requirement for the sound emission of road markings which can be applied in the future. In the next paragraphs two functional requirements are discussed in more detail.

9.1 Requirement based on CPXP level

The method for assessing the noise of road markings is based on the CPX method. So the most obvious approach is to investigate a requirement based on CPXP levels. The possible annoyance for people living nearby the road is caused by the difference in noise level at that specific location between driving on the asphalt and driving on the road marking. The requirement shall indicate a maximum allowed increase of the CPXP level when driving over the road marking compared to the CPXP-level of the road surface on which it is applied.

To apply the difference in CPXP level between road marking and road surface as a requirement, it is necessary to use reference CPXP levels for the different road surface types in new condition. Based on several measurements [10, 16] a proposal of reference CPXP levels is given in table II.

table II *Proposal of reference CPXP-levels for different road surface types*

type	road surface	CPXP level [dB(A)]
dense	DAC SMA	100
porous	PAC	96
	DLPAC	94

As mentioned in paragraph 2.1 Rijkswaterstaat used a limit value of 6 dB(A) in the past as maximum allowed difference between road marking and road surface. It was stated that the nearest houses should be located at a distance of at least 1000 m if this limit value was exceeded. Based on the current measurement results we propose to tighten the limit value a little to 5 dB(A).

In figure 26 the CPXP-levels of the different road markings are displayed. The red lines are the proposed limit values for DLPAC, PAC and DAC/SMA road surfaces. These limit values are obtained by adding 5 dB(A) to the proposed reference values in table II. Except for the “zaagtand” and “rammelstrook” marking (influence road surface) one can see which road marking can be applied on which road surface type without exceeding the limit value.

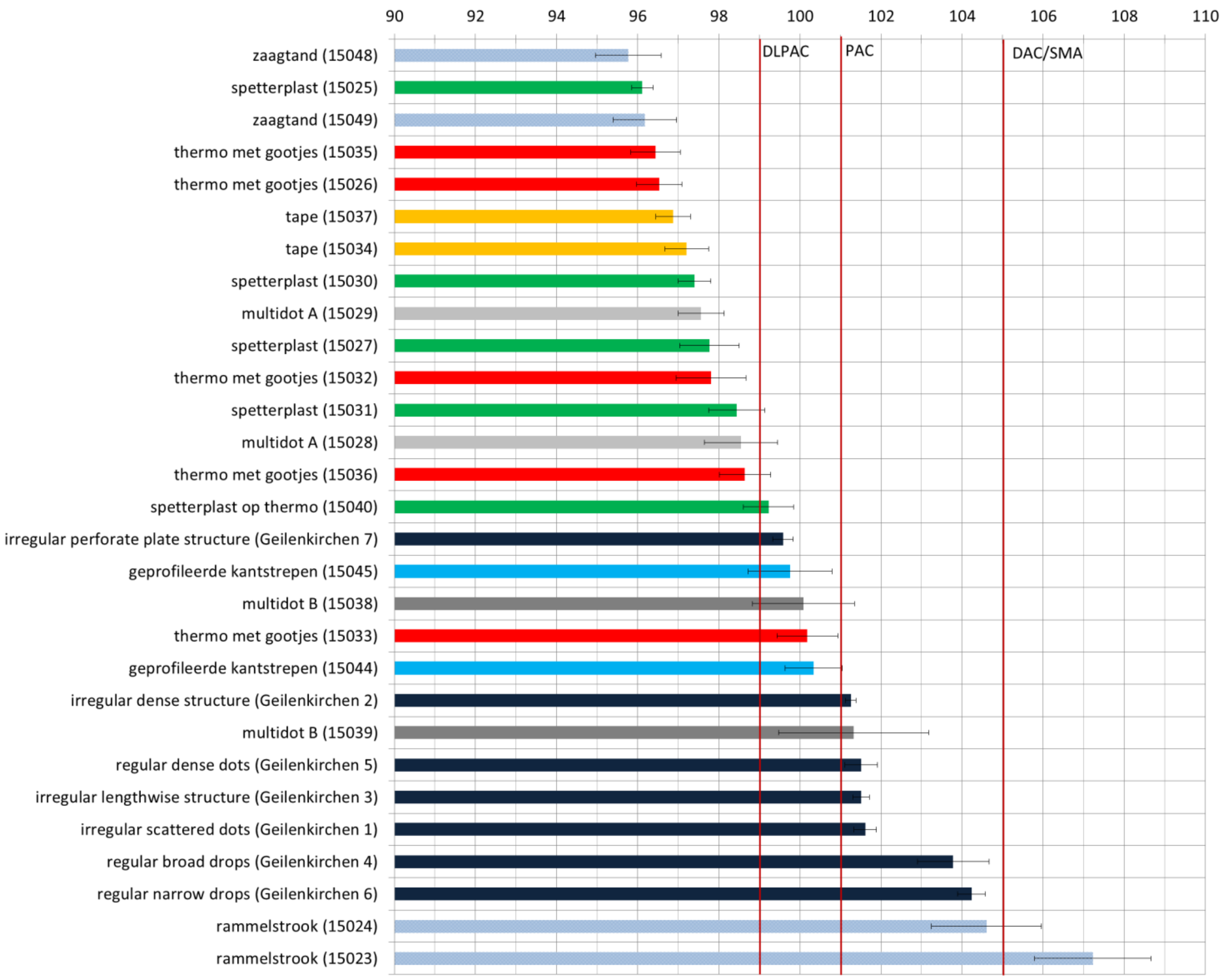


figure 26 *CPXP-levels of the marking. The red lines indicate the proposed limit values for applying a marking on a specific road surface type*

As can be seen in figure 26 almost all measured road markings on the Dutch highways do not exceed the limit value when applying the road markings on the standard PAC road surface. Applying those road markings on DLPAC reduces the number of road markings. One can consider even to tighten the limit value when applying road markings on DLPAC to further minimize the possible annoyance for people living nearby the road.

9.2 Requirement based on loudness

Another approach for a functional requirement is to look at the differences in loudness instead of differences in CPXP-levels between marking and road surface. This might have an advantage as it better takes into account effects like tonality. In figure 27 for each road section the difference in loudness and the difference in CPXP level are compared.

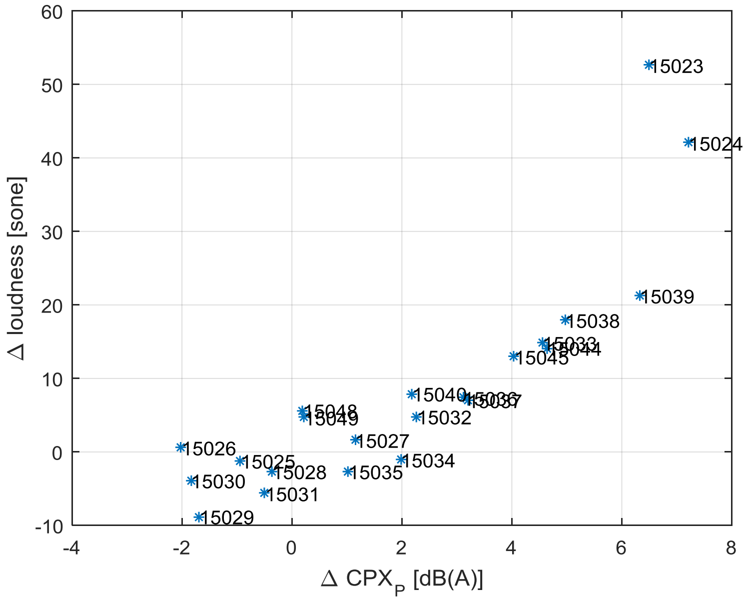


figure 27 Difference in loudness compared to the difference in CPXP level for all measured markings (section numbers see Appendix A)

The two outliers (no. 15023 and 15024) in figure 27 are “rammelstrook” road markings. As can be seen the other results are comparable and a linear regression line can be fitted through the data points with relatively small deviations from the individual data points. This means that a requirement based on loudness will yield approximately the same results as a requirement based on CPXP levels. As loudness is a derivative of the CPXP results, a requirement based on CPXP levels would be preferable.

10 Conclusions and recommendations

10.1 Conclusions

In this research project more knowledge has been gained about the acoustic properties of road markings which are nowadays applied on highways in the Netherlands. At 9 locations measurements have been performed on 22 road marking sections. It concerns different road marking types applied on standard road surfaces types on the Dutch highways.

The noise measurements have been performed according to the Close Proximity (CPX) method with some additions. These additions are proposed by the CEN task group *Noise* which develops a measuring method for determining the acoustic properties of road markings. The measurements performed on the Dutch road markings show that with some adjustments, this seems to be a suitable measurement method. An important adjustment is how to deal with the relatively small width of the Dutch road markings.

To be able to compare measurement results of different CPX-systems, it is necessary to know more about the reproducibility of the measuring method. Therefor within the framework of the CEN task group *Noise* a Round Robin Test (RRT) has been performed. The results show small differences between the M+P and BRRC CPX-systems. However the results of the BASt CPX-system show results which are approximately 2 dB(A) lower. It seems to be a systematic difference. The task group *Noise* will look into this further.

The CPX-measurements performed on the 22 road marking sections showed difference in CPXP-level of 11 dB(A). If not taking the “zaagtand” and “rammelstrook” marking into account the difference is approximately 5 dB(A). Within a road marking type differences have been found up to 3 dB(A).

Besides the CPX-measurements also the height of the road markings above the road surface has been measured using a mobile laser texture measuring system. The height of the measured road markings varies from approximately 2 mm till 11 mm. Within a road marking type significant differences in height have been found. The results also show that an increase of the height often results in an increase of the CPXP-level.

The SPERoN / AOT model was used to predict the noise levels while driving on the markings. A representative part of the height profile was used as input parameter for texture. For the other input parameters sound absorption, flow resistance and mechanical impedance assumptions were made which were not representative for all road markings. The calculations however showed that most of the predicted CPXP-levels by the SPERoN/AOT model are within
± 2 dB(A) of the measured CPXP-levels.

Trying to better understand possible annoyance of road marking noise for people living nearby, the loudness of the markings and the asphalt on which it was applied, were determined according to DIN 45631. The calculations showed that the maximum difference in loudness between all measured road markings is around 60%. The maximum difference in loudness between the asphalt on which those road markings were applied, is 35%. On several sections there was no significant difference in loudness between the road marking and the asphalt on which the road marking was applied.

A functional requirement was proposed based on the maximum allowed increase of CPXP-level when driving on the road marking versus driving on the asphalt. For the CPXP-levels on asphalt, reference CPXP-levels were proposed for the road surface types DAC, SMA, PAC and DLPAC. Calculations have been made by using a limit value of 5 dB(A). Using this limit value almost all measured road markings can be applied on PAC and approximately half of the markings can be applied on DLPAC.

10.2 Recommendations

The measured road markings concern different types. However in most cases the number of measured road markings within a type is very small. This raises the question how representative the results are for the mentioned road marking type. Therefor it is recommended to perform more noise measurements on the specific and representative road marking types.

To improve the accuracy of the SPERoN/AOT calculations, more reliable input parameters have to be defined. This requires measurements of 3D surface texture, sound absorption, flow resistance, and possibly mechanical impedance of various road marking types. An option is to perform these measurements on the road marking test sections on the airbase in Geilenkirchen.
The Dutch road markings have a standard width of 200 mm. This makes it difficult to let the tyre roll for 100% on the marking. Therefor it was ensured that the tyre rolled for at least 85% on the marking to have a valid measurement run. BASt expects significant differences to occur when rolling less than 80% on the marking. To determine this in more detail, further research is necessary.

All CPX-measurements on road markings so far have been performed with the SRTT tyre mounted on the right side of the CPX-trailer. However, in some cases it is not possible to measure with the right side mounted tyre . In these cases the measurements can only be performed with the left side mounted tyre. It is unknown whether the results of the left and right side mounted tyre are comparable for all road marking types.

Usually all CPX-results on road surfaces are corrected for air temperature to a reference temperature of 20 °C. However it is unknown if these temperature correction coefficients can also be applied for CPX-measurements on road markings.

For several road markings the acoustic properties of the road surfaces on which they are applied, have no significant influence on the acoustic properties of the road marking. Special attention has to be paid to the “spetterplast” marking. Depending on the degree of filling the acoustic properties of the road surface can influence the acoustic properties of the “spetterplast” marking. More research is necessary to find out the influence of the degree of filling.

11 Literature

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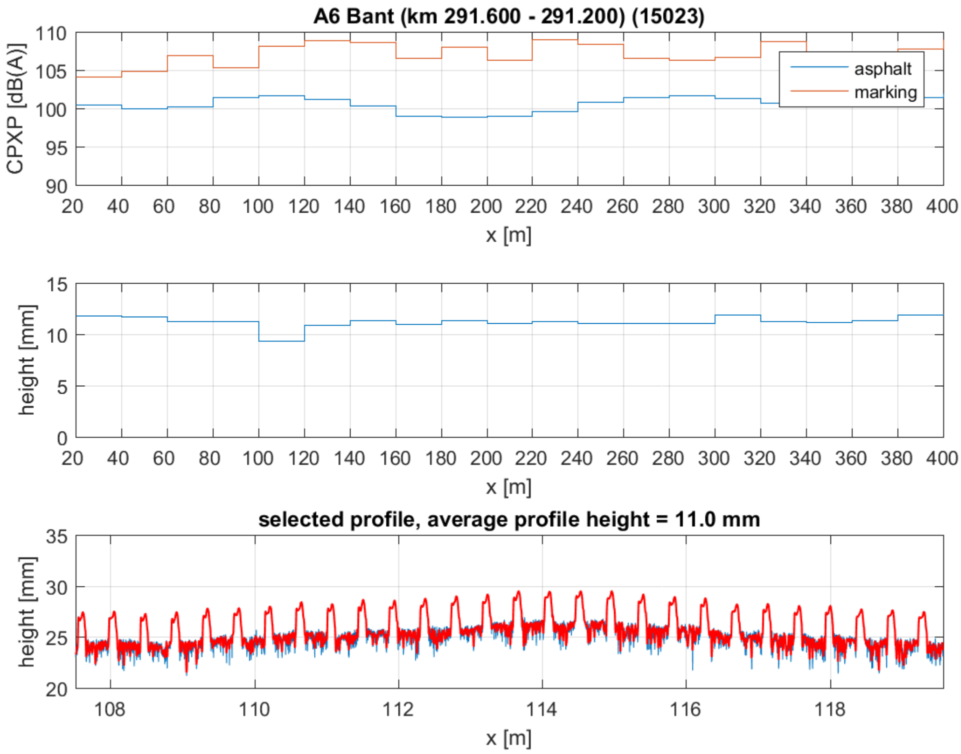
Appendix A

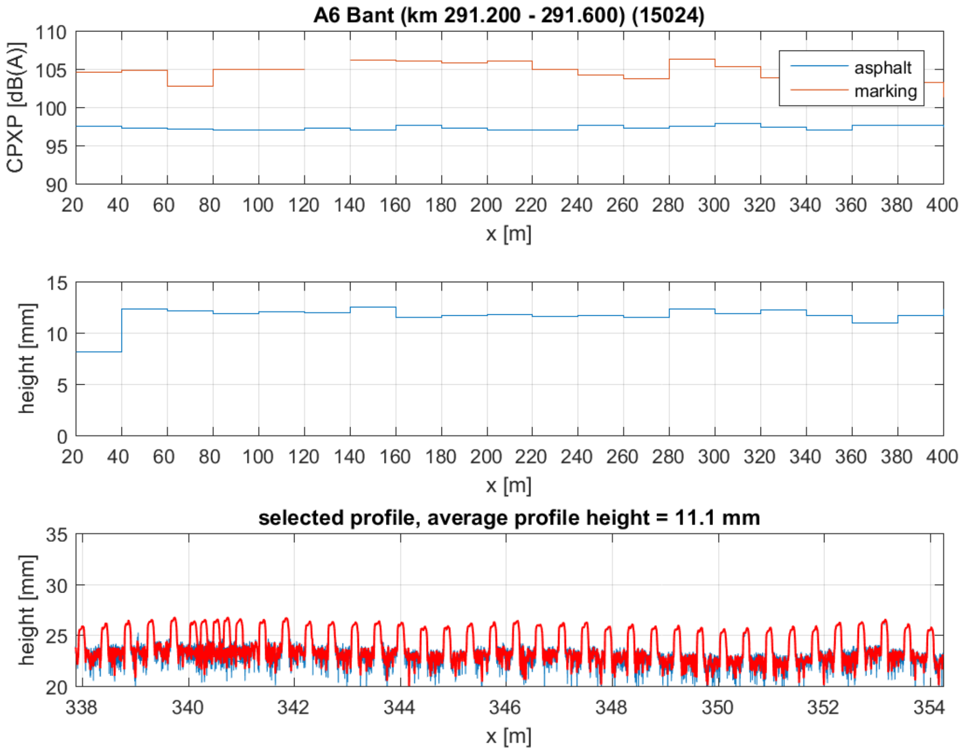
Overview of road marking sections

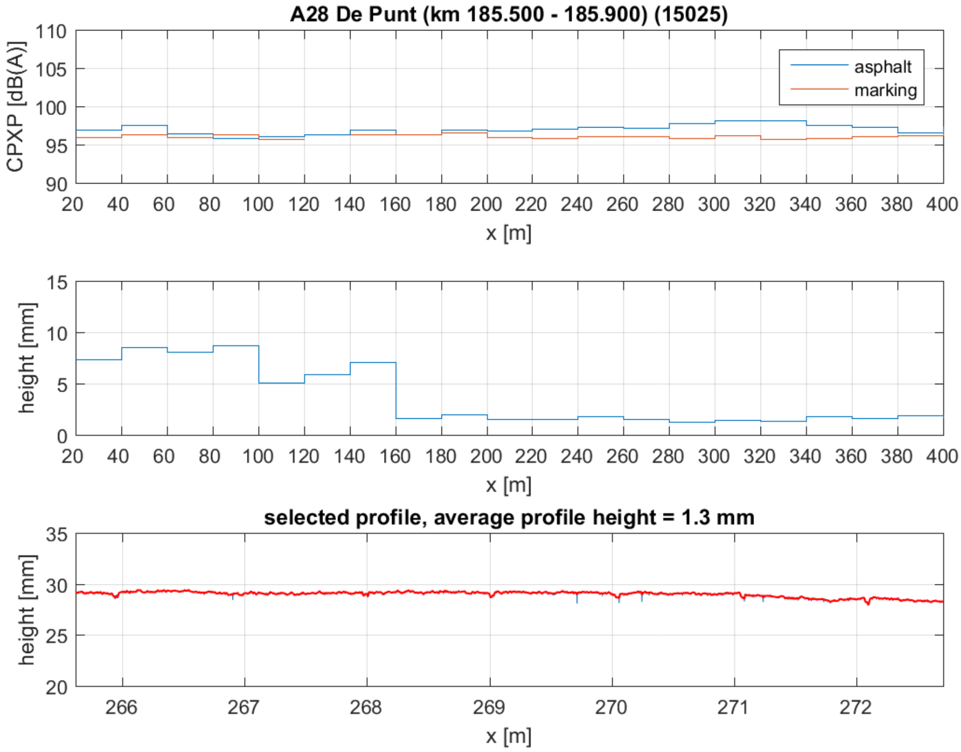
Location	section number			ch from	ch to	length	marking type	road surface type	year of construction	category
A10 2e Coentunnel (mrk)	15046	1HR-R	4R-R	29.300	29.650	0.350	Thermo met gootjes	SMA 2013		thermoplast
	15047	1HR-R	4R-R	29.700	30.100	0.400	Rammelstrook	SMA 2013		ribbed
A6 Bant (mrk)	15023	1HR-L	1V-L	291.600	291.200	0.400	Rammelstrook naast kantstreep	ZOAB+ 2007	2011	ribbed
	15024	1HR-R	1V-R	291.200	291.600	0.400		ZOAB 2005		ribbed
A28/N34 De Punt (mrk)	15025	1HR-R	2R-R	185.500	185.900	0.400	Spetter	n.t.b	2012	agglomerate
	15026	1VW-a	1R-R	108.500	108.900	0.400	Thermo met gootjes, VWeg N34-A28 vanaf de Punt	n.t.b		thermoplast
	15027	1HR-R	1W-R	189.900	190.300	0.400	Spetter, Afrit Eelde, Vliegveld	n.t.b	2006	agglomerate
A33 Appingedam (mrk)	15028	0HR-M	1R-R	61.800	62.200	0.400	Rechterkantstreep, multidot	SMA 2006	2006	dot
	15029		1R-R	67.200	67.600	0.400				dot
	15030		1R-L	67.600	67.200	0.400	As-streep, spetterplast			agglomerate
	15031		1R-L	62.200	61.800	0.400				agglomerate
N36 Rheezerveen (mrk)	15044	0HR-M	1R-R	36.700	37.100	0.400	Kantstrepen geprofileerd	TWZOAB	2013	thermoplast
	15045		1R-L	34.400	34.000	0.400				thermoplast
N65 Vught (mrk)	15048	1HR-R	2R-R	7.800	8.700	0.900	Zaagtandmarkering	DAB 2010		thermoplast
	15049	1HR-L	2R-L	7.800	7.200	0.600				thermoplast
A2 Best (mrk)	15032	1HR-R	2R-R	136.500	136.900	0.400	Thermolit Fabiola	TWZOAB	2013	thermoplast
	15033			137.100	137.500	0.400	Thermo met onderbrekingen			thermoplast
A2/A67 Eindhoven (mrk)	15034	1HR-L	3R-L	168.400	168.000	0.400	Stamark A380ESD (2009)	TWZOAB	2013	tape
	15035			167.700	167.300	0.400	Thermo met onderbrekingen (2009)			thermoplast
A50 Nijnsel (mrk)	15036	1W-R	2R-R	97.800	98.200	0.400	Thermo let op w eefstrook, vanaf John F Kenndylaan beginnen	TWZOAB	2013	thermoplast
	15037	1HR-R	2R-R	103.500	103.900	0.400	Stamark A380ESD (2009)			tape
A4 Steenbergen (mrk)	15038	1HR-L	2R-L	224.700	224.300	0.400	Viatherm NI50 Agglo Visispot	TWZOAB	2013	agglomerate
	15039	1HR-R	2R-R	215.800	216.200	0.400				agglomerate
	15040	1HR-R	2R-R	228.300	228.700	0.400	Spetterplast op thermo			agglomerate

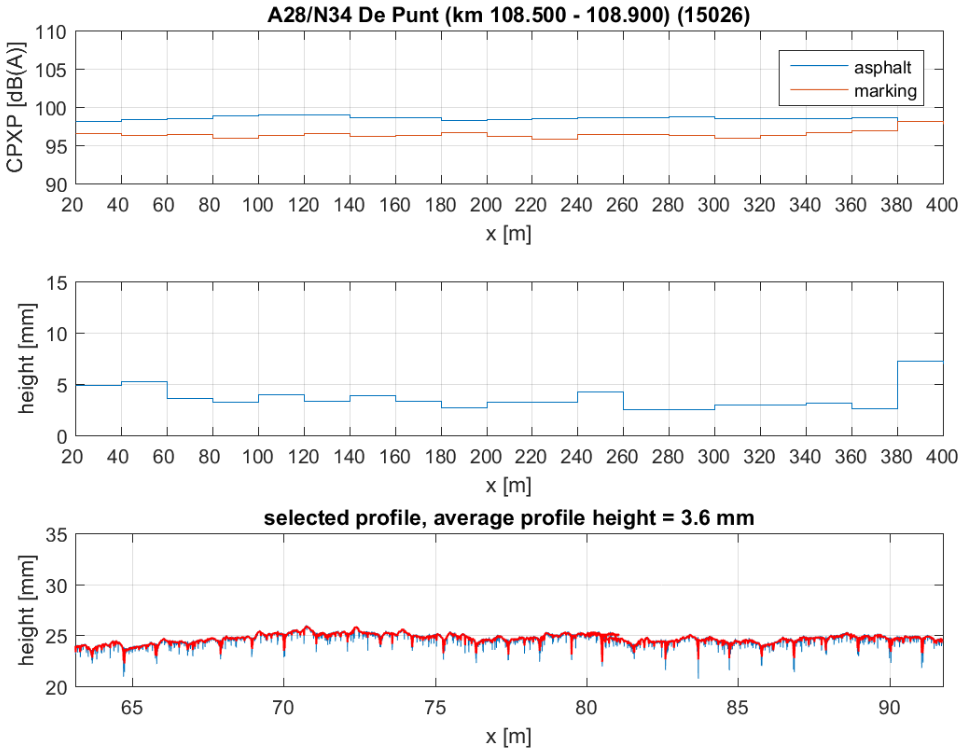
Appendix B

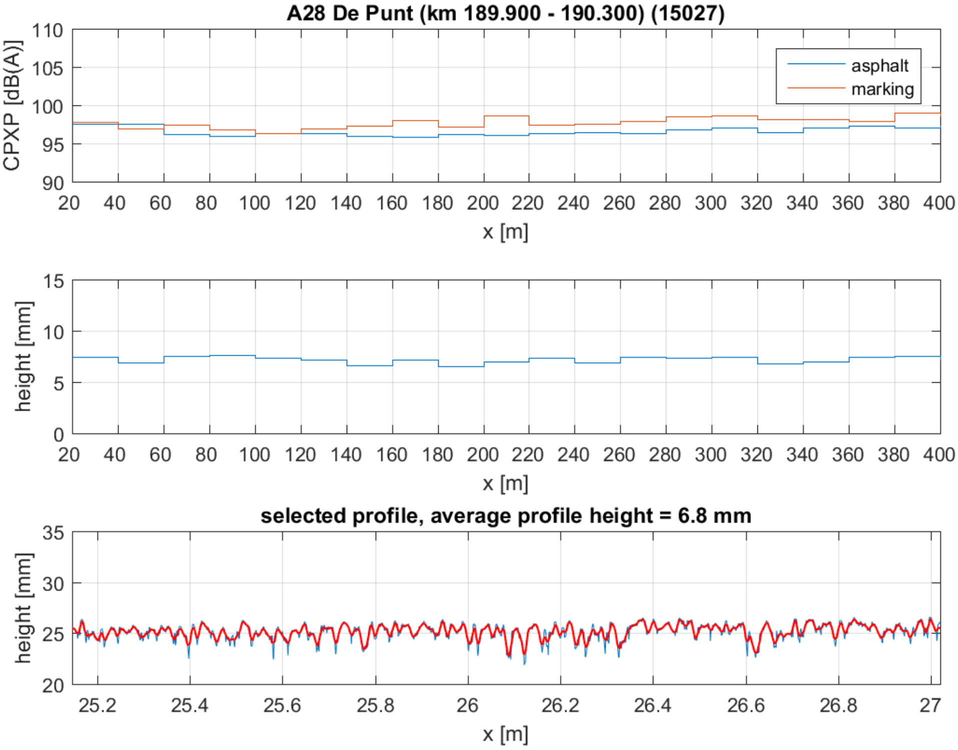
CPX level and height of road markings per section

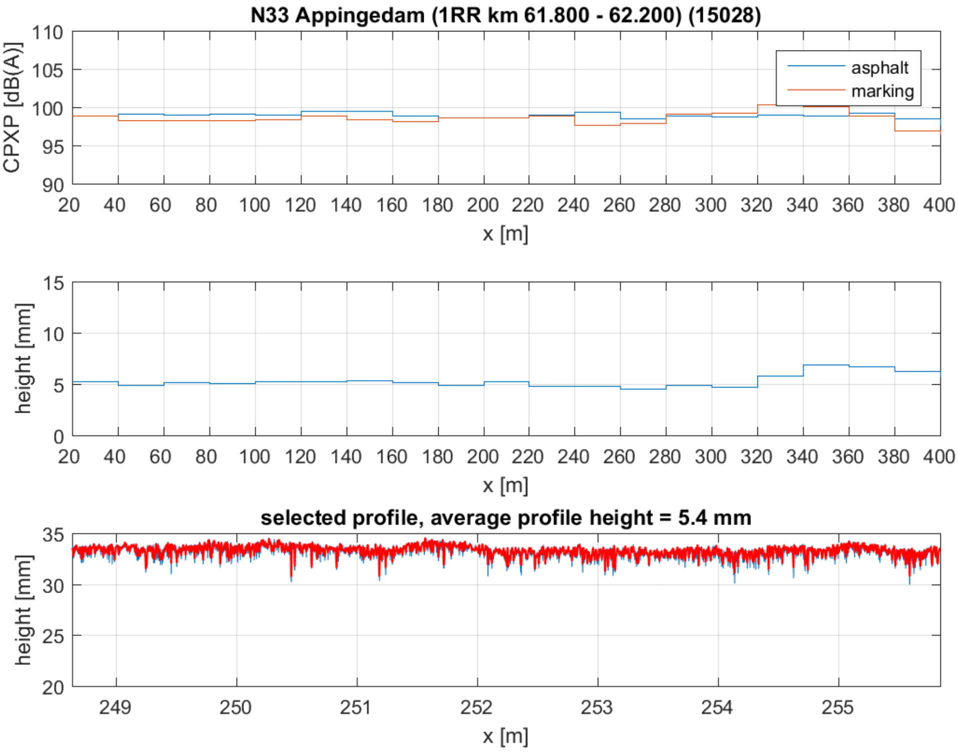

A6 Bant (km 291.600 - 291.200) (15023)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
selected profile, average profile height = 11.0 mm

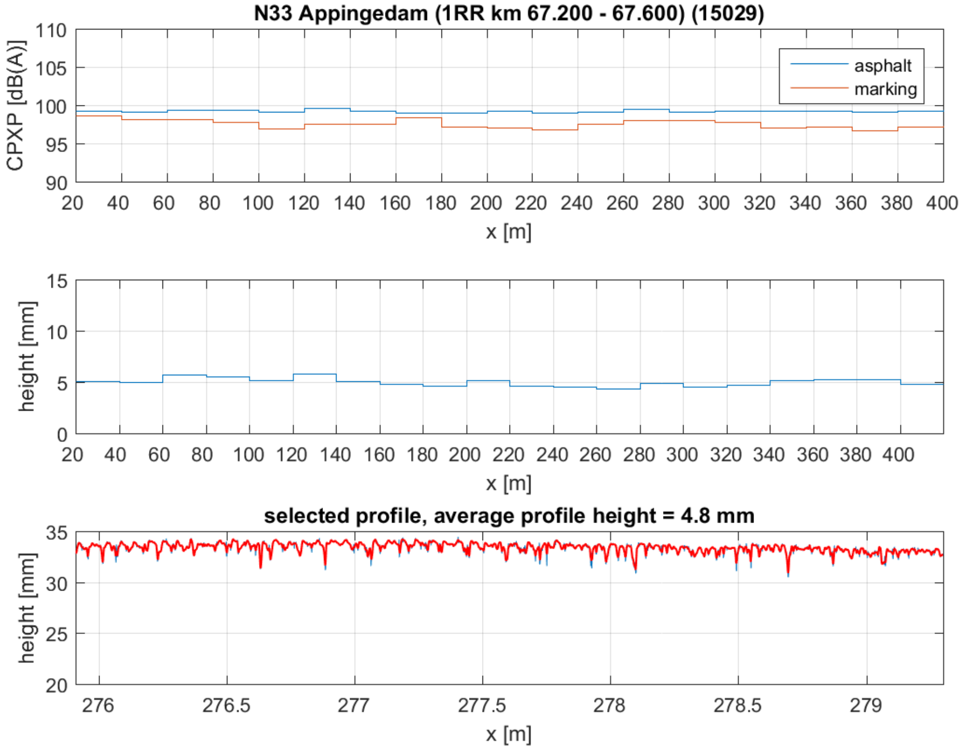

A6 Bant (km 291.200 - 291.600) (15024)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
selected profile, average profile height = 11.1 mm

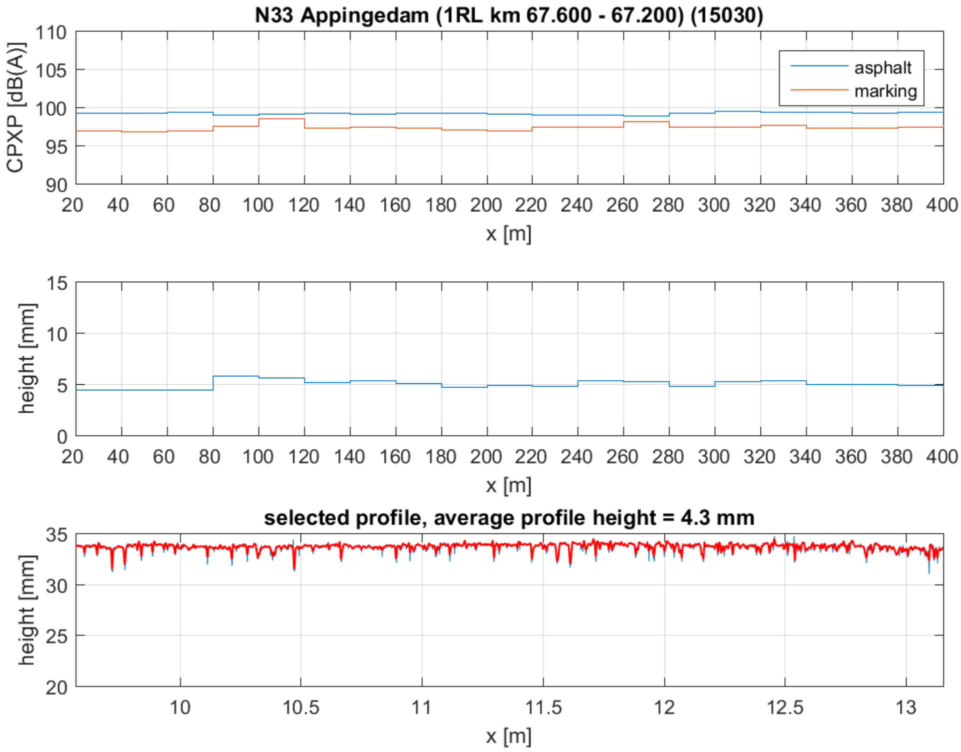

A28 De Punt (km 185.500 - 185.900) (15025)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 1.3 mm
height [mm]
x [m]

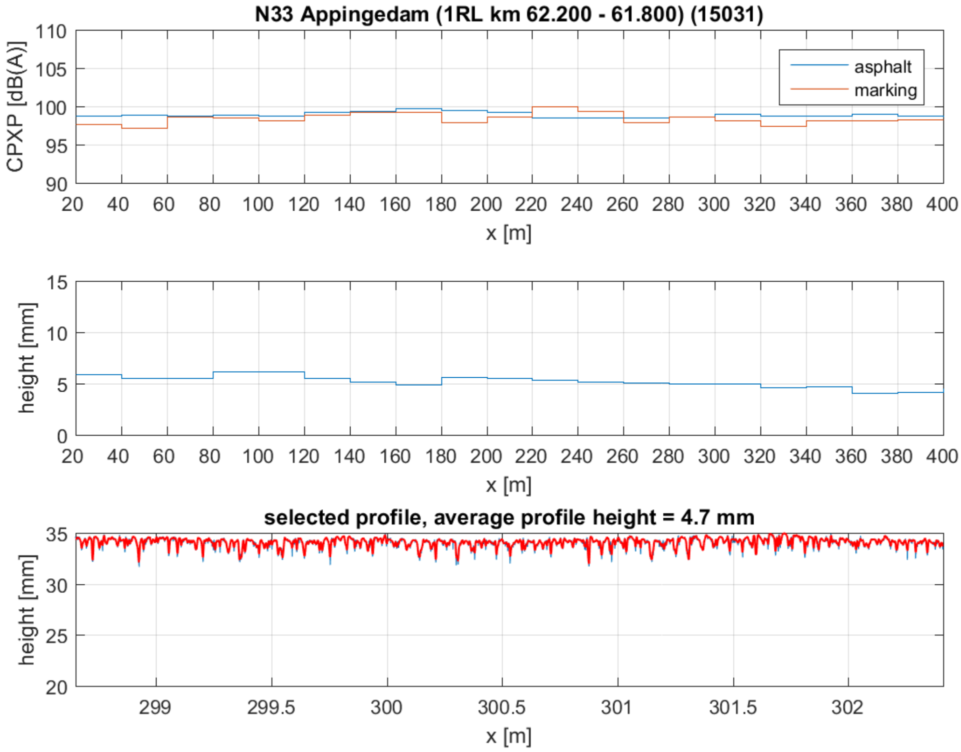

A28/N34 De Punt (km 108.500 - 108.900) (15026)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 3.6 mm
height [mm]
x [m]

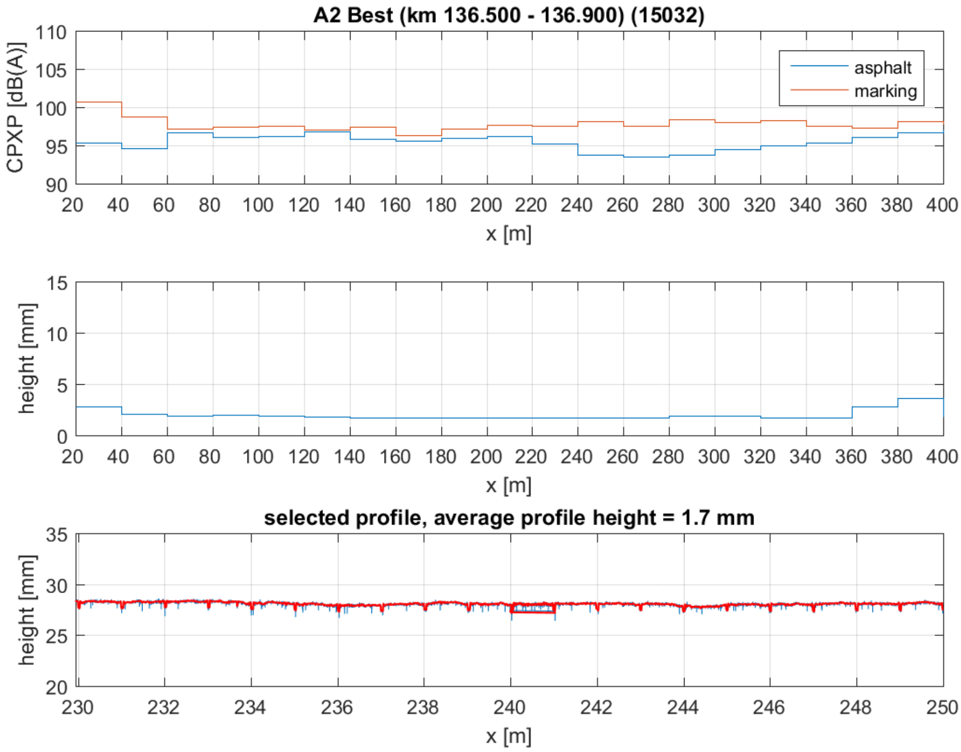

A28 De Punt (km 189.900 - 190.300) (15027)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 6.8 mm
height [mm]
x [m]

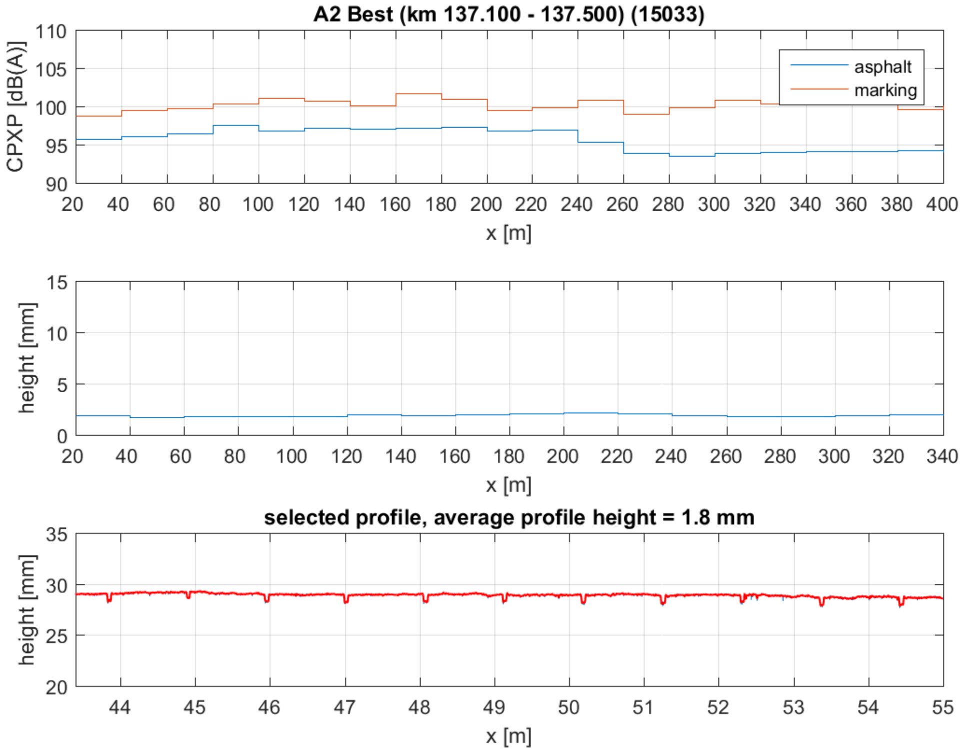

N33 Appingedam (1RR km 61.800 - 62.200) (15028)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 5.4 mm
height [mm]
x [m]

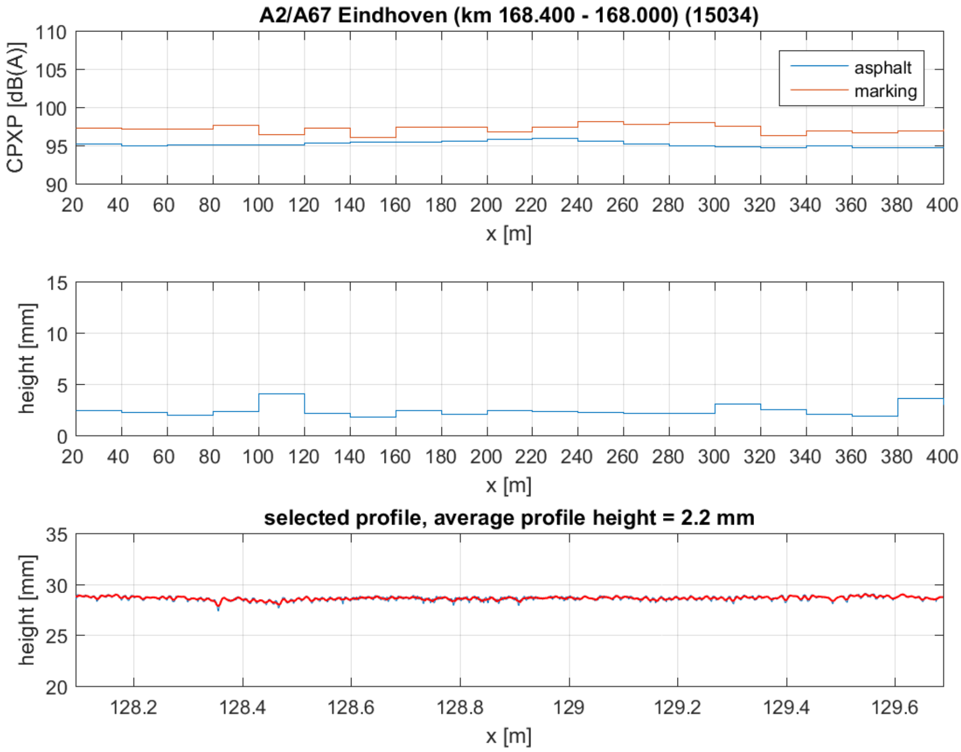

N33 Appingedam (1RR km 67.200 - 67.600) (15029)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 4.8 mm
height [mm]
x [m]

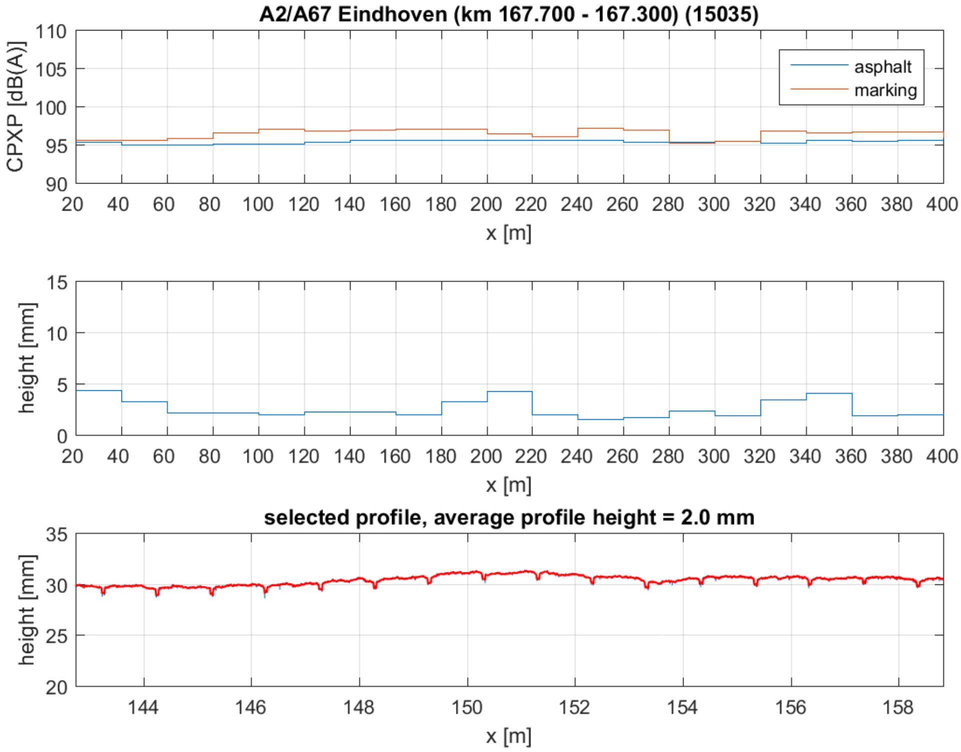

N33 Appingedam (1RL km 67.600 - 67.200) (15030)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 4.3 mm
height [mm]
x [m]

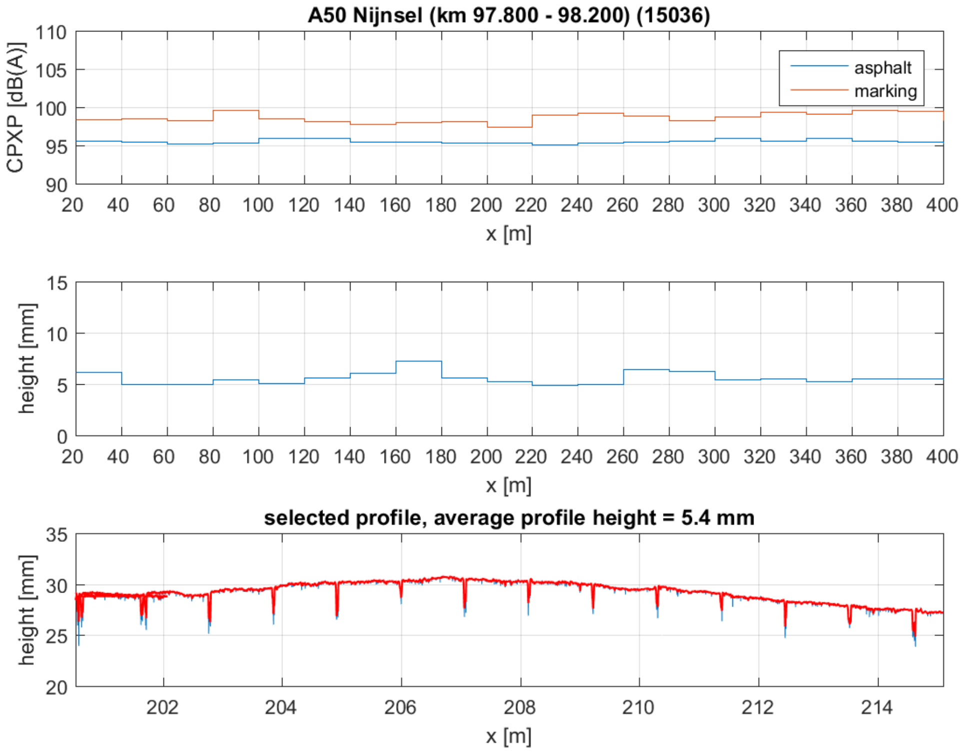

N33 Appingedam (1RL km 62.200 - 61.800) (15031)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 4.7 mm
height [mm]
x [m]

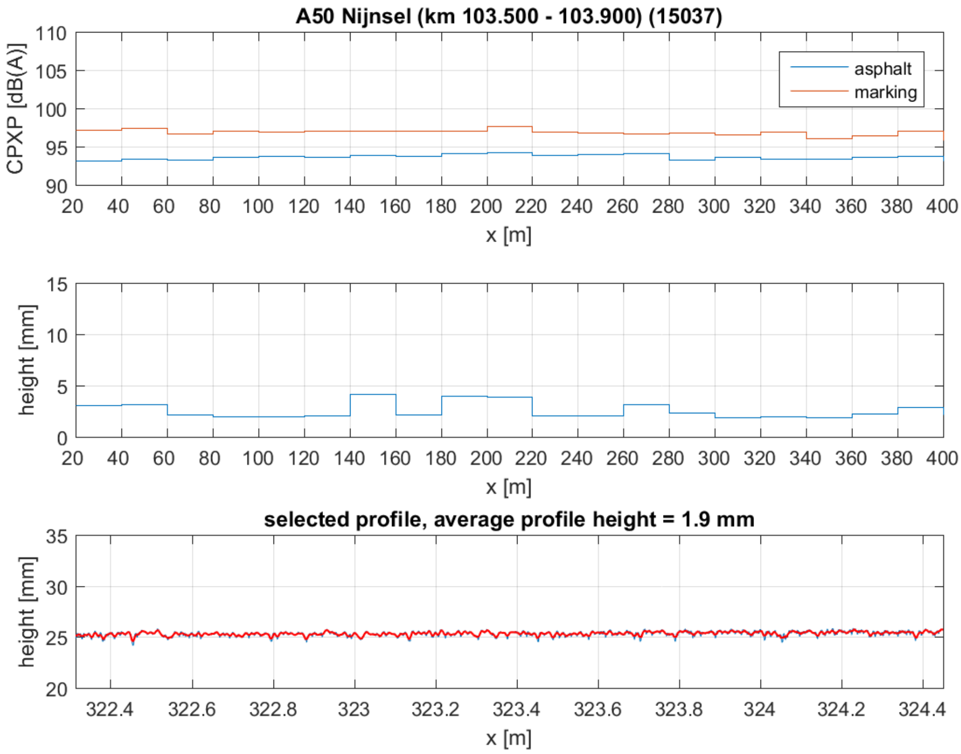

A2 Best (km 136.500 - 136.900) (15032)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 1.7 mm
height [mm]
x [m]

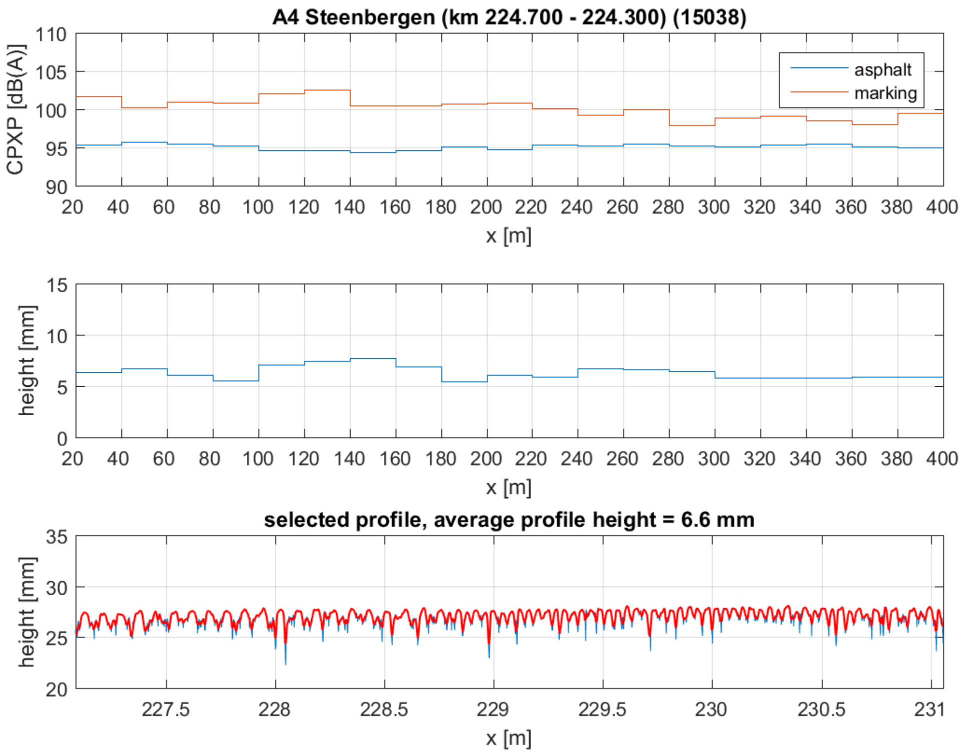

A2 Best (km 137.100 - 137.500) (15033)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 1.8 mm
height [mm]
x [m]

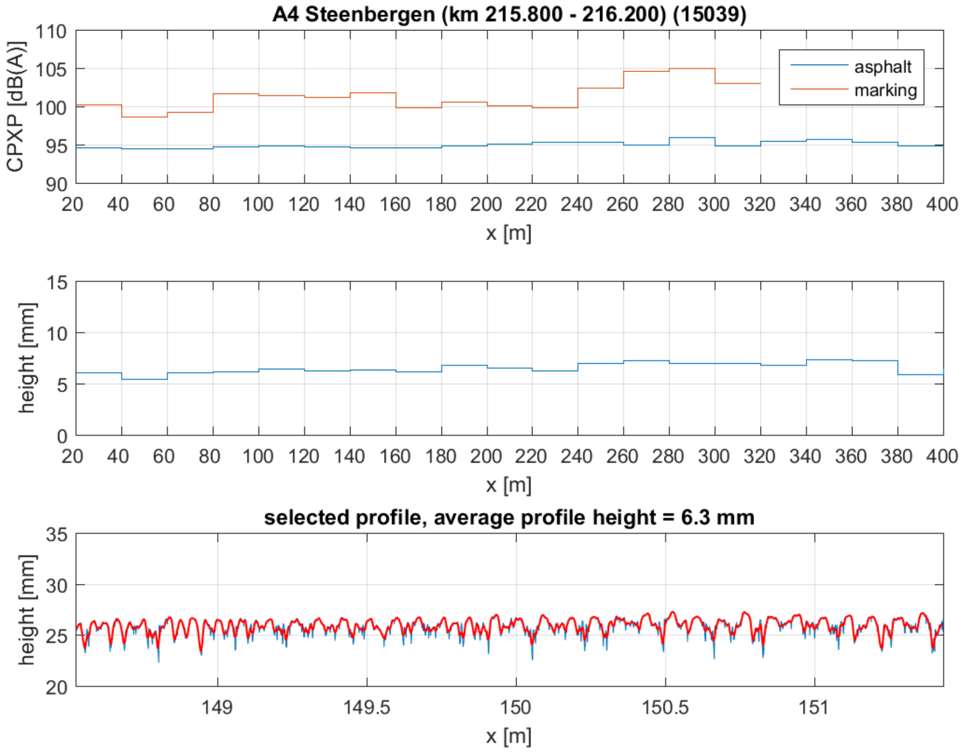

A2/A67 Eindhoven (km 168.400 - 168.000) (15034)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 2.2 mm
height [mm]
x [m]

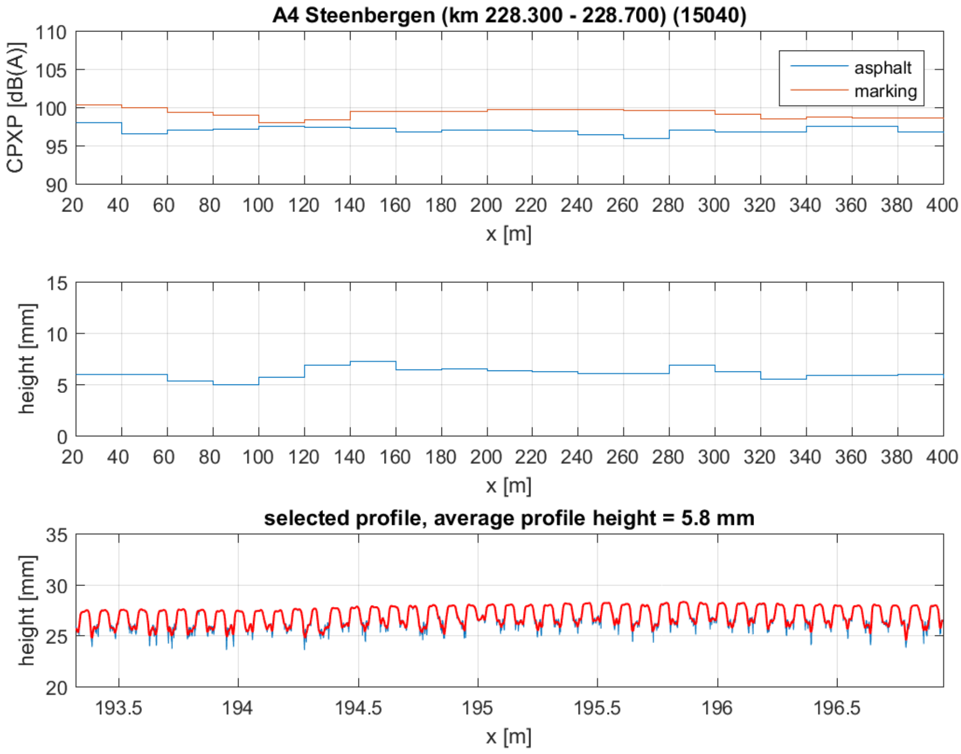

A2/A67 Eindhoven (km 167.700 - 167.300) (15035)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 2.0 mm
height [mm]
x [m]

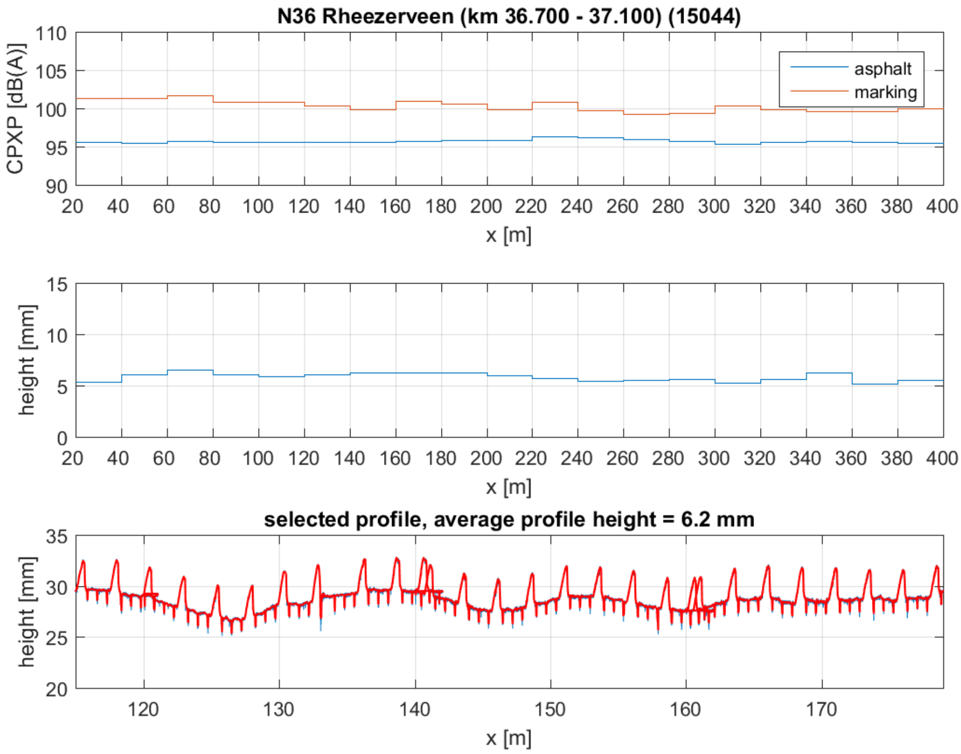

A50 Nijnsel (km 97.800 - 98.200) (15036)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 5.4 mm
height [mm]
x [m]

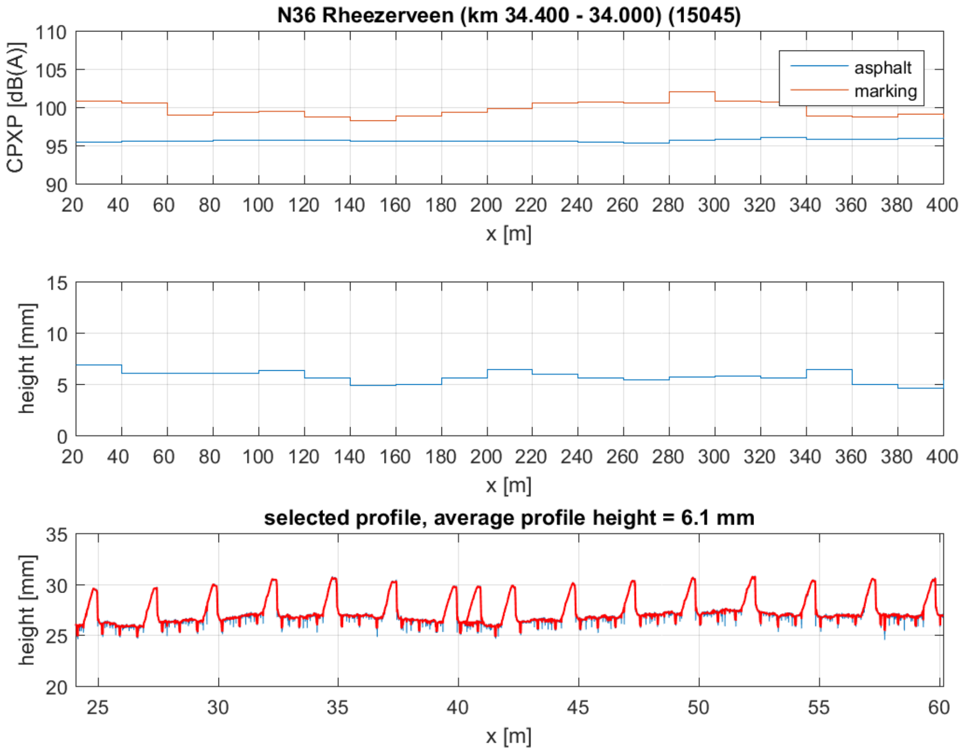

A50 Nijnsel (km 103.500 - 103.900) (15037)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 1.9 mm
height [mm]
x [m]

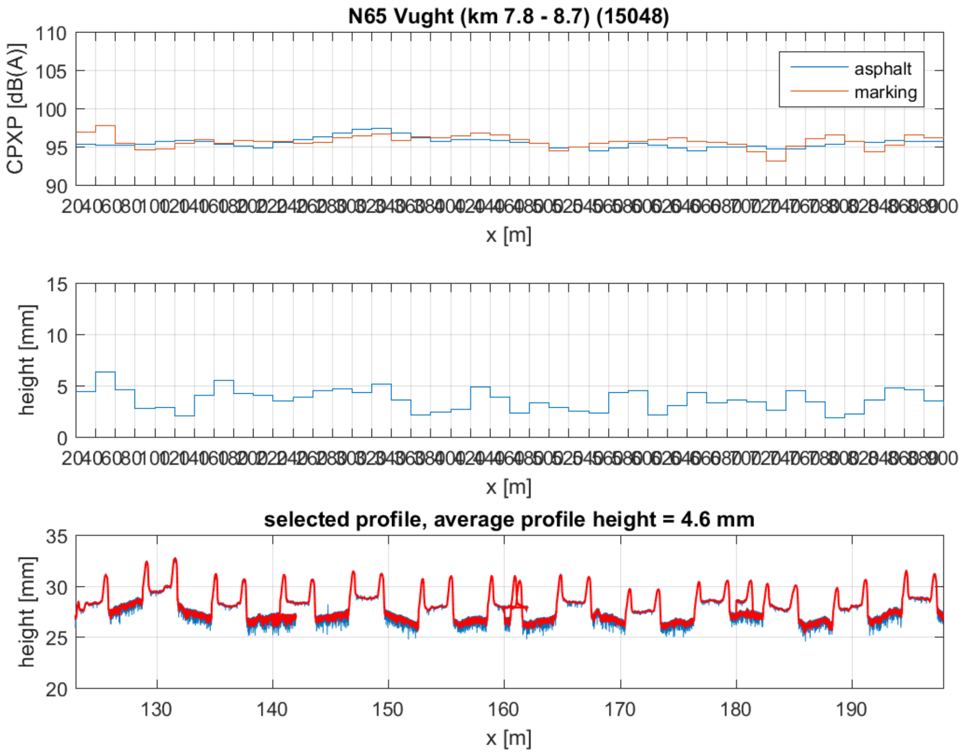

A4 Steenbergen (km 224.700 - 224.300) (15038)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 6.6 mm
height [mm]
x [m]

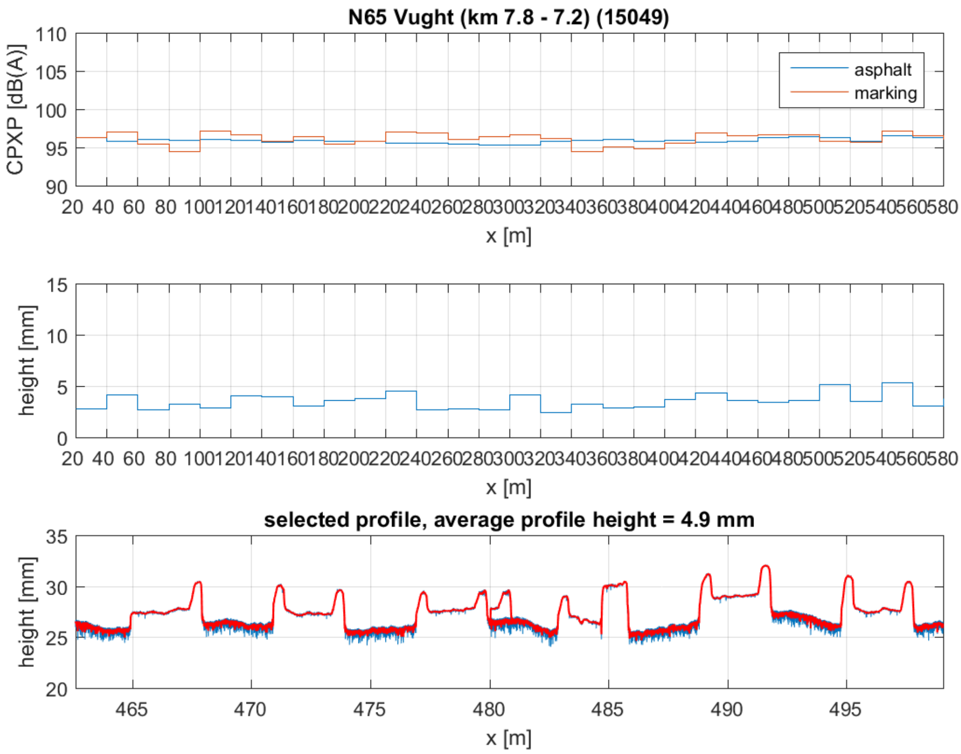

A4 Steenbergen (km 215.800 - 216.200) (15039)
asphalt
marking
CPXP [dB(A)]
x [m]
height [mm]
x [m]
selected profile, average profile height = 6.3 mm
height [mm]
x [m]


A4 Steenbergen (km 228.300 - 228.700) (15040)
asphalt
marking
CPXP [dB(A)]
x [m]
height [mm]
x [m]
selected profile, average profile height = 5.8 mm
height [mm]
x [m]


N36 Rheezerveen (km 36.700 - 37.100) (15044)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 6.2 mm
height [mm]
x [m]


N36 Rheezerveen (km 34.400 - 34.000) (15045)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 6.1 mm
height [mm]
x [m]


N65 Vught (km 7.8 - 8.7) (15048)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 4.6 mm
height [mm]
x [m]


N65 Vught (km 7.8 - 7.2) (15049)
CPXP [dB(A)]
asphalt
marking
x [m]
height [mm]
x [m]
selected profile, average profile height = 4.9 mm
height [mm]
x [m]