Results from first Danish full scale test section with poroelastic road surface

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ABSTRACT

The first Danish test section with poroelastic road surface (PERS) was constructed on August 27th 2013 at the Kalvehave test site in Denmark, as a part of the EU project PERSUADE. The test section is 75 m long and has the width of one driving lane. The yearly daily traffic is 4000 with 10 % heavy vehicles. The speed limit is 80 km/h and the estimated real speed is somewhat lower. The pavement is optimized for low emission of tyre-road noise by using a high built in air void, small aggregates and elastic material. The pavement has a porous structure and is composed of stone and rubber aggregates with a maximum aggregate size of 5 mm and the binder used is polyurethane. The pavement type has been developed and tested in the laboratory. An intensive monitoring program was started at the Kalvehave test site even before the test section was opened for normal traffic. The monitoring program includes measuring noise, acoustical absorption, elasticity, permeability, friction, rolling resistance and visual inspections. Measurements of noise using the SPB road side and the CPX trailer methods have been repeated continuously over the first 9 months of the lifetime of the PERS pavement.

Keywords: 52.3 Road traffic noise. 11.7.1 Tires and road-tire interactions

1. INTRODUCTION

PERSUADE is the acronym for PoroElastic Road SUrface: an innovation to Avoid Damage to the Environment [1]. The project aims at developing the experimental concept of poroelastic road surfacing (PERS) into a feasible noise-abatement measure as an alternative to, for example, noise barriers. It is expected that PERS may provide substantially higher noise reductions than the best of conventional road paving materials. The specific feature of this new type of road surfacing is that it includes a substantial proportion of rubber granulates from recycled car tyres bound with the synthetic resin polyurethane.

To gain experiences mixing and laying the PERS material outside the laboratory on a real road a small scale pre-test was constructed at the Danish Arnakke test site in October 2011. A series of measurements has been performed on this 10 square meter PERS pavement. The results indicate that this pavement has a good potential for achieving a high noise reduction, better than conventional porous asphalt [2]. On the background of these experiences a full scale test section with PERS material was constructed at the Kalvehave test site in Denmark 27th August 2013 on a 75 m long section in one lane of a two lane highway in a rural area (see Figure 1 and 2). The width of the lane is about 3.5 m. The yearly daily traffic is 4000 with 10 % heavy vehicles. The speed limit is 80 km/h and the estimated real speed is somewhat lower. The test section was opened for normal traffic on August 30th. The PERS material is composed of stone aggregates and rubber particles and the gluing agent is polyurethane. The maximum aggregate size is 5 mm both for stone aggregates and rubber particles.

Since the PERS test section at Kalvehave was constructed a comprehensive series of measurements have been performed over a period of around 250 days in order to characterize the PERS pavement in relation to surface characteristics and noise [3].

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Figure 1 - The PERS test section just after construction.

Figure 2 - Close up photo of the PERS test section. The light aggregates are stone material and the black are rubber material.

2. PROPERTIES OF THE PAVEMENT

2.1 Texture laser measurements

The texture of the surface was measured with the DRD in-situ laser device at five places in the left wheel track. The texture profiles were recorded in five 1.5 m long parallel lines separated with 1 cm. The resolution of the instrument is 0.1 mm in the length direction (x) and 9 µm in the height direction (z). The laser is an LMI Selcom SLS5000 with 16 kHz sampling frequency and a spot size of 0.1 mm, and the sample distance was set to 0.18 mm. For each recorded profile the mean profile depth (MPD) was determined per 100 mm according to the ISO 13473-1 standard.

The average MPD of the five test positions is illustrated in Table 1. The results show that the average MPD are the same for position 9 m and 24 m, and for position 39 m and 69 m. The position 54 m is not similar to any of the other positions. When this 54 m position is left out the average MPD is 0.67 mm. For comparison the MPD of a new dense asphalt concrete with 11 mm aggregates is around 0.57 mm and for a new porous asphalt with 8 mm aggregates 0.86 mm.

Table 1 - Average MPD over the 1.5 m distance at different positions in the left wheel track [3].

Position	9 m	24 m	39 m	54 m	69 m	Avg. (excl. 54 m)
Average MPD	0.58 mm	0.58 mm	0.75 mm	0.90 mm	0.75 mm	0.67 mm

The texture spectrum were determined in 1/3 octave bands, in the range from 100-0.4 mm according to the technical specification ISO/TS 13473-4 from FFT analysis using an evaluation length of 1.475 m with offset and slope suppression. The average spectrums of the different positions are illustrated in Figure 3, together with a new porous asphalt ((PA) aggregate size 8 mm), an old asphalt concrete ((AC11d) aggregate size 11 mm) and a new stone mastic asphalt ((SMA6+8) aggregate size 6 mm). In comparison with the spectrums for AC11d and PA the PERS should according to the Descornet/Sandberg model [6] have a lower noise level, as the texture levels are generally higher in the wavelength range from 8-0.4 mm, and lower or similar from 100-10 mm.

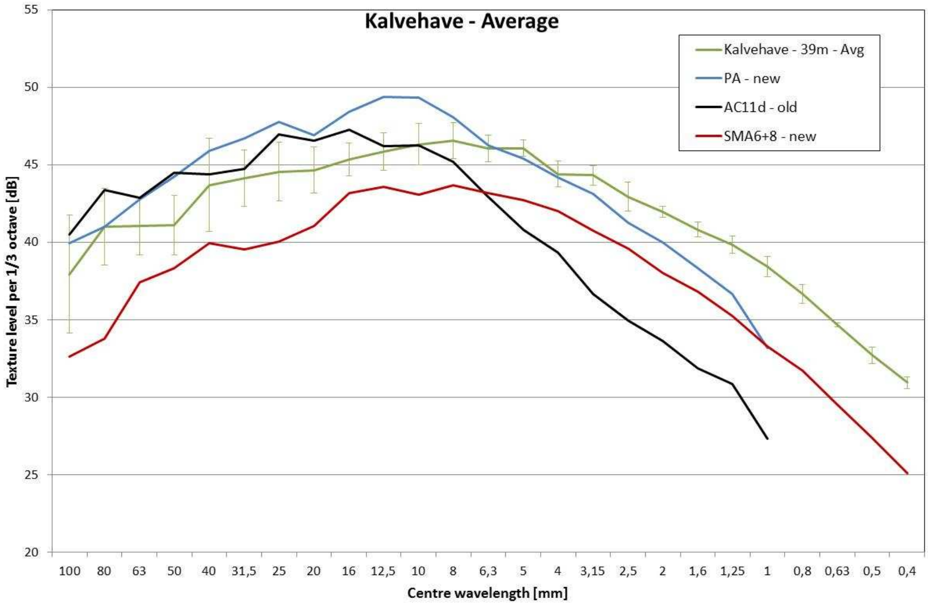

Figure 3 - Average texture level in 1/3 octave bands at the Kalvehave PERS. Texture levels likewise measured with the in-situ laser, are included for a new porous asphalt (PA), an old asphalt concrete (AC11d) and a new stone mastic asphalt (SMA6+8) are included as references [3].

2.2 Air void and permeability

The built in air void has been measured to 27.7%. This must be considered as a high built in air void for example compared to the air void of two-layer porous pavements at the Danish Øster Søgade test site at 23 to 27 % when new [4].The DRD has used the Becker tube for determining the permeability. The principle of the method is measuring the time a certain height (100 mm) of a column of water uses to run out of the tube and into the asphalt. A transparent tube with a diameter of 140 mm is placed on the road, and the joint between the tube and the road is sealed with putty. The permeability is given as the flow out time in seconds. The average result from the Becker tube is 6.9 seconds which is the same as for a new two-layer porous asphalt [4]. It must be concluded that the PERS has a very fine permeability.

2.3 Mechanical impedance testing

The mechanical impedance of the PERS at the Kalvehave test site was measured by IFSTTAR using the experimental setup described in [3]. Five different spots were tested along the 75 meters long test section. The measurement spots were equally spaced every 15 meters. The tests were performed in autumn 2013, in closed traffic conditions. The air temperature varied between 10.9°C and 12.9°C and the road surface temperature varied between 12.5°C and 24.0°C.

Figure 4 gives the magnitude and the phase of the direct mechanical impedance measured at each spot. A similar behaviour is observed. At low frequency, there is a linear decrease which is typical of an ideal spring. At high frequencies, there is a linear increase which is typical of an ideal mass. At medium frequencies, there is a minimum value at a frequency corresponding to the resonance of the mass spring system. The minimum value corresponds to the damping of the system. At the resonance frequency a typical phase shift is also observed.

The dynamic Young’s modulus of the PERS has been assessed from a simple Single Degree Of Freedom (SDOF) system consisting in a mass over a parallel spring/dashpot assembly. The dynamic Young’s modulus averaged on the five spots was 63.6 ± 26.4 MPa. The dynamic Young modulus of the PERS is about 150 times smaller than the dynamic Young modulus of a dense asphalt concrete (AC).

Thus, despite some inhomogeneity of the PERS section, a rolling noise reduction due to elasticity may be expected since the stiffness of the PERS is close to the stiffness of standard tyres, leading to less tyre deflection and vibrations.

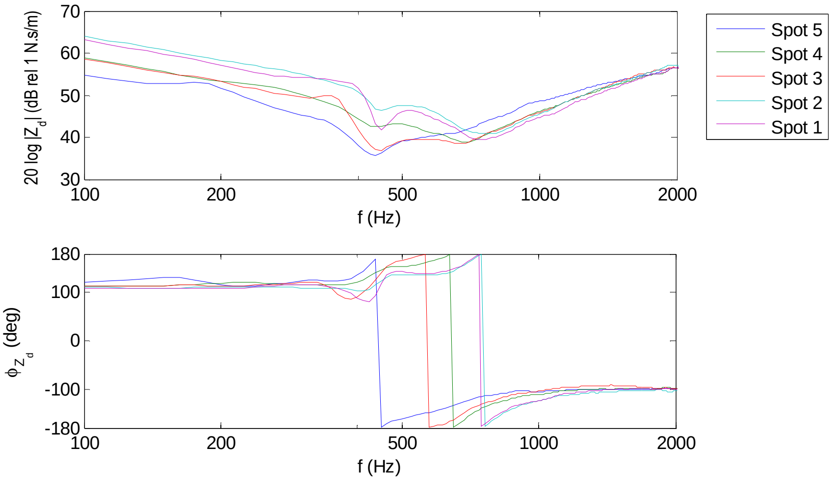

Figure 4 – Comparison of the direct mechanical impedance for the five spots of the PERS [3].

3. SPB NOISE RESULTS

SPB roadside noise measurements have been performed by DRD three times in the first month after the construction of the PERS test section where the pavement was in a fine condition with no significant ravelling. It is not recommendable to perform SPB measurements during the winter season in Denmark where cars normally are using winter tyres that can have a different influence on the measured noise levels than summer tyres. The measurements were repeated in May 2014 where significant ravelling had occurred on the PERS test section. The number of vehicles included in the SPB measurements and the air temperature is presented in Table 2. It can be seen that the requirement for SPB measurements of 100 passenger cars is generally fulfilled. But there are all too few heavy vehicles. To get an impression of the order of magnitude of the noise from heavy vehicles for the PERS pavement all the four measurements have been clustered into one “artificial” measurement.

Table 2 - Number of vehicles included and the air temperature recorded during the SPB measurements at the PERS pavement at Kalvehave [3].

Day	1	5	68	248
Number of passenger cars	92	88	100	99
Number of two axle heavy vehicles	6	6	6	8
Number of multi axle heavy vehicles	2	15	5	14
Air temperature [°C]	20.2	20.0	10.2	11.8

The L_{Amax} levels for passenger cars can be seen in Table 3 were also the Danish reference levels from the Nordic prediction model Nord2000 are included for comparison. The Nord2000 reference is the average noise level for an eight years old dense asphalt concrete (AC11d) with 11 mm maximum aggregate size [5]. The noise for passenger cars has been corrected to 20 ºC using the normal conversion factor of -0.05 dB/ºC for asphalt concrete. It can be argued that the temperature conversion factor for a PERS pavement with a high content of rubber differs from -0.05 dB/ºC, but there is no better correction factor for PERS available.

The average speed for passenger cars at the test site is around 65 km/h. The analysis has been performed at each SPB measurement at 50, 60 and 80 km/h. The speed of 50 and 80 km/h is just outside the confidence interval for these measurements and therefore the uncertainty is a little higher than for the results at 60 km/h.

Table 3 - L_{Amax} levels for passenger cars measured with the SPB method at three different speeds corrected to 20º Celsius [3].

Date	Age; days after opening	Speed		
		50 km/h [dB]	60 km/h [dB]	80 km/h [dB]
30. Aug. 2013	1	66.8	69.1	72.7
5. Sep. 2013	5	64.8	67.4	71.5
8. Nov. 2013	68	65.6	67.7	70.9
5. May 2014	246	64.0	67.0	71.7
Nord2000 ref.	8 years old	71.8	74.3	78.6

The SPB results are also shown in Figure 5 where it can be seen that from the day the test section was opened to traffic and 6 days later there is a reduction of the noise. For 60 km/h this is 1.7 dB which is quite remarkable. In the period from day 5 to day 68 the noise levels seems to be stabilised. The noise reduction in relation to Nord 2000 is after 68 days 6.2, 6.6 and 7.7 dB respectively for 50, 60 and 80 km/h. It must be remarked that a new dense asphalt concrete will have a noise level that will be around 2 dB lower than the Nord2000 reference levels. After 248 days the noise level decreases about 1 dB for speeds of 50 and 60 km/h.

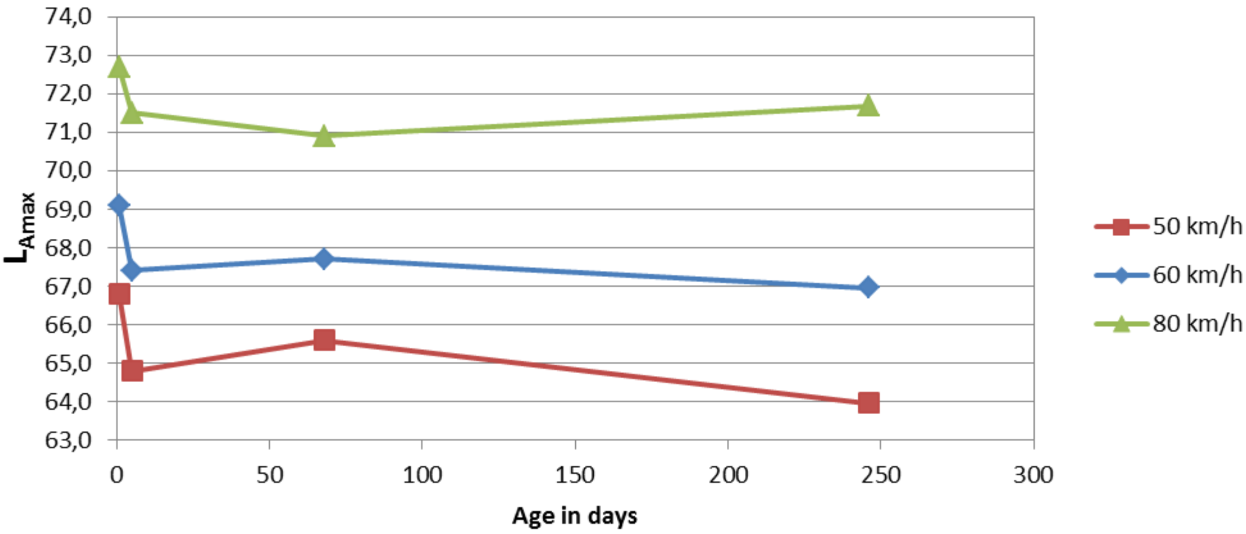

Figure 5 - L_{Amax} levels for passenger cars measured with the SPB method at three different speeds corrected to 20º Celsius [3].

Figure 6 shows the spectra for passenger cars at 60 km/h. The 1.7 dB reduction in the SPB level from the first day to the fifth day occurs in the frequency range from 800 to 1600 Hz where the noise from vibrations in the tyre caused by the surface texture is dominant. This can indicate that the surface texture becomes more even and smooth. After 248 days in May 2014 there is a remarkable change in the spectra. Below 630 Hz the noise level increases up to 5 dB and over 630 Hz the noise level decreases up to 4 dB. At this time significant ravelling has occurred on the PERS pavement and most of the stone aggregates are warn of leaving an uneven surface with a high proportion of soft rubber aggregate. This might partly be the explanation for the reduction in the frequency range from 630 to around 2000 Hz. A series of stripes with an angle of around 60˚ to the driving direction can be observed with a distance of around 2 to 5 meter. Other damaged areas on the pavement surface can also be observed. It is the judgement of the authors that this is caused by a snowplough driving on the road in the snow periods. This unevenness of the pavement might be part of the explanation for the increased noise under 630 Hz.

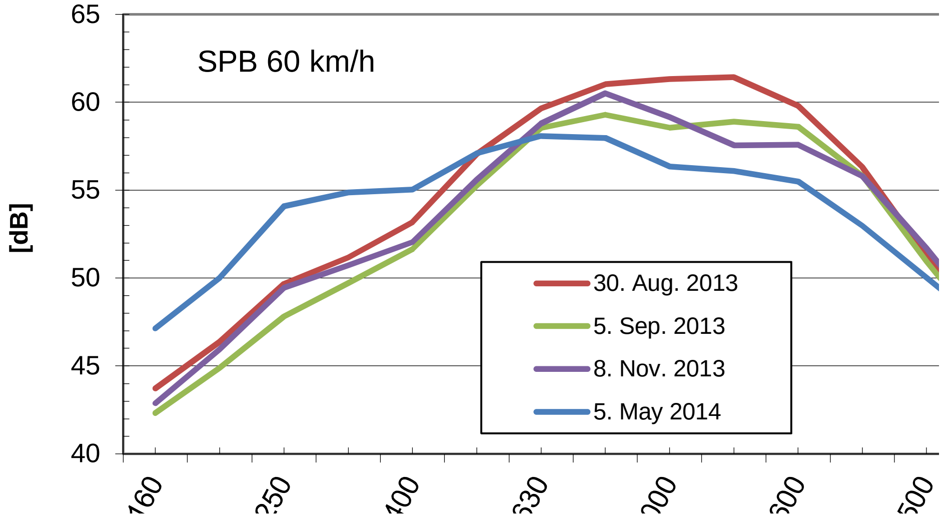

Figure 6 - SPB spectra for passenger cars at 60 km/h [3].

In Figure 7 the spectra for the PERS pavement 68 days old having an SPB level of 67.7 dB is compared to a new dense asphalt concrete with 11 mm aggregates (AC11d) at the Danish test section at Kongelundsvej [5] having an SPB level of 71.9 dB. Comparing these two spectra the following can be seen:

1. From 160 to 800 Hz the PERS is 2 dB lower than the AC11d. This can indicate that the PERS have smother texture caused by the smaller aggregate size (5 mm versus 11 mm) and is elastic compared to the AC11d.
2. From 1000 Hz to 2000 Hz the PERS is 5-6 dB lower than the AC11d. In this frequency range the noise generated from vibrations in the tyre caused by the surface texture of the pavement is one of the dominant noise sources. This can also indicate that the PERS have smother texture than the AC11d.
3. From 2000 to 4000 Hz the PERS is 7 to 8 dB below the AC11d. In this frequency range noise generated from air pumping is dominant. This indicates that the PERS has an open and porous structure.

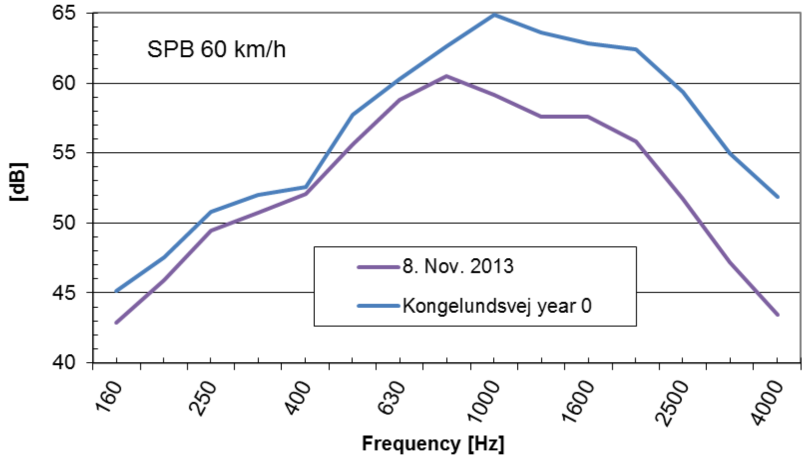

Figure 7 - SPB spectra for passenger cars at 60 km/h for the PERS when 68 days old [3] and data from

new dense asphalt concrete with 11 mm aggregates at the Danish test section at Kongelundsvej [5].

During the SPB measurements it was for practical reasons only possible to include very few heavy vehicles (see Table 2) and therefore results from these vehicle categories cannot be included in the analysis. To get an impression of the order of magnitude of the noise from heavy vehicles for the PERS pavement all the four measurements have been clustered into one "artificial" measurement. The results are shown in Table 4 for a speed of 60 km/h where also the Danish reference levels from the Nordic prediction model Nord2000 are included for comparison. The result gives an indication that the PERS pavement for heavy vehicles has a SPB noise level 5 to 6 dB below the Nord2000 reference level. This is around one dB less noise reduction than for passenger cars.

Table 4 - "Artificial" SPB level for heavy vehicles predicted by clustering the 4 SPB measurements performed at 60 km/h corrected to 20º Celsius [3].

Vehicle type	Two axle heavy vehicles	Multi axle heavy vehicles
PERS at Kalvehave [dB]	77.0	78,6
Nord2000 ref. [dB]	81.7	84.3

4. CPX NOISE RESULTS

DRD have performed CPX measurements at 50, 70 and 80 km/h four times after the opening of the test section. The main results as L_{Amax} levels can be seen in Table 5 as well as in Figure 8. The results has been corrected to 20 °C using the normal conversion factor of -0.03 dB/°Cused by DRD for the SRTT tyre. The same tendencies as observed for the SPB results can be seen. For practical reasons the measurements at 70 km/h were not conducted on the 5th of May 2014.

Table 5 - Results of the CPX measurements with the SRTT tyre corrected to 20ºC [3].

Date	Age (days after opening)	Speed		
		50 km/h [dB]	70 km/h [dB]	80 km/h [dB]
30. Aug. 2013	1	87.0	91.9	93.6
5. Sep. 2013	5	85.9	90.4	92.0
23. Sep. 2013	23	85.4	90.5	91.7
5. May 2014	246	84.0	-	92.4

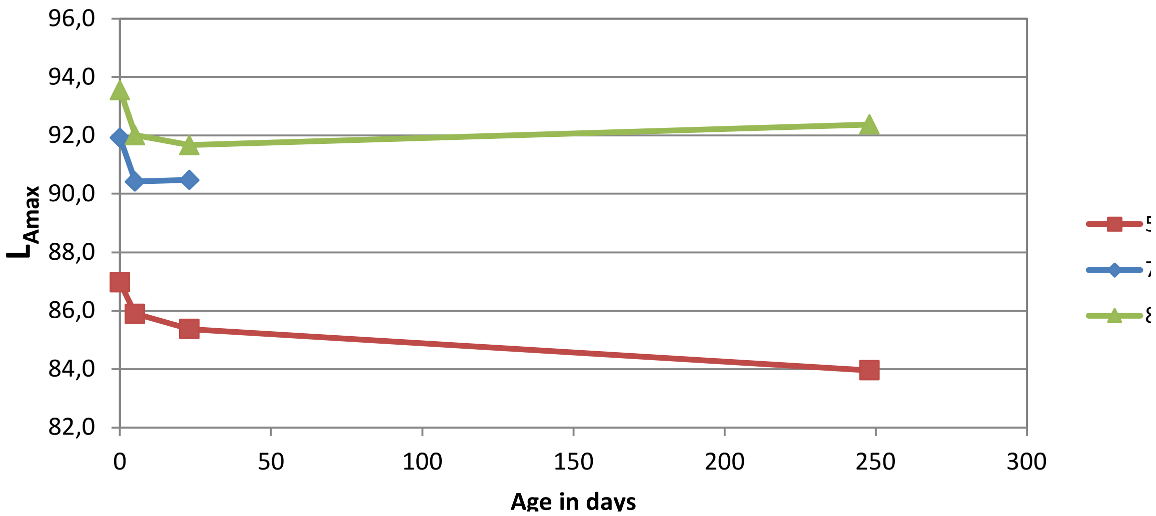

Figure 8 - L_{Amax} levels measured with the CPX method at three different speeds corrected to 20ºC [3].

The spectra for the CPX measurements with the SRTT tyre at 50 km/h are shown in Figure 9. The same tendencies as seen for the SPB results can be seen.

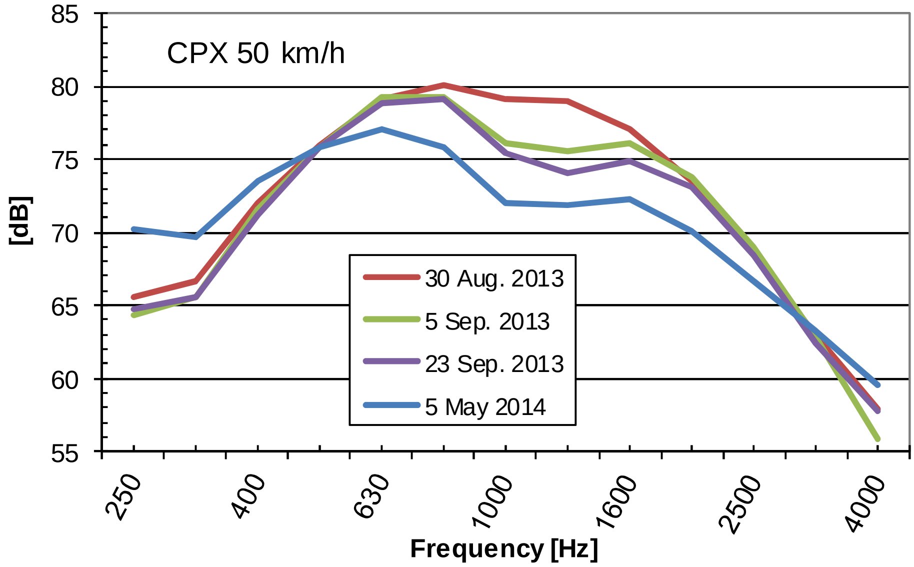

Figure 9 - CPX spectre for passenger cars at 50 km/h [3].

At day 5 the noise was also measured on the old asphalt concrete close to the PERS at Kalvehave. The results can be seen in Table 6. The noise reduction for the PERS in relation to the old pavement is around 7 dB.

Table 6 - CPX results for the old asphalt concrete and the PERS measuredon the 5th of September 2013 with the SRTT tyre corrected to 20ºC [3].

Pavement	50 km/h [dB]	80 km/h [dB]
PERS	85.9	92.0
Old asphalt concrete	92.4	99.2

5. ACOUSTICAL ABSORPTION

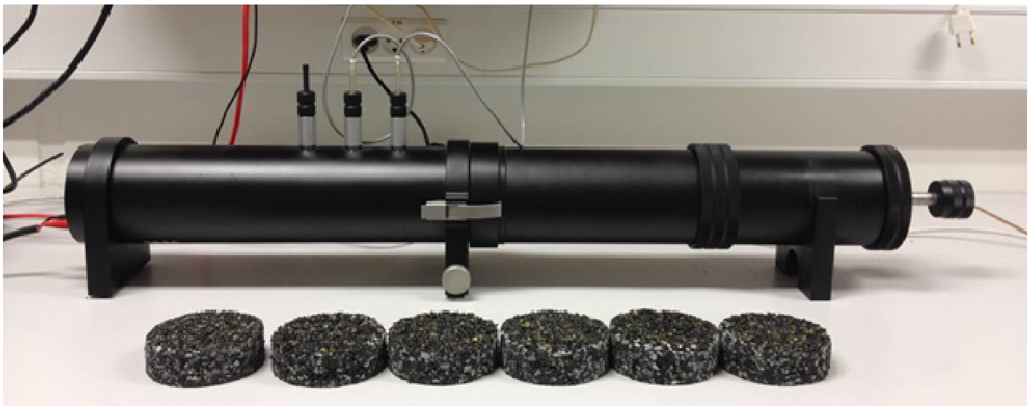

Figure 10 - Impedance tube for measuring acoustical absorption.

The acoustical absorption has been measured on drill cores taken from the pavement slabs that were produced at the roadside when the PERS pavement was constructed. Measurements are carried out according to ISO 10534-2 (Acoustics – Determination of sound absorption coefficient and impedance

I impedance tubes – Part 2: Transfer-function method). The acoustical absorption measured in a B&K Type 4206 impedance tube, is measured at six cores drilled from test slabs. The impedance tube can be seen at Figure 10.

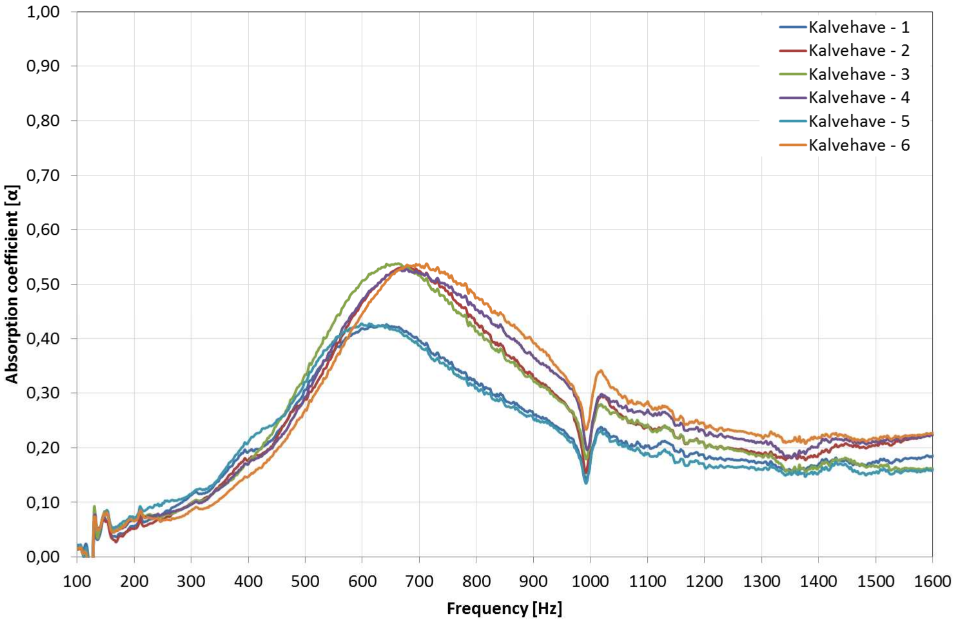

Figure 11 - FFT spectrums of the absorption of the six cores [3].

The absorption measured at the six cores is illustrated in Figure 11. The absorption spectra for all of the cores have the same characteristics. Cores number 1 and 4 both have the maximum peak at 600-625 Hz, with a maximum absorption coefficient of 0.42. Cores number 2, 3, 5 and 6 have the maximum peak at 650-700 Hz, with a maximum absorption coefficient of 0.53. All of the six cores looked similar by visual inspection, and difference in maximum absorption coefficient could not be justified from that method.

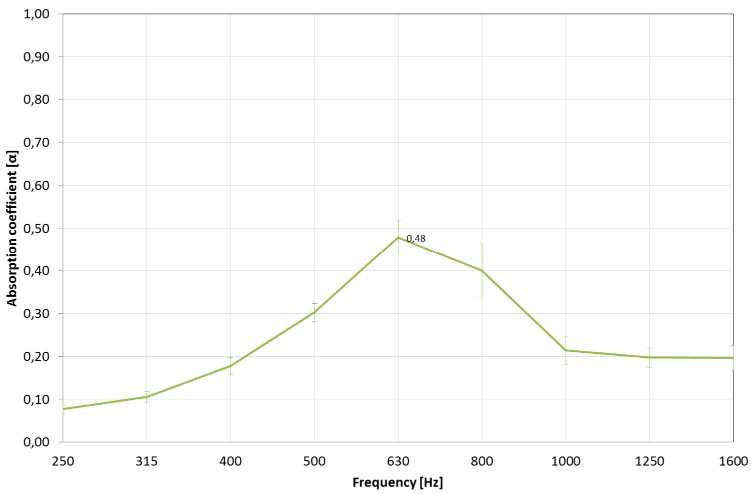

Figure 12 - Average absorption spectra in 1/3-octave bands [3].

The average absorption spectra in 1/3-octave bands is illustrated in Figure 12. The figure illustrates that the maximum absorption is in the 630 Hz band, with an absorption coefficient at 0.48. The absorption spectrum is a bit more shifted to lower frequencies, than expected from the thickness of the cores. A maximum absorption in the 1000 Hz band would be preferred, as the A-weighted sound pressure level emitted from the vehicles, are highest in that frequency band.

6. CONCLUSION

The SPB result for passenger cars at 60 km/h is 69.1 dB. After 5 days the level has decreased 1.7 dB which is quite remarkable. In the period from days 5 to 68 the noise level seems to be stabilized. The noise reduction in relation to Nord 2000 is after 68 days is 6.6 dB. It must be remarked that a new dense asphalt concrete will have a noise level that will be around 2 dB lower than the Nord2000 reference levels. After 248 days the noise level decreases about 1 dB. The CPX measurements generally confirm these results.

Comparing the spectra of the PERS to a new dense asphalt concrete with 11 mm aggregates (AC11d) the following can be observed:

1. From 160 to 800 Hz the PERS is 2 dB lower than the AC11d. This can indicate that the PERS have smother texture caused by the smaller aggregate size (5 mm versus 11 mm) and is elastic compared to the AC11d.

2. From 1000 Hz to 2000 Hz the PERS is 5 to 6 dB lower than the AC11d. In this frequency range the noise generated from vibrations in the tyre caused by the surface texture of the pavement is one of the dominant noise sources. This can also indicate that the PERS have smother texture than the AC11d.

3. From 2000 to 4000 Hz the PERS is 7 to 8 dB below the AC11d. In this frequency range noise generated from air pumping is dominant. This indicates that the PERS has an open and porous structure.

The result gives an indication that the PERS pavement for heavy vehicles has a SPB noise level 5 to 6 dB below the Nord2000 reference level. This is one dB less noise reduction than for passenger cars

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