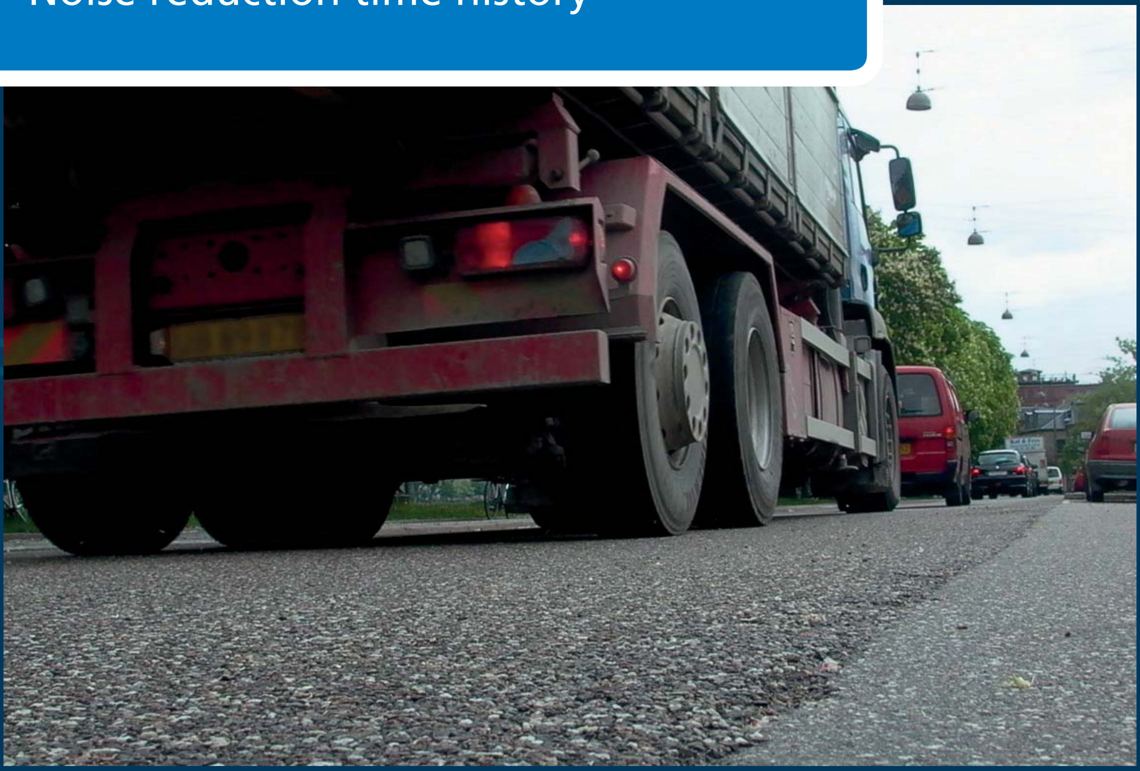
Road Surfacings

- Noise reduction time history



Danish Road Institute
Report 161
2008

Road Directorate
Ministry of Transport and Energy

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Contents

Preface

Subproject F of the SILENCE project was concerned with the role of road surfaces in the generation of road traffic noise. The focus was on noise abatement in urban areas. Work packages in subproject F dealt with the following topics:

- WP F1: New production technologies for surfacings on urban streets
- WP F2: New production technologies for surfacings on urban main roads
- WP F3: Improved systems for the maintenance of quieter surfacings
- WP F4: Noise classification methods for urban road surfacings
- WP F5: Testing of novel road surfacing materials

Subproject WP F4 provided tools for other work packages to assess the success of new types of road surfacings or the maintenance of pavements. The tasks were:

- Task F4.1: State of the art
- Task F4.2: Measurement methods
- Task F4.3: Classification by type, condition and location
- Task F4.4: Corrections for local discontinuities
- Task F4.5: Noise performance development model

The present report on task F4.5 is concerned with the development over time of the traffic noise level at various types of road surface. It relies on deliverable F.D12 on measurement methods and their fields of application, and on experience from the European Project SILVIA.

Project partners made new data available: new Danish measurements and extracts from French and German databases. New measurements were carried out in the present task of SILENCE to repeat earlier SPB- and CPX-measurements to determine the change in noise level with pavement age. These organisations were active in WP F4:

- Danish Road Institute/Road Directorate, DRI, Denmark
- Arsenal Research, Austria
- Federal Highway Institute, BASt, Germany
- Belgian Road Research Centre, BRRC, Belgium
- Road and Bridge Research Institute, IBDiM, Poland
- French Public Works Research Laboratory, LCPC, France
- Swedish National Road and Transport Research Institute, VTI, Sweden

The analyses and the present report have been made by Jørgen Kragh, DRI, as a part of the work carried out in work package F4 of the SILENCE project by the Forum of European Highway Research Laboratories (FEHRL).

Forord

Delprojekt F i SILENCE-projektet handlede om vejbelægningens betydning for støjen fra trafikken, med særlig vægt på trafikstøjen ved gader i bymæssig bebyggelse. I delprojektet indgik følgende arbejdsopgaver:

- WP F1: Ny teknologi til bygning af vejbelægning på bygader
- WP F2: Ny teknologi til bygning af vejbelægning på hovedveje i byområder
- WP F3: Bedre systemer til vedligeholdelse af støjreducerende vejbelægning
- WP F4: Støjklassificering af vejbelægninger
- WP F5: Afprøvning af nye typer materialer til vejbelægning.

Delprojekt WP F4 bidrog med bedømmelse af nye typer vejbelægning og af vedligeholdelsens kvalitet. Delprojektet omfattede følgende delopgaver:

- Task F4.1: Status på området
- Task F4.2: Målemetoder
- Task F4.3: Klassificering efter type, tilstand og vejtype
- Task F4.4: Korrektion for lokal diskontinuitet
- Task F4.5: Model for de støjmæssige egenskaber som funktion af tid.

Nærværende resultat af delopgave F4.5 behandler udviklingen over tid af niveauet af trafikstøjen ved forskellige typer af vejbelægninger. Resultaterne bygger på delrapporten F.D12 om målemetoder og deres anvendelsesområde og på erfaringer fra det europæiske projekt SILVIA.

Nogle deltagere i SILENCE-projektet stillede nye data til rådighed: nye danske måleresultater og udtræk fra en fransk og en tysk database. Der blev også gennemfør nye målinger inden for rammen af delopgave F4.5 som gentagelse af tidligere udførte SPB- and CPX-målinger for at fastlægge ændringen af støjniveauet med ældningen af vejbelægningen. Følgende partnere deltog i delprojekt F4:

- Vejteknisk Institut/Vejdirektoratet, DRI, Danmark
- Arsenal Research, Østrig
- Bundesanstalt für Strassenwesen, BASt, Tyskland
- Belgian Road Research Centre, BRRC, Belgien
- Road and Bridge Research Institute, IBDiM, Polen
- French Public Works Research Laboratory, LCPC, Frankrig
- Statens väg-och transportforskningsinstitut, VTI, Sverige.

Analyserne er gennemført og nærværende rapport er udarbejdet af Jørgen Kragh, Vejteknisk Institut, som led i indsatsen i SILENCE-projektet fra Forum of European Highway Research Laboratories (FEHRL).

Summary

The European project SILENCE contained at task to provide models for the effect of pavement ageing on the noise reducing effect of road surfacings. The basis was existing historical data on noise performance, analyses of data from sections of road with known history, and data from new supplementary measurements at sites where measurements had been carried out in the past. This task complements the pavement classification made in another task based on the pavement acoustic performance when new.

No indication was found that any model (polynomial, logarithmic or exponential) would yield better fit to the data than a simple linear relation between vehicle noise level and pavement service time. This may be due to large scatter in measurement results. A clearer pattern might have appeared if each surface had been characterized by the total traffic load it had carried rather than by its number of years in service. However, such data were not available.

The slopes to be expected for the linear time history of vehicle noise levels are:

For both light and heavy vehicles, the slope at dense asphalt surfacings is in the order of 0.1 dB per year of pavement service time. This applies to high speed as well as low speed roads.

For porous or open graded asphalt surfacings, the expected time history slope for light vehicles is in the order of 0.4 dB per year at high speed roads and 0.9 dB per year at city streets with low traffic speed. Heavy vehicle noise levels can be expected to increase with 0.2 per year at high speed roads with porous or open graded asphalt surfacings.

Sammenfatning

I det europæiske projekt SILENCE indgik et delprojekt om hvordan støjreduktionen påvirkes af, at belægningen bliver ældre. Det supplerer en klassificering af belægningers støjreducerende egenskaber udarbejdet i et andet delprojekt baseret på resultater fra nye belægninger. Projektet blev baseret dels på eksisterende sammenstillinger af historiske data, dels på nye analyser af data fra målesteder med kendt historie og dels på enkelte nye målinger udført på steder, hvor der for år tilbage var gennemført målinger.

Der blev ikke fundet tegn på at for eksempel et polynomium, et logaritmisk eller et eksponentielt udtryk for sammenhængen mellem støjniveauet og belægningens alder ville være bedre end en enkel lineær sammenhæng. Dette skyldes måske den store spredning der måtte konstateres at være i de foreliggende data. Måske ville det have givet et klarere mønster hvis modellen - ud over belægningens alder - også omfattede den samlede trafik, belægningen havde været udsat for i sin levetid. Der forelå imidlertid ikke sådanne data.

Den lineære sammenhæng mellem belægningens alder og støjniveauet ved bilers forbikørsel kan forventes at være:

For både lette og tunge køretøjer på tæt asfaltbelægning: 0,1 dB forøgelse pr. år. Dette gælder både for veje med høj og med lav fart.

For porøs eller åbent graderet asfaltbelægning: For lette køretøjer en forøgelse på 0,4 dB pr. år ved veje med høj fart og 0,9 dB pr. år r ved veje med lav fart. For tunge køretøjer på veje med høj fart: en forøgelse på 0,2 pr. år.

1. Introduction

Noise from road traffic is the most important source of noise pollution in the industrialised world. No other means of transport can match the volume of road traffic and the pervasiveness of the road networks. Therefore substantial effort is undertaken to protect the populations from the noise generated by road traffic. In rural and suburban areas this often takes the form of noise barriers, but in urban areas where noise sources and residential buildings are much closer together, the construction of barriers is often difficult if not impossible. For this reason the interest is turning to the generation mechanisms of road traffic noise, because noise reduction at the source promises to be very effective.

The noise generated by individual road vehicles typically originates from three major sources, namely 1) the engine and its attached components, 2) the tyre/road contact and 3) aerodynamic turbulence. For a typical urban speed range of 0 - 80 km/h, only engine and tyre/road noise need to be considered, with tyre/road noise dominating from 30 - 50 km/h upwards and engine noise dominating at lower speeds. Tyre/road noise is heavily dependent on the type of road surface, whereas the generation of engine noise is not influenced by the road surface. However, especially in the case of porous road surfaces, the propagation of both types of noise can be influenced by the pavement properties.

Noise reducing pavement has been used with success in high-speed road networks to reduce vehicle noise emission. This kind of road surface can also help mitigating traffic noise in urban areas, where the construction of noise barriers is problematic. Replacing block pavement with smoother surfacing or using modern porous pavement on main streets with speed limits of up to 70 or 80 km/h can reduce traffic noise exposure.

Task F 4.3 of the SILENCE project establishes a system for the classification of road surfacings in terms of correction factors to the noise levels from vehicles travelling on the surfaces, cf. Deliverable F.D14A. These correction factors to the noise levels occurring under standard conditions represent the initial noise reducing properties, i.e. the noise reduction encountered at newly built surfacings.

In the present report an attempt has been made to differentiate the correction factors in F.D14A by describing the likely development over time of the initial noise reduction of different types of noise reducing surfacings. The aim has been to complement the pavement classification dealt with in Task 4.3, based on the initial pavement acoustic performance

2. Method

Data from SPB- and CPX-measurements of noise levels at surfacings from the same family but with different age have been looked at. The data were available from partners a) extracting data from their databases for the SILENCE project, or b) repeating earlier measurements within the SILENCE project to increase the time span of observations.

At first all data for a given family of pavement were plotted as a function of the pavement age at the time of measurement. Later data were normalised. The time history for each measurement site was looked at separately and plotted with the measured noise level at the new pavement as zero dB. However, with such normalisation the initial noise level became particularly crucial. After discussions in the work package team it was decided to look for linear relationships between the noise level and the pavement age, and the final analyses were made by computing - by linear regression analysis per measurement site - the initial noise level L_0 = 0 dB at time t_o. For all measurement sites with a given family of pavement the time histories were the plotted as the change in noise level with pavement age relatively to the initial noise level. Finally, linear regression analyses were made of all these noise level changes on time. The standard deviation of the residuals has been used to characterize the quality of the fit.
The procedure is illustrated in Section 4.1.2 and 4.2.1.

3. Available data

Data from the following sources were available for the final analyses documented in the present report:

- The database established in the SILVIA project with SPB data from many sources [Andersen-2005]
- Extracts from the French LCPC database with SPB values for passenger cars on various types of pavement [Berengier-2007]
- Extracts from the German BASt database with SPB values for passenger cars and trucks on various sections of road with porous asphalt pavement [Bartolomaeus-2007]
- Time series from Danish sections of road with single layer porous asphalt [Kragh-1998] and two-layer porous pavement [Kragh-2006b & 2007b]
- Time series from a Belgian road with two-layer porous pavement [Goubert-2007]
- CPX data from many sites in Denmark collected in a Dutch-Danish cooperative project within the IPG programme [Kragh-2006a]
- Californian OBSI-data from many sites [Kohler-2007]
- CPX-data from repeated measurements at the same sites on Swedish roads [Sandberg-2007]
- Measurements repeated by the Danish Road Institute within the SILENCE project [Appendix 1]

4. SPB-measurement results

4.1 Combined SPB-data from many sites

4.1.1 SILVIA database

A total of almost 200 SPB noise measurement results were available from ten different types of pavement [Andersen-2005]. The measurements have been carried out in seven North, East and Central European countries and they cover urban roads, highways and motorways. The pavement families are defined in Table 1 and Table 2 gives an overview of the sources of data. Figure 1 shows the range and average value of passenger car SPB noise levels for each pavement family. Data labels are the number of measurement sites within each family of pavement type. The reasons for the variation within each family of pavement are: the tear and wear of the total traffic load during surfacing lifetime, the surfacing age itself at the time of measurement, the maximum aggregate size, the void content and the temperature during measurement.

In the present task F 4.5 all data have been temperature corrected to 20 °C (0.05 dB lower noise level from passenger car tyres, 0.03 dB lower noise levels from trucks per °C higher air temperature). Groups of results comprising a large number of sites with similar surfacing were selected and data for each group were plotted as a function of the pavement age at the time of measurement.

Table 1. Surface families.

Pavement type	**Designation**
Dense asphalt concrete	DAC
Stone mastic asphalt	SMA
Mastic asphalt (Gussasphalt, German type)	MA
Single layer Porous Asphalt	PAC
Double layer Porous Asphalt	DPAC
Thin layers	TSF
Hot rolled asphalt	HRA
Surface dressing	SD
Exposed aggregate concrete	EACC
Burlap textured concrete (longitudinally structured)	CCb
Porous cement concrete	PCC

Table 2. Overview over SILVIA partners' contributions to the database.

Partner	**Pavement types**											
	DAC	**PAC**	**DPAC**	**TSF**	**SMA**	**HRA**	**SD**	**CC**	**PCC**	**EACC**	**CCb**	**Other**
DRI	X		X	X								
VTI	X	X	X		X							
TUG	X				X		X	X			X	X
CROW				X								
TRL				X	X	X	X			X	X	
BASt		X	X		X				X		X	X
BRRC	X	X	X		X				X	X		
DWW	X	X	X		X							

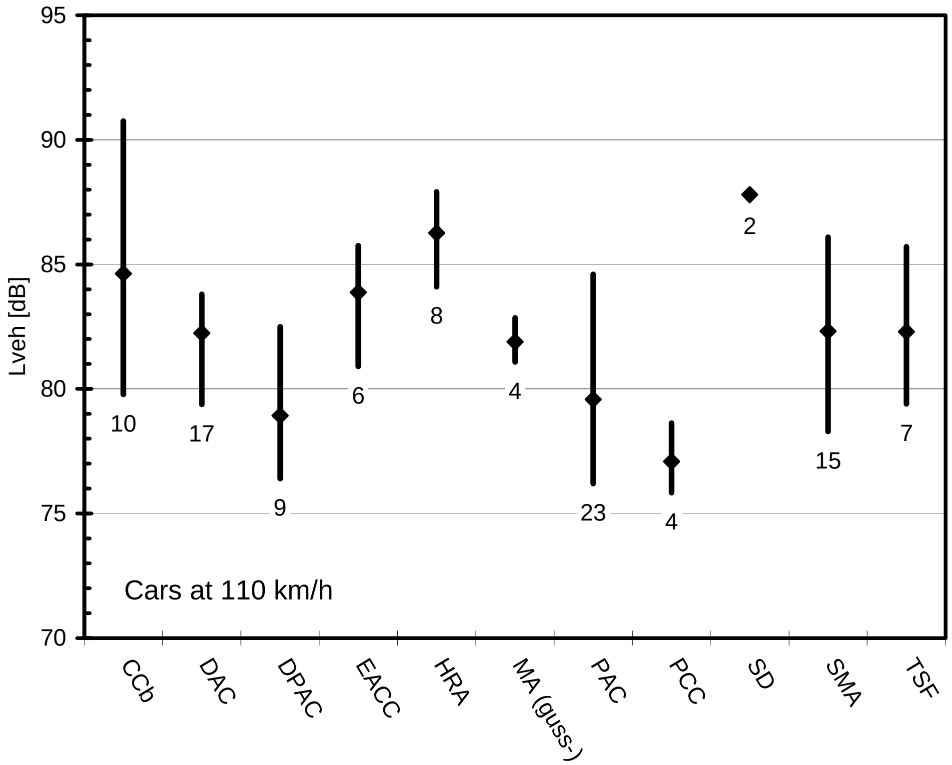


Figure 1. Average values and range of data in the SILVIA database.

Typical results for passenger cars are shown in Figure 2 - Figure 6 while Figure 9 - Figure 13 show some results for heavy vehicles. Each figure shows the pass-by vehicle noise level according to ISO 11819-1 as a function of the age of the pavement at the time of measurement. The figures show linear regression lines and the standard deviation s_R of the residuals in the y-direction. Note that the scales on the x-axes are different.

Data in Figure 2 - Figure 6 are to a certain degree redundant because most of the DWW-data from a certain site contain a result for both 110 km/h and 80 km/h, or for both 80 km/h and 50 km/h. DWW data constitute about half of the results in these figures.

The minimum slope seen in Figure 2 - Figure 6 is 0 dB per year, the maximum slope is 0.3 dB per year. The results show rather large spread, presumably because many different measurement teams in different countries were involved as well as many different production teams building the pavement with many different product batches.

Figure 7 and Figure 8 show a logarithmic and a second order polynomial trend line, respectively. The standard deviation s_R of the residuals in the y-direction is the same. Judged by the explained fraction of variance (R^2, not shown in the figures) the polynomial fit is slightly less bad than the linear and logarithmic fit. The Harmonoise and Nord2000 projects decided for polynomials to represent pavement ageing during the first 2 years for dense surfaces (DAC/SMA) and for the time history of noise performance of porous asphalt, cf. Section 6.1, and after that constant noise emission until some time before the end of surfacing structural lifetime when ravelling becomes strong enough to influence noise generation significantly.

Only a limited fraction of the variation in individual measurement results is explained by age. There are many possible explanations and chances are in reality non-existing to have the explanations identified for each data point.

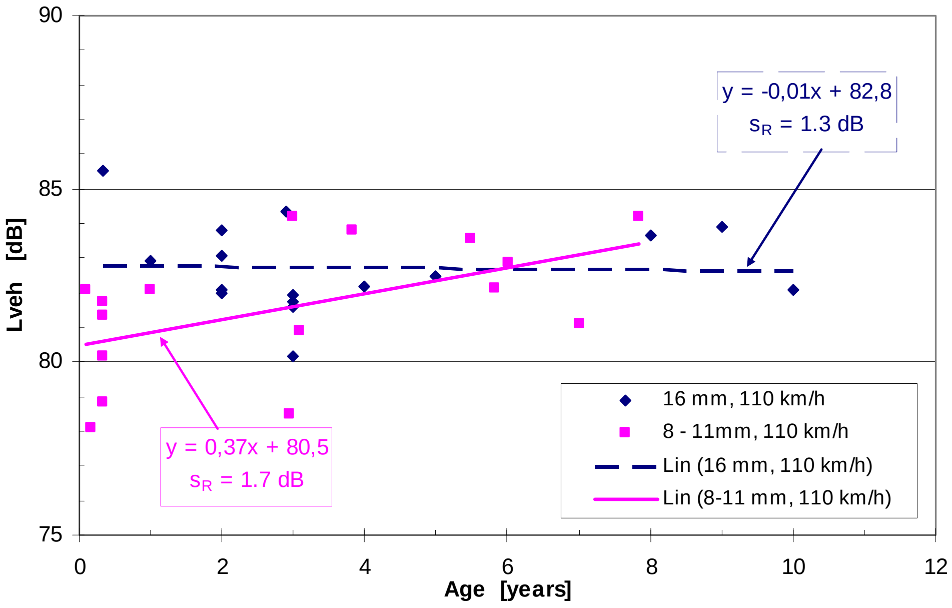


Figure 2. Pass-by noise levels from passenger cars on DAC + SMA, 110 km/h

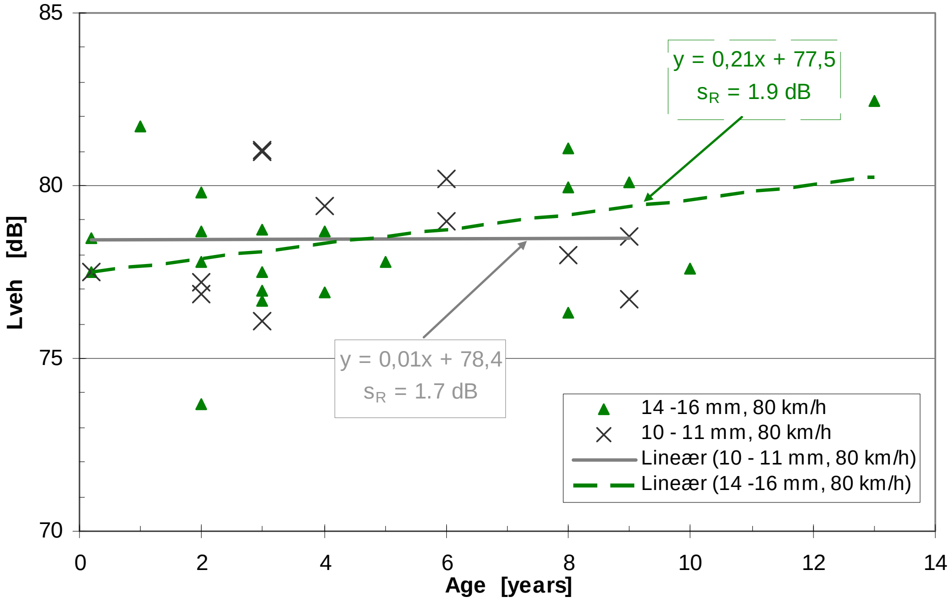


Figure 3. Pass-by noise levels from passenger cars on DAC + SMA, 80 km/h.

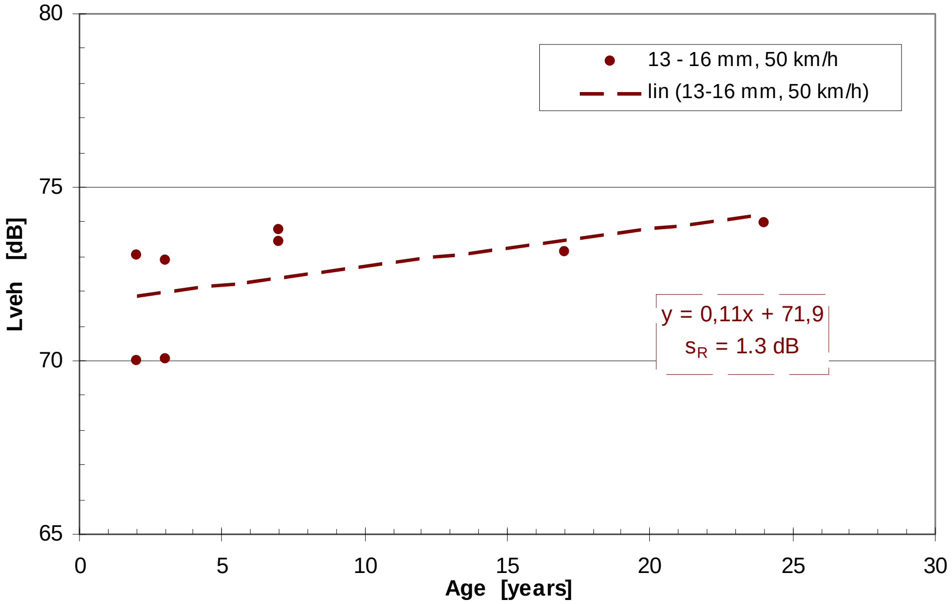


Figure 4. Pass-by noise levels from passenger cars on DAC + SMA, 50 km/h.

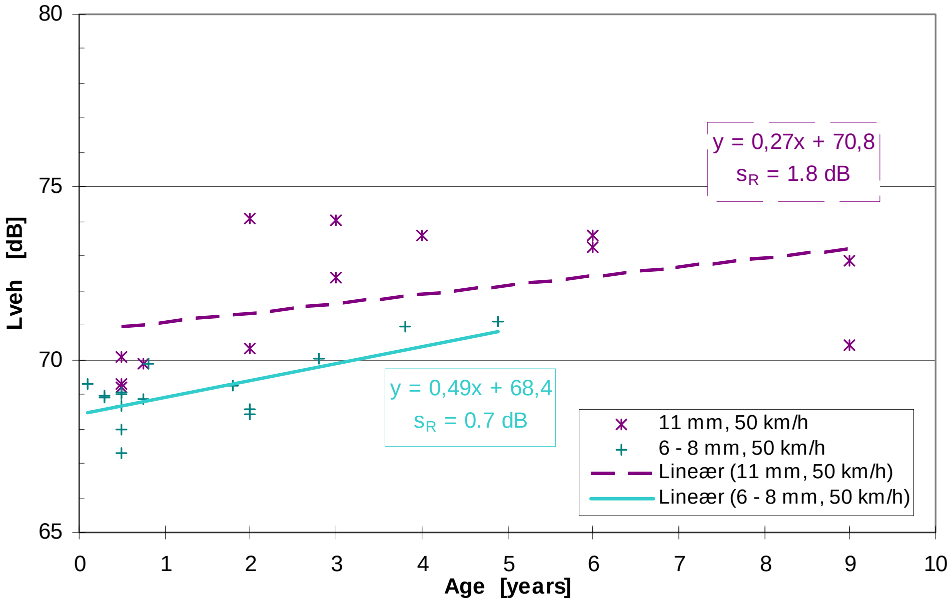


Figure 5. Pass-by noise levels from passenger cars on DAC + SMA 50 km/h.'

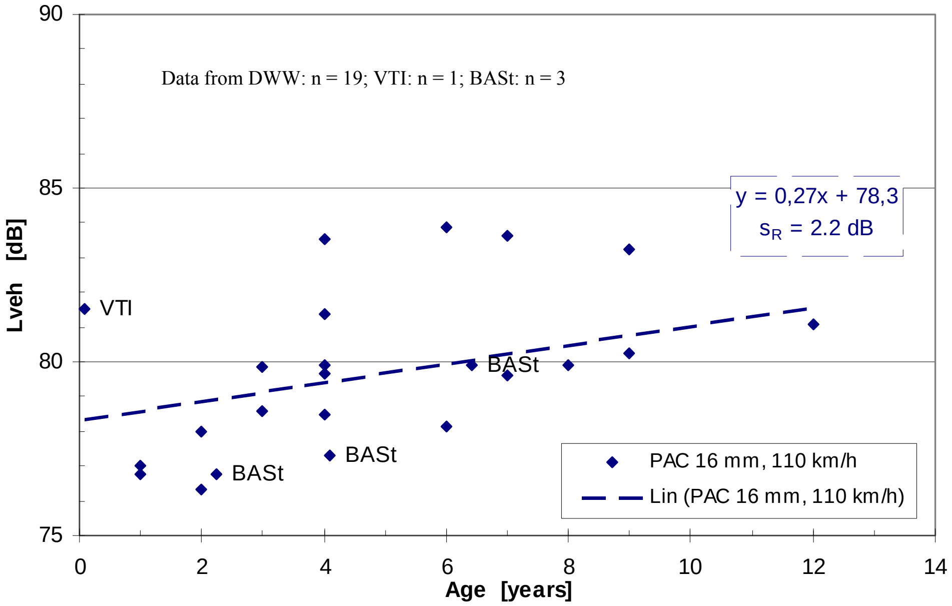


Figure 6. Pass-by noise levels from passenger cars on PAC 0/16 110 km/h.

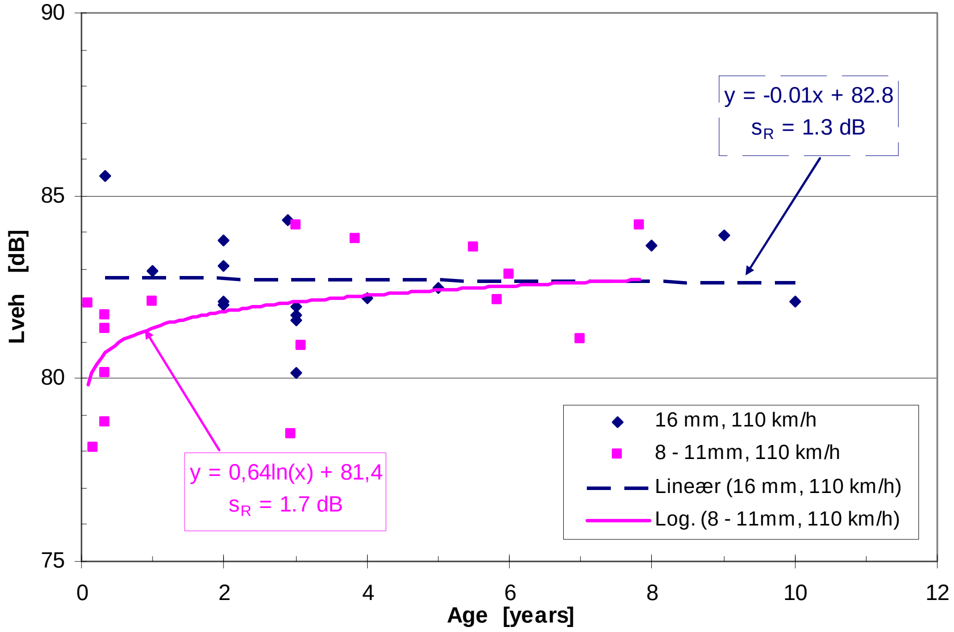


Figure 7. A logarithmic trend line does not give smaller s_R. Same data as in Figure 2.

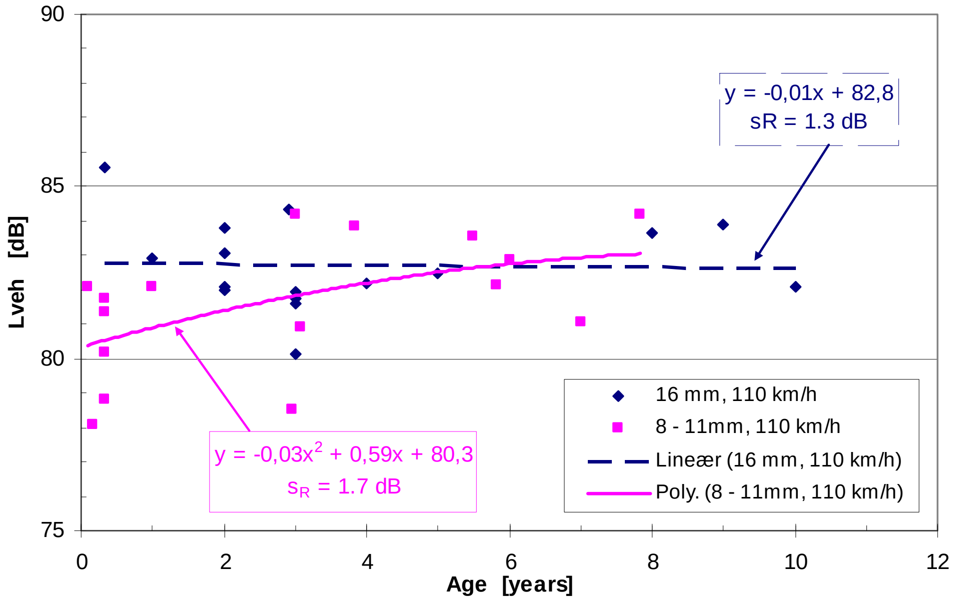


Figure 8. A polynomial fit does not give smaller s_R. Same data as in Figure 2.

In Table 3 the regression line slopes and residual standard deviations from Figure 2 - Figure 6 are listed and the number of pavements in the database is given. The results have been grouped according to the vehicle speed (High: 80 -110 km/h; Low: 50 km/h) and the maximum aggregate size (Large: > 11 mm; Small: ≤ 11 mm) hypothesizing that large aggregate would be associated with smaller slopes than small aggregate. Inspection of the results in the table reveals that this true in some but not in all cases.

Table 3. Summary for passenger car data in the SILVIA database.

Speed	**Aggregate**	**Pavement**	**Slope [dB/yr]**	**s_R [dB]**	**N [-]**
High	**Large**	DAC + SMA	-0.01	1.3	16
		DAC + SMA	0.21	1.9	20
		PAC 16	0.27	2.2	24
	Small	DAC + SMA	0.37	1.7	16
		DAC + SMA	0.01	1.7	12
Low	**Large**	DAC + SMA	0.11	1.3	8
	Small	DAC + SMA	0.27	1.8	13
		DAC + SMA	0.49	0.7	17

Figure 9 shows Pass-by noise levels from two-axle trucks at a speed of 85 km/h and 50 km/h, respectively, on DAC and SMA pavements. The data recorded at 85 km/h are a mix of data from BASt (4 pavements with 8 mm or 11 mm max. aggregate, 4 – 8 years old); DRI (4 pavements, all 3 months old and with 8 mm or 11 mm max. aggregate); TRL (2 pavements, with 10 mm max. aggregate, 2 months and 3 years old, resp.); TUG (3 pavements, with 8 - 16 mm max. aggregate,. 1 - 2 years old, resp.) and VTI (2 pavements, with 11 mm or 16 mm max. aggregate, 1 month and 3 months old, resp.). These 15 results indicate an increase in truck pass-by noise level of less than 0.5 dB in 10 years.

The data recorded at 50 km/h indicate an increase which is 3 times this value. These data are all from DRI (15 pavements, all less than 2 years old and with 6 – 11 mm max. aggregate) and TUG (6 pavements with 11 – 16 mm max. aggregate aged 2 – 24 years). The one result at 85 dB at 3 years of age seems erroneous. Deleting this result does not change the slope but reduces s_R to 1.6 dB in stead of 2.3 dB. The trend for a 1.5 dB increase in 10 years could be a result of a bias in the data: the older pavements systematically have larger aggregate size than the younger pavements.

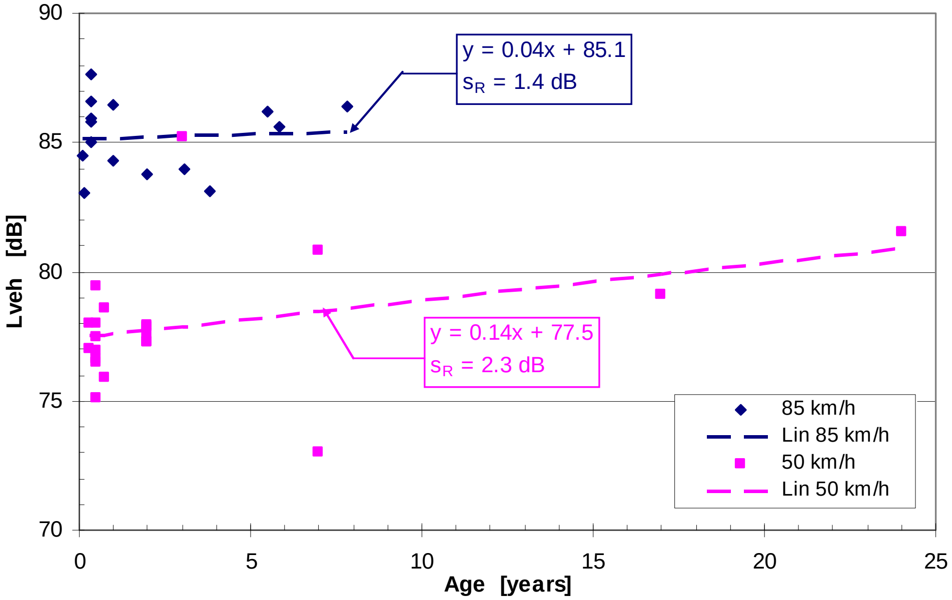


Figure 9. Pass-by noise levels from two-axle trucks on DAC + SMA, 50 and 85 km/h.

Figure 10 shows results for two-axle trucks on German brushed cement concrete pavement (CCb) with 2 mm max. aggregate size and on British pavements of cement concrete with exposed max. 10 mm aggregate (EACC). The regression line is steeper for the CCb pavements than for the EACC pavements which initially seem to yield higher noise levels but to stay more stable with time than the CCb. The number of data is small and the spread is large. Note that two 6 years old CCb-surfacings yielded more than 6 dB different noise levels causing a 2.3 dB standard deviation of the residuals. These were both based on less than 20 pass-bys.

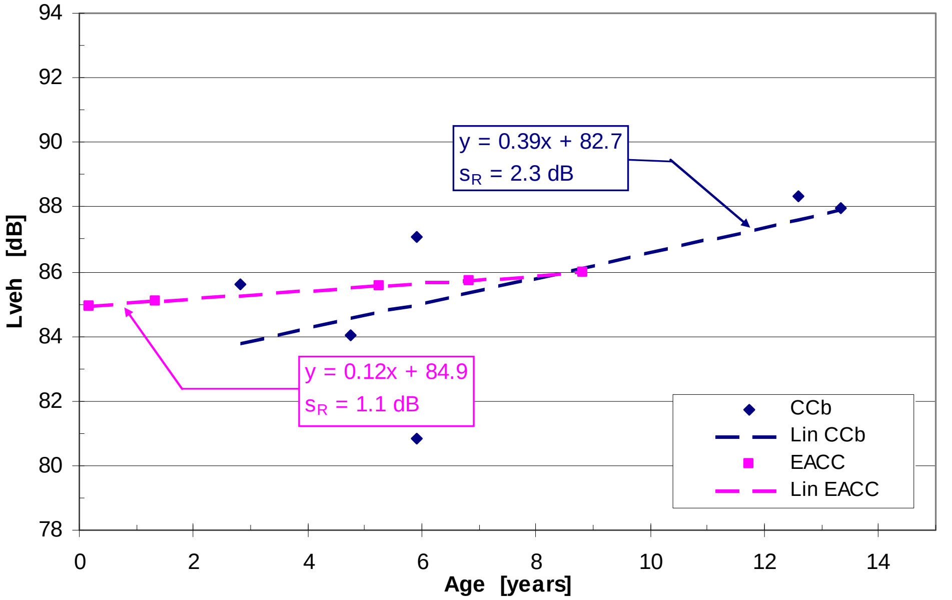


Figure 10. Pass-by noise levels from two-axle trucks on CCb and EACC, 85 km/h

Figure 11 - Figure 13 show results for multi-axle trucks. In Figure 11 data from 17 measurements made at Dutch roads with single-layer porous asphalt (PAC 16) indicate an increase in truck pass-by noise level of 1.4 dB in 10 years. This is a little less than the increase of 2 dB in 10 years seen at two-layer porous asphalt, cf. Section 4.2.5.

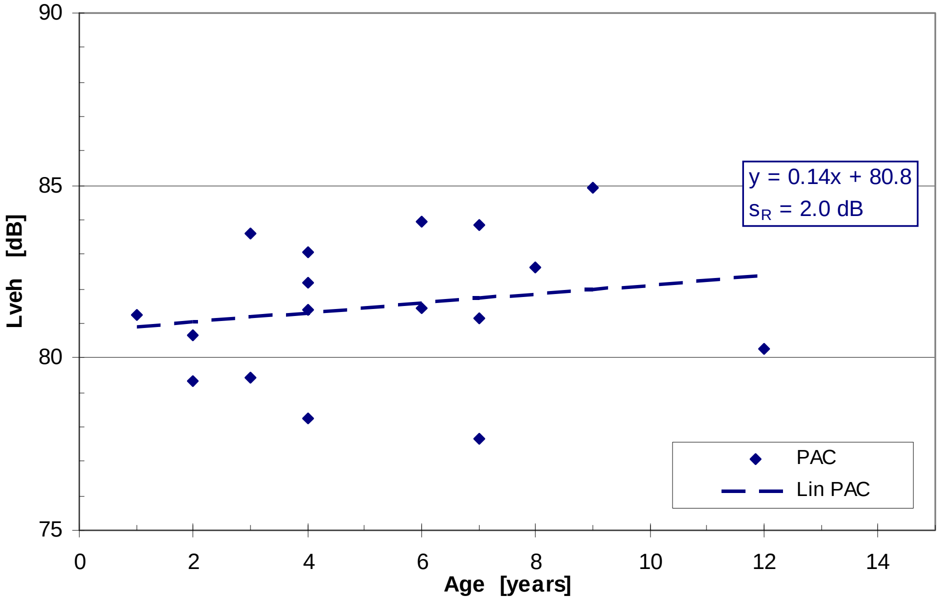


Figure 11. Pass-by noise levels from multi-axle trucks on PAC 16, 70 km/h.

Figure 12 shows data from 34 measurements at sites with DAC or SMA pavement with 8 - 16 mm maximum aggregate size. Figure 13 attempts at separating DAC from SMA results but the difference is insignificant. These results indicate an increase of truck pass-by noise levels of 1.3 dB in 10 years.

The overall trend – which is also found in the results given in Section 4.2.2 and 4.2.5 - is for an increase in heavy vehicle pass-by noise levels in the order of 0.1 – 0.2 dB per year with the exception of brushed cement concrete pavement where the initially low noise levels increase by 0.4 dB per year. The latter, however, is based on rather few observations with a large spread.

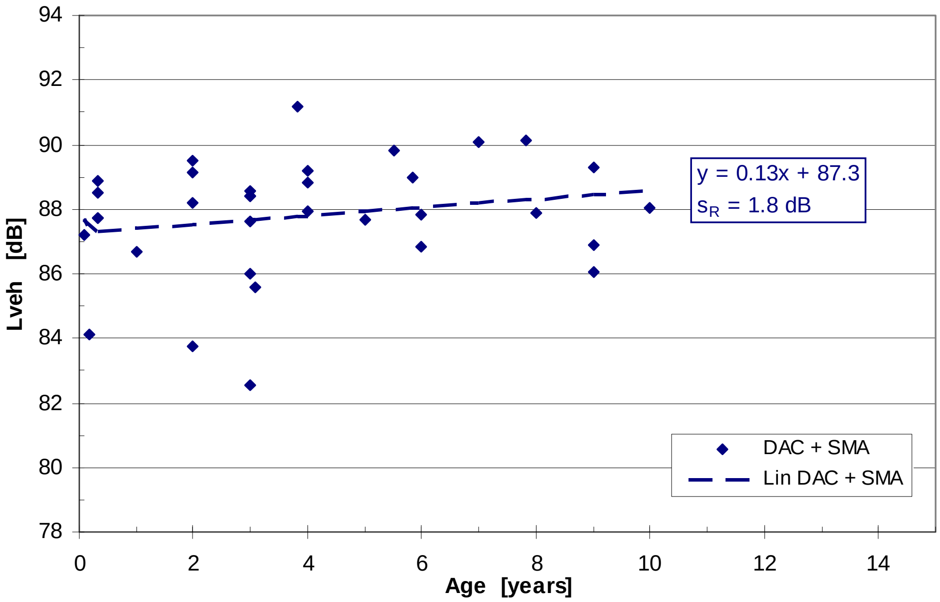


Figure 12. Pass-by noise levels from multi-axle trucks on DAC and SMA, 85 km/h.

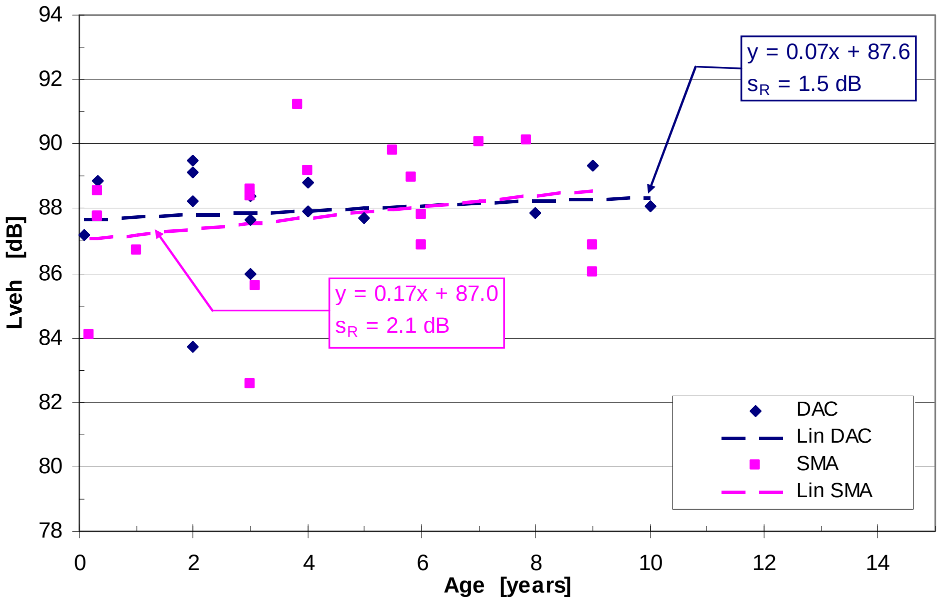


Figure 13. Pass-by noise levels from multi-axle trucks on DAC and SMA, 85 km/h.

Considering the large spread in the data illustrated in the above figures, the work package team concluded that it would probably be better to look at time series of results of measurements repeated at the same spot. LCPC [Berengier-2007] and BASt [Bartolomaeus-2007] provided extensive extracts from their data base, see Section 4.2.1 - 4.2.2, while DRI, BRRC and VTI provided their time series of measurement results from the same sites. DRI in 2006 carried out new measurements at sites where measurements had been made 6 – 7 years earlier, cf. Section 4.2.5.

4.1.2 LCPC database

The data provided by LCPC [Berengier-2007] are part of the French national database stored at the Strasbourg Regional Public Work Laboratory and mainly financed by a National Technical Department of the French Ministry for Ecology, Sustainable Development and Spatial Planning, SETRA: Technical Department for Transport, Roads and Bridges Engineering and Road Safety.

Figure 14, as an example, shows SPB vehicle noise levels from passenger cars at 90 km/h as a function of the pavement age on all of the low noise surfaces of category R1 in the LCPC database, a total of 200 measurements made at different times at 65 different sites. The pavement types comprised by Category R1 are given in Table 4. The picture is the same as that seen in the SILVIA-database results: a large spread and a standard deviation s_R of the residuals in the y-direction of the same order of magnitude. The slope of the regression line is almost 0.5 dB per year which is larger than the largest slope seen in the SILVIA results above.

Table 4. Pavement types in French database.

Category R1	*n*	Category R2	*n*	Category R3	*n*
Two-layer Porous Asphalt 4/6 10/14	4	Dense Asphalt Concrete 0/10	3	Dense Asphalt Concrete 0/14	1
Porous Asphalt 0/10	20	Very Thin Asphalt Concrete 0/10-type1	4	Very Thin Asphalt Concrete 0/14	1
Porous Asphalt 0/6	4	Ultra Thin Asphalt Concrete 0/10	2	Surface Dressing 6/10	3
Very Thin Asphalt Concrete 0/6-type 1	11	Surface dressing 4/6	1	Surface Dressing 10/14	3
Very Thin Asphalt Concrete 0/6-type 2	17	Thin Asphalt Concrete 0/10	2	Surface Dressing 6/8	2
Very Thin Asphalt Concrete 0/10-type 2	7				
Ultra Thin Asphalt Concrete 0/6	2				

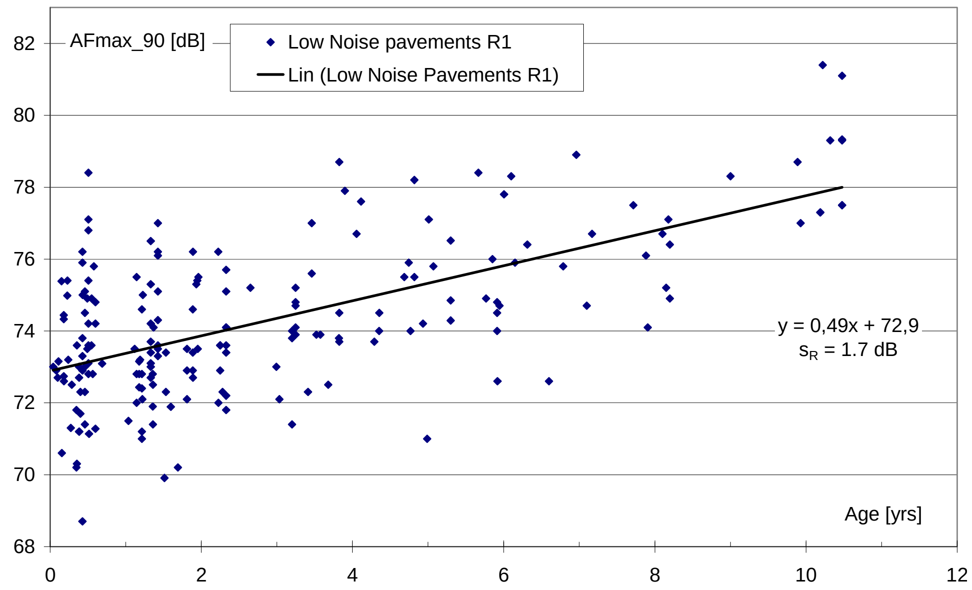


Figure 14. Pass-by noise levels from passenger cars at 90 km/h on French pavement category R1.

Figure 15 shows an extract of the data in Figure 14, a total of 66 measurements from 20 sites with single-layer porous asphalt PA 0/10. The slope and the average noise levels are approximately the same as seen in Figure 14 while the standard deviation of the residuals is reduced by a third.

The slope of the regression line in Figure 15 is almost twice as large as the slope for single-layer porous asphalt PA 16 in the SILVIA results, cf. Figure 6.

The results behind Figure 14 and Figure 15 have been further analysed by looking at the time history recorded at each individual section of road, cf. Section 4.2.1.

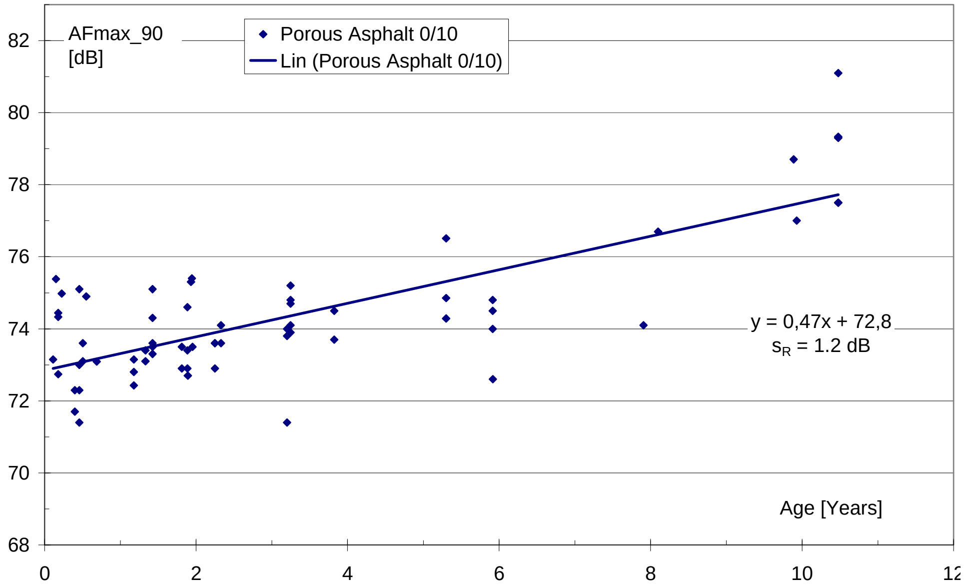


Figure 15. Pass-by noise levels from passenger cars at 90 km/h on French PA 0/10.

4.1.3 BASt database

Figure 16 and Figure 17 show the pass-by noise levels as a function of pavement age for German single layer porous asphalt pavements PA 0/8. Data are from a total of 13 different test sections at some of which measurements were made at several measurement positions the same year [Bartolomaeus-2007. Such data have been averaged.

The trend line in Figure 16 indicates an increase in passenger car noise levels at single-layer porous asphalt on a rural motorway of 0.3 dB per year while Figure 17 indicates an increase of 0.1 dB per year for heavy vehicle noise levels.
The results behind Figure 16 and Figure 17 have been further analysed by looking at the time history recorded at each individual section of road, cf. Section 4.2.2.

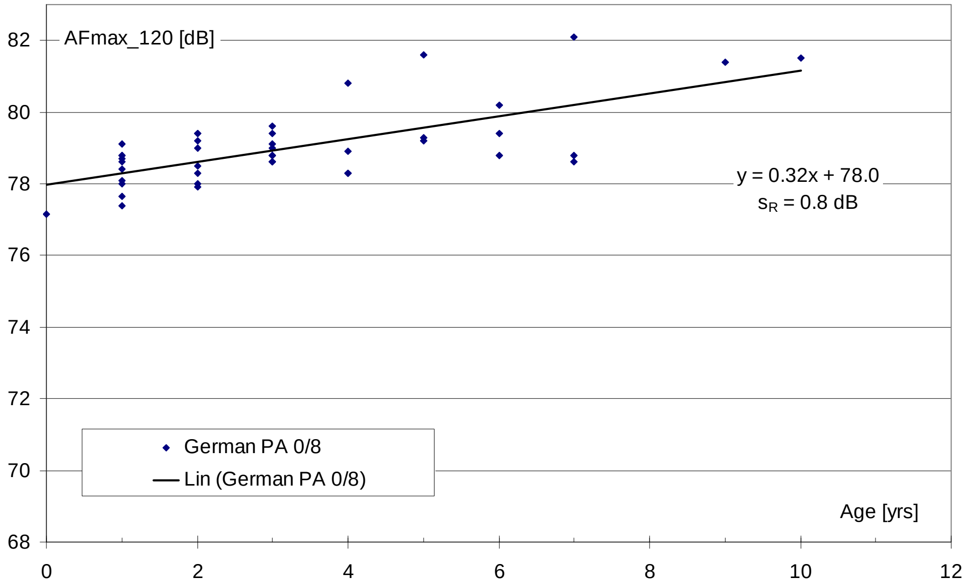


Figure 16. Pass-by noise levels from passenger cars at 120 km/h on German PA 0/8.

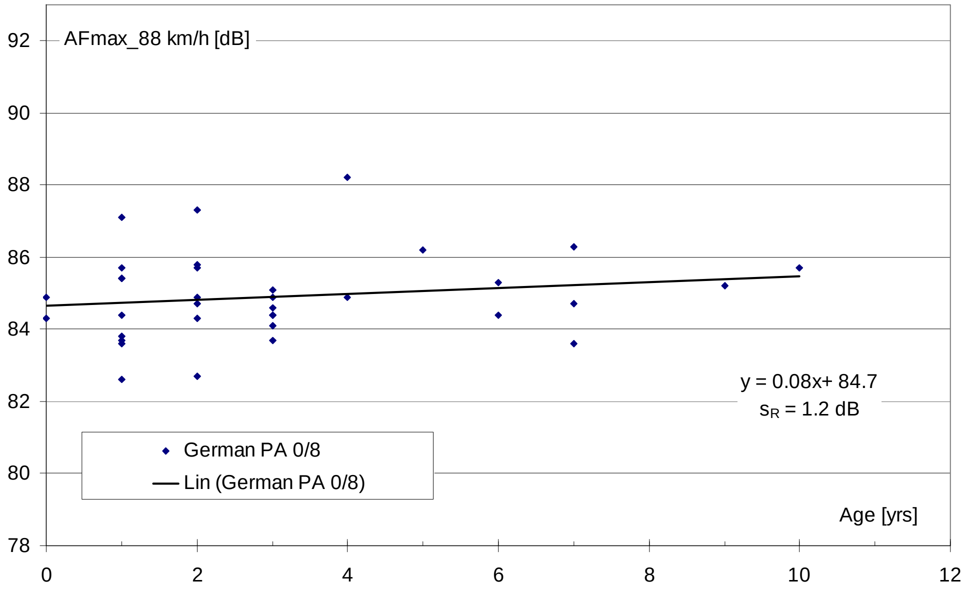


Figure 17. Pass-by noise levels from heavy vehicles at 88 km/h on German PA 0/8.

4.1.4 IPG analysis of compiled data for two-layer porous asphalt

As part of the Dutch IPG-programme a compilation was made of the effects of two-layer porous pavement ageing on vehicle pass-by noise levels, [Goubert-2005]. The study focussed on local and secondary roads, and the conclusion is not valid for high speed roads, due to the more efficient “self-cleaning” on such roads. The results have been summarised in Figure 18 and Table 5.

The results were scattered, probably due to differences in pavement "performance". Only a few data points were available from sections more than three years old. The data points were grouped into classes of elapsed time: (1 ± 0.5) year, (2 ± 0.5) years, and (3 ±0.5) years. An average increase in L_{veh} was calculated for each class, see Table 5.

Goubert concluded that on the average the pass-by noise levels on two-layer porous asphalt seemed to increase by 1 dB during the first year and by yet another 1 dB during the second year in service, probably as a consequence of the pores in the pavement gradually getting clogged. The data indicated that on the average the pass-by noise levels remain more or less stable between three years of age and the end of the pavement structural lifetime, but there were very few data points to support this suggestion. Since the publication of the report evidence has been found, e.g. [Kragh-2006b] and Section 4.2.3 that the loss of reduction does in fact not stabilise after three years but seems to continue more or less at the same pace. The three mean values of the first "elapsed time classes" are indicated in Figure 18 as pink squares. The trend line (in pink) is an empirical fit made by Goubert to the mean values.

If considered a linear increase, the mean value of 2.5 dB/3 years corresponds to an increase of 0.8 dB per year.

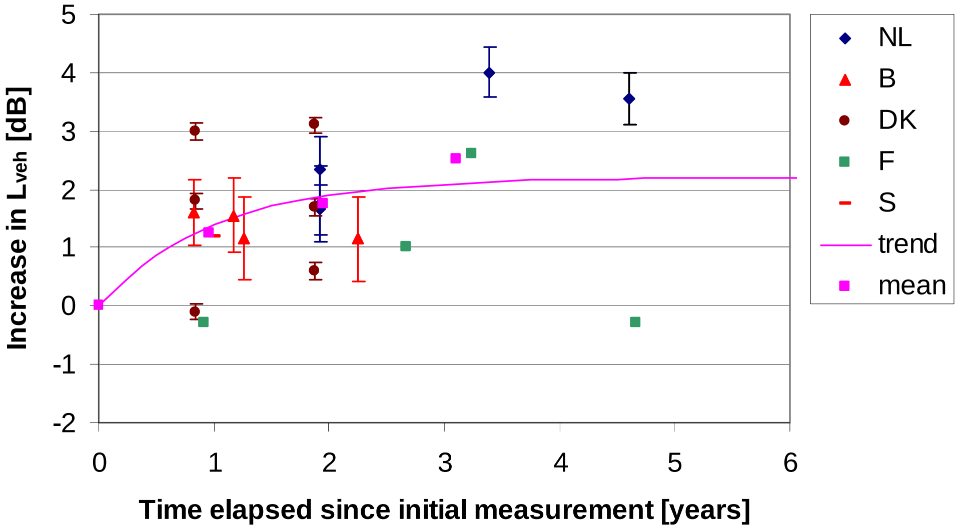


Figure 18. Increase in passenger car noise level at 50 km/h at two-layer porous asphalt, [Goubert-2005].

Table 5. Mean values and standard deviation per time class, [Goubert-2005].

Elapsed time class	**(1 ± 0.5) year**	**(2 ± 0.5) year**	**(3 ± 0.5) year**
Number of points	8	7	3
Mean elapsed time	1.0	1.9	3.1
Mean increase L_{veh}	1.2	1.8	2.5
Std. deviation increase L_{veh}	1.1	0.8	1.5

4.2 Time series of SPB-data collected at the same spot

4.2.1 LCPC database

In this section the results from the LCPC-database [Berengier-2007] have been analysed further than in Figure 15. This analysis is illustrated in Figure 19 - Figure 22.

Figure 19 shows the data as a function of the pavement age for each individual of the 20 sections of road with PA 0/10. Figure 20 shows the same time history data as Figure 19 but for each individual section of road the time history has been transposed to origin at $L_0 = 0$ dB at the time $t_0 = 0$. Figure 21 again shows the same data but this time zero dB has been defined not as the initial measurement result but as the value at the time $t_0 = 0$ of the linear regression line of noise level on pavement age.

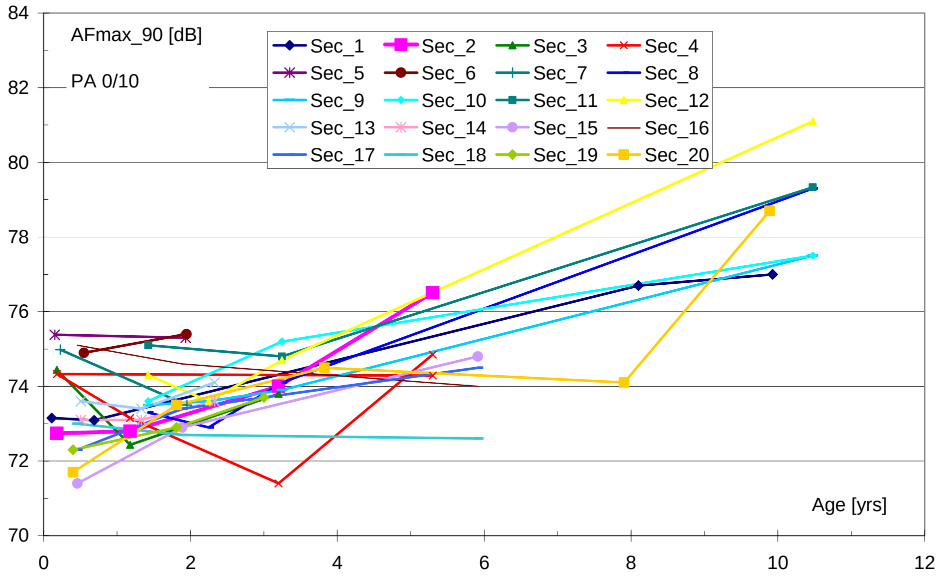


Figure 19. Passenger car pass-by noise level at each of 20 PA 0/10 sections in LCPC database.

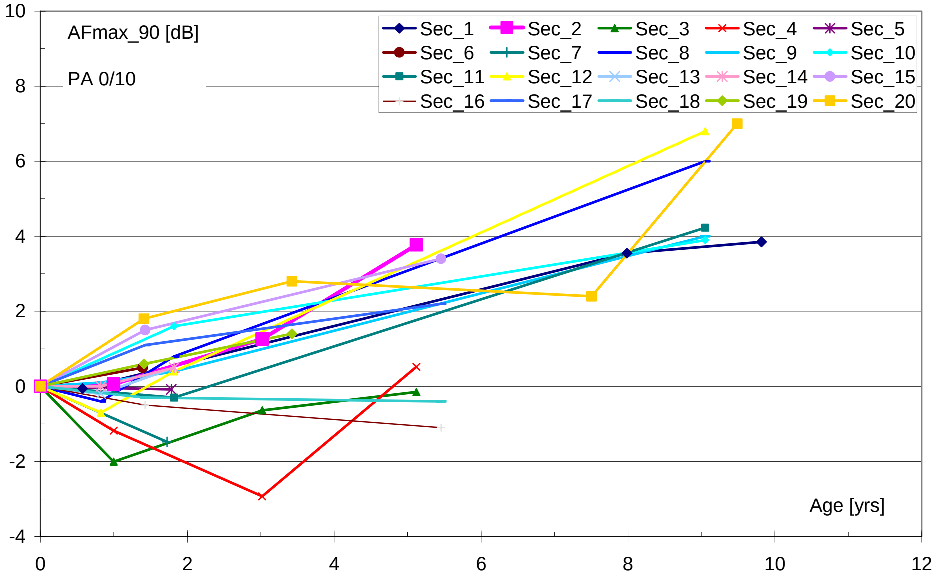


Figure 20. Data from Figure 19 but with origin 0 dB at time zero.

Finally, Figure 22 again shows the data from Figure 21 but this time a linear trend line has been added as well as the standard deviation s_R of the residuals in the y-direction. According to Figure 22 the slope of the trend line is 0.4 dB per year and $s_R = 1.3$ dB. Compared to the more "crude" treatment made in Section 4.1.2 the slope in Figure 22 is slightly smaller than the slope of almost 0.5 dB per year in Figure 15 while the standard deviation of the residuals is the same.

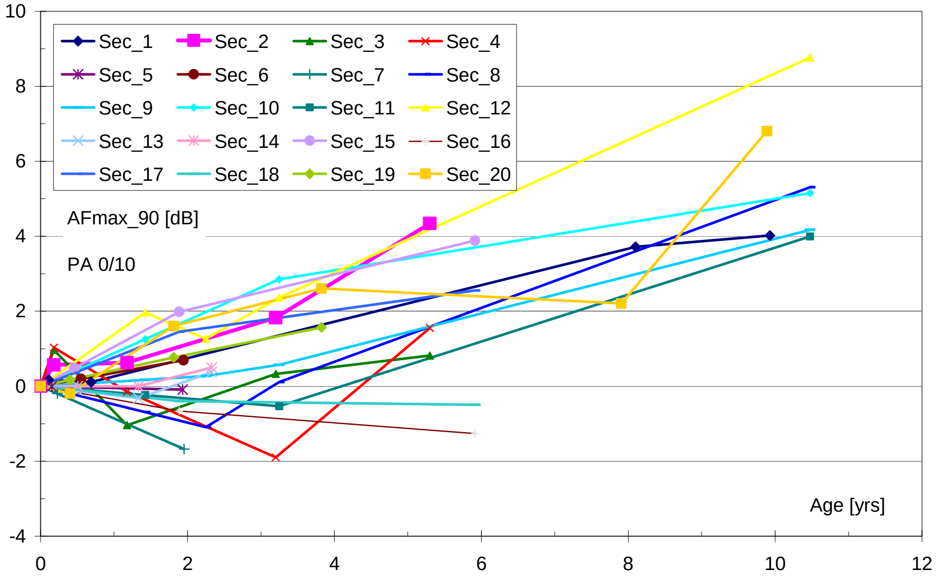


Figure 21. Data from Figure 19 but with their origin at regression line value 0 dB at time zero.

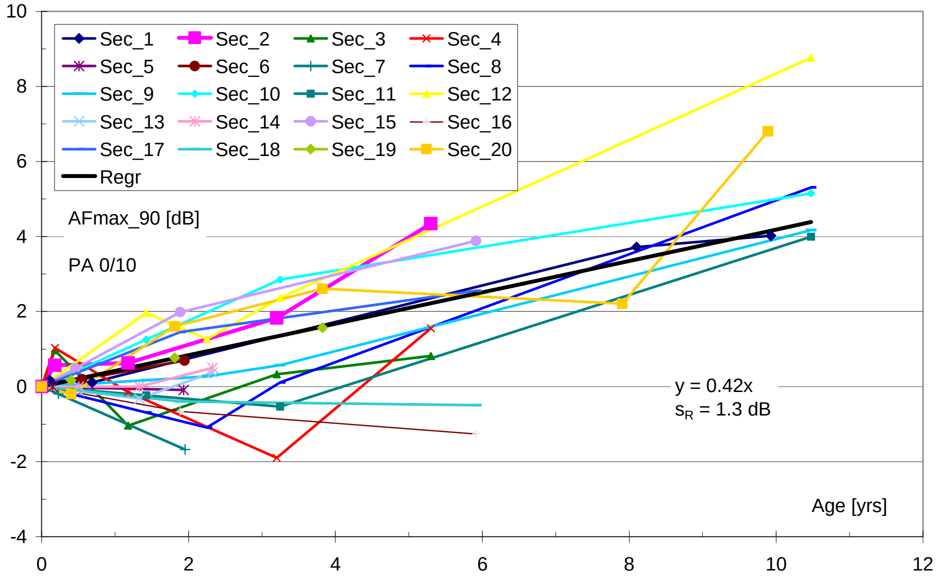


Figure 22. Data from Figure 21 with linear trend line.

Figure 23 - Figure 28 show data from the LCPC database in the same way as the data for porous asphalt is displayed in Figure 22. For example, Figure 23 shows the data for 17 sections with very thin asphalt concrete (BBTM) 0/6-type 2. For these thin layer surfacings the slope is almost 0.8 dB per year and the standard deviation of residuals is almost 2 dB.

Figure 24 - Figure 28 show the data for each of the remainder of pavement types in Category 1. The number of sections per type varies from n = 11 for very thin asphalt concrete 0/6-type 2 to n = 2 for ultra thin asphalt concrete 0/6, the slope of the regression lines are between 0.2 dB per year for four sections of two-layer asphalt and 0.8 dB per year for four sections of single layer porous asphalt. The standard error of the residuals in the y-direction is between 1.2 dB and 2.0 dB. The slopes, residual standard deviation and the number of measurement sites are summarized in Table 6.

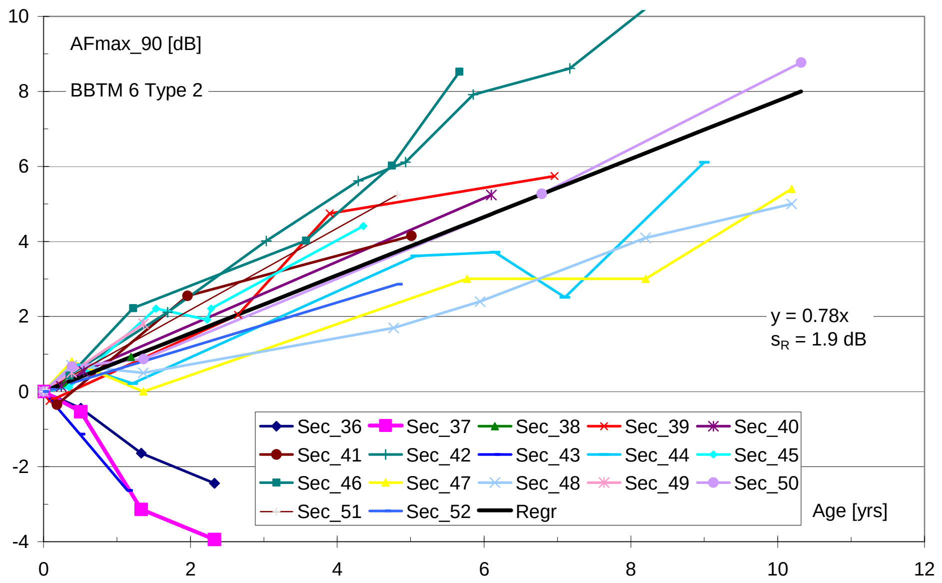


Figure 23. As Figure 22 but for 17 sections of very thin asphalt concrete 0/6-type 2.

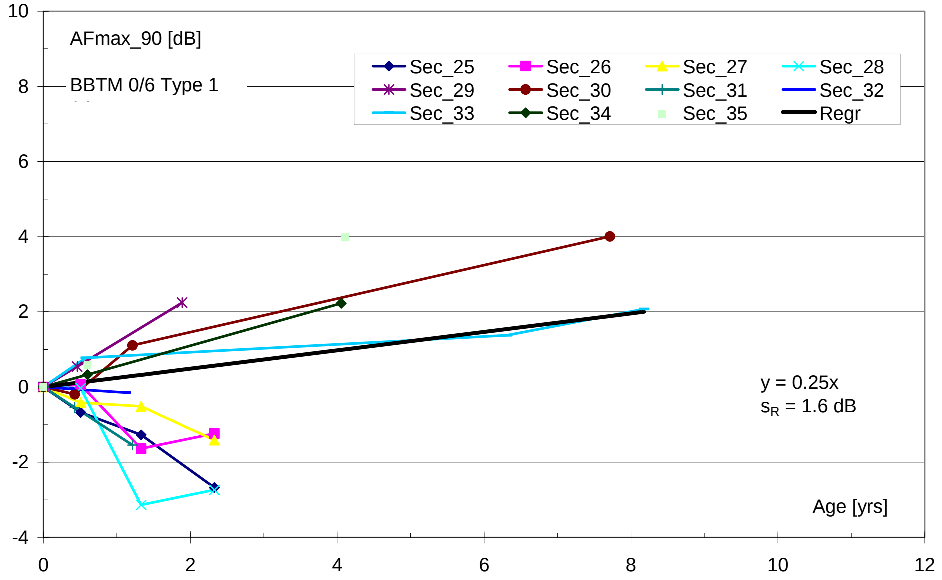


Figure 24. As Figure 22 but for 11 sections of very thin asphalt concrete 0/6-type 1.

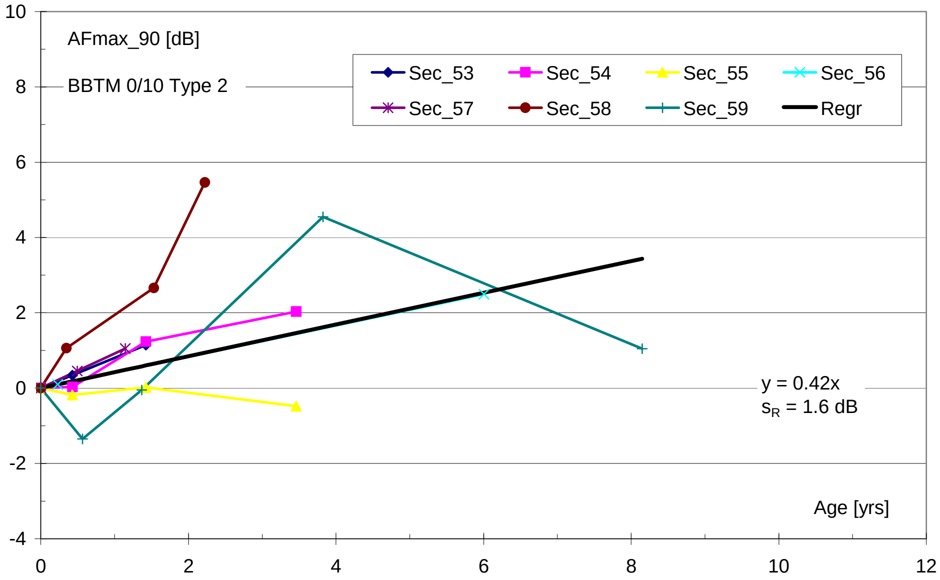


Figure 25. As Figure 22 but for 7 sections of very thin asphalt concrete 0/10-type 2.

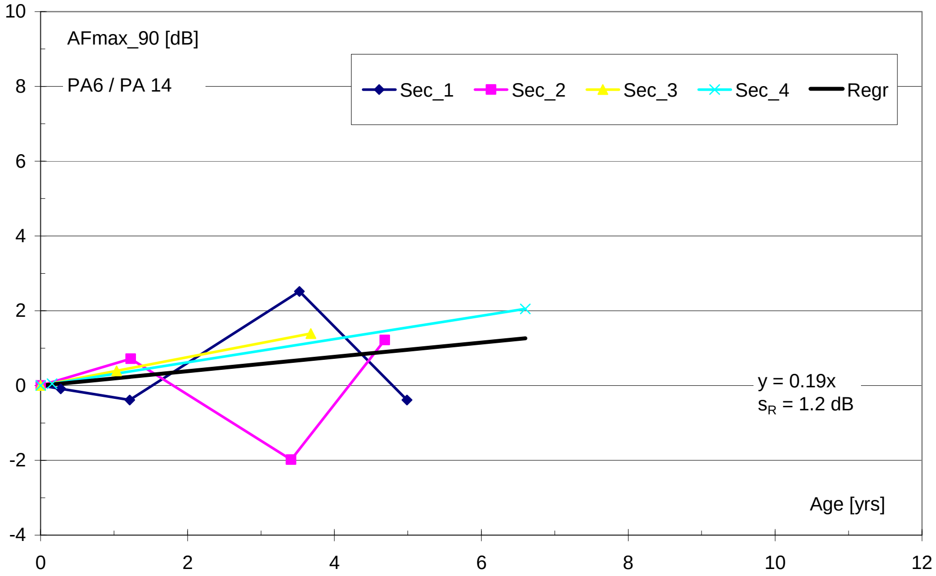


Figure 26. As Figure 22 but for 4 sections of two-layer porous asphalt.

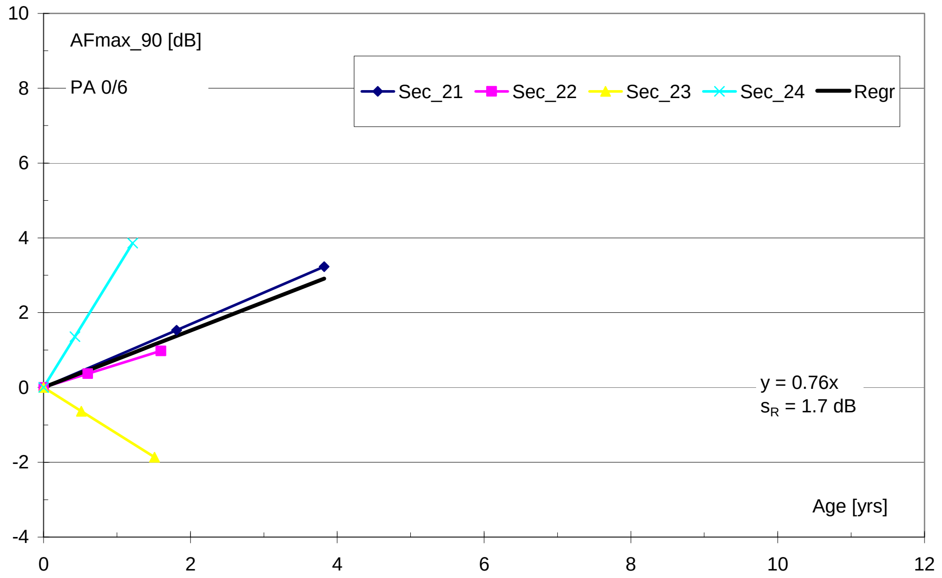


Figure 27. As Figure 22 but for 4 sections of porous asphalt 0/6.

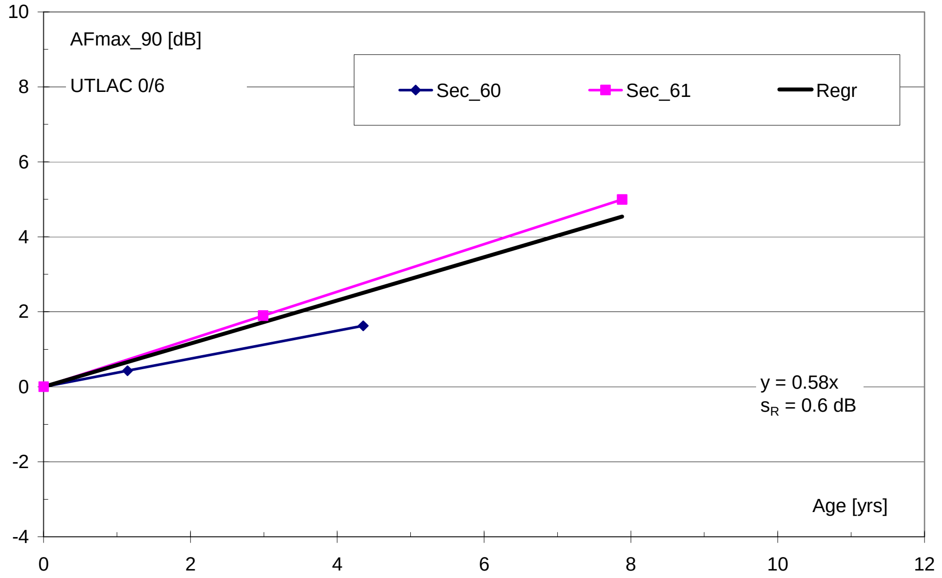


Figure 28. As Figure 22 but for 2 sections of ultra thin asphalt concrete 0/6.

Figure 29 and Figure 30 show the data for pavement types of Category R2 and Category R3 in the LCPC database. The database contains fewer time histories for pavement types within these categories than for the pavement types in Category R1, and the ageing performance of all pavement types in each of the Categories R2 and R3 have been shown together. The slopes, residual standard deviation and the number of measurement sites are summarized in Table 6.

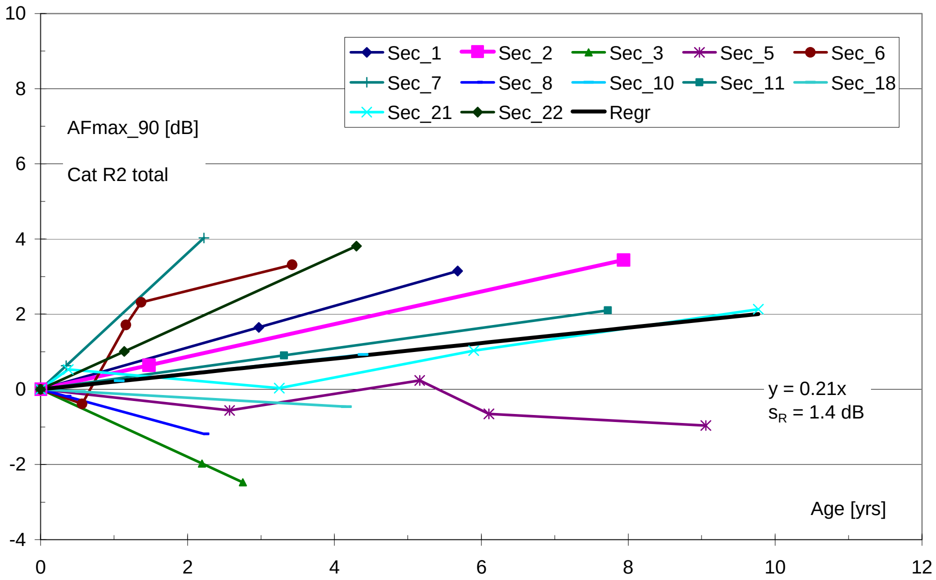


Figure 29. As Figure 22 but for 12 sections of Category R2 pavement.

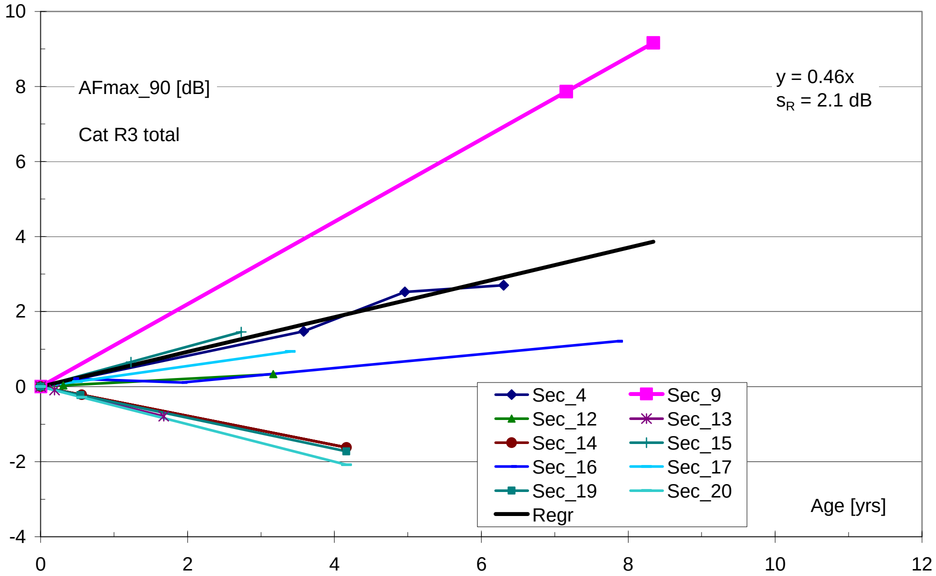


Figure 30. As Figure 22 but for 10 sections of Category R3 pavement.

Table 6. Summary of ageing performance derived from LCPC data.

Pavement	**v [km/h]**	**Slope [dB/yr]**	**s_R [dB]**	**N [-]**
Two-layer Porous Asphalt 4/6 10/14	90	0.19	1.2	4
Porous Asphalt 0/10		0.42	1.3	20
Porous Asphalt 0/6		0.76	1.7	4
Very Thin Asphalt Concrete 0/6-type 1		0.25	1.6	11
Very Thin Asphalt Concrete 0/6-type 2		0.78	1.9	17
Very Thin Asphalt Concrete 0/10-type 2		0.42	1.6	7
Ultra Thin Asphalt Concrete 0/6		0.58	0.6	2
Category R2		0.21	1.4	12
Category R3		(0.46)	(2.1)	(10)
Category R3, excl. Section 9		0.12	1.2	9

In the table, the slope and standard deviation for Category R3 is also given excl. of section 9. For this section only data from a pavement aged 7.2 and 8.3 years, respectively, are available. To use L_0 based on regression line in this case does not seem reasonable.

4.2.2 BASt database

Figure 31 shows individual time histories of passenger car pass-by noise levels recorded at 13 sites with single layer porous asphalt on German rural motorways [Bartholomaeus-2007]. The figure shows the same data as Figure 16 in Section 4.1.3.

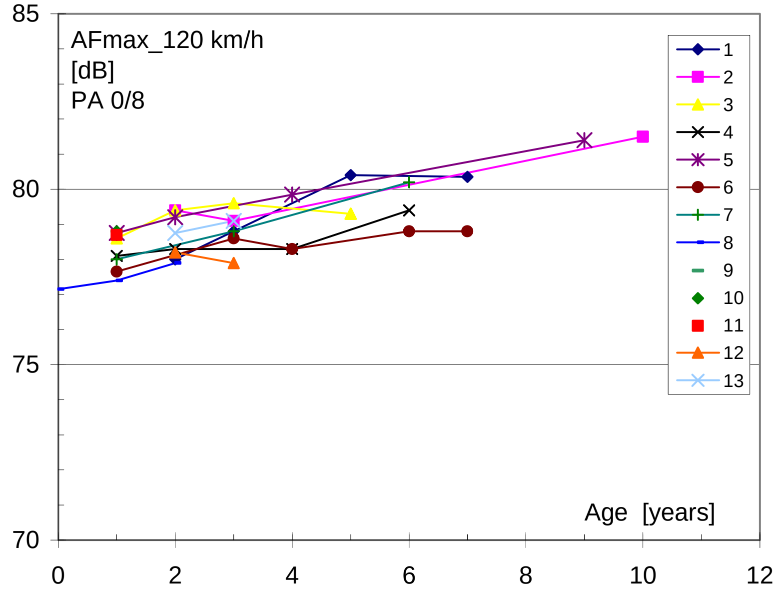


Figure 31. BASt data per site, passenger cars on single-layer porous asphalt.

The data in Figure 31 were processed as follows, as it was done to the French data: 1) For each data series a linear regression analysis was made to determine the pass-by noise level L_0 = 0 dB at time t_0 = 0; 2) All data were then expressed as the change in pass-by noise level since the time t_0 = 0. In a few cases (Series 9 – 11) there was only one observation available made when the pavement was 1 one year old. In these series zero dB was defined as the average of the L_0-values from the remainder of data series.

The resulting changes in pass-by noise levels for passenger cars are shown in Figure 32. The figure also shows the linear regression line for all the data and the standard deviation s_R of the residuals in the y-direction. Figure 32 indicates an increase in passenger car noise level of 0.3 dB per year, which is the same as reflected by the trend line of Figure 16 in Section 4.1.3. The standard deviation of the residuals is 1.4 dB, which is almost twice the standard deviation in Figure 16. In this case the more detailed analysis does not seem to have led to an improved relation between pavement age and pass-by noise level.

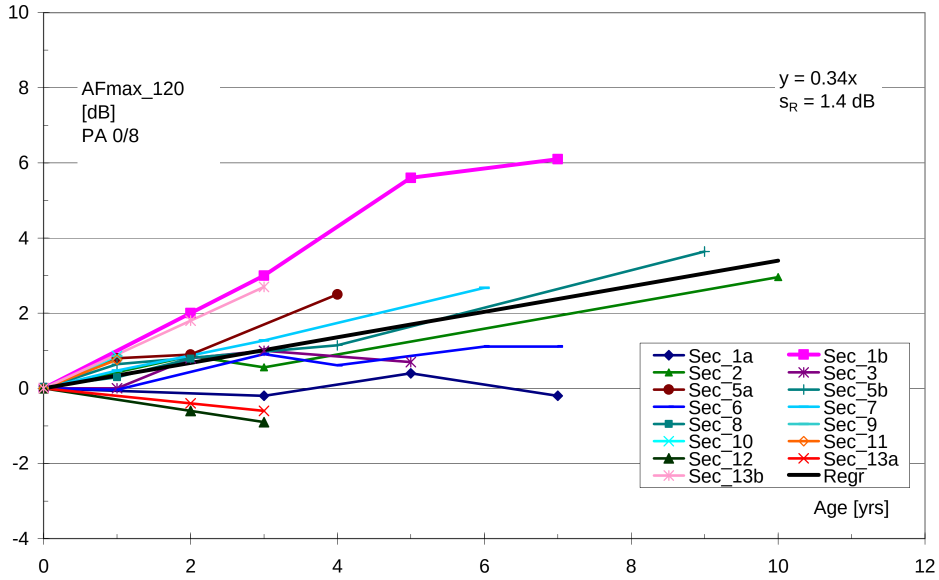


Figure 32. Data from Figure 31 expressed as changes in noise level since year No. 0.

Figure 33 shows the individual time histories of heavy vehicle pass-by noise levels recorded at the 13 German sites with single layer porous asphalt. There seems to be no reason to try to further analyse the data for heavy vehicles. The average increase in noise level is smaller than 0.1 dB per year.

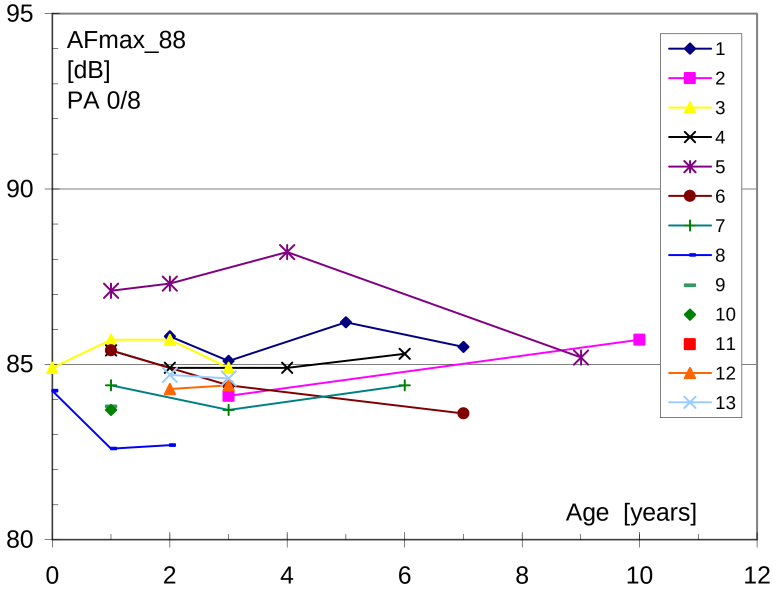


Figure 33. BASt data per site as in Figure 31 but for heavy vehicles on single-layer porous asphalt.

4.2.3 DRI time series of SPB-data

Figure 34 and Figure 35 show pass-by noise exposure levels at three single layer porous asphalt surfaces and at two sections with dense asphalt concrete, based on [Kragh-1998]. The noise levels increased gradually during the pavement lifetime.

The pavement lifetime was deliberately made short in this experiment. It could have been longer if the binder had been modified.

At the dense surfaces the increase in truck noise level was 0.2 – 0.3 dB per year while for passenger cars the increase was approximately 0.4 dB per year, cf. Table 7.

Until ravelling occurred in year No. 7 the increase of passenger car noise levels was in the order of 0.7 – 0.8 dB per year at the porous pavements. If data from year No. 7 are included in the regression analysis for the porous asphalt then the slope increases a bit, cf. Table 7. For trucks the increase was in the order of 0.1 – 0.4 dB per year.

Perhaps one should in the present case a deliberately short lifetime concentrate on the total increase in noise level during pavement lifetime rather than on the increase per year. This would lead to a smaller increase in noise level, in the order of 0.4 dB per year for passenger cars and 0.2 dB per year for trucks. These figures would be more in line with French, German and Dutch data than the above figures. However, this would require the increase in noise levels to be caused by ravelling rather than clogging of the voids. According to notes taken during the experiment, noticeable ravelling began between year No. 6 and Year No. 7. This again implies that clogging was the main reason for the increase in noise level.

The reason for the faster increase in noise level in these Danish time series than the average values in the French, German and Dutch data may be the lower traffic speed (80 km/h vs. 90 – 120 km/h).

The results in Figure 34 - Figure 35 illustrate that the regression line value L_0 at time zero is overall preferable to the result of the initial noise measurement as an origin of the time histories of noise levels at the porous asphalts although linear regression is not ideal in the present case. The regression leads to lower initial noise levels than actually measured. The results indicate that the process between year No. zero and year No. 1 is different from that between year No. 1 and the end of pavement lifetime.

Table 7. Summary of data in Figure 34 and Figure 35. Rural road, 80 km/h.

Section	**Passenger cars**				**Multi-axle trucks**			
	Slope	**s_R**	**Slope**	**s_R**	**Slope**	**s_R**	**Slope**	**s_R**
	[dB/year]	**[dB]**	**[dB/year]**	**[dB]**	**[dB/year]**	**[dB]**	**[dB/year]**	**[dB]**
	Year 0 - 6		**Year 0 – 7 or 8**		**Year 0 - 6**		**Year 0 – 7 or 8**	
PA 8 18-22%	0.78	0.5	0.88	0.6	0.31	0.6	0.37	0.6
PA 8 >22%	0.69	0.6	0.81	0.7	0.09	0.8	0.20	0.8
PA 12 >22%	0.71	1.0	0.83	1.0	0.35	0.7	0.44	0.7
AC 12d REF	-	-	0.40	0.3	-	-	0.15	0.4
AC 12o	-	-	0.37	0.6	-	-	0.32	0.1

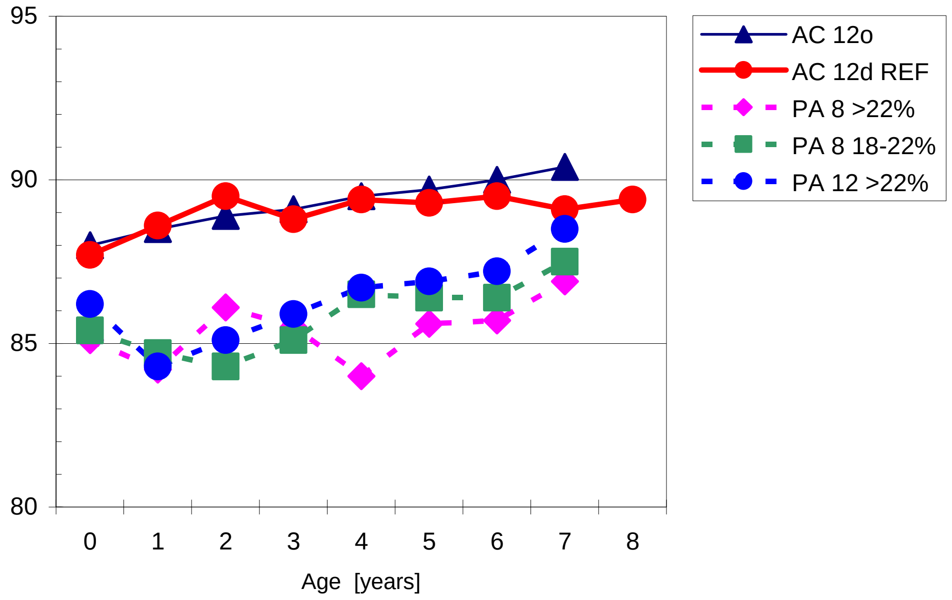


Figure 34. Noise exposure levels from for multi-axle trucks, rural road 80 km/h.

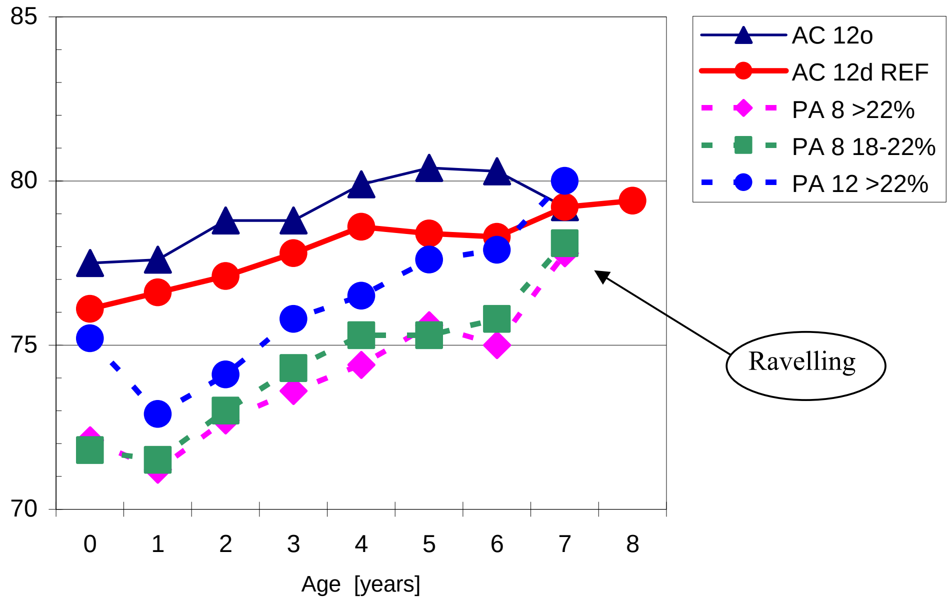


Figure 35. Noise exposure levels from passenger cars, rural road 80 km/h.

Figure 36 shows results of Danish measurements at test sections with three different two-layer porous asphalt surfacings on a city street with 50 km/h speed limit. The figure also shows results of measurements at a reference surface with dense asphalt concrete with 8 mm maximum aggregate size.

The porous asphalt was cleaned twice a year, in spring and in autumn, by high pressure water spraying and subsequent suction of the water. Nevertheless, the voids gradually got clogged, resulting in a faster increase in pass-by noise levels than seen at the dense reference surface, [Kragh-2007b]. The average increase in noise level was approximately 1 dB per year at the porous surfaces.

The last set of data in Figure 36 was collected in 2007 after the top layer of the porous surface had been replaced by a new top layer of PA 8. After replacing the top layer the lost initial noise reduction of 6 – 7 dB was almost regained at section I and II, when comparison is made with the reference pavement of he same age. At section II, for unknown reasons this did not happen.

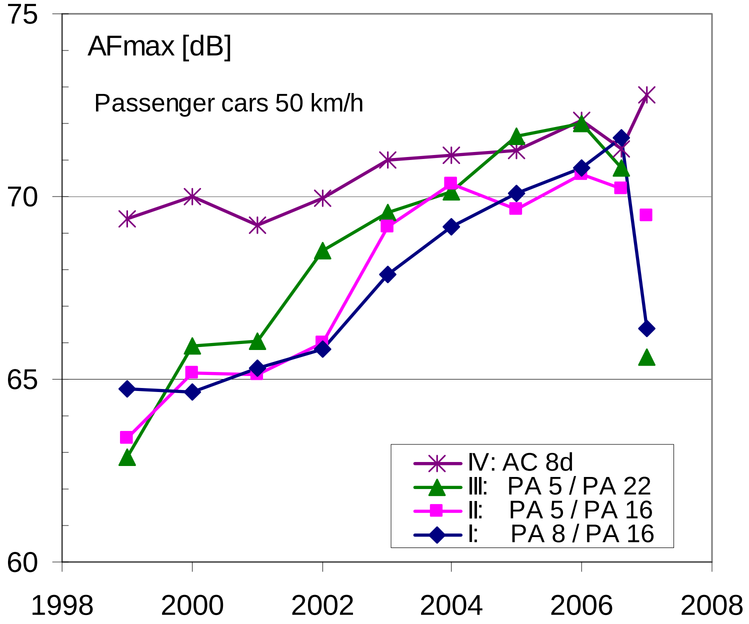


Figure 36. Noise levels at two-layer porous surfaces and dense asphalt on Øster Søgade [Kragh-2007b].

Table 8. Summary of data in Figure 36. City Street, 50 km/h.

Section	Slope [dB/year]	s_R [dB]
I: PA 8 / PA 16	1.00	0.5
II: PA 5 / PA 16	0.98	0.9
III: PA 5 / PA 22	1.09	1.0
IV: AC 8d	0.33	0.4

DRI has several time series of SPB noise levels recorded at thin layer sections. However these time series are yet too short to be the basis for estimating the time history of their noise performance.

4.2.4 BRRC time series of SPB-data

Figure 37 shows the passenger car pass-by noise level as a function of time at a rural Belgian test section of two-layer porous asphalt at Bambois with 7 mm maximum aggregate in the top layer. After the third measurement the surface was cleaned. The figure is based on [Goubert-2006].

If we consider the surface as a surface being regularly cleaned the time history indicates an increase of 0.3 dB per year. If we consider it a surface not being cleaned then we have two very short time histories indicating 1.3 and 0.5 dB per year increase, respectively.

The total time history in the top of the figure fits with the trend for an increase in the order of 0.4 dB per year seen in the French and German results for single-layer porous asphalt.

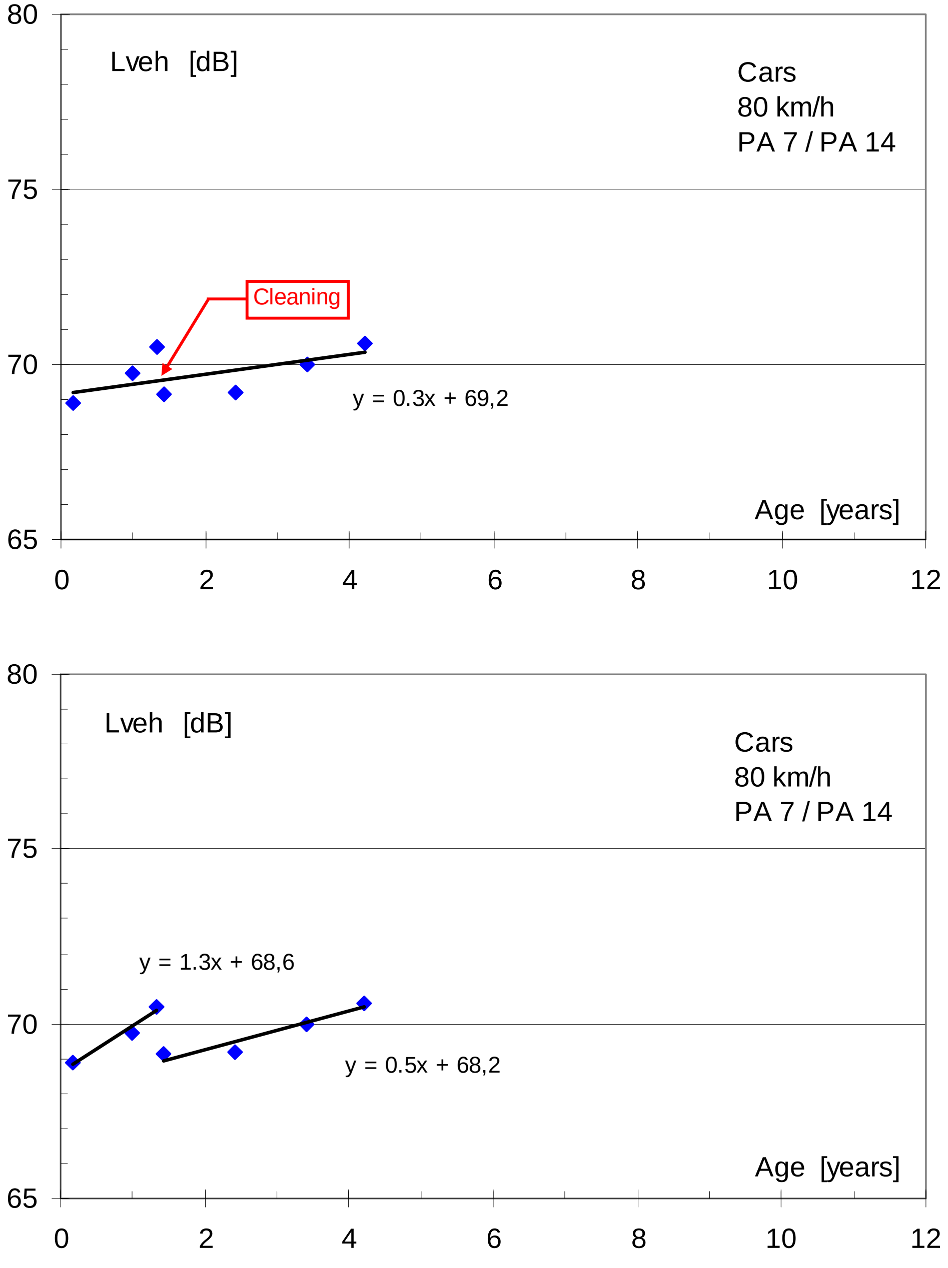


Figure 37. Passenger car pass-by noise levels at Belgian two-layer porous asphalt at Bambois.

4.2.5 DWW series of SPB data

Figure 38 - Figure 39 show pass-by noise levels for heavy vehicles and passenger cars, respectively, on sections with of two-layer porous asphalt pavement (PA 4/8 / PA 11/16) on two Dutch motorways, [Kragh2007a]. At motorway A28 measurements were carried out at the new surface and the measurements were repeated some years before the end of its 11 years of structural lifetime. At motorway A27 measurements were carried out at the new surface and after approximately 1, 2 and 3 years. Figure 38 shows the results for heavy vehicles and Figure 39 shows the results for passenger cars.

The trend for the heavy vehicle noise levels is an increase of 2 dB/11 years, i.e. 0.2 dB per year, and for passenger car noise levels an increase of 4 – 5 dB/11years, i.e. 0.4 dB per year.

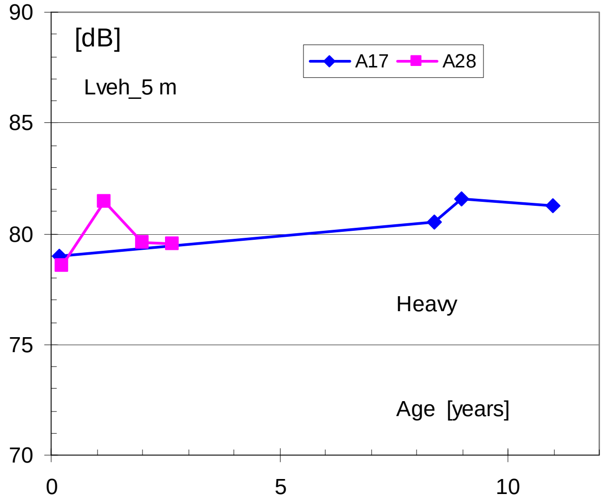


Figure 38. Truck noise level as a function of pavement age. Dutch motorways, 85 km/h.

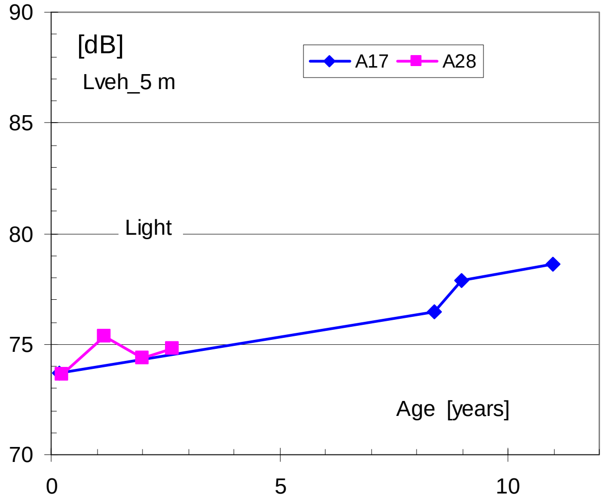


Figure 39. Passenger car noise level vs. pavement age. Dutch motorways, 110 km/h.

4.3 Measurements Repeated as part of SILENCE F4.5

DRI has repeated measurements at six or seven sites years after original measurements were carried out 1999 – 2000 as a basis for source data for the new Nordic prediction method for road traffic noise, Nord2000 [Kragh-2001]. Statistical pass-by measurements of passenger car noise levels were made because these were presupposed to determine noise levels changes du to changes in road surface properties more accurately than heavy vehicle noise levels. The pavement was dense asphalt concrete with 11 mm maximum aggregate size. The measurements were made at a microphone height of 4 m above the road surface.

The results are shown in Figure 40 and Figure 41. The error bars in figures show the standard uncertainty of the regression line value at 110 km/h and 50 km/h, respectively.

In three cases the noise levels were higher seven years later, while in the remainder three cases the noise levels were lower seven years later. However, the differences are rather small and could to some extent be attributed to measurement uncertainty.

In the original report [Kragh-2001] it was noted that the noise levels measured at the sites named Ringsted Ringvej and Helsingørmotorvejen (cf. Figure 40 and Figure 41) were significantly higher than noise levels measured at similar sites in the same measurement series. We were not able to explain why but in the report then mentioned the possibility that the engine load might have been higher at Ringsted Ringvej than at the other similar sites or that there may have been some differences in road surface that we had not been aware of.

The figures show lines with a slope of 0.2 dB per year placed at an arbitrarily chosen level, and the data – in spite of the opposite trend at the two sites mentioned above – do support the general picture that the noise levels at dense asphalt concrete increases with increasing age at a rate in the order of 0.2 dB per year.

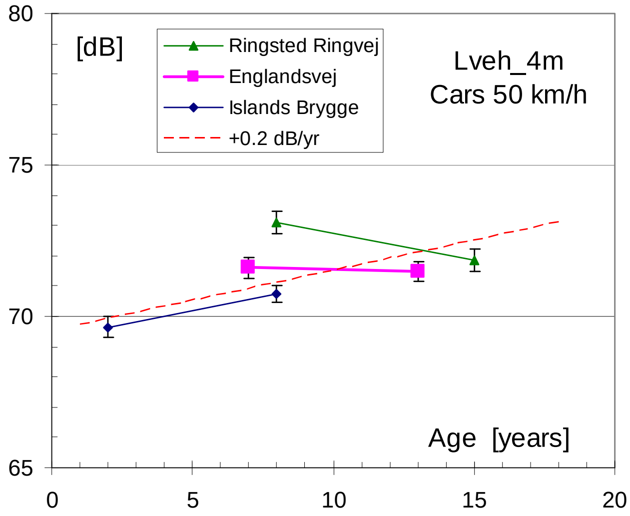


Figure 40. Pass-by noise levels at 4 m height, cars at 50 km/h.

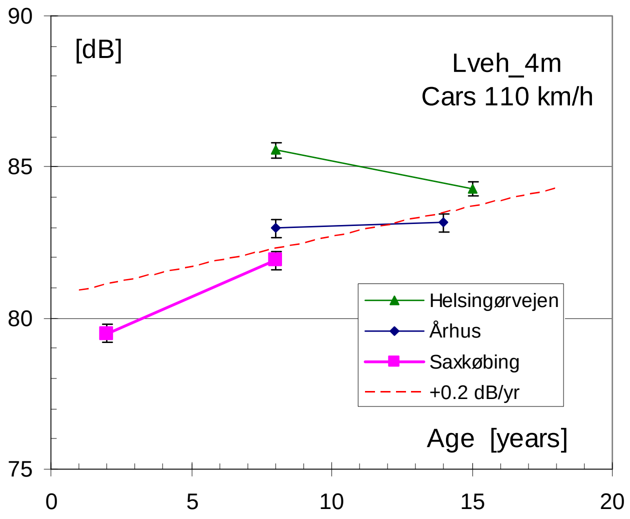


Figure 41. Pass-by noise levels at 4 m height, cars at 110 km/h.

5. CPX-measurement results

5.1 Different sites combined

5.1.1 Danish pavements

In a Dutch-Danish cooperative research project CPX-measurements were carried out on a variety of Danish pavements [Kragh-2006a]. For some types of pavement, measurement results were available for pavements of different age. These are shown in Figure 42 and Figure 43. For the asphalt concrete pavements the trend is an increase in noise level of 0.11 – 0.17 dB per year, while the (fewer) data for stone mastic asphalt show a decrease in noise level with increasing age. The latter was thought to be a consequence of differences in initial surface texture rather than an effect of ageing [Kragh-2006a], but the surface texture in combination with an empirical relationship between surface texture and pass-by noise level could not explain the differences [Andersen-2007]. The four results of measurement at six years of pavement age in Figure 43 are from four different lanes of the same road.

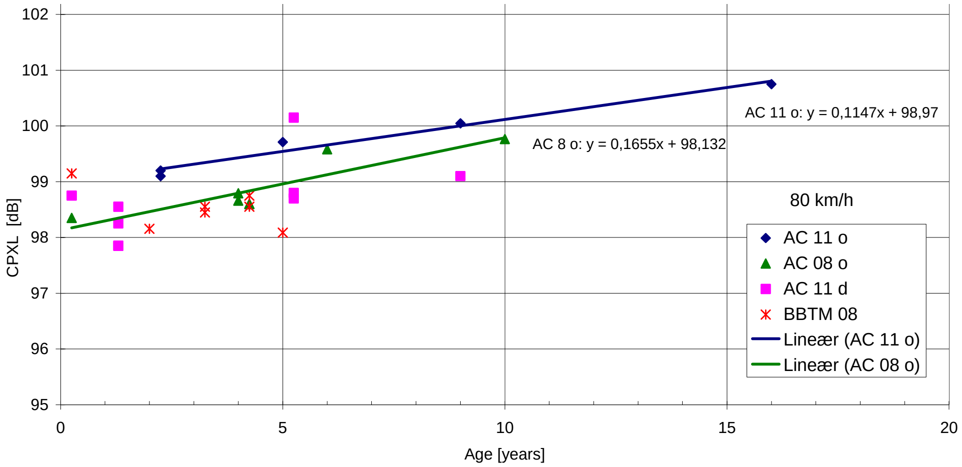


Figure 42. CPXL at 80 km/h. Dense open graded asphalt concrete on Danish roads.

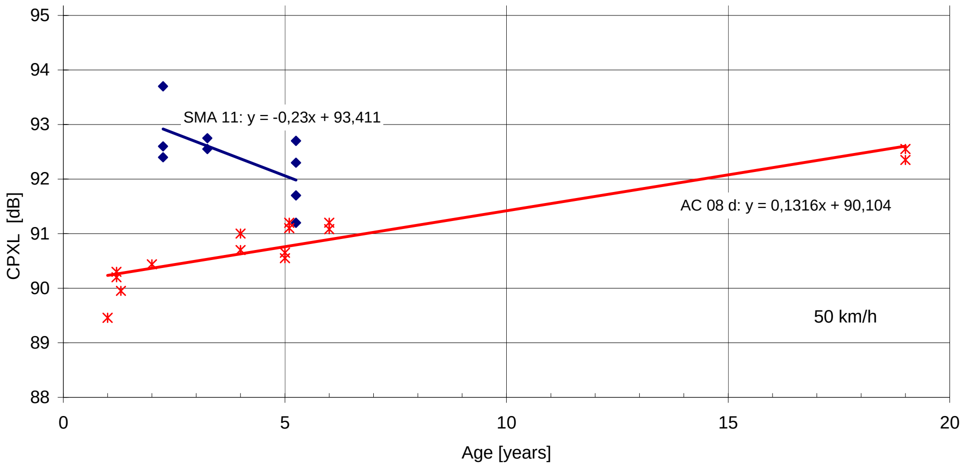


Figure 43. CPXL at 50 km/h. Dense graded asphalt concrete and stone mastic asphalt on Danish roads.

5.1.2 Californian pavements

The results of measurements of sound intensity levels (On Board Sound Intensity, OBSI) near a car tyre on a total of 74 sections of road in California/Arizona were presented at the Transportation Research Board Committee ADC40 summer meeting in 2007 [Kohler-2007]. The measurements were carried out by the University of California, Pavement Research Center (UCPRC).

The pavement characteristics are summarized in Table 9. Figure 44 shows the total set of data as a function of the pavement age at the time of measurement. The overall trend is an increase of: +0.2 dB per year. No correction has been made for the effect of temperature.

Figure 45 shows the results grouped by pavement type. For rubberized, gap graded asphalt concrete and open graded asphalt concrete the trend is an increase of 0.3 dB per year, while for dense graded asphalt concrete the average increase is less than 0.5 dB/14 years, i.e. +0.03 dB per year.

Table 9. Characteristics of the pavements mentioned in [Kohler-2007].

Type	Designation	Open?	Void content [%]	Rubber?	No. of sections
DGAC	Dense graded AC	0	3 - 9	0	18
OGAC	Open graded AC	1	8 - 22	0	18
RAC-G	Rubberized, Gap graded	?	8 - 14	1	13
RAC-O	Rubberized, Open graded	1	8 - 21	1	20
F-mix	Special mix, Northern CA	1	-	0	5

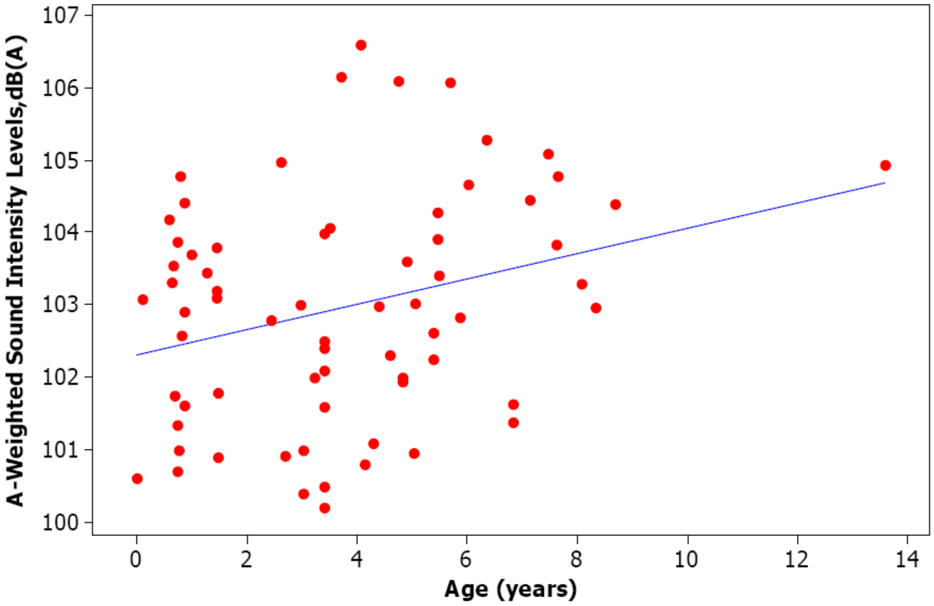


Figure 44. Total set of OBSI-data at 97 km/h from California/Arizona, [Kohler-2007].

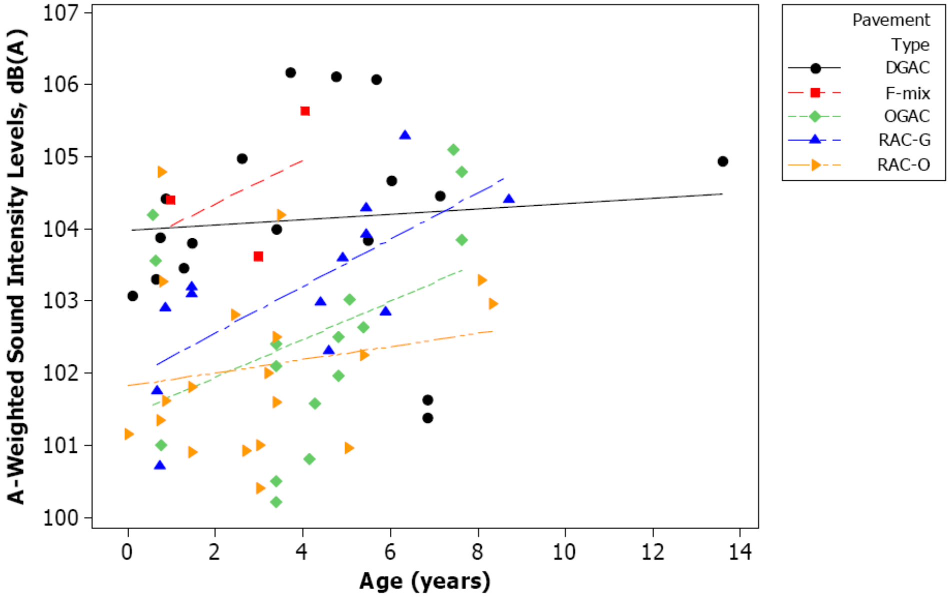


Figure 45. OBSI-data at 97 km/h from California/Arizona, per pavement type, [Kohler-2007].

5.1.3 Time series of CPX-data collected on the same road

The data displayed in Figure 46 from CPX measurements made on the same four sections of rural road in Sweden during four consecutive years indicate a slight increase in noise level on the dense surfacings. The noise level on the two-layer porous asphalt shows an increase of 3 – 4 dB in three years while there seems to be an error in the measurement made on the single layer porous asphalt leading to a significantly lower noise level in year No. 3 than the initial noise level.

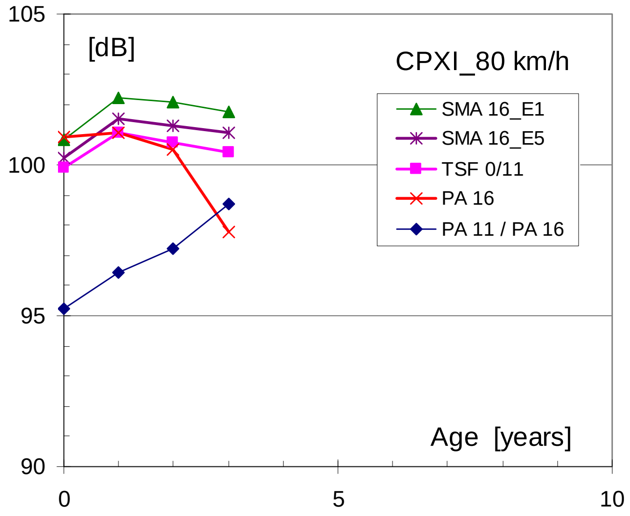


Figure 46. VTI CPX-data at 80 km/h based on [Sandberg-2007].

6. Models for tyre road noise development in time

6.1 HARMONOISE and Nord2000

HARMONOISE and Nord2000 uses a virtual reference road surface based on a "cluster" of DAC and SMA surfaces [Jonasson-2004]. The reference is a mix of DAC 11 and SMA 11 with an age of 2 years or more but not at the end of its lifetime. From two years of age until ravelling begins these prediction models assume constant tyre/road noise emission while for such a surface younger than 2 years the noise level is lower. The correction for the ageing is

$$\Delta L_{age} = -(0.2T^2 - 1.2T + 1.6) \qquad T \leq 2 \ years \tag{1}$$

where T = surface age in years, cf. Figure 47.

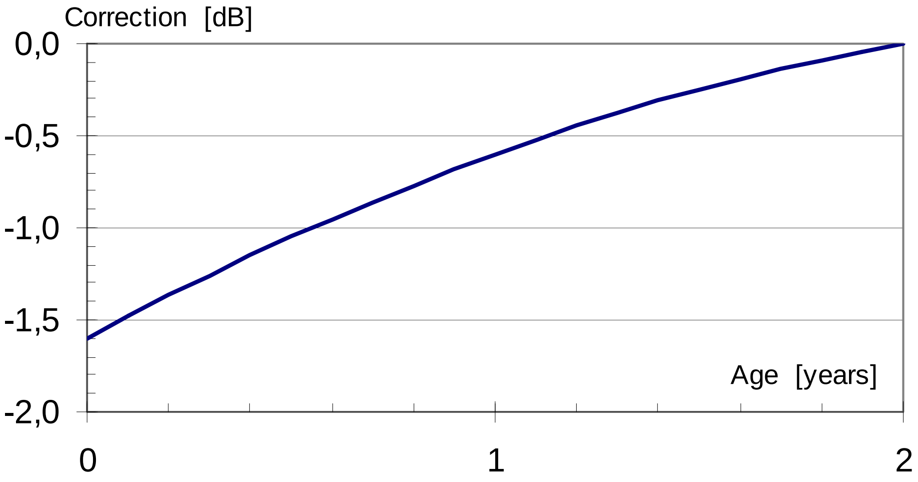


Figure 47. Harmonoise / Nord2000 Correction for dense asphalt surface age.

In general, also newly laid porous surfaces are quieter than older ones. While for dense surfaces within the "reference cluster" the deterioration becomes stable after two years, for porous surfaces the deterioration continues for seven years. For porous surfaces like PAC, PCC, PERS and OGAC the correction in each frequency band for the rolling noise component is

$$\Delta L_{age} = \Delta L_0 (1 - (0.25T - 0.016T^2)) \qquad T \leq 7 \ years \tag{2}$$

where T = surface age in years, ΔL_0 is the sound pressure level for the individual frequency band relatively to the reference tyre/road noise level at the time T = 0 years, cf. Figure 48.

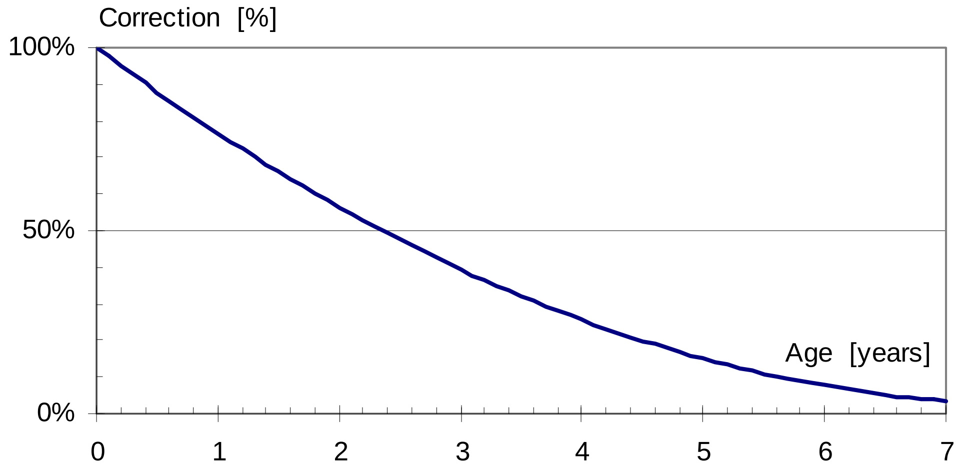


Figure 48. Harmonoise / Nord2000 correction for porous asphalt surface age.

Considering the large spread in measurement results the SILENCE work package team decided to base performance models on a linear relation between noise level and pavement time in service.

6.2 Discussion

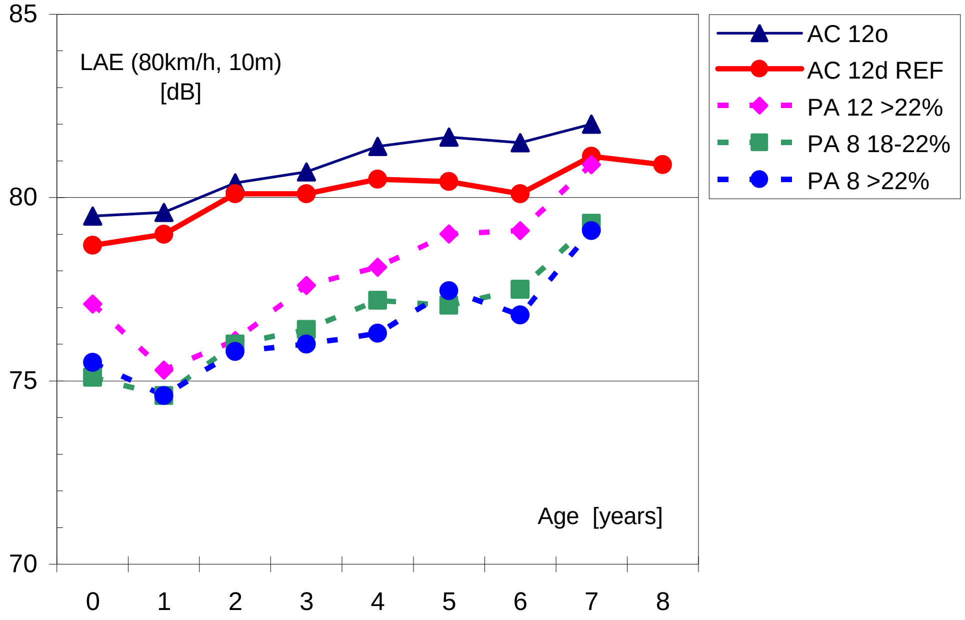
6.2.1 Tyre changes with time

The change over time of tyre size and design is included in any time series of SPB measurement results. The magnitude of this in largely unknown but has been estimated to be in the order of 0.5 dB during the latest 10 years [Bartolomaeus-2007]. The time series shown in the present report have been recorded during different periods of time although most observations have been made during the latest decade or so. The work package team decided to neglect the effect of tyre development over time and to consider it an unavoidable inherent uncertainty.

6.2.2 Definition of noise reduction

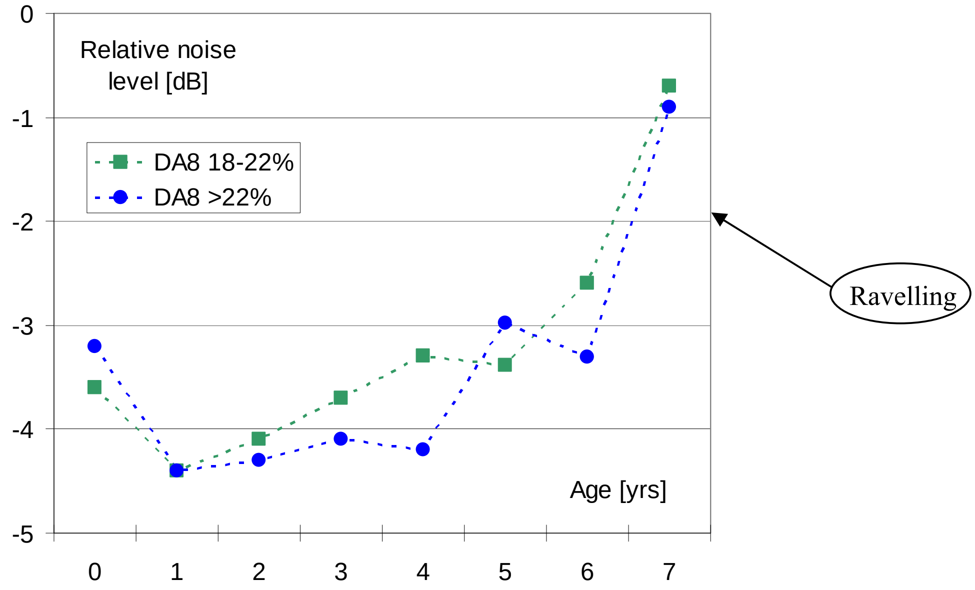
Figure 49 shows the acoustical behaviour during the lifetime of Danish single layer porous asphalt surfaces, expressed as the noise exposure level from pass-by of a vehicle representing a mix of light and heavy vehicles, after [Kragh-1998]. The increase in noise level during the years before ravelling occurred in year No. 7 was in the order of 0.4 – 0.5 dB per year at PA 8 and 0.6 dB per year at PA 12.

Figure 50 shows the noise reduction compared to the dense asphalt concrete of the same age. During their (relatively short) lifetime the noise reduction at the two porous pavements with max 8 mm aggregate was relatively constant when compared with the dense asphalt concrete *of the same age* until ravelling occurred. For such a situation and with this definition the lifetime average noise reduction is approximately the same as the initial noise reduction.



Results for a mix of light and heavy vehicles.

Figure 49. Pass by noise exposure levels on single layer porous and dense asphalt [Kragh-1998].



Results for a mix of light and heavy vehicles.

Figure 50. Noise reduction at porous asphalt relatively to dense asphalt of the same age [Kragh-1998].

Figure 36 in Section 4.2.3 shows time series of passenger car noise levels at Danish test sections with two-layer porous asphalt in a city street with 50 km/h speed limit. Although the pavements were cleaned twice a year they gradually got clogged and lost their noise reduction. The increase in noise level happened faster at the porous surfacings than at the dense reference pavement [Kragh-2007b]. The last set of data was recorded in 2007 after the top layer of the porous surfacings had been replaced, and the lost noise reduction had been partly regained.

The rate of increase in noise level at the dense surface was around 0.3 dB per year and in the order of 1 dB per year at the porous pavements. Figure 51 - Figure 54 illustrate different scenarios: Figure 51 shows the measured noise levels and idealized time histories of the noise level at the dense reference surface and at the porous pavements, respectively. In Figure 52 the time histories have been prolonged in Scenario 1 assuming linear future development of the surface properties. Figure 53 illustrates a Scenario 2 in which the top layer of the porous pavement is replaced by a new layer of porous asphalt. Figure 54 shows the same time histories as Figure 53 but with the average noise level during the 14 years considered in the figure. The difference between the average noise level at the porous and the dense asphalt surface could be defined as the average lifetime noise reduction.

Finally, Figure 55 illustrates three other definitions of the noise reduction met in literature and product descriptions: 1 = initial noise reduction compared to a new reference surface; 2 = initial noise reduction compared to the average lifetime noise level at the reference surface. This average, for example, is the reference value in Nord2000, the Nordic prediction method for road traffic noise; 3 = the noise reduction obtained by replacing old dense asphalt concrete by new two-layer porous asphalt. This is the immediate improvement experienced by road neighbours.

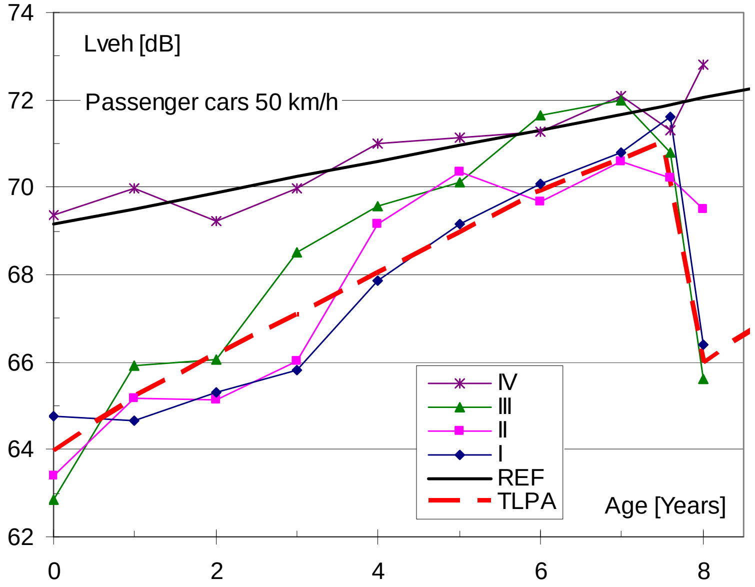


Figure 51. Idealised time histories based on the results in Figure 36, [Kragh-2007b].

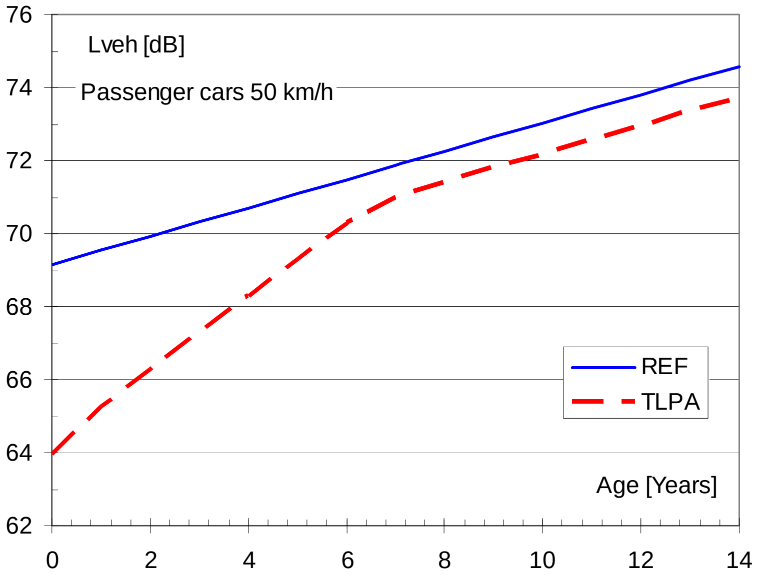


Figure 52. Time history Scenario 1: The porous top layer is not renewed

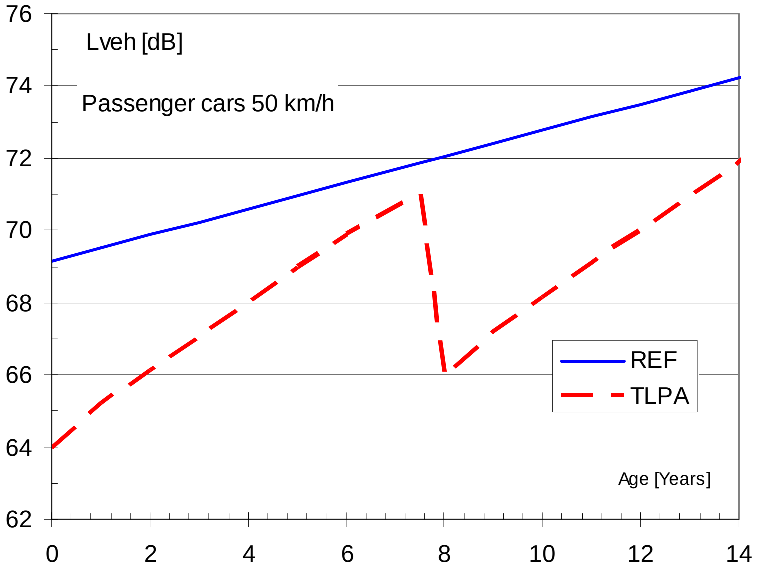


Figure 53. Time history Scenario 2: The porous top layer is renewed in Year No. 8.

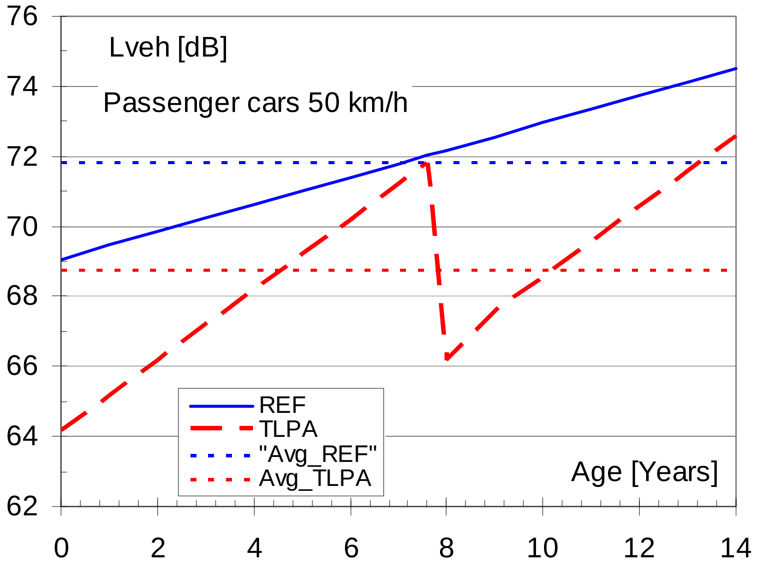


Figure 54. Time history Case 2 with average noise levels and average noise reduction.

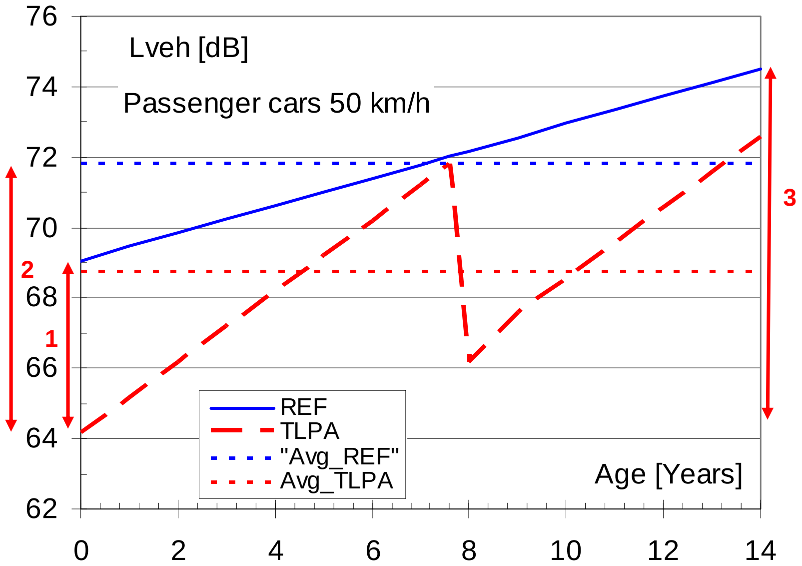


Figure 55. Illustration of other definitions than the average noise reduction.

6.2.3 Total traffic load as a parameter in pavement ageing

One can speculate that the total traffic load during the pavement time in service might a more appropriate parameter to characterize the ageing than the pavement age in years as has been done in the present report. However, it has not been possible within the project to collect such information on the total traffic load.

6.2.4 Summary of regression line slopes.

In Table 10 a summary is given of the regression line slopes determined in the previous sections. The table distinguishes between SPB data and CPX data and groups the results into families of pavement: dense surfaces, thin layer surfaces with an open structure, open graded asphalt, and porous asphalt. The results have been grouped into passenger car noise levels and heavy vehicle noise levels, respectively. High speed is 110 – 120 km/h, medium speed 70 – 90 km/h and low speed 50 km/h.

Inspection of the table will reveal a large variation in the results. The slope varies between zero and almost 0.5 dB per year at dense surfaces such as DAC and SMA. This applies to both passenger car noise levels and heavy vehicle noise levels although the slope of 0.39 dB per year for heavy vehicles is associated with large uncertainty, cf. the comments to Figure 10.

There is a trend for steeper slopes of regression lines for porous and open graded surfacings than for dense surfaces, and the few data available for porous pavement in city streets indicate steeper regression lines for porous pavement on roads with slow traffic than for porous pavements on roads with high speed traffic. In Table 11 an overall summary has been attempted.

Table 10. Summary of regression line slopes, dB per year.

	Source	Passenger cars			Heavy vehicles	
	Speed	**High**	**Medium**	**Low**	**Medium**	**Low**
Dense						
SPB	SILVIA	0.00 / 0.37	0.01/0.21	0.11/0.49	0.04 / (0.39)	-
	LCPC (R2)	-	0.21	-	-	-
	BASt	< 0.05	-	-	< 0.05	-
	DRI	-	0.40	0.33	0.15	-
CPX	DRI	-	0.11 / 0.16	0.13	-	-
	UCPRC	0.03	-	-	-	-
Thin layer						
SPB	LCPC BBTM-1	-	0.25	-	-	-
	BBTM-2		0.42 / 0.78	-	-	-
OGAC						
SPB	DRI	-	0.37	-	0.32	-
CPX	UCPRC	0.30	-	-	-	-
Porous						
SPB	SILVIA *)	0.27	-	-	0.04	0.14
	LCPC	-	0.42	-	-	-
	BASt	0.34	-	-	0.08	-
	DRI	-	0.69 / 0.78	0.98 / 1.09	0.09 / 0.35	-
	DWW	0.41	-	-	0.18	-
	BRRC	-	0.28	-	-	-

*) almost exclusively DWW data

7. Conclusions

No indication could be found that any model (polynomial/logarithmic/exponential) would yield better fit to the data than a simple linear relation between vehicle noise level and pavement service time. This may be due to large scatter in measurement results.

It may be speculated that a clearer pattern might have appeared if each surface had been characterized by the total traffic load it had carried rather than by its number of years in service.

In Table 11 a summary is given of the slopes to be expected for the linear time history of vehicle noise levels.

For both light and heavy vehicles, the slope to be expected at dense asphalt surfacings is in the order of 0.1 dB per year of pavement service time. This applies to high speed as well as low speed roads.

For porous or open graded asphalt surfacings the time history slope for light vehicles can be expected to be in the order of 0.4 dB per year at high speed roads and 0.9 dB per year at city streets with low traffic speed. Heavy vehicle noise levels can be expected to increase with 0.2 per year at high speed roads.

Table 11. Overall proposed time history slopes, dB per year of pavement service time.

	Light vehicles		**Heavy vehicles**	
Surface family \ Traffic Speed	**High**	**Low**	**High**	**Low**
Dense asphalt	0.1	0.1	0.1	0.1
Porous / Open asphalt	0.4	0.9	0.2	-

The traffic noise reduction can be expressed in different ways, please refer to Figure 54 and Figure 55 :

- initial noise reduction relatively to the noise level at a new reference surface
- initial noise reduction relatively to a fixed reference value
- average lifetime noise reduction relatively to a fixed reference value
- noise reduction occurring (and experienced) when a specific old pavement is replaced by a new surfacing.

Whether to express the noise reduction as an initial or an average value is controversial and still under discussion.

Concerning the initial noise reduction, reference is made here to the SILENCE deliverable F.D14A with a pavement noise classification. The average noise reduction can be computed using the time history slope given in Table 11.

The reference value to use as a basis for stating noise reduction may be established regionally or nationally. For example, reference values exist - although they are different - in Denmark and the Netherlands.

8. References

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Appendix SPB measurements repeated in SILENCE F4.5

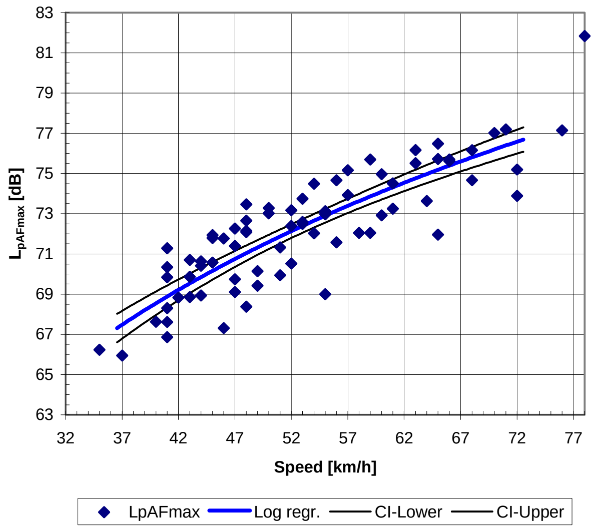
This appendix illustrates the measurement sites and summarizes the results of measure-ments carried out in 1999-2000 and repeated in 2006 by the Danish Road Institute in the present SILENCE project. All measurements were made at a microphone height of 4 m. Other information on the sites can be found in [Kragh-2001].

SPB

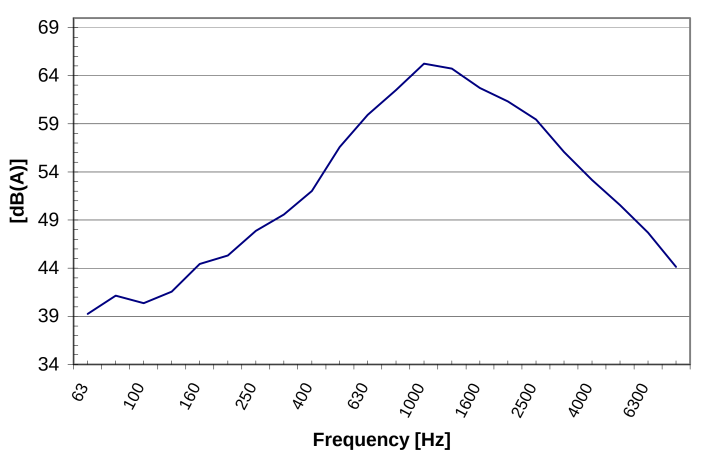
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Englandsvej	L_{veh} at ref. Speed [dB]	71,6	Min	35,0
Number of vehicles	78	Speed constant A	18,1	Max	95,0
Side of road		Speed constant B	31,5	Avg	54,7
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,2	Sdev	12,1
Air temperature [ºC]	25	Temperature correction	Yes		
Road temperature [ºC]	28				
Measurement date	15 Aug. 2000	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
38	67,8	0,7
39	68,2	0,6
40	68,5	0,6
41	68,9	0,6
42	69,2	0,5
43	69,5	0,5
44	69,8	0,5
45	70,2	0,4
46	70,5	0,4
47	70,8	0,4
48	71,0	0,4
49	71,3	0,4
50	71,6	0,4
51	71,9	0,3
52	72,1	0,3
53	72,4	0,3
54	72,7	0,3
55	72,9	0,3
56	73,1	0,3
57	73,4	0,4
58	73,6	0,4
59	73,9	0,4
60	74,1	0,4
61	74,3	0,4



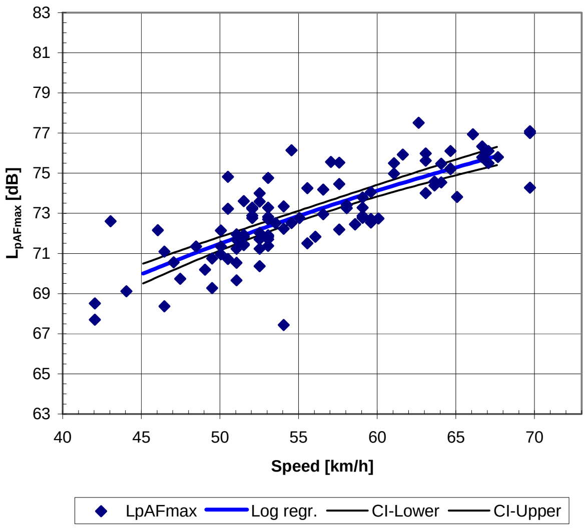
f [Hz]	Lp [dB]
63	38,8
80	40,7
100	39,9
125	41,1
160	43,9
200	44,8
250	47,4
315	49,1
400	51,5
500	56,1
630	59,4
800	62,0
1000	64,7
1250	64,2
1600	62,2
2000	60,8
2500	58,9
3150	55,6
4000	52,7
5000	50,1
6300	47,2
8000	43,6

SPB

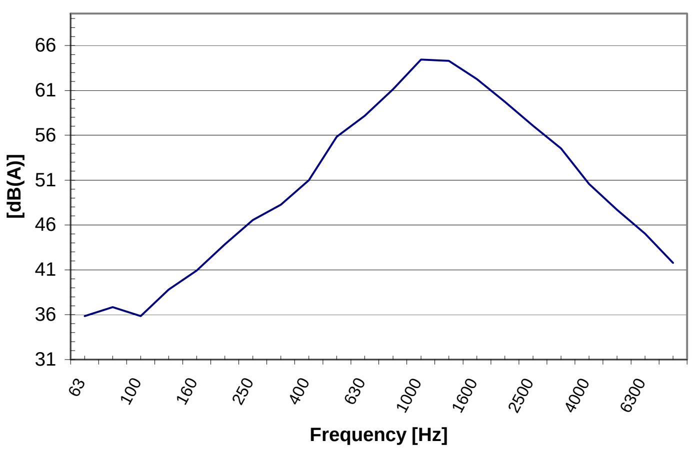
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Englandsvej	L_{veh} at ref. Speed [dB]	71,5	Min	42,0
Number of vehicles	102	Speed constant A	14,8	Max	85,1
Side of road		Speed constant B	33,4	Avg	56,5
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,2	Sdev	7,6
Air temperature [ºC]	17	Temperature correction	Yes		
Road temperature [ºC]	24				
Measurement date	28 Juni 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
45	70,0	0,5
46	70,3	0,5
47	70,6	0,4
48	70,9	0,4
49	71,2	0,4
50	71,5	0,3
51	71,8	0,3
52	72,1	0,3
53	72,3	0,3
54	72,6	0,3
55	72,9	0,3
56	73,1	0,3
57	73,4	0,3
58	73,6	0,3
59	73,9	0,3
60	74,1	0,3
61	74,4	0,3
62	74,6	0,3
63	74,8	0,3
64	75,1	0,4
65	75,3	0,4
66	75,5	0,4
67	75,7	0,4
68	75,9	0,5



f [Hz]	Lp [dB]
63	36,3
80	37,3
100	36,3
125	39,2
160	41,3
200	44,3
250	47,0
315	48,7
400	51,4
500	56,3
630	58,6
800	61,5
1000	64,8
1250	64,7
1600	62,7
2000	60,1
2500	57,5
3150	54,9
4000	51,0
5000	48,1
6300	45,5
8000	42,2


DATE: 28 JUN 06
ROAD: ISLANDS BRYGGE
SURFACE: AB12t

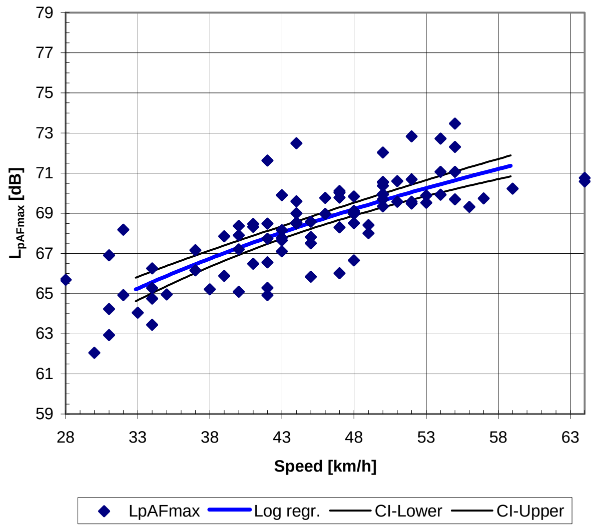

DATE: 29JUN06 ROAD: RINGSTED
SURFACE: AB12t

SPB

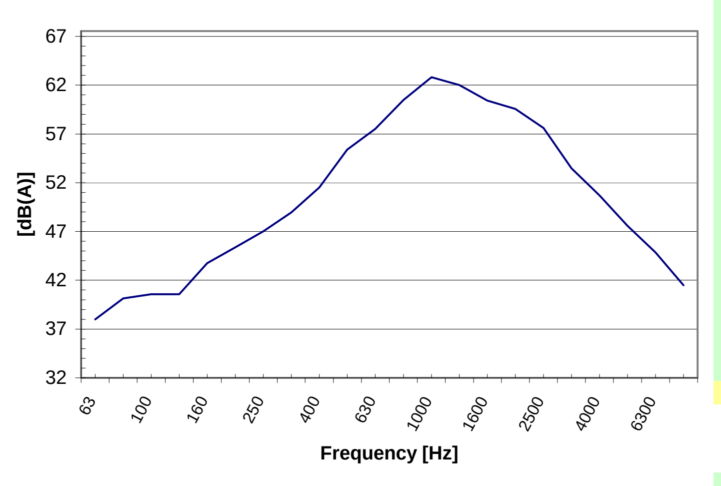
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Islands Br.	L_{veh} at ref. Speed [dB]	69,6	Min	28,0
Number of vehicles	91	Speed constant A	28,3	Max	70,0
Side of road		Speed constant B	24,3	Avg	45,9
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,2	Sdev	8,7
Air temperature [ºC]	25	Temperature correction	Yes		
Road temperature [ºC]	30				
Measurement date	14 Aug. 2000	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
38	66,7	0,4
39	67,0	0,4
40	67,3	0,4
41	67,5	0,3
42	67,8	0,3
43	68,0	0,3
44	68,3	0,3
45	68,5	0,3
46	68,8	0,3
47	69,0	0,3
48	69,2	0,3
49	69,4	0,3
50	69,6	0,3
51	69,9	0,4
52	70,1	0,4
53	70,3	0,4
54	70,5	0,4
55	70,6	0,4
56	70,8	0,5
57	71,0	0,5
58	71,2	0,5
59	71,4	0,5

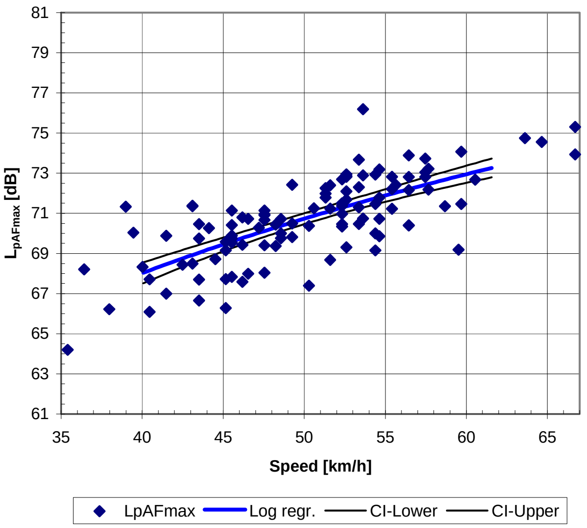


f [Hz]	Lp [dB]
63	37,8
80	40,0
100	40,4
125	40,4
160	43,6
200	45,2
250	46,9
315	48,8
400	51,4
500	55,2
630	57,4
800	60,3
1000	62,7
1250	61,9
1600	60,3
2000	59,4
2500	57,5
3150	53,3
4000	50,6
5000	47,4
6300	44,7
8000	41,4

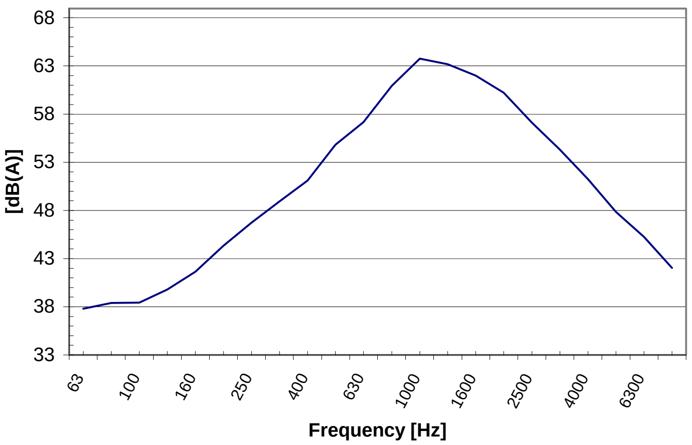
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Islands Br.	L_{veh} at ref. Speed [dB]	70,7	Min	35,4
Number of vehicles	112	Speed constant A	23,2	Max	77,9
Side of road		Speed constant B	28,0	Avg	50,9
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,1	Sdev	7,2
Air temperature [ºC]	16	Temperature correction	Yes		
Road temperature [ºC]	22				
Measurement date	28 Juni 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
40	68,0	0,5
41	68,3	0,5
42	68,6	0,4
43	68,9	0,4
44	69,2	0,4
45	69,4	0,3
46	69,7	0,3
47	70,0	0,3
48	70,2	0,3
49	70,5	0,3
50	70,7	0,3
51	71,0	0,3
52	71,2	0,3
53	71,4	0,3
54	71,7	0,3
55	71,9	0,3
56	72,1	0,3
57	72,3	0,4
58	72,5	0,4
59	72,7	0,4
60	72,9	0,4
61	73,1	0,5
62	73,3	0,5

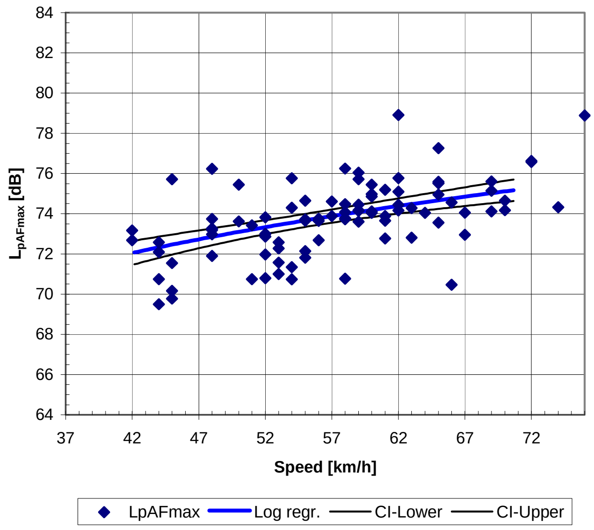


f [Hz]	Lp [dB]
63	38,0
80	38,6
100	38,6
125	40,0
160	41,8
200	44,5
250	46,9
315	49,1
400	51,3
500	55,0
630	57,4
800	61,1
1000	64,0
1250	63,4
1600	62,2
2000	60,4
2500	57,3
3150	54,5
4000	51,5
5000	48,0
6300	45,4
8000	42,2

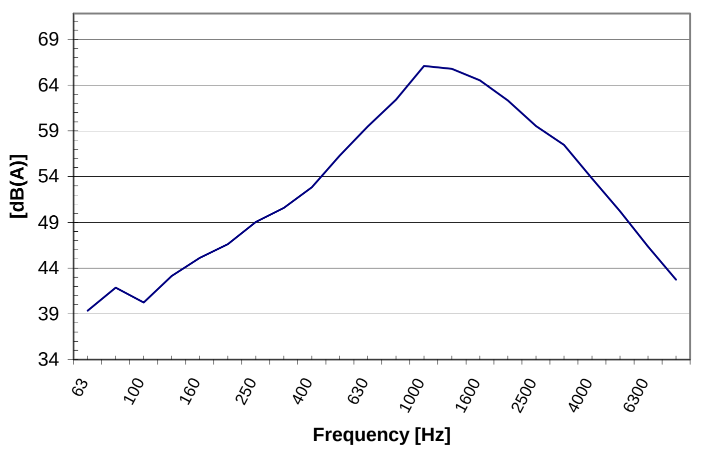
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Ringsted	L_{veh} at ref. Speed [dB]	73,1	Min	27,0
Number of vehicles	96	Speed constant A	49,7	Max	80,0
Side of road		Speed constant B	13,8	Avg	56,5
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,2	Sdev	9,6
Air temperature [ºC]	5	Temperature correction	Yes		
Road temperature [ºC]	2				
Measurement date	15 Nov. 1999	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
42	72,1	0,6
43	72,2	0,6
44	72,3	0,5
45	72,5	0,5
46	72,6	0,5
47	72,7	0,4
48	72,9	0,4
49	73,0	0,4
50	73,1	0,4
51	73,2	0,4
52	73,3	0,3
53	73,4	0,3
54	73,6	0,3
55	73,7	0,3
56	73,8	0,3
57	73,9	0,3
58	74,0	0,3
59	74,1	0,3
60	74,2	0,4
61	74,3	0,4

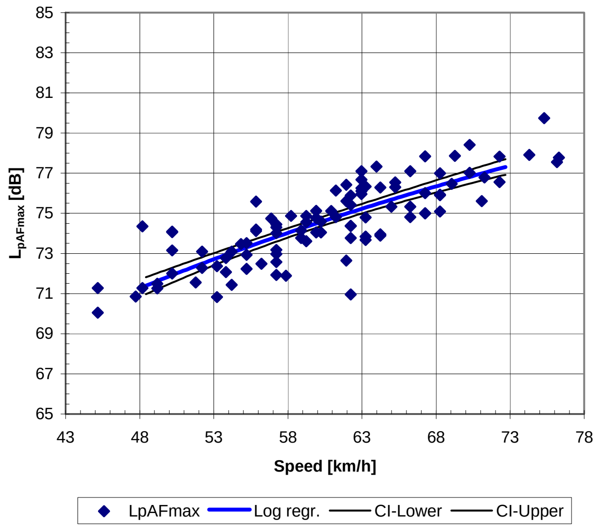


f [Hz]	Lp [dB]
63	39,6
80	42,1
100	40,5
125	43,4
160	45,4
200	46,9
250	49,3
315	50,8
400	53,1
500	56,6
630	59,8
800	62,7
1000	66,4
1250	66,0
1600	64,8
2000	62,6
2500	59,8
3150	57,7
4000	54,1
5000	50,5
6300	46,6
8000	43,0

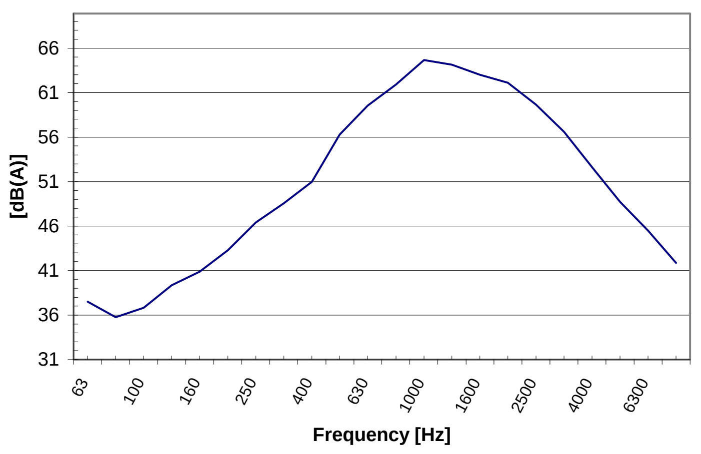
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Ringsted	L_{veh} at ref. Speed [dB]	71,9	Min	39,2
Number of vehicles	103	Speed constant A	14,9	Max	85,3
Side of road		Speed constant B	33,6	Avg	60,6
Reference speed [km/h]	50	Statistical uncertainty [dB]	0,2	Sdev	8,1
Air temperature [ºC]	15	Temperature correction	Yes		
Road temperature [ºC]	22				
Measurement date	29 Juni 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
48	71,3	0,4
49	71,6	0,4
50	71,9	0,4
51	72,2	0,4
52	72,4	0,3
53	72,7	0,3
54	73,0	0,3
55	73,3	0,3
56	73,5	0,3
57	73,8	0,2
58	74,0	0,2
59	74,3	0,2
60	74,5	0,2
61	74,8	0,2



f [Hz]	Lp [dB]
63	37,6
80	35,8
100	36,9
125	39,4
160	40,9
200	43,4
250	46,5
315	48,6
400	51,0
500	56,4
630	59,6
800	62,0
1000	64,7
1250	64,2
1600	63,1
2000	62,2
2500	59,7
3150	56,7
4000	52,7
5000	48,8
6300	45,6
8000	41,9


DATE: 18okt06 ROAD: HELSINGØRMOT
SURFACE: SMA12

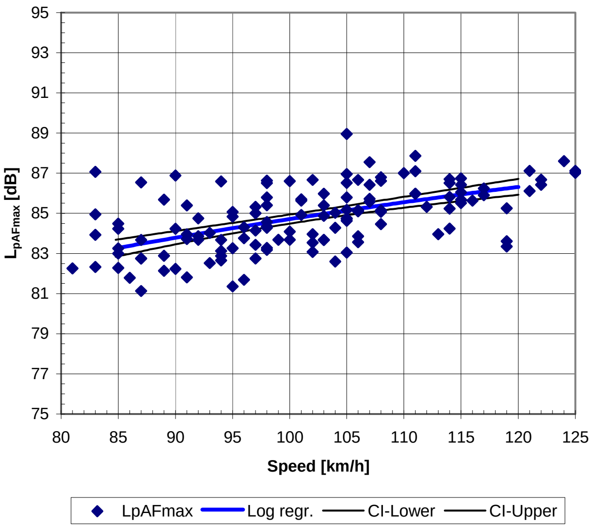

DATE: 29JUN06 ROAD: SAKSKØBING
SURFACE: AB8 t

SPB

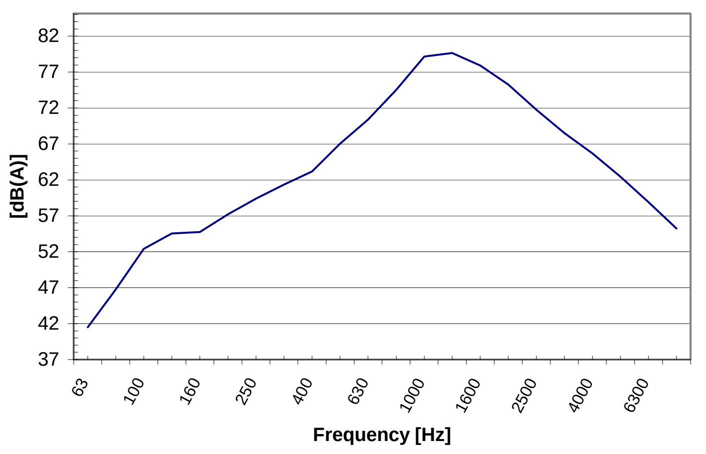
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	SMA 12			**Speed statistics [km/h]**	
Road name	Helsingør	L_{veh} at ref. Speed [dB]	85,6	Min	81,0
Number of vehicles	134	Speed constant A	44,2	Max	142,0
Side of road		Speed constant B	20,3	Avg	102,5
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,1	Sdev	11,8
Air temperature [ºC]	10	Temperature correction	Yes		
Road temperature [ºC]	12				
Measurement date	25 Okt. 1999	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
98	84,5	0,2
99	84,6	0,2
100	84,7	0,2
101	84,8	0,2
102	84,9	0,2
103	85,0	0,2
104	85,1	0,2
105	85,1	0,2
106	85,2	0,2
107	85,3	0,2
108	85,4	0,3
109	85,5	0,3
110	85,6	0,3
111	85,6	0,3
112	85,7	0,3
113	85,8	0,3
114	85,9	0,3
115	85,9	0,3
116	86,0	0,3
117	86,1	0,4
118	86,2	0,4
119	86,2	0,4
120	86,3	0,4

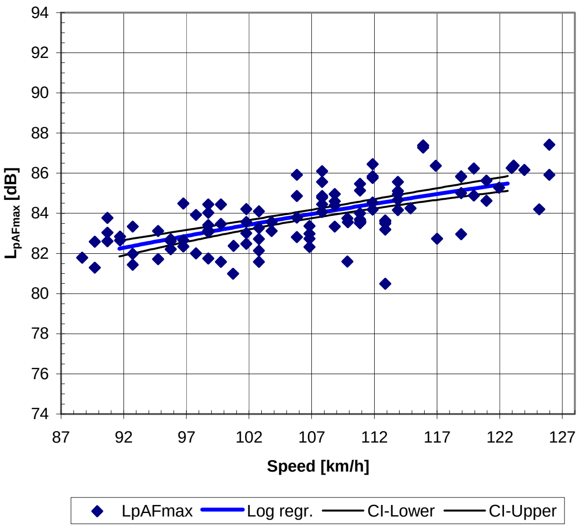


f [Hz]	Lp [dB]
63	41,4
80	46,7
100	52,4
125	54,5
160	54,7
200	57,2
250	59,3
315	61,3
400	63,1
500	67,0
630	70,3
800	74,5
1000	79,1
1250	79,6
1600	77,8
2000	75,2
2500	71,7
3150	68,4
4000	65,6
5000	62,4
6300	58,8
8000	55,1

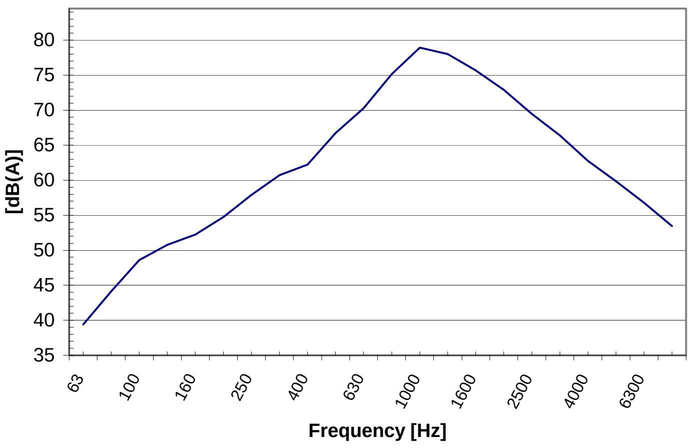
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	SMA 12			**Speed statistics [km/h]**	
Road name	Helsingør	L_{veh} at ref. Speed [dB]	84,3	Min	85,7
Number of vehicles	113	Speed constant A	31,9	Max	134,3
Side of road		Speed constant B	25,7	Avg	107,3
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,1	Sdev	10,4
Air temperature [ºC]	8	Temperature correction	Yes		
Road temperature [ºC]	10				
Measurement date	4 Juli 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
98	83,0	0,3
99	83,1	0,3
100	83,2	0,3
101	83,3	0,2
102	83,4	0,2
103	83,5	0,2
104	83,6	0,2
105	83,8	0,2
106	83,9	0,2
107	84,0	0,2
108	84,1	0,2
109	84,2	0,2
110	84,3	0,2
111	84,4	0,2
112	84,5	0,2
113	84,6	0,2
114	84,7	0,3
115	84,8	0,3
116	84,9	0,3
117	85,0	0,3
118	85,1	0,3
119	85,2	0,3
120	85,2	0,3
121	85,3	0,3

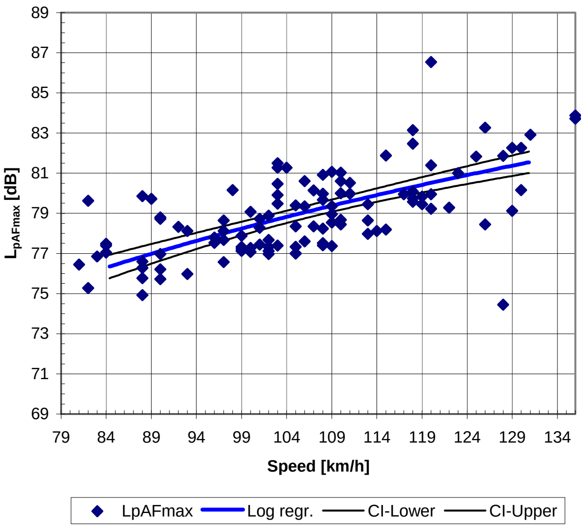


f [Hz]	Lp [dB]
63	39,2
80	43,9
100	48,4
125	50,6
160	52,0
200	54,5
250	57,7
315	60,5
400	62,0
500	66,5
630	70,0
800	74,9
1000	78,7
1250	77,8
1600	75,4
2000	72,7
2500	69,2
3150	66,2
4000	62,5
5000	59,6
6300	56,5
8000	53,2

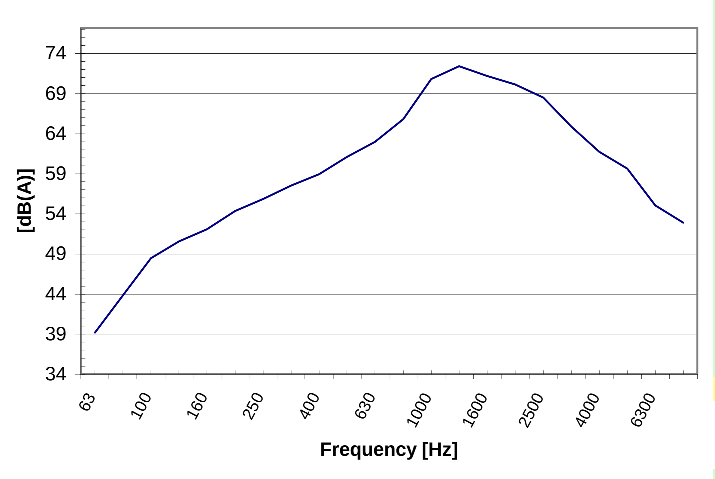
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 8			**Speed statistics [km/h]**	
Road name	Saxkøbing	L_{veh} at ref. Speed [dB]	79,5	Min	78,0
Number of vehicles	116	Speed constant A	23,9	Max	168,0
Side of road		Speed constant B	27,2	Avg	107,6
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,2	Sdev	15,5
Air temperature [ºC]	24	Temperature correction	Yes		
Road temperature [ºC]	28				
Measurement date	29 Aug. 2000	Total uncertainty [dB]			



V [km/h]	**Lpafmax[dB]**	**CI 95%**
98	78,1	0,4
99	78,2	0,3
100	78,4	0,3
101	78,5	0,3
102	78,6	0,3
103	78,7	0,3
104	78,8	0,3
105	78,9	0,3
106	79,0	0,3
107	79,2	0,3
108	79,3	0,3
109	79,4	0,3
110	79,5	0,3
111	79,6	0,3
112	79,7	0,3
113	79,8	0,3
114	79,9	0,3
115	80,0	0,3
116	80,1	0,4
117	80,2	0,4
118	80,3	0,4
119	80,4	0,4
120	80,5	0,4
121	80,6	0,4

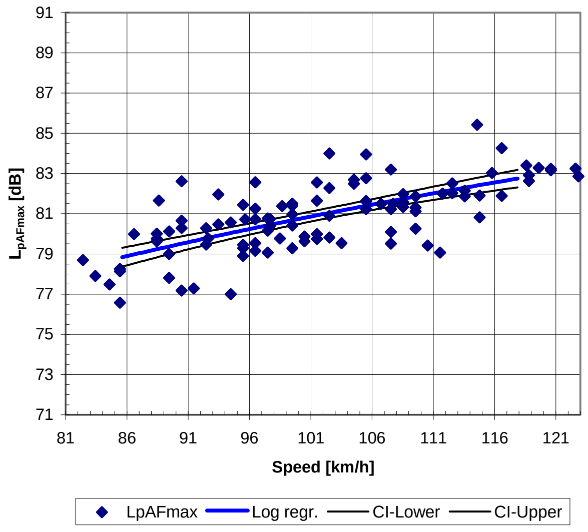


f [Hz]	**Lp [dB]**
63	39,6
80	44,2
100	48,8
125	50,9
160	52,4
200	54,7
250	56,2
315	57,9
400	59,3
500	61,5
630	63,4
800	66,2
1000	71,2
1250	72,8
1600	71,6
2000	70,5
2500	68,9
3150	65,2
4000	62,1
5000	60,0
6300	55,4
8000	53,3

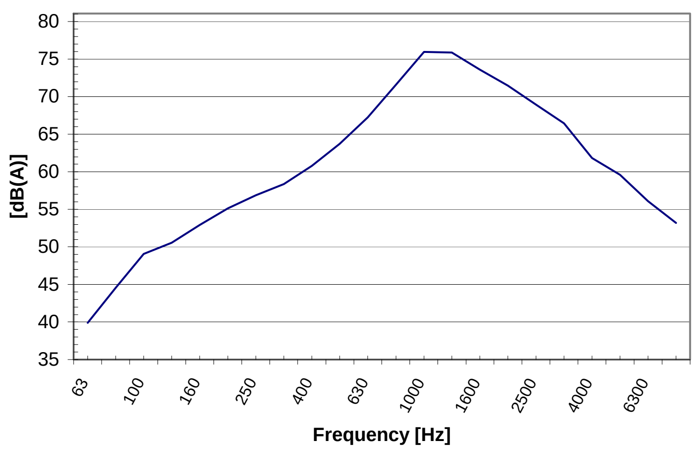
SPB
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 8			**Speed statistics [km/h]**	
Road name	Saxkøbing	L_{veh} at ref. Speed [dB]	81,9	Min	79,4
Number of vehicles	102	Speed constant A	24,4	Max	135,7
Side of road		Speed constant B	28,2	Avg	101,8
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,2	Sdev	10,8
Air temperature [ºC]	18	Temperature correction	Yes		
Road temperature [ºC]	30				
Measurement date	29 Juni 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
98	80,5	0,3
99	80,6	0,3
100	80,7	0,2
101	80,9	0,2
102	81,0	0,2
103	81,1	0,3
104	81,2	0,3
105	81,3	0,3
106	81,5	0,3
107	81,6	0,3
108	81,7	0,3
109	81,8	0,3
110	81,9	0,3
111	82,0	0,3
112	82,1	0,3
113	82,2	0,4
114	82,3	0,4
115	82,4	0,4
116	82,6	0,4
117	82,7	0,4
118	82,8	0,4



f [Hz]	Lp [dB]
63	39,6
80	44,3
100	48,8
125	50,3
160	52,6
200	54,8
250	56,6
315	58,1
400	60,5
500	63,5
630	66,9
800	71,3
1000	75,7
1250	75,6
1600	73,3
2000	71,2
2500	68,6
3150	66,2
4000	61,5
5000	59,3
6300	55,8
8000	52,9

DATE: 4 JUL 06 ROAD: ÅRHUS S km 166.1

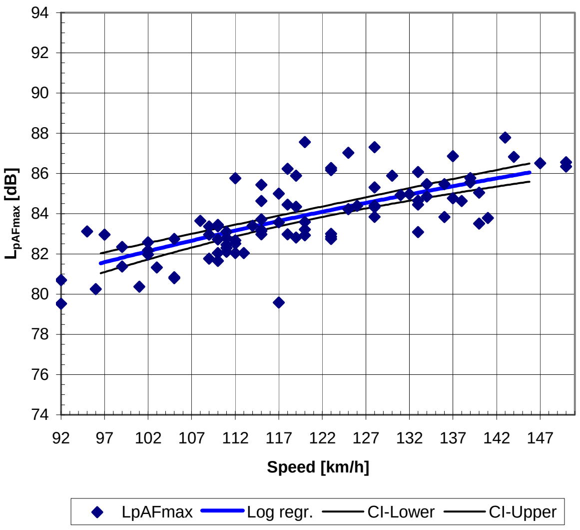
SURFACE: AB12t

SPB

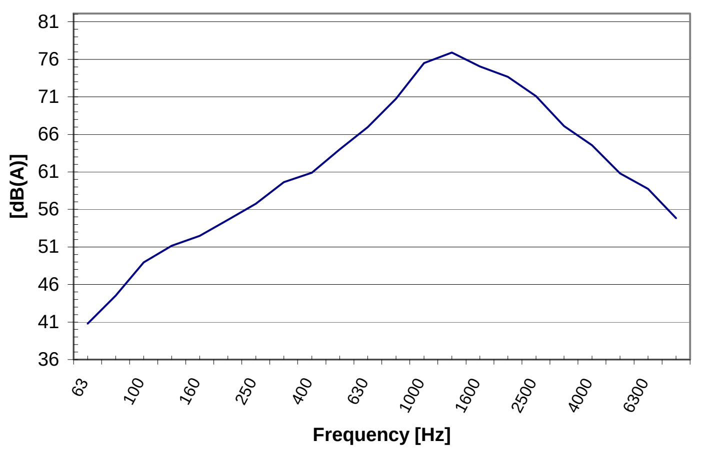
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Århus	L_{veh} at ref. Speed [dB]	83,0	Min	90,0
Number of vehicles	97	Speed constant A	31,5	Max	174,0
Side of road		Speed constant B	25,2	Avg	121,4
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,2	Sdev	16,5
Air temperature [ºC]	16	Temperature correction	Yes		
Road temperature [ºC]	18				
Measurement date	31 Aug. 2000	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
98	81,7	0,5
99	81,8	0,5
100	81,9	0,4
101	82,0	0,4
102	82,1	0,4
103	82,2	0,4
104	82,3	0,4
105	82,5	0,4
106	82,6	0,4
107	82,7	0,3
108	82,8	0,3
109	82,9	0,3
110	83,0	0,3
111	83,1	0,3
112	83,2	0,3
113	83,3	0,3
114	83,4	0,3
115	83,5	0,3
116	83,5	0,3
117	83,6	0,3
118	83,7	0,3
119	83,8	0,3
120	83,9	0,3
121	84,0	0,3



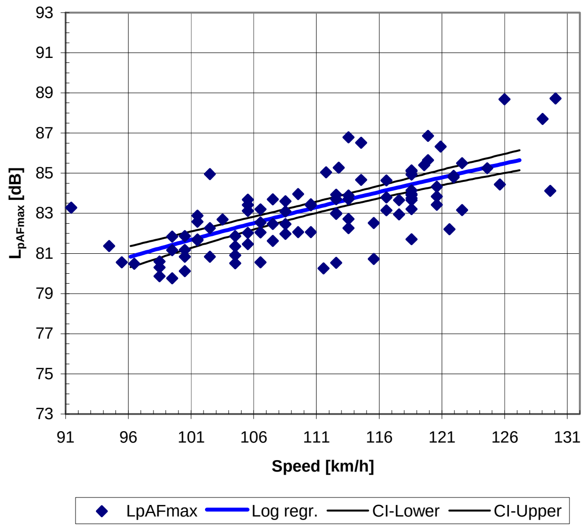
f [Hz]	Lp [dB]
63	40,9
80	44,6
100	49,0
125	51,2
160	52,6
200	54,7
250	56,8
315	59,7
400	61,0
500	64,1
630	67,0
800	70,9
1000	75,6
1250	77,0
1600	75,1
2000	73,8
2500	71,2
3150	67,2
4000	64,7
5000	60,9
6300	58,8
8000	54,9

SPB

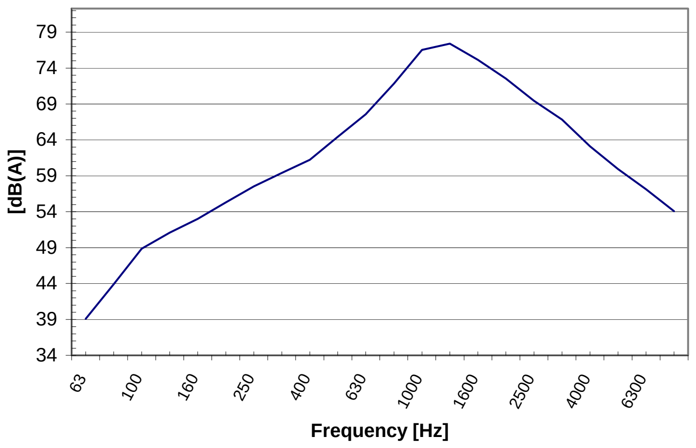
Light vehicles

Road Directorate
Ministry of Transport and Energy

Pavement	DAC 11			**Speed statistics [km/h]**	
Road name	Århus	L_{veh} at ref. Speed [dB]	83,2	Min	85,4
Number of vehicles	103	Speed constant A	2,3	Max	143,3
Side of road		Speed constant B	39,6	Avg	111,7
Reference speed [km/h]	110	Statistical uncertainty [dB]	0,1	Sdev	10,3
Air temperature [ºC]	22	Temperature correction	Yes		
Road temperature [ºC]	30				
Measurement date	4 Juli 2006	Total uncertainty [dB]			



V [km/h]	Lpafmax[dB]	CI 95%
98	81,2	0,5
99	81,3	0,5
100	81,5	0,4
101	81,7	0,4
102	81,9	0,4
103	82,0	0,4
104	82,2	0,4
105	82,4	0,3
106	82,5	0,3
107	82,7	0,3
108	82,8	0,3
109	83,0	0,3
110	83,2	0,3
111	83,3	0,3
112	83,5	0,3
113	83,6	0,3
114	83,8	0,3
115	83,9	0,3
116	84,1	0,3
117	84,2	0,3
118	84,4	0,3
119	84,5	0,4
120	84,6	0,4
121	84,8	0,4



f [Hz]	Lp [dB]
63	39,0
80	43,8
100	48,8
125	51,0
160	52,9
200	55,2
250	57,5
315	59,3
400	61,2
500	64,3
630	67,5
800	71,8
1000	76,5
1250	77,3
1600	75,1
2000	72,4
2500	69,4
3150	66,8
4000	63,0
5000	59,9
6300	57,1
8000	54,0

Rapport / Report		
Nr. No.	Titel/Title/Shortcut	Forfatter/Author
142	Economic assessment of traffic noise in planning – Danish experiences	Lars Ellebjerg Hans Bendtsen
143	Organising urban noise abatement - New ideas	Hans Bendtsen Lene Nøhr Michelsen Brian Kristensen
144	Two-layer porous asphalt - for urban roads	Hans Bendtsen Bent Andersen Jørn Råberg Lars Ellebjerg Jørgen Kragh
145	Thin noise reducing pavements - Experiences	Hans Bendtsen Bent Andersen
146	Cost-benefit analysis on noise-reducing pavements	Lars Ellebjerg
147	Traffic management and noise - INTER-NOISE 2006	Hans Bendtsen Lars Ellebjerg
148	Noise reducing thin layers for highways - INTER-NOISE 2006	Hans Bendtsen Sigurd N. Thomsen
149	Noise reducing thin pavements – urban roads	Sigurd N. Thomsen Hans Bendtsen Bent Andersen
150	Integration of noise in PM Systems - Pavement Management and noise	Hans Bendtsen Bjarne Shmidt
151	Noise Control through Traffic Flow Measures - Effects and Benefits	Lars Ellebjerg
152	Noise from Railway Crossings – Inter·Noise Paper 2007	Hans Bendtsen Sigurd Thomsen
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154	Noise from streets with paving stones - paper for Inter-Noise 2007 in Istanbul	Bent Andersen Hans Bendtsen Jørgen Kragh Sigurd Thomsen
155	Traffic management and noise - Paper for Inter·Noise 2007 in Istanbul	Lars Ellebjerg Hans Bendtsen
156	Traffic noise at rumble strips – Inter·noise paper 2007	Jørgen Kragh Bent Andersen Sigurd Thomsen
157	Assessment of porous pavements – How to look inside	Carsten B. Nielsen
158	Dutch – Danish Pavement Noise Translator	Jørgen Kragh
159	DRI – DWW Thin Layer Project – Final report	Hans Bendtsen Erik Nielsen
160	Thin Asphalt Layers for Highways – Optimised for low tyre / road noise	Bent Andersen Hans Bendtsen
161	Road Surfacings – Noise reduction time history	Jørgen Kragh

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