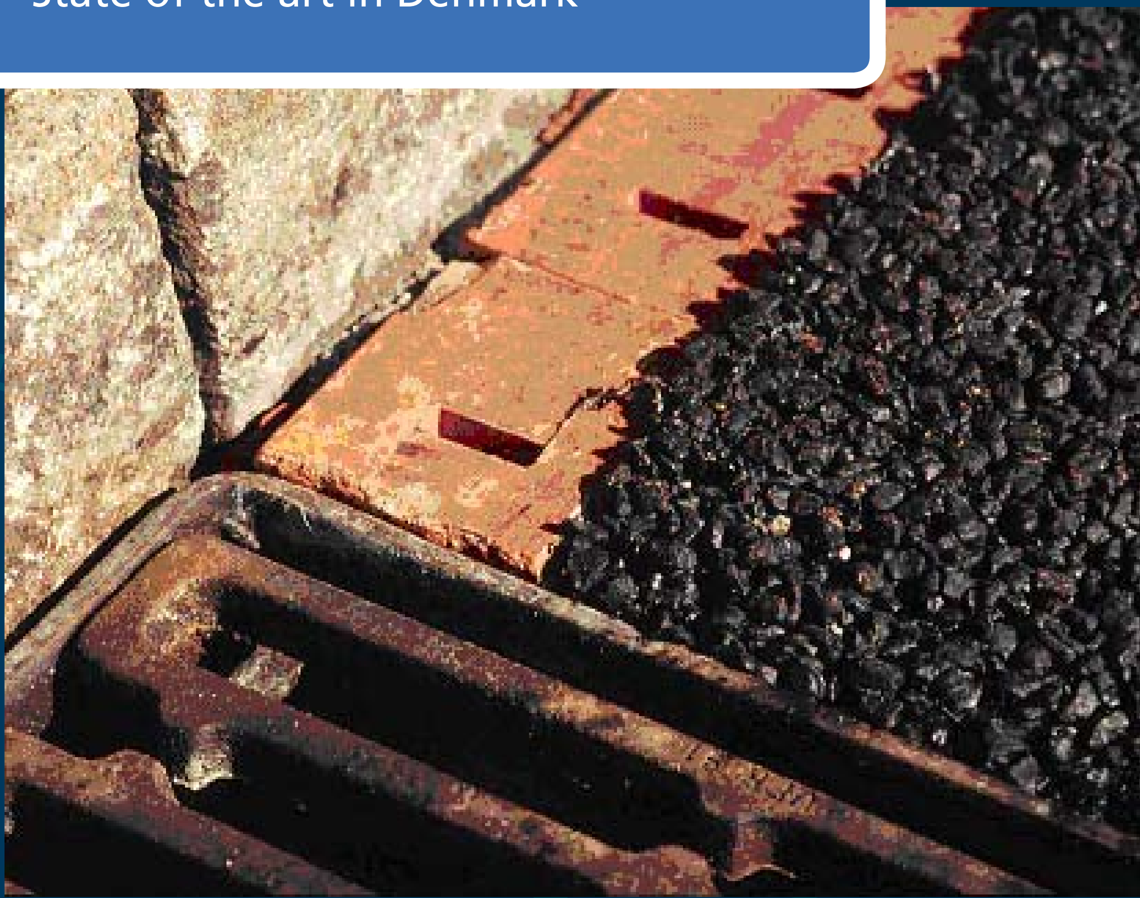
Noise reducing pavements

- State of the art in Denmark



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2005

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Abstract

Noise is one of the most serious environmental problems caused by road traffic. About 28 % of all Danish homes are exposed to more than 55 dB, which is the official recommended noise limit for road traffic noise. The Danish government has a long-term goal to reduce the noise to a level that is considered satisfactory for the health. According to the national road noise strategy, one of the most cost-effective means of noise abatement is the use of noise-reducing pavements.

In this paper, the on-going Danish research to develop and test different types of noise-reducing pavements is presented and discussed. Single-layer porous pavements with a high built-in air void and a small maximum aggregate size have been tested on a highway with a speed-limit of 80 km/h. Over the structural lifetime, the noise reduction of the porous pavements was 3-4 dB relative to dense asphalt concrete with a maximum aggregate size of 12 mm. In order to achieve the same noise reduction, the traffic volume should be reduced by more than 50 %. On an urban test road with a speed-limit of 50 km/h, similar single-layer porous pavements have been tested. Here, the observed noise reduction of 3 dB disappeared within 2 years, because the pores of the pavement were clogged. Three new types of two-layer porous asphalt are now being tested on an urban road with a speed limit of 50 km/h. These pavements are designed and constructed to avoid clogging and to improve durability. The pavements are cleaned with special equipment using water under high pressure twice a year. After four years, noise reductions of approximately 3 dB have been measured compared to a dense asphalt concrete with a maximum aggregate size of 8 mm. In order to develop new types of cost-effective noise-reducing pavements for urban application, research and testing of different kinds of thin surface layers have been started in the framework of an EU research project (SILVIA).

Forord

Denne rapport er produceret som et indlæg på AAPT (Assosiation of Asphalt Paveing Technologists) konferencen i Californien i marts 2005, beskriver igangværende forskning, udvikling og prøvning af støjreducerende belægninger. Et-lags drænasfalt med et højt antal indbyggede hulrum og en lav maksimum kornstørrelse har været testet på motorveje hvor hastighedsgrænsen er 80 km/t. Gennem dens levetid har støjreduktionen på drænasfalten været mellem 3-4 dB i forhold til tæt asfaltbeton med en maksimalkornstørrelse på 12 mm. For at opnå samme støjreduktion på asfaltbeton skulle trafikken reduceres med mere end 50 %. Et lags drænasfalt her på lignende vis også været testet på byvejr hvor hastighedsgrænsen er 50 km/t. Her har man set, at den 3 dB støjreduktion forsvandt efter 2 år formodentligt på grund af tilstopningen af den øverste del af porerne i belægningen. Tre nye typer to-lags drænasfalt bliver i øjeblikket testet på byveje hvor hastighedsgrænsen er 50 km/t. Disse belægninger blev udviklet og bygget med henblik på at undgå tilstopning og at forlænge levetiden. Belægningerne renses med vand under højt tryk ved hjælp af specielt udstyr. Efter 4 år kan man stadig måle støjreduktioner på ca. 3 dB også i forhold til tæt asfaltbeton med en maksimum kornstørrelse på 8 mm. For at kunne udvikle nye typer prisgunstige, støjreducerende belægninger til byområder, forskes og udvikles i SILVIA projektet (delvist EU-finansieret forskningsprojekt) i forskellige typer tynde belægninger.

1. Introduction

According to the latest national noise mapping from 2000, around 28% of all homes in Denmark are exposed to noise from road traffic over 55 dB (as $L_{Aeq,24h}$), which is the official guideline. Therefore, noise is one of the most important environmental problems from road traffic. In order to protect new residential areas, noise has for more than 20 years been an integrated factor in the local urban planning. The guideline of 55 dB must be followed when new houses are constructed. Noise barriers, façade insulation and the design of houses are used as measures to reduce the noise in new dwellings. When new roads are planned and existing roads are enlarged, noise abatement is an integrated part of the projects. The Road Directorate has an on-going program where noise barriers are built along the parts of the national road network where the highest noise levels are found, in order to improve the situation for the neighbors. The planning of the enlargement of the highway ring around Copenhagen is ongoing. It has been decided to use a combination of noise-reducing pavements and noise barriers to reduce the noise in the surrounding built-up residential areas.

In 2003, the government published a national action plan for road traffic noise [1]. According to the plan, noise causes expenses to society because of annoyance, which reduces the house prices and because the noise has an effect on the health. The yearly expenses were stipulated to more than 1 billion US dollars for Denmark with 5 million inhabitants. The cost effectiveness of different means of noise abatement was investigated. It was concluded that the use of noise-reducing road surfaces is a very cost effective tool. There is still a big unsolved noise problem at existing houses along existing roads. The plan encourages local authorities to take up the challenge of noise abatement. Integration of noise as an important factor in the ongoing road maintenance could encourage the use of noise-reducing pavements when the pavements on roads in built-up areas have to be renewed anyway.

There is a big public focus on road traffic noise. Noise is often the most important topic at public hearings on projects of new roads or the enlargement of existing roads. In 2002, EU agreed on a new European directive on external noise [2]. This directive is now being implemented in the 25 member countries. According to this noise directive, noise must be mapped and noise action plans produced. This material shall be published and discussed at public hearings. It is expected that the directive will lead to an increased public demand for noise abatement. Here, the road authorities and the contracting industry can contribute with sustainable solutions encouraging the development and use of noise-reducing pavements as much as it is technically and economically efficient.

While noise barriers provide a good solution in open built-up areas, they are not efficient in urban areas with high buildings. In this case, reduction of the emitted noise is very important – either by reducing the direct noise emission from the vehicles or by reducing the tire/road noise using noise-reducing pavements.

For around 20 years, the Danish Road Directorate has been conducting research and development programs on noise-reducing pavements. The research is characterized by:

- A comprehensive approach including factors as noise, structural durability, traffic safety etc.
- Long-time series of measurements through the lifetime of the pavements.
- A cooperation between research institutes, private consulting companies, contracting companies, and public authorities like the Environmental Protection Agency and road owners (local municipalities).
- International cooperation and knowledge exchange.

Some main results from these research and development activities are presented in this paper.

2. Vehicle noise

Since 1970, the EU has regulated the noise emission from new vehicles sold in Europe. The limit values for type approval of new vehicles have been reduced by 8 to 11 dB from 1970 until today. In the type approval test procedure, a car is driven at a speed of 50 km/h in second or third gear. When the vehicle passes a line, the accelerator is pressed to full acceleration. After 10 meters, the noise is measured under full acceleration where the engine is working under high load and number of revolutions/minute. Because of this, the engine noise is the dominating noise source, and tire/road noise has much less importance. In order to match the tightened noise standards, car manufacturers have reduced the engine noise to fulfill the reduced limit values for noise. Whereas, it has not been necessary to reduce the tire/road road noise as this is not dominant under full acceleration. Figure 1 shows a principal relationship between engine noise and tire/road noise for a passenger car driving with constant speed. It can be seen that, for speeds over 40 km/h, the tire/road noise is the dominant noise source; whereas, the engine noise has little or no influence on the total noise emitted from the vehicle. For trucks and busses, the cross-over between engine noise and tire/road noise occurs at higher speed (60 – 70 km/h).

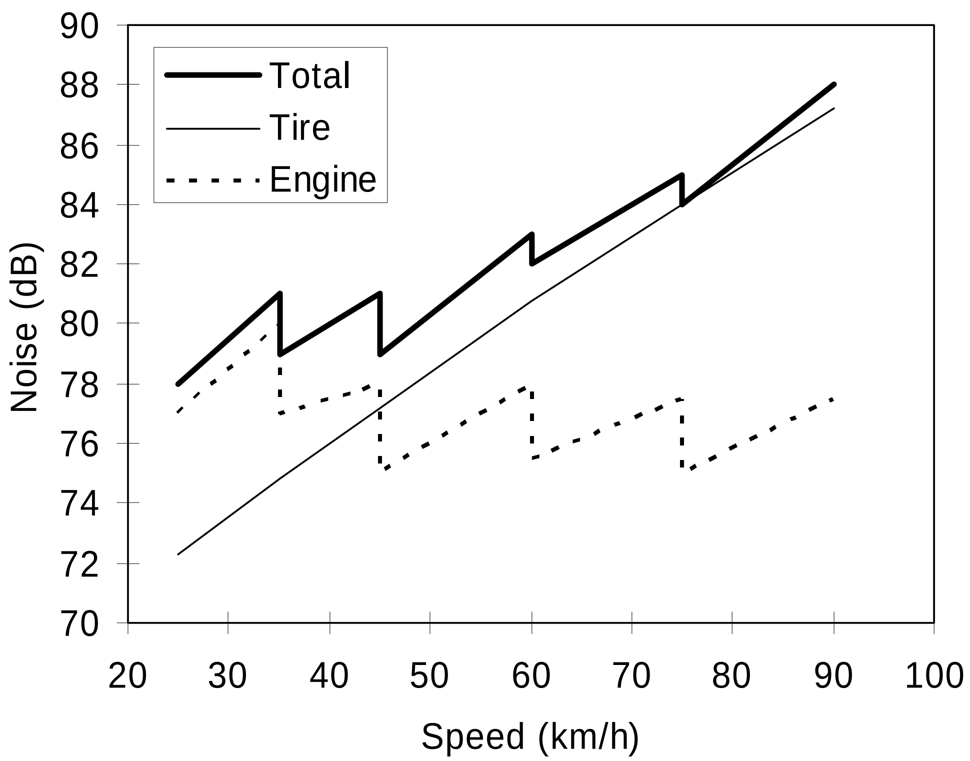

Figure 1. The total noise emitted from a passenger car under normal driving conditions with constant speed. Engine noise, tire-road noise and total noise are shown by different curves.

The first noise emission standards from the 1970s were so high that most of the vehicles on the market could fulfill them. In the beginning, the primary effect of the noise standards was that the most noisy vehicle types disappeared from the market. As the standards were tightened, car manufacturers had to encourage new development and implement constructive changes mainly with a focus on the engine noise. The latest tightening of the noise standards came in to force in 1996. The tightening of the EU standards for type approval of new vehicles have primarily had the following effect:

- The nosiest vehicles have disappeared from the market.
- Noise emission has not increased even though the engines has become bigger and the tires wider.

Detailed noise measurements along the Danish road network have shown that noise emission from cars has generally only decreased about 1 dB in the period from the 1970s to the 1990s [3]. Similar experiences have transpired in other European countries. The reason for this very limited effect is primarily that the type approval is conducted under full acceleration, which does not reflect the real driving pattern on the roads where the speed is much more constant.

Evaluations for the situation in 2020 of the combined effect of the EU regulations on vehicle noise and tire/road noise combined with the expected increase in traffic volume indicate that the general noise level on urban roads will decrease 0.6 dB where as on highways an increase of 0.7 dB will be seen.

It can not be expected that new vehicle technology will solve the noise problems in the coming decades. From this perspective, there is a great challenge for the road sector to develop and test noise-reducing pavements, which can be used to improve the living conditions for the relatively big proportion of the population who are exposed to annoying levels of road traffic noise.

3. Tire road noise generation mechanisms

A number of mechanisms are responsible for the generation of noise from vehicles passing by on a road [4]. One source is the engine and transmission system where the most important frequencies typically are less than 1000 Hz. This noise propagates from the vehicle directly and as a reflection from the road surface. The surface structure is therefore important for the propagation and reflection. If the surface to some degree is absorbant the total noise may be reduced.

The second main source is the tire/road noise, which can be subdivided and described by different mechanisms:

- The aerodynamic noise generated by air pumping, when air is forced out (and sucked in) between the rubber blocks of the tire as the tire rolls on the road surface. This is typically most important in the frequency range between 1000 and 3000 Hz. If the road surface is porous with a high built-in air void, the air can be pumped down into the pavement structure, and the noise generated from air pumping will be reduced.
- The noise from vibrations. The aggregate at the top layer of the pavement forms the pavement texture. When the rubber blocks of the tire hit these stones, vibrations are generated in the tire structure. These vibrations generate noise typically dominated by the frequency range between 100 and 1000 Hz. With a smoother pavement structure, the generation of vibrations and noise is reduced.
- In the driving direction, the pavement surface and the curved structure of the tire forms an acoustical horn which amplifies the noise generated by the tire/road interaction. If the pavement side of this horn is noise absorbing, the noise amplification by the horn effect is reduced.

These mechanisms for noise generation are the background for the acoustical design of the noise-reducing porous drainage asphalt pavements.

When working with noise-reducing pavements, it is very important to have a reference pavement in relation to noise, as this has a significant influence on the noise reductions that can be achieved. In Denmark, dense asphalt concrete with an aggregate size of 8-11 mm is generally used. Pavements containing larger aggregate sizes as well as cement concrete pavements will generally cause higher noise levels than these Danish reference pavements (and hence apparently higher noise reduction figures). Since tire/road noise generation changes with the age of the pavement, it is important to construct reference sections along with test sections. In this way, the influence of age on the noise reduction can be eliminated.

4. Porous pavements first generation

The first generation of porous pavements was tested in two previous Danish experiments. These experiments were started around 1990 [7], with the objective to develop and test a noise-reducing single-layer porous asphalt on a national road (at a speed of 80 km/h near Viskinge) and an urban road (in Copenhagen - at a speed of 50 km/h).

4.1 National road

Five test sections were placed in 1990 on a national highway at Viskinge with a signed speed limit of 80 km/h:

- Dense asphalt concrete (AB12t), as a reference surface.
- Fine-graded porous asphalt (maximum aggregate size: 8 mm), with interconnected pores and 20 % built-in air voids (DA8 18-22 %).
- Fine-graded porous asphalt (maximum aggregate size: 8 mm), with interconnected pores and more than 22 % large built-in air voids (DA8 >22 %).
- A slightly coarser porous asphalt (maximum aggregate size: 12 mm), with interconnected pores and more than 22 % large built-in air voids (DA12 >22 %).
- Open asphalt concrete (AB12aa), (maximum aggregate size: 12 mm) a dense pavement which was considered to offer a possible noise-reducing effect due to its open surface structure.

All noise measurements on the national road [5] were performed using a method very similar to the so-called "Statistical Pass-By" (SPB) method [7]. Noise and speed were measured for individual vehicles passing by. The vehicles were subdivided into 4 categories: passenger cars, vans, trucks with 2 axles, and trucks with more than 2 axles. The results are normalized to 80 km/h and traffic with 80% passenger cars, 10 % vans, 9 % trucks with 2 axles, and 1 % trucks with more than 2 axles. Because of very high traffic intensity on the urban road, it was necessary to measure the noise for the total flow of vehicles. Speed was also measured and the results were normalized to 50 km/h and traffic with 90 % passenger cars and 10 % heavy vehicles.

The noise level of the reference surface (AB12t) increased gradually over the first years by about 1 dB (see Figure 2). In fact, all of the pavements exhibited noise level increases of about 1 dB during the first 2 years of the surface's life cycle.

The open asphalt concrete surface, AB12å, was a little noisier than the reference. During this period, the difference in noise level between the open and dense asphalt concrete increased from about 0.5 dB when the pavements were new to 1 dB at the end of the 7-year period. The hypothesis that this open surface would have a certain noise-reducing effect was disproved. The reason for this is probably the slightly coarser surface texture obtained with 12 mm stones. However, open surfaces of small aggregate size (5 to 8 mm) might still offer some noise-reducing potential.

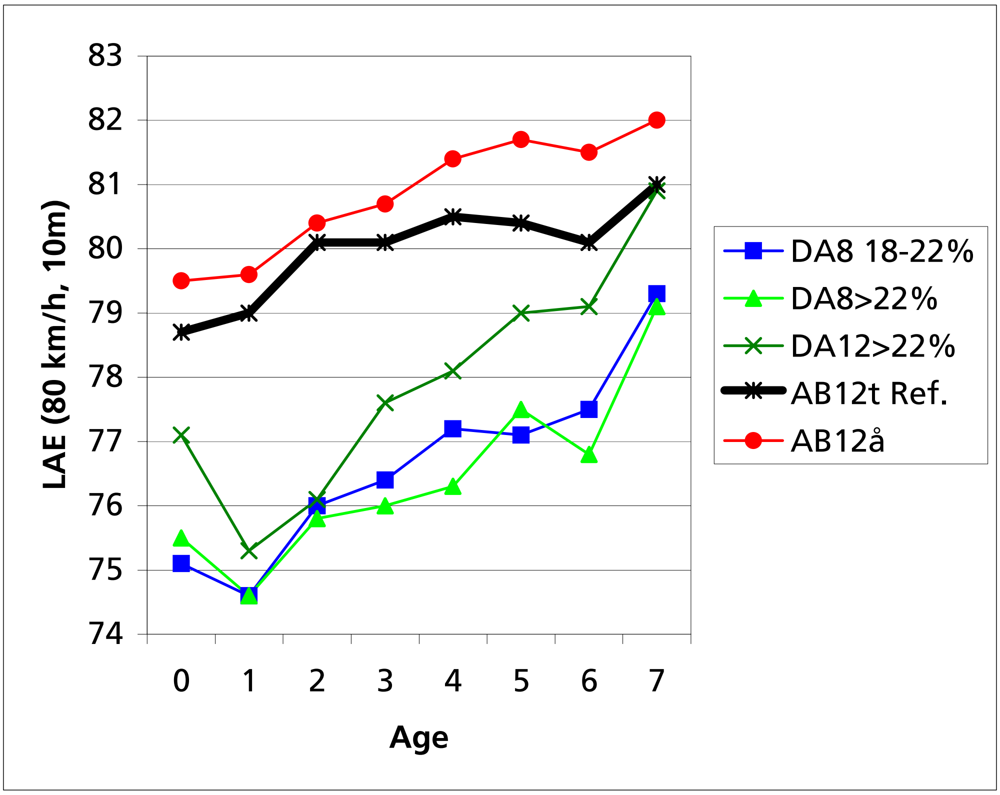

Figure 2. Noise level on test sections at a highway, expressed as L_{AE} values, at 10 m distance in dB, at 80 km/h, for an eight-year period [5, 8].

During each year until year 7, noise levels of the porous asphalt surfaces at the highway were lower than those of the reference surface. In the case of the 2 fine-graded surfaces (DA8), the noise reductions obtained were 3 to 4 dB. In year 7, the noise reduction was still 2 dB. By visual inspection, it was obvious that these pavements were worn down. The surfaces were, after 7 years, very rough because of loss of aggregate at the surface (raveling), and the pavements therefore had to be replaced.

When new, the porous asphalt with a maximum aggregate size of 12 mm (DA12) resulted in 1.5 dB less noise than the dense reference asphalt. Thus, it produced a 2 dB higher noise level than the 2 fine-graded porous asphalt's. During years 1 and 2, the attenuation was largely the same for the 3 porous asphalt pavements, after which the noise level for DA12 increased again over the following years to a reduction of only 1 dB in year 6. After 7, years the noise reduction was gone for this pavement and it was worn down.

4.2 Urban road

An urban test section in Copenhagen (speed-limit 50 km/h) was surfaced with a porous asphalt, with 24 % air voids, which corresponded to the most porous fine-graded porous asphalt (DA8 > 22 %) at Viskinge and had the same maximum aggregate size, i.e., 8 mm [5]. A reference surface like the one on the national test road was also placed on the Copenhagen test road. In relation to the reference surface (AB12t), it can be concluded that the noise reduction level of this porous asphalt was about 3 dB when the surfaces were new. During year 1, the noise reduction decreased to about 1 dB, only to disappear almost entirely during years 2 and 3.

A hypothesis could be that, at the highway at a speed of 80 km/h, the pores of the surface are purged when rain water is forced down (or sucked up) under high pressure by car tires, into the surface structure [5]. The higher the speed, the greater the pressure and the better the cleaning effect. In contrast to the highway tests, the upper layer of the drainage surface at the urban road was not kept open by high-pressure purging, since the pressure caused by the lower speed was insufficient for this [5]. Consequently, the pores of the surface were clogged by roadside dirt, rubber particles, etc.

5. Porous pavements - second generation

5.1 Two-layer drainage asphalt

In the Netherlands, there is a long tradition for using porous pavements as a tool to reduce tire/road noise. The first generation of these pavements was single-layer porous asphalt like the pavements tested in Denmark in the 1990s. The second generation is two-layer porous asphalt that was developed for urban roads to prevent clogging. The second generation of drainage asphalt at an early stage had a very small aggregate size of 4 mm in the top layer [9]. The objective of a Danish project (started in 1998) was to develop, optimize, and test noise-reducing pavements for urban roads with a long-term noise-reducing capacity, based on the Dutch experience with two-layer porous asphalt. The approach of the project is multi-disciplinary. A project group including specialists from research institutions, public administration and the private sector covering the technical fields of acoustics, pavement technology, social surveys, environment, and traffic safety was established. A comprehensive research program was developed to monitor the pavements every year. Factors such as noise, pavement texture, porosity, skid resistance, speed, traffic safety, winter maintenance, and the annoyance of the residents are measured.

Table 1. Overview of the 4 test sections with two-layer porous asphalt on an urban road (Øster Søgade) in Copenhagen.

Test section	Description	Total Thick-ness	Top Layer		Bottom Layer	
			Thickness	Aggregate	Thickness	Aggregate
DA8-70	Porous asphalt	70 mm	25 mm	5/8 mm	45 mm	11/16 mm
DA5-55	Porous asphalt	55 mm	20 mm	2/5 mm	35 mm	11/16 mm
DA5-90	Porous asphalt	90 mm	25 mm	2/5 mm	65 mm	16/22 mm
AC8dense (ref.)	Dense asphalt	30 mm	30 mm	0/8 mm	-	-

The mechanisms for noise generation on road surfaces are the background for the acoustical design of the noise-reducing drainage asphalt pavements to be tested in the project. Three different twin-layer porous pavements were developed. All of the pavements have a high porosity with air voids about 22 to 27 %. This high porosity results in a high noise-absorbing effect, which can reduce the engine noise when it is reflected on the road surface and reduce the horn effect from the tire/road interaction. In order to improve the noise absorption, rather thick porous asphalt structures are tested (55 to 90 mm) (Table 1). The porous pavement structure also has the effect that the air pumping noise will be reduced. In order to minimize the vibrations and noise from the tires, pavements with small aggregate in the top layer are used (5 and 8 mm) in order to get a smooth pavement texture.

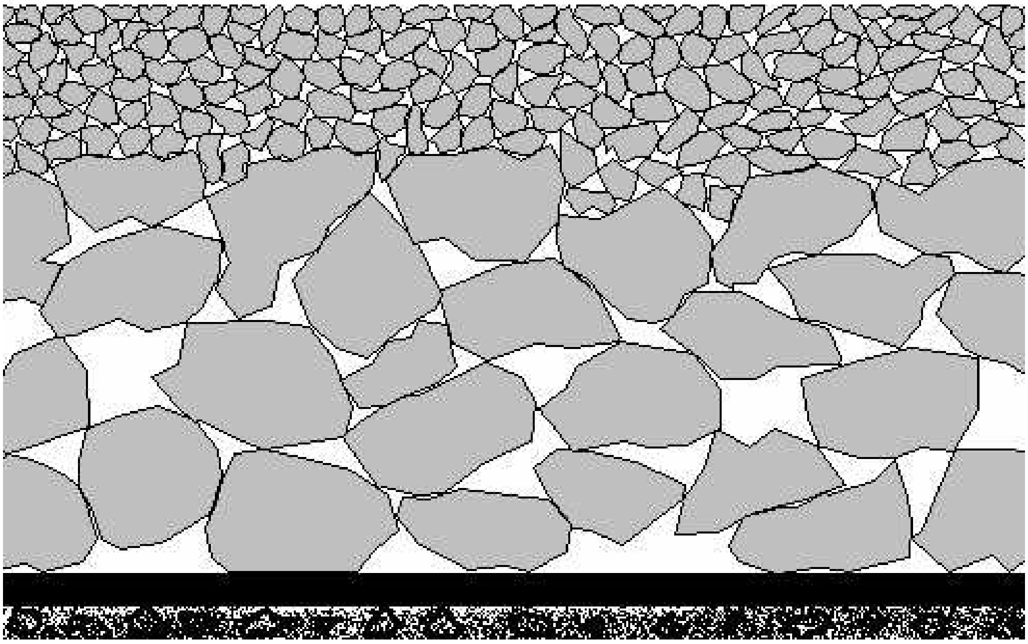

Figure 3. The twin-layer porous asphalt with small aggregates and small pores at the top layer and large aggregate and big pores at the bottom layer.

Figure 4. The drainage blocks at the roadside by the curbstones leading rainwater from the structure of the drainage pavements to the gully. The blocks have a canal inside and holes both on top and on the sidewall.

It is important to design and maintain the porous pavements in such a way that they do not clog and thus maintain their porosity over their whole lifetime. The basic principle is to keep the pores of the pavement open by the use of two-layer drainage asphalt combined with cleaning by high-pressure water and air suction twice a year. The top layer of porous asphalt has a small aggregate size. This ensures small pores in the structure, which prevents big particles and stones from entering the open structure of the pavement. The bottom layer has a large aggregate size (16 or 22 mm) to ensure large pores where water and dirt can run away to the roadside, thereby preventing the pavement from clogging [5, 9]. The principle of the two-layer construction is shown in Figure 3. To conduct rainwater through the bottom of the porous pavement structure at the roadside to the public stormwater system, special drainage blocks are placed at the roadside next to the curbstones to allow rainwater to run to the gully (see Figure 4).

5.1.1 Noise measurements

Noise measurements were made just after the test sections were opened for traffic and one and two years later. Specifications of the SPB method [6] were followed to the extent possible. Maximum noise levels, L_{AFmax}, in 1/3-octave bands, were measured as well as the speed of each vehicle (by radar). Noise is expressed as a slightly modified SPB index assuming the vehicle categories to consist of 80 % passenger cars, 10 % vans, 7.5 % heavy trucks with two axles, and 2.5 % trucks with more than two axles.

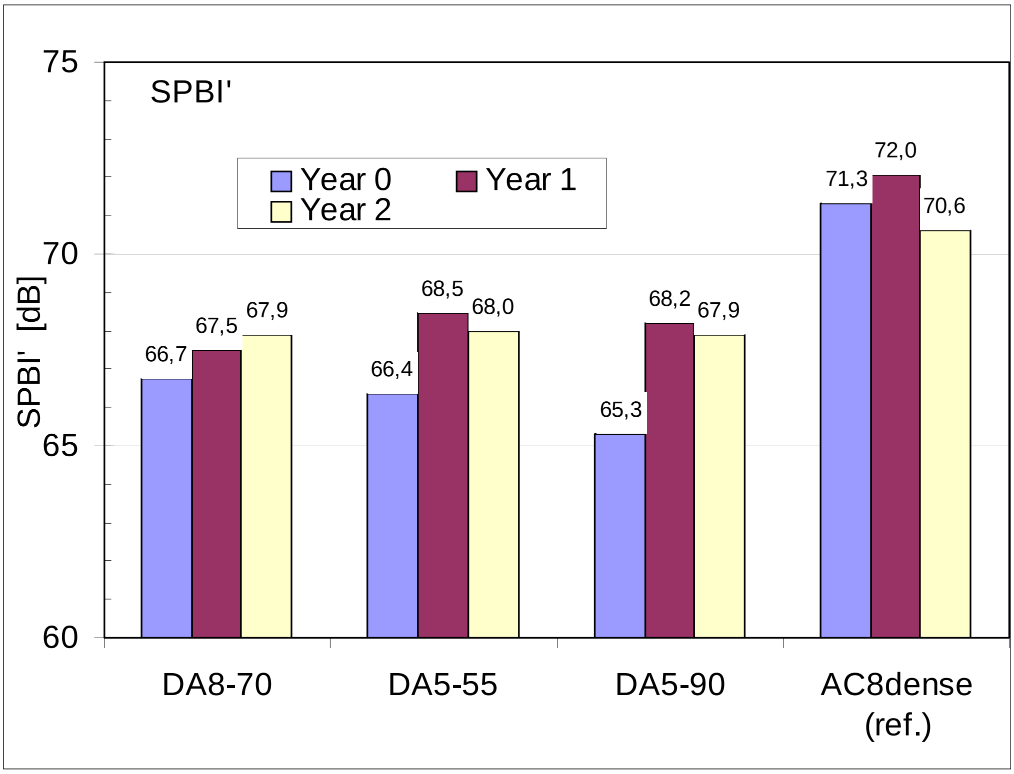

Figure 5. L_{AFmax} for each test section calculated as an average for three measuring positions on each test section in Year 0, Year ,1 and in Year 2 [10, 11].

Figure 5 shows the main results of the noise measurements in year 0, year 1, and year 2. Noise levels increased on all 4 sections from year 0 to year 1. The increase on the reference pavement and the DA8-70 drainage pavement is nearly 1 dB. This was to be expected, as it is known from other projects [5] that the noise level generally increases by 1 dB during the first years of the lifetime of a pavement (see figure 2). On the two fine-graded porous pavements, a larger increase of 2-3 dB was recorded. From year 1 to year 2, there were no significant changes in the noise levels for the three porous pavements. But on the reference pavement, the noise level decreased significantly by 1.4 dB. This was not at all expected (and might be explained by an unusual driving pattern in year 2 due to a big road construction work nearby).

The noise reduction for the porous pavement with the largest aggregate size in the top layer (DA8-70) did not change during the first two years. The noise reduction was 4.4 dB in year 0 and 4.5 dB in year 1. The thin pavement with 5-mm aggregates (DA5-55) exhibited a decrease in the noise reduction from 4.9 to 3.5 dB from year 0 to 1. For the thickest pavement with 5-mm aggregates, there was a 2.2 dB decrease in noise reduction; so the reduction in year 1 was 3.8 dB. From the first to the second year, the noise-reducing effects of all three pavements have been slightly reduced and is now 2.7 dB for all three porous pavements. As the noise at the reference pavement was unrealistically low in year 2, the level from year 1 might be used instead. Under this assumption the noise reduction was 4 dB for all 3 pavements in year 2. The measurement program is still ongoing, and the goal is to follow the pavements throughout their lifetime.

6. Thin layers

As described above, twin-layer porous pavements can reduce noise on urban roads. They are very cost-effective as a noise abatement tool compared to noise barriers and façade insulation [11], but more costly than ordinary pavements. Therefore, there is a need for cheaper types of noise-reducing pavements. Pavements that are cost competitive with “ordinary” pavement types and, at the same time, have a noise-reducing capacity, even though it might not be as good as twin-lay porous pavements. In order to develop and test such pavements, a project was started in Denmark in 2003. The goal was to develop and test thin, open layers as noise-reducing pavements. The project is a part of the European SILVIA project started in September 2002 with 15 partners from 11 countries [13].

The research in work package 4 of the SILVIA project is focused on investigation and testing of existing and new noise-reducing pavement materials, technologies, and maintenance methods to produce guidelines on how to design, build, and maintain sustainable noise-reducing road surfaces. As a part of SILVIA, it has been decided to carry out a subproject in Denmark, where the goal is to develop and test open thin layers as noise-reducing pavements under Nordic conditions (snow and ice during winter but without studded tires). As a nickname, the Danish project is called “SILVIA.DK”. In order to carry out SILVIA.DK, a Danish project group has been established. Experts from the Environmental Protection Agency, The Road Directorate, 3 municipalities as well as the road pavement industry have been invited to be part of the working group.

Thin, open pavements are open only at the upper part of the pavement with cavities having a depth less than the size of the largest aggregate. The basic concept for noise reduction is to create a pavement structure, with as big cavities at the surface as possible in order to reduce the noise generated from the air pumping effect, and at the same time, ensuring a smooth surface to reduce noise generated by vibrations of the tires. Thirteen test sections have been constructed on 3 urban roads in Danish cities. Three different pavement types are included:

1. Open-graded asphalt concrete.
2. Stone mastic asphalt.
3. A thinlayer constructed as a combination pavement. A bitumen emulsion is sprayed on the road and a very open thin layer is placed afterwards. The emulsion fills the pores of the pavement leaving only the top surface very open.

Dense asphalt concrete with 8 and 11-mm aggregate are included as reference pavements.
A comprehensive measurement program will cover noise, structural behavior, durability, traffic safety and energy consumption. Noise measurements are performed using the SPB method.

Table 2. Pavements tested on the Copenhagen test road [12]. Specified data.

Type	Aggregate size, mm	Bitumen	Thickness (approx.), mm	Weight kg/m^2
AC11 dense (reference)	11	70/100 (B85)	30	70
AC8 dense (reference)	8	70/100 (B85)	25	55
AC6 open	6	160/220 1,5 % elastomer	20	45
SMA	6 (+5-8)	70/100	20	45
TP 6k	6	100/150	17	35

The first preliminary results for passenger cars from the measurements on the test road in Copenhagen are shown in Figure 6. The results at 60 km/h show that, even the other dense surface with maximum 8-mm aggregate, gives an 0.8 dB-noise reduction relative to AC11d. The noise reduction for the stone mastics surface is 1 dB greater, while the thin combined pavement gives 1-dB further reduction, almost -3 dB in relation to the AC11d reference surface. When evaluating these attenuations, it should be noticed that the uncertainty on the noise levels is expected to be approximately 0.5 – 1 dB.

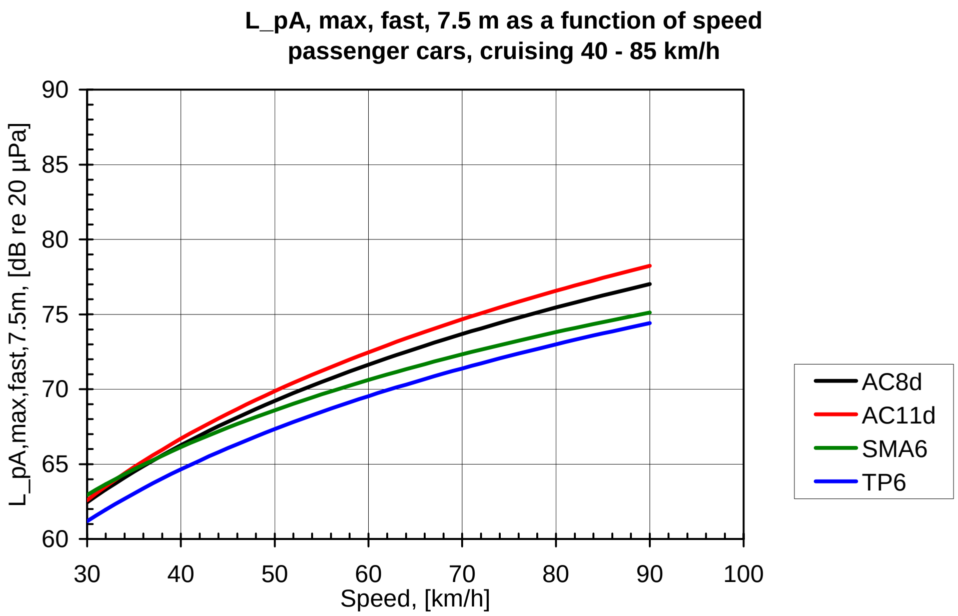

Figure 6. Maximum A-weighted sound pressure level with time-weighting “fast” measured at 7.5-m distance as a function of speed for passenger cars on four different surfaces [12].

7. International cooperation

International cooperation and knowledge transfer has always been an integrated part of the Danish research on noise-reducing pavements. As a new initiative, the Road and Hydraulic Engineering Institute (DWW) in the Netherlands and the Danish Road Institute of the Danish Road Directorate (DRI) have established cooperation for the period 2004 to 2007, called the DRI-DWW Noise Abatement Program. The goal is to carry out joint research and development in issues related to abatement of road traffic noise within the framework of the Dutch Noise Innovation Program (the IPG program [14]). Seven main themes will be highlighted in this joint DRI-DWW research program on noise abatement that includes the following projects:

- Raveling of porous pavements.
- Clogging of porous pavements.
- Thin silent durable pavements.
- Modified bitumen used for porous pavements.
- CPX noise measurements.
- Cost-benefit evaluation.
- Knowledge transfer.

8. Conclusion and perspective

Noise-reducing pavements have been developed and tested in Denmark since around 1990. Test sections have been constructed with different types of pavements optimized for good noise reduction and comprehensive measurement and research programs have been conducted. As a reference pavement in relation to noise, dense asphalt concrete with an aggregate size of 8 or 11 mm were used. The noise emission from pavements changes over the years. Therefore, it is necessary to continue measurements over the lifetime of pavements in order to get true and valid results on the noise reduction.

On a highway (speed 80 km/h), single-layer porous pavement with an aggregate size of 8 mm, have proven to give a noise reduction of 3 to 4 dB over the lifetime of the pavement. A similar pavement used on an urban road (speed 50 km/h) had an initial noise reduction of 3 dB, but due to clogging of the pores of the pavement, the noise reduction disappeared after only two years. In order to prevent clogging and to optimize the noise reduction, two-layer porous pavements were developed for urban roads. In an ongoing experiment in Copenhagen, a noise reduction of 4 dB has been measured after the pavements were two years old. Thin, open layers were also developed and tested as noise-reducing pavements. On an urban road, a noise reduction of 2-3 dB has been measured for passenger cars on very new pavements.

Measurement programs on the urban test sections with two-layer porous asphalt as well as with thin, open layers will be continued in the years to come. The goal is to follow these test pavements throughout their lifetime. A new test section with thin layers on a highway was opened in 2004, and a measurement program has been started. Internationally, the Danish Road Institute is working together with DWW from the Netherlands and is now joining a new upcoming EU program “SILENCE” in order to further strengthen international research in noise-reducing pavements. All of these research and development activities will contribute to the long-term goal, that the road sector obtains efficient tools for reducing noise. This will make it possible for the road sector to contribute actively to the struggle of the societies against road traffic noise by integrating noise as an important parameter in the planning of new roads as well as when maintaining existing roads.

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- Danish Transport Research Institute.
- The Environmental Protection Agency
- The union of Danish pavement contractors and the companies NCC and Skanska.
- The municipalities of Copenhagen, Randers and Aarhus.
- The regional council of Western Zeeland.
- Delta Acoustics and Vibration.
- Atkins Denmark.

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