DVS-DRI
SUPER QUIET TRAFFIC
International search for pavement providing
10 dB noise reduction

DANISH ROAD INSTITUTE
REPORT 178 - 2009
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Road administrations face a challenge to control road traffic noise. Growing public awareness of the annoyance caused by the noise and the adverse effects on citizen health and real estate value imply urgent needs for developing and applying noise reducing pavement.

DVS (Dutch Centre for Transport and Navigation) and DRI (Danish Road Institute/Road Directorate) carried out a joint project to clarify available pavement solutions yielding 10 dB traffic noise reduction when applied on high speed roads (with 85 % light vehicles at 115 km/h and 15 % heavy vehicles at 85 km/h), and to identify potentials for future development aimed at such high noise reduction. DVS-DRI invited VTI (Swedish National Road and Transport Research Institute) to take part in the research.

The work consisted of collecting, analyzing and evaluating information by searching the literature and patents, patent applications and trademarks. The authors’ extensive network was utilized to contact industry representatives and researchers active in national or international projects for the latest news.

The main outcome of the project is that none of the available “ready-to-use” commercial products are able to provide the magnitude of noise reduction we are looking for, namely 10 dB relative to the present Dutch reference.

The most promising product the authors have identified, which is undergoing road testing in Japan, is a poroelastic road surface produced by Yokohama and Nippon Road. The authors’ estimation, based on Japanese measurement results, is that this surface in new condition provides a 10 dB reduction of passenger car noise compared to the Dutch reference. The reduction of heavy vehicle noise has not been tested, but the authors estimate it to be significantly smaller than 10 dB.

Another promising product is a thin layer open graded asphalt wearing course with small maximum aggregate. However, it is uncertain whether such a wearing course is applicable on Dutch and Danish motorways. And if so, it will almost certainly not provide 10 dB reduction of the noise from a traffic mix of heavy and light vehicles, because it is probably not efficient in reducing heavy vehicle noise. Optimized two-layer porous asphalt will probably be more efficient in this respect.
To progress in obtaining a traffic noise reduction of 10 dB it will be necessary to add more porosity and/or to develop a wearing course having an elastic skeleton. This can perhaps be realized by adding rubber to the asphalt mix combined with using special aggregates and binders. Various more or less sophisticated solutions are discussed in the present report. Some may be realistic after further development while others may prove to be purely speculative.

At present an assessment of the durability, cost or other properties of such future solutions is not feasible.

This result is based on a world wide search for pavement types and concepts. The main objective of this search was - on the background of the most recent knowledge - to point at design principles and criteria for pavements with high potentials for noise reduction, focused on optimum mix designs.
RESUMÉ

Vejmyndighederne står over for en udfordring med at begrænse støj fra trafikken. Befolkningens voksende opmærksomhed på støjens generende virkning og de negative virkninger på helbred og på boligernes ejendomsværdi har skabt behov for at udvikle og anvende støjreducerende vejbælægninger.

Det hollandske vejdirektorat (Dutch Centre for Transport and Navigation, DVS) og Vejteknisk Institut/Vejdirektoratet (DRI) har gennemført et fælles projekt for at finde ud af om der noget sted i verden findes specielle vejbælægninger som kan give 10 dB lavere niveauer af støjen fra trafik på motorveje (defineret som 85 % personbiler med 115 km/h og 15 % lastbiler med 85 km/h), og at pege på muligheder for i fremtiden at opnå en så stor støjreduktion. DVS-DRI bad det svenske Statens väg- och transportforskningsinstitut (VTI) om at bidrage til projektet.

Arbejdet i projektet har bestået i at indsamle, analysere og evaluere oplysninger ved søgning i litteraturen, patenter, patentansøgninger og varemærker. Forfatterne udnyttede deres netværk til at kontakte repræsentanter for industri og forskere, som er aktive i nationale og internationale projekter med henblik på at indsamle de seneste nyheder.

Projektets hovedkonklusion er at der blandt commercielle produkter ikke findes nogen "klar-til-brug" løsning, som kan give en støjreduktion af den størrelse, som vi er ude efter, nemlig 10 dB i forhold til den nuværende hollandske referenceværdi.


Et andet lovende produkt er en tynd åben belægning med lille maksimal stenstørrelse. Det er dog uvist om en sådan belægning er egnet til brug på danske og hollandske motorveje, og selvom dette skulle være tilfældet, vil den med stor sandsynlighed ikke give de søgte 10 dB reduktion af støj fra blandet trafik, idet den formentlig ikke er effektiv over for støj fra tunge køretøjer. Optimert to-lags porøs asfalt vurderes at være mere effektiv hvad dette angår.
For at opnå en støjreduktion på 10 dB, vil det være nødvendigt at etablere yderligere porøsitet og/eller at udvikle slidlag med et elastisk skelet. Dette kan muligvis gøres ved at tilsætte gummi til asfaltblandingen sammen med særlige tilslagsmaterialer og bindemidler. Flere mere eller mindre udviklede løsninger diskuteres i nærværende rapport. Nogle af disse kan vise sig at være realistiske, hvis de bliver yderligere udviklet, mens andre formentlig er helt hypotetiske.

For tiden er en vurdering af holdbarhed, omkostninger og andre egenskaber ved sådanne fremtidige løsninger ikke mulig.

Dette er resultatet af en søgning verden over efter specielt støjreducerende vejbelægninger, for - på baggrund af den nyeste tilgængelige viden - at pege på principper og kriterier for optimal mix design med henblik på at opnå meget stor reduktion af trafikstøj.
The Dutch Centre for Transport and Navigation (DVS) and the Danish Road Institute/Road Directorate (DRI) assisted by the Swedish National Road and Transport Research Institute (VTI) in 2008 agreed to search for possibilities to apply special road surfaces in an attempt to reduce traffic noise to a high degree, 10 dB or so relative to the Dutch reference. The costs of the joint research are shared between DVS and DRI.

The present report contains the first results of the project. Another part of the research being conducted in parallel deals with acoustic effects of pavement ageing.

In the Netherlands, Denmark and other European countries, contractors produce various types of noise reducing pavement, and they put their proprietary products on the market. Many such companies and products lack mentioning in the present report. This was decided on because the main objective was to focus on pavements with rather extreme noise reducing potential, a noise reduction beyond what is normally provided by noise reducing pavement.

The work described in the present report was carried out by

DRI Jørgen Kragh (coordinator), Erik Nielsen, Erik Olesen, Katrine Handberg, Hans Bendtsen
DVS Hans Nugteren, Rob Hofman, WillemJan van Vliet
VTI Ulf Sandberg

The sections titled “Ongoing projects in Japan”, “Quiet City Transport (Qcity)” and “STRAIL” were written by DRI, editing input received from VTI. VTI collected and compiled these contributions with shared sponsoring from the EU project PERSUADE, and VTI intends also to contribute these results to the PERSUADE project. The section titled “Expected improvement potential” contains contributions from VTI, co-sponsored by a project for the Swedish Road Administration (SRA). The latter VTI contributions are expected to appear in a VTI report to the SRA.

The study and analysis was based on information from open sources and from experts in public research institutes and in the private sector. The authors express their gratitude to each individual in the pavement and noise sector whose important work have made it possible to compile the comprehensive contents of the present report.

Nærværende rapport indeholder de første resultater af projektet. En anden del af projektet, som stadig er i gang, beskæftiger sig med den akustiske virkning af vejbelægningens ældning.

I Holland, Danmark og andre Europæiske lande udvikler asfaltfirmaer gode støjreducerende vejbelægninger og markedsfører deres produkter. Mange virksomheder og produkter er ikke omtalt i rapporten her, fordi målet var at fokusere på belægninger med særligt stor støjreduction, væsentligt større end for almindelige støjreducerende vejbelægninger

Arbejdet blev udført af:

DRI       Jørgen Kragh (koordinator), Erik Nielsen, Erik Olesen,
           Katrine Handberg, Hans Bendtsen
DVS       Hans Nugteren, Rob Hofman, WillemJan van Vliet
VTI       Ulf Sandberg

Afsnittene ”Ongoing projects in Japan”, “Quiet City Transport (Qcity)” og ”STRAIL” er udarbejdet af DRI ved at redigere materiale modtaget fra VTI. VTI indsamlede og sammenstillede dette materiale med økonomisk støtte fra EU projektet PERSUADE, og VTI agter at formidle resultaterne til deltagerne i PERSUADE. Afsnittet ”Expected improvement potential” indeholder bidrag fra VTI, som er indsamlet i et projekt for det svenske Vägverket, og disse delbidrag forventes publiceret i en VTI-rapport til Vägverket.

De indsamlede og bearbejdede data stammer fra åbne kilder og fra eksperter i offentlige organisationer og private firmaer. Forfatterne takker de støj- og asfalteksperter, hvis indsats har gjort det muligt at sammenstille en så omfattende mængde information, som tilfældet er i nærværende rapport.
1. BACKGROUND AND AIM

1.1 POLITICAL BACKGROUND

Increasing road traffic combined with growing public awareness of annoyance and adverse health effects caused by road traffic noise puts pressure on Dutch, Danish and other road administrations. There is a need for developing and applying noise reduction solutions which are cost-effective, durable, and preferably also contribute in a positive way to the efforts in reducing CO₂ emission.

National and European legislation on traffic noise reduction aims at

- Preventing growth in traffic noise annoyance
- Minimizing the number of citizens exposed to very high traffic noise levels (e.g. 60 dB in the Netherlands), and
- Using source oriented noise reduction measures when possible.

As a consequence, for roads in densely populated areas, pavement with superior noise reducing capacity is needed. It is foreseen that during the next decade, in some cases more than 10 dB of noise reduction will be needed in the Netherlands.

Anticipating that no such pavement is commercially available, the Rijkswaterstaat has initiated the SSW project (Dutch: Super Stil Wegverkeer = Super Quiet Traffic). The aim of SSW is to test - under “semi-traffic” conditions – pavements providing 10 dB of noise reduction. These pavements shall be safe and cost-effective.

To reach the goal of really applying pavement providing 10 dB of traffic noise reduction by the mid of the next decade, SSW interest is focused on pavement ready for testing under traffic exposure. A world wide study was needed to trace down pavement solutions meeting this criterion. Such solutions will be valuable for both the Dutch and the Danish road sectors.

1.2 THE DVS-DRI JOINT RESEARCH PROGRAMME

The positive outcome of the “DRI – DWW noise abatement programme” [Bendtsen-2005a] in 2004 – 2007 integrated in the Dutch IPG programme [IPG-2002], encouraged the continuation of joint research and development in road traffic noise abatement between the national public road research institutes DVS (Centre for Transport and Navigation) and DRI (Danish Road Institute/Road Directorate). DVS-DRI decided also to take advantage of the expertise of VTI (Swedish National Road and Transport Research Institute).
1.3 PURPOSE AND LIMITATIONS OF THE PRESENT REPORT

The project focused on the influence of road pavement while no attention was paid to potential vehicle tyre development since such development is out of the hands of road administrations. The effects of noise screens, façade insulation etc. were also deliberately excluded from the project described here.

The study was limited to pavement types having a potential of providing 10 dB of traffic noise reduction. To this end, also pavement types having been demonstrated to provide 7-9 dB of noise reduction have been considered in cases where the authors believe that they have a potential for further development to reach 10 dB of noise reduction.

In certain cases also other pavement types are mentioned and/or commented upon since they may have been thought or speculated to provide extraordinary noise reduction under certain circumstances and/or assumptions.

No particular search for Dutch products was carried out because DVS is already familiar with these, although a few of such products patented in other countries are tabled in the present report, and a brief state-of-the-art is included to inform Danish stakeholders.
# 2. LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ADT or AADT</td>
<td>Annual Daily Traffic or Annual Average Daily Traffic</td>
</tr>
<tr>
<td>AOT</td>
<td>Acoustic Optimization Tool</td>
</tr>
<tr>
<td>BBTM</td>
<td>Beton Bitumineux Tres Mince or Asphalt Concrete for Very ThinLayers (EN 13108-2)</td>
</tr>
<tr>
<td>BRRC</td>
<td>Belgian Road Research Centre</td>
</tr>
<tr>
<td>CPX</td>
<td>Close proximity measurement method</td>
</tr>
<tr>
<td>CROW</td>
<td>Acronym: Dutch Technology Centre for Transport and Infrastructure</td>
</tr>
<tr>
<td>C_{surf}</td>
<td>Correction for road surface influence in traffic noise computation</td>
</tr>
<tr>
<td>DAC</td>
<td>Dense Asphalt Concrete (In Europe part of EN 13108-1)</td>
</tr>
<tr>
<td>dB</td>
<td>decibel</td>
</tr>
<tr>
<td>DEUFRAKO</td>
<td>German-French Cooperation on traffic research</td>
</tr>
<tr>
<td>DRI</td>
<td>Danish Road Institute/Road Directorate</td>
</tr>
<tr>
<td>DVS</td>
<td>Dutch Centre for Transport and Navigation</td>
</tr>
<tr>
<td>DWW</td>
<td>Dutch Road and Hydraulic Engineering Institute</td>
</tr>
<tr>
<td>ECLA</td>
<td>European patents and classification system</td>
</tr>
<tr>
<td>HAPAS</td>
<td>Highways Authorities Product Approval Scheme</td>
</tr>
<tr>
<td>HOLDDA</td>
<td>Danish Project: Development of durable porous asphalt mixes from lab experiments</td>
</tr>
<tr>
<td>HRA</td>
<td>Hot Rolled Asphalt (EN 13108-4)</td>
</tr>
<tr>
<td>HSE</td>
<td>Health, Safety and Environment</td>
</tr>
<tr>
<td>IPG</td>
<td>Dutch Noise Innovation Program</td>
</tr>
<tr>
<td>LA_{E}</td>
<td>A-weighted sound exposure level (SEL)</td>
</tr>
<tr>
<td>LA_{Fmax}</td>
<td>Maximum A-weighted sound pressure level with time weighting F</td>
</tr>
<tr>
<td>LCPC</td>
<td>Laboratoire Central des Ponts et Chaussées</td>
</tr>
<tr>
<td>LeiStra2</td>
<td>German research program 'Low Noise Road Traffic No. 2'</td>
</tr>
<tr>
<td>N/A</td>
<td>Not Available/Not Applicable</td>
</tr>
<tr>
<td>NMAS</td>
<td>Nominal Maximum Aggregate Size</td>
</tr>
<tr>
<td>OBSI</td>
<td>On-Board Sound Intensity</td>
</tr>
<tr>
<td>PA</td>
<td>Porous Asphalt (EN13108-7)</td>
</tr>
<tr>
<td>PERS</td>
<td>Poroelastic Road Surface</td>
</tr>
<tr>
<td>PERSUADE</td>
<td>PoroElastic Road SUrface: an innovation to Avoid Damages to the Environment</td>
</tr>
<tr>
<td>PWRI</td>
<td>Japanese Public Works Research Institute</td>
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<tr>
<td>Qcity</td>
<td>EU Project: Quiet City Transport</td>
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<tr>
<td>REACH</td>
<td>Registration, Evaluation, Authorisation of Chemicals</td>
</tr>
<tr>
<td>RSI or RSI_{hi}</td>
<td>Road Surface Influence or Road Surface Influence on High speed roads</td>
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<tr>
<td>SBS</td>
<td>Styrene Butadiene Styrene Co-block polymer</td>
</tr>
<tr>
<td>SILENCE</td>
<td>EU Project: Quieter Surface Transport in Urban Areas</td>
</tr>
<tr>
<td>SILVIA</td>
<td>EU Project: Sustainable Road Surfaces for Traffic Noise Control</td>
</tr>
<tr>
<td>SMA</td>
<td>Stone Mastic Asphalt (EN 13108-5)</td>
</tr>
<tr>
<td>SPB</td>
<td>Statistical Pass-By measurement method</td>
</tr>
<tr>
<td>SRA</td>
<td>Swedish Road Administration</td>
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<tr>
<td>SSW</td>
<td>Dutch: Super Stil Wegverkeer = Super Quiet Traffic</td>
</tr>
<tr>
<td>TESS</td>
<td>Trademark Electronic Search System, American Patent and Trademark Office</td>
</tr>
<tr>
<td>TLPA</td>
<td>Two-Layer Porous Asphalt</td>
</tr>
<tr>
<td>TRL</td>
<td>Transport Research Laboratory, UK</td>
</tr>
<tr>
<td>VTI</td>
<td>Swedish National Road and Transport Research Institute</td>
</tr>
<tr>
<td>WIPO</td>
<td>World Intellectual Property Organization (office under the United Nations)</td>
</tr>
<tr>
<td>WnT</td>
<td>Dutch: Roads to the Future</td>
</tr>
</tbody>
</table>
3. INTRODUCTORY REMARKS

3.1 WHAT IS MEANT BY “NOISE REDUCTION” HERE?

The term “noise reduction” refers to the noise level of something in relation to a reference, and assumes that the former is lower than the latter. A “noise reduction” in dB shall be a positive value if it really means a reduction, while a negative value for the noise reduction implies that the observed noise level is higher than the reference. This basic rule is often misinterpreted. The reference value for the noise characteristics of pavements is often unclear and may vary from case to case.

All noise levels stated in the present report are A-weighted sound pressure levels and all noise reductions are differences between A-weighted sound pressure levels.

Unless otherwise noted “noise reduction” means the difference in noise level from traffic composed of a mix of light and heavy vehicles relative to the Dutch reference value for the same traffic, see [CROW-2002]. In the present report, noise reduction shall be the difference in noise levels from traffic consisting of 85 % light vehicles at 115 km/h and 15 % 5-axle heavy vehicles at 85 km/h.

The noise reduction stated in the present report is the initial value, i.e. the noise reduction at a newly laid pavement, derived from SPB measurement results. The average noise reduction during the service life of a pavement is dealt with in another part of the DVS-DRI joint research programme. This average noise reduction depends on how the traffic noise level develops over time. If this development differs from that at the reference surface, then the initial noise reduction is different from the life-time average noise reduction.

3.2 REFERENCE VALUES AND NOISE REDUCTIONS

A variety of procedures are used for characterizing the noise reducing capabilities of road surface products in various countries. Some of these have been dealt with in “Annex A – Reference values”. The variations in reference values looked at are all in all in a reasonable range considering the differences in basic assumptions. A noise reduction in the Danish or British classification system may be translated into a 1 dB smaller noise reduction in the Dutch system. The corrections $C_{wegdek}$ in [CROW-2002] are based on rather low reference values. See “Annex A – Reference values” for further discussion.
3.3 EFFECT OF REDUCING LIGHT AND HEAVY VEHICLE NOISE

The graph in Figure 1 illustrates how the goal of 10 dB mixed traffic noise reduction can be achieved in various ways. For example, a pavement reducing both light and heavy vehicle noise emission by 10 dB will of course reduce the level of mixed traffic noise by 10 dB. But also a pavement reducing light vehicle noise by more than 10 dB and heavy vehicle noise by less than 10 dB may be a candidate. If, for example, heavy vehicle noise is reduced by 7 dB, it takes almost 15 dB of light vehicle noise reduction to get a 10 dB reduction of traffic noise. 8 dB of light vehicle noise reduction combined with 4 dB of heavy vehicle noise reduction yields a 6 dB reduction of the noise from mixed traffic.

Figure 1. Reduction (in decibels shown in the legend) of noise from mixed traffic (85 % light vehicles at 115 km/h and 15 % 5-axle heavy vehicles at 85 km/h), as a function of heavy and light vehicle noise reduction, cf. text.
4. DUTCH STATE OF THE ART - IPG

This section is intended as a summary of findings concerning pavement noise reducing properties in the Dutch IPG project, which amongst others the Danish stakeholders may not be familiar with.

4.1.1 IPG TARGETS
The noise reduction targets within the IPG concerning pavements are summarised in Table 1, derived from [Morgan-2008b].

Table 1. IPG noise reduction targets for pavement technology.

<table>
<thead>
<tr>
<th>Status</th>
<th>Noise reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed, implementable products</td>
<td>4 dB average over technical lifetime</td>
</tr>
<tr>
<td>Demonstrated products (further work required before implementation)</td>
<td>6 dB average over technical lifetime</td>
</tr>
</tbody>
</table>

4.1.2 IPG RESULTS
The most relevant results of IPG - quoted from [Morgan-2008b] - in the context of the present report are:

**Single-layer PA**
The average initial noise reduction for single-layer porous asphalt is 4 dB.

**Two-layer PA**
Optimized two-layer porous asphalt (TLPA) provides an initial noise reduction of 6 dB - and an average deterioration in acoustic performance of 2 dB over the technical lifetime of the pavement.

**Thin layer wearing course systems**
Thin layers provide an initial noise reduction of 4.7 dB on the average with a standard deviation of 0.8 dB.

**Note:** It was pointed out that while the thin layer noise reduction for passenger cars can be comparable to that of TLPA, thin layers perform poorer for heavy vehicle noise than TLPA. An average noise reduction for light vehicles of 4 – 6 dB, corresponds to 3 dB reduction of heavy vehicle noise.

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1) Thin layer pavements cover a wide range of pavement material.
3rd generation surfaces, WnT

The IPG was preceded by the Dutch program "Roads to the Future" (WnT 2), [Rijkswaterstaat-2005]. In this program very quiet pavements were designed and constructed. While IPG focused on the short term and on the quietest roads currently available, i.e. TLPA, the WnT focused on the long term and on very quiet roads, preferably laid with innovative fast construction techniques and also quickly replaceable. WnT was an innovation programme of the Dutch Ministry of Transport to challenge the market to propose innovative solutions.

Rollpave

Rollpave is a porous thin layer surface manufactured off-site under factory conditions as single-layer porous asphalt and rolled onto a drum. The drums are transported to the site and the asphalt is unrolled.

The noise reduction at the Rollpave surface was expected to be 6 - 7 dB. On the basis of the measured initial noise reduction from the test section on A50, the noise reduction for light vehicles (100 km/h) was found to be 6 dB. Status is that the noise reduction equals that of Dutch thin surface layers (for passenger cars at 80 km/h: 4.0 dB (type A) or 5.2 dB (type B)).

However, the measured initial noise reduction on the A35 and A37 test sections was only 4 - 5 dB.

Modieslab

Modieslab pavement consists of piled foundations, concrete support slabs and a two-layer porous cement concrete pavement.

The expected noise reduction - based on the WnT project - for the Modieslab surface was 6-7 dB. The measured initial noise reduction for light vehicles was 6 - 7 dB at a test section on A50 and 6.1 dB at an IPG test section on A12.

‘Quiet Transport’

The principle of the ‘Quiet Transport’ surface is to have different surfaces across the width of a single lane to optimize noise reduction.

This complex solution was abandoned by IPG because its acoustic performance was no better than the performance of TLPA and the cost-effectiveness was poorer than for TLPA.

2) Dutch: Wegen naar de Toekomst
4th generation solutions

4th generation solutions such as poroelastic and elastic road surfaces were only dealt with in a qualitative manner in the IPG Research Report. Experimental tests sections were built at Kloosterzande using PERS tiles from a Japanese contractor and with commercially available rubber sheet products for preliminary testing of noise performance at to provide data for the modelling work with the AOT.
5. STRATEGY FOR GATHERING INFORMATION

5.1 GENERAL
Various sources of information were available in the quest for pavement types that potentially can or after some development may provide a high level of noise reduction. Some general remarks are valid for many of them.

The issue of this information gathering has been to touch the front line of either scientific or commercial research for extreme solutions. This fact immediately limited how far back in time we needed to search for information. Approximately 10 years is sufficient in most cases because substantial information on this topic, which has been in focus for many years in industrialised countries, would have been put into practise by now.

The strong focus on noise reducing pavement types and "noise reduction" as a buzz word has also the tendency - when a search is conducted - to "contaminate" the result. An example: Descriptions of pavement solutions for extreme weather and for water retention often include undocumented statements concerning noise reducing capability.

In a previous paragraph we highlighted the purpose and limitations of this search but caution also must be exercised in order not to exclude potential candidates that might be developed into the sought solutions. This brings about another issue concerning available information. To search the front line of a field with commercial interests involved may yield limited output - even though you contact research centres and institutes. On the other hand if a commercial research activity has been ceased, this may be a strong signal that no practical and commercial application can be expected beyond the present level of knowledge.

5.2 PATENTS, PATENT APPLICATIONS AND TRADEMARKS
A search for information for a given innovative product or product application involves search for patents and patent applications. This field bears to some extent resemblance to the field of trademarks as they both can be placed under the heading "intellectual property". As some of the better performing proprietary products may be registered with a trademark (nationally or internationally) it is relevant to include this in the search for information.

The strategy has been to use possible combinations of the 1st, 2nd and 3rd term in the lines of Table 2. When multiple words were used, the words were placed within "   ". The term dB was used as an additional filter to prioritize ranking hits in patent literature with documented noise reduction data.
Table 2. Terms used in search for patents, patent applications and trademarks.

<table>
<thead>
<tr>
<th>1st term</th>
<th>2nd term</th>
<th>3rd term used in search outside patent databases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>Noise</td>
<td>AND Patent</td>
</tr>
<tr>
<td>Road material</td>
<td>Noise reduction</td>
<td></td>
</tr>
<tr>
<td>Pavement</td>
<td>Noise reducing pavement</td>
<td></td>
</tr>
<tr>
<td>Pavement material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poroelastic</td>
<td></td>
<td>AND Patent</td>
</tr>
<tr>
<td>Poro-elastic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2.1 PATENTS AND PATENT APPLICATIONS

The search has been conducted in several databases, because even if a database claims to include global or world wide data, these are often limited to some other database with similar content.

The following databases and web sites have been used in the search for patents:

- **www.FreePatentsOnline.com**
  - **Covers:**
    - US Patents
    - US Patents applications
    - European patents
    - Abstracts of Japan
    - World Intellectual Property Organization (PCT).

- **www.espacenet.com**
  - **Covers:**
    - European patents and classification system (ECLA).

- **scholar.google.dk**
  - Focuses on scientific literature.

- **www.google.com/patents**
  - Focuses on patents etc.

In this study we searched for innovative/outstanding results with respect to noise reduction by applying a road material. For this reason, only references which document or claim a superior noise performance have been mentioned in the present report. In a patent, a claim shall normally be documented or stated based on a measurement on the product.
This imposes a particular problem in the case of a patent application with a brief abstract but with no documented claim available. Such applications have been mentioned, but it has not been possible to assess their potential for noise reduction. At best an engineering judgement can be given. This is in fact the most common case.

Finally a few general comments with respect to patents:

- In some cases patents are not applied for in order to protect your invention but rather in order to eliminate competitors' possibility for taking out a patent that eventually would limit your legal right to proceed with your present activities. Such patents cover large ranges of product composition that they allow you to continue but they do not reveal what composition you are actually using, so they are poor sources of information.
- Often the real secret of a product is not patented but preserved by secrecy inside the company.
- In some public research facilities (like universities), patent applications have become a way to obtain citations either as a scientist or as an institute. This may play a role in budget-planning and resource allocation between university institutes or in "marketing" towards industry. Such patent applications may imply limited or no practical potential.

5.2.2 TRADEMARKS

Under the World Intellectual Property Organization (WIPO; an office under the United Nations) a treaty exists called the Madrid Agreement which regulates and keeps track of trademarks. These are classified in 45 different classes (Class 1-34 Goods; Class 35-45 Services) where Class No. 19 is "Non-metallic construction products". This includes among other things road construction products like asphalt and bituminous binders. The search for registered trademarks was conducted in the field called "Goods and Services" which more or less acts as an "abstract" for the scope of the trademark.

The following databases and websites were used searching for trademarks:

www.wipo.int/ipdl/en/search/madrid/search-struct.jsp

and

http://www.wipo.int/romarin/

MADRID and ROMARIN cover trademarks registered worldwide under the Madrid Agreement.

http://tess2.uspto.gov/bin/gate.exe?f=tess&state=4009:vsitdk.1.1

covers TESS (Trademark Electronic Search System) which refers to the American Patent and Trademark Office.
5.3 INDUSTRY CONTACTS AND PROPRIETARY PRODUCTS

A search for innovative noise reducing pavement products was carried out through personal contacts to key persons from asphalt companies in Denmark. These companies have been working on research and development of noise reducing pavement for more than five years. Some asphalt contractors have an international parent company and key persons were asked to promote contacts.

Also a search for information on innovative noise reducing pavement products was carried out among known proprietary noise reducing pavement products to obtain up-dated information on the noise reducing properties. The companies are known to improve their products regularly to keep up with international development of noise reducing pavements.

Table 3. Key words used in the literature search.

<table>
<thead>
<tr>
<th>Noise reduction pavement</th>
<th>Silent bituminous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise reduction overlay</td>
<td>Rubber pavement</td>
</tr>
<tr>
<td>Noise reduction asphalt</td>
<td>Rubber overlay</td>
</tr>
<tr>
<td>Noise reduction wearing course</td>
<td>Rubber asphalt</td>
</tr>
<tr>
<td>Noise reduction bituminous</td>
<td>Rubber wearing course</td>
</tr>
<tr>
<td>Noise reducing pavement</td>
<td>Rubber bituminous</td>
</tr>
<tr>
<td>Noise reducing overlay</td>
<td>Poroelastic pavement</td>
</tr>
<tr>
<td>Noise reducing asphalt</td>
<td>Poroelastic overlay</td>
</tr>
<tr>
<td>Noise reducing wearing course</td>
<td>Poroelastic asphalt</td>
</tr>
<tr>
<td>Noise reducing bituminous</td>
<td>Poroelastic wearing course</td>
</tr>
<tr>
<td>Low noise pavement</td>
<td>Poroelastic bituminous</td>
</tr>
<tr>
<td>Low noise overlay</td>
<td>Slurry seal noise reduction</td>
</tr>
<tr>
<td>Low noise asphalt</td>
<td>Slurry seal noise reducing</td>
</tr>
<tr>
<td>Low noise wearing course</td>
<td>Slurry seal low noise</td>
</tr>
<tr>
<td>Low noise bituminous</td>
<td>Quiet slurry seal</td>
</tr>
<tr>
<td>Quiet pavement</td>
<td>Slurry surfacing noise reduction</td>
</tr>
<tr>
<td>Quiet overlay</td>
<td>Slurry surfacing noise reducing</td>
</tr>
<tr>
<td>Quiet asphalt</td>
<td>Slurry surfacing low noise</td>
</tr>
<tr>
<td>Quiet wearing course</td>
<td>Quiet slurry surfacing</td>
</tr>
<tr>
<td>Quiet bituminous</td>
<td>Micro surfacing noise reduction</td>
</tr>
<tr>
<td>Silent pavement</td>
<td>Micro surfacing noise reducing</td>
</tr>
<tr>
<td>Silent overlay</td>
<td>Micro surfacing low noise</td>
</tr>
<tr>
<td>Silent asphalt</td>
<td>Quiet micro surfacing</td>
</tr>
<tr>
<td>Silent wearing course</td>
<td></td>
</tr>
</tbody>
</table>
5.4 ONGOING NATIONAL AND INTERNATIONAL PROJECTS
The review of ongoing projects has been covered via the research team’s contacts and awareness of proceedings from conferences such as InterNoise.

5.5 LITERATURE REVIEW
A literature search was carried out for information on innovative noise reducing products or product applications with epoch-making noise reduction. This search was conducted with the assistance of DRI librarian Katrine Handberg. The key words used in the search are given in Table 3.
6. RESULTS

6.1 PATENTS AND PATENT APPLICATIONS

The documentation in this section of the report was sorted by decreasing level of information stated in the document dealt with.

6.1.1 POROELASTIC SURFACE #1

An elastic pavement material originating from Japan is described in a European patent application [Fukuda-1999]. It consists of crumb rubber from recycled tyres and/or coloured rubber particles together with 0.5-3.0 mm stone aggregate (40 - 75 % by volume) and it is glued together by polyurethane and latex (15 - 30 %). The patent application documents achieved noise reductions of 5.6-7.0 dB compared to Porous Asphalt (with 13 mm nominal maximum aggregate size) which in its turn gives a noise reduction of 3.2 dB, that is a total noise reduction of 9 – 10 dB.

The noise levels at the pavements were determined by measuring the noise from the tires of a passenger car running on the pavement past the test point. The vehicle speed is not documented and it is not specified whether the measured noise level is a maximum level ($L_{AF_{max}}$) or an exposure level ($L_{AE}$).

Note: In Japan, the reference usually is dense asphalt concrete with 13 mm nominal maximum aggregate size, which dominated Japanese motorways and highways before porous asphalt was introduced. When porous pavement is used as a reference in Japan it is usually single-layer porous asphalt with 13 mm nominal maximum aggregate size, which is much the same as Dutch single-layer porous asphalt, but with 13 mm rather than 16 mm nominal maximum aggregate size.

6.1.2 POROELASTIC SURFACE #2

A similar product, also originating from Japan, is described in a European patent application [Satoru-2000]. This product consists of a hard aggregate and an elastic aggregate in which the hard aggregate is 10-75 % by volume. The hard aggregate shall have at least 5 % passing a 1.18 mm sieve, and the elastic aggregate consists of rubber or coloured rubber particles with a diameter of 10 mm or less. The aggregates are bound together by a two-component urethane binder with an addition of organic silane in 0.1 - 5.0 % by the weight of the polyurethane binder. The patent application documents achieved noise reductions of 6.4-9.8 dB measured by a kind of "OBSI" (On Board Sound Intensity) method (quote): "Noise (dB) in the vicinity of a tire of a passenger vehicle running on a dense grain pavement" was measured, and noise (dB) in the vicinity of a tire of a passenger vehicle running on the pavement material

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3) "dense grain pavement" is a direct quote, presumably it means "dense graded"
in accordance with the present invention was measured. The difference was calculated and is defined as the noise reduction effect.”

6.1.3 POROELASTIC SURFACE #3

In a patent application [Maeda-2004] from USA a Japanese team describes an elastic pavement material containing waste rubber. The material consists of crumb rubber from recycled tires (30-70 %) and polyurethane binder (10-30 %) and shall be placed in a layer thickness of 5-30 mm as a topcoat on either cement concrete or porous asphalt. (Porous Asphalt is preferable). The noise reduction was measured using a commercially available car by comparing the pass-by noise level with the noise level on a dense-graded pavement under the same condition. The noise reduction compared to cement concrete pavement was 9-13 dB, corresponding to an estimated 6 – 10 dB light vehicle noise reduction according to Dutch scale.

6.1.4 MISCELLANEOUS PRODUCTS

In the following paragraphs patents are listed with brief comments. The common denominator is that the patents or patent applications have been found as a result of applying the search strategy but based on their English abstract. As the whole text of the documents is either non available or in a language outside the reading ability of the project team, documented noise reductions cannot be evaluated but at best based on an engineering judgement of the abstract content.

They are mentioned in order not to exclude potential candidates. It may be assumed that had the patents mentioned shown very high noise reduction, then a patent application would have been filed somewhere (in USA or in Europe) in full English text. On the other hand, several are quite recent and patent applications in English may be in progress.

The next five Japanese patents are presumed to describe various kinds of poroelastic material with high potential for noise reduction but unknown characteristics with respect to durability and driving properties (amongst other things friction).

[Ishii-2002] describes a resin pavement material containing an elastic aggregate (size not mentioned, presumably rubber particles) glued together by a resin mortar consisting of an inorganic powder 0-300 µm and resin binder.

[Nakajima-2001] describes a cured pavement material comprising rubber-based granules and a polyurethane-based binder on a base or the possibility to adhere a cured paving material on the base. The rubber-based granules are obtained by activating the surface of the rubber-based granules and treating them with an acidic reaction retarder corresponding to isocyanate.
[Nakamura-1997, Nakamura-1998] describes in two patents a porous paving material used in a layered structure consisting of rubber particles bound together with polyurethane based resins into a porous structure.

[Kobayashi-1999] describes a paved layer consisting of hard aggregate, elastic aggregate and polyurethane binder, and the proportion of the hard aggregate to the whole aggregate is made larger than 40 %. The percentage of void is set to 15 to 40 % by using 15 to 30 % (by volume) of polyurethane binder. This patent is not identical with the European patent [Fukuda-1999], but to a large extent the same group of inventors apply for the two patents.

The next patent [Kikuchi-2005] seems to concern a three layered structure of cementitious pavement materials. On normal cement concrete mixture a water retaining material is placed. As capping layer a porous concrete is poured through a mesh on the retaining layer. This last operation is difficult to understand from the abstract as the mesh is called "mesh member 12". Mesh # 12 has an opening of the sieve cloth of 1.78 mm, but it could also be a metric notation meaning 12 mm.

A list of patents or applications was found in a worldwide database as a result of a search pattern related to noise reducing asphalt. However, the documents only have a brief abstract in English while the original documents are in the Chinese, Japanese or Korean language. The abstracts do not contain detailed findings like noise reductions, but some information can be extracted from the original documents as units normally are written using English characters.

The original documents have been scanned for the unit decibel (dB) but this unit has only surfaced in [Masuyama-2005] who describes a combination of function recovery methods for noise reduction of a porous pavement following a washing operation. A resin based emulsion containing finely grained aggregate (maximum aggregate size 0.2 mm) and/or rubber particles are applied to form a coat on the pavement matrix. Apart from the fact that this patent may have the ability to extend the functional lifetime of an existing porous asphalt pavement it is not judged to improve performance beyond traditional porous asphalt with respect to noise reduction.

[Zhongjun-2007, Zhongjun-2008] concern materials consisting of 100 parts coloured asphalt cement, 3-10 parts of thermal plastic elastic particles, 3-10 parts of rubber particle, 3-10 parts of thermal plastic resins and a vulcanizing agent (0.05-0.30 parts). No results of noise reduction measurements are given.

Bridgestone Corp. has in [Nukui-2007] a patent for reducing the clogging effect of porous pavement by constructing a pavement material from bituminous binder and ethylene vinylacetate coblock polymer as binder in a porous matrix of aggregate and rubber chips and/or rubber powder in the voids near the surface. No measurement results are stated.
[Oishi-2005] describes a presumably poroelastic material, but almost no information is given apart from the title.

6.2 TRADEMARKS

The results of our search for international trademarks describing proprietary products (pavement materials) aimed at achieving high noise reduction have been rather meagre. Actually no worldwide trademarks whatsoever were found related to road construction materials (NICE Classification = 19\(^4\), non-metallic construction products).

The focus was then changed to search for the existence of registered trademarks for known proprietary products in this field where asphalt contractors were identified.

Colas:
International asphalt contractor with France as its primary base.

MICROVILLE [Colas-2009a] is a very thin surfacing (i.e. thickness 20 – 30 mm; no information is given on % voids) designed to reduce noise on urban and suburban roads.

NANOSOFT [Colas-2009b] is hot asphalt concrete for application in thin wearing courses (thickness 25 – 40 mm; no information is given on % voids but the air void content is appr. 23%, cf. Section 6.3.1) designed to provide a substantial reduction of vehicle noise. The in-situ trials seem to show spectacular results, at least for light vehicle noise; see the section “Industry contacts and proprietary products” below. NANOSOFT is not registered as a trademark.

RUGOSOFT [Colas-2009c] is a noise reducing, skid-resistant asphalt mix, which reduces vehicle rolling noise by 7 dB. (Measurement details from LRPC in Blois, France, March 2004: drive-by at 90 km/h (isolated passenger vehicle standard)). Two versions of RUGOSOFT exist: thin 30 – 40 mm; very thin 20 – 30 mm; no information is given on % voids). RUGOSOFT is not registered as a trademark.

Eurovia:
International asphalt contractor with France as its primary base.

VIAPHONE [Eurovia-2009] has a 0/6 gap-graded 2/4 mineral structure with a high percentage of 4/6 chips, giving a very coarse particle size distribution curve (the thickness is 20 – 30 mm; no information is given on % voids). Noise reduction according to standard NF S 31-119-2 [NF-1999] is more than 4 dB compared to French 0/10 semi-coarse asphalt mix.

\(^4\) The database is called MADRID and inside it there is a NICE classification and a VIENNA classification.
Heijmans:
Asphalt contractor with its primary base in the Netherlands 5).

TWINLAY is two-layer porous asphalt (TLPA) offering around 4 dB of noise reduction compared to Porous Asphalt 0/16 mm [Masonda-2001]. The thickness is: upper layer 25 mm; bottom layer 45 mm. TWINLAY is a registered trademark in Belgium, France, Italy, Luxembourg, Netherlands, Portugal, Switzerland and Spain.

Tarmac:
Asphalt contractor primarily based in UK. On the company website two proprietary products are mentioned for their noise reducing capability.

MASTERFLEX [Tarmac-2009a] thin asphalt surfacing. Claim from the webpage: "Tests show Masterflex to be one of the quietest surfacings available, giving a high speed Road Surface Influence (RSI_H 6)) of 5.5 dB below that of a standard Hot Rolled Asphalt surface." MASTERFLEX is not a registered trademark.

MASTERPAVE [Tarmac-2009b] Claim from webpage: "Independent noise tests carried out on 14 mm Masterpave on the M40 indicate that the product can significantly reduce traffic noise levels. It is expected that the installation will maintain a significant negative RSI_H during its service life." MASTERPAVE is not a registered trademark.

6.3 INDUSTRY CONTACTS AND PROPRIETARY PRODUCTS

6.3.1 INDUSTRY CONTACTS

France
Through Colas Denmark, Colas France was contacted. According to [Michaut-2009], Colas has designed a bituminous wearing course called Nanosoft.

Nanosoft is the newest generation of noise reducing surfacing. The aggregates and filler in the asphalt mix has 0/4 mm grading curve and the bituminous binder is modified with SBS. The thickness of the Nanosoft asphalt surfacing is given as 25 to 40 mm and the built-in air void content is approximately 23%.

Nanosoft asphalt can be manufactured in any normal type of hot-mix asphalt plant and the laying process is with common pavers and rollers.

5) This reference has been included because the product is patented outside of the Netherlands
6) See “Annex A – Reference values”
In France Nanosoft has been tested in full scale on Route RD 974 – Côte-d’Or region with the following noise values ($L_{A\text{Fmax}}$) for passenger cars at 1.2 m height, 90 km/h after six months of exposure to T1 traffic [Colas-2009d].

<table>
<thead>
<tr>
<th>Surface</th>
<th>Noise Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanosoft</td>
<td>69.4 dB</td>
</tr>
<tr>
<td>BBTM 0/10 reference</td>
<td>78.6 dB</td>
</tr>
</tbody>
</table>


The corresponding Danish reference value is 80.5 dB (at 90 km/h), the Dutch reference 79.5 dB7), and the noise reduction is 11.1 dB relative to Nord2000 DK and 10.1 dB relative to the Dutch reference. However, it must be mentioned that the value for the Nanosoft surface refers to only light vehicles. The amount of heavy vehicles was too low on the site to be measured [Anfosso-2009]. It is expected that the efficiency for heavy vehicle noise is much lower, primarily due to the small aggregate. To truck tyres, the Nanosoft surface texture will be as smooth as DAC 0/6 or similar. Drive axle truck tyres are quietest on rough-textured surfaces, such as surface dressing and on porous surfaces with relatively large aggregate. Nanosoft pores are probably too small to effectively remove all air in truck tyre tread patterns without causing air pressure build-up.

Nanosoft has also been tested in full scale on Ave. Saint-Jean-Baptiste – Nice with the following noise values (CPX close proximity) at 50 km/h after two weeks of exposure to traffic (of both the Nanosoft and the reference surface).

<table>
<thead>
<tr>
<th>Surface</th>
<th>Noise Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanosoft</td>
<td>84.1 dB</td>
</tr>
<tr>
<td>Asphalt 0/10 reference</td>
<td>93.7 dB</td>
</tr>
</tbody>
</table>

The noise reduction is 9.6 dB. The authors assess these measurement results to represent only light vehicle noise.

In September 2007, a Nanosoft wearing course was laid on a rural road near Vejle, Denmark. The Danish Road Institute carried out CPX measurements for Colas Denmark according to the Danish SRS-system [Kragh-2007a]. The results were [DRI-2008]:

- 50 km/h: $CP_{X_{DK}} = 87.0$ dB, noise reduction: 7.0 dB => SPB = 64.8 dB (Figure 2).
- 80 km/h: $CP_{X_{DK}} = 93.1$ dB, noise reduction: 8.9 dB => SPB = 71.0 dB (Figure 2).

The Dutch reference is 1 dB lower than the Danish reference, see Annex A – Reference values, so the noise reduction relative to the Dutch reference was almost 8 dB for light vehicles at 80 km/h.

7) See “Annex A – Reference values”
Due to production mistakes, the durability of the surfacing was not satisfactory and in August 2009 it was replaced by a new Nanosoft wearing course. Figure 3 shows an overall view of the site and Figure 4 shows the surface structure three weeks after it was built.

\[ y = 1.0216x - 24.094 \]
\[ R^2 = 0.9718 \]
\[ s_R = 0.7606 \]

Figure 2. Connection between CPX and SPB results, based on reanalysis of data from [Kragh-2006].

Many references conclude that rubberized hot mix asphalt and rubberized slurry seal reduces the traffic noise. Colas was asked about experience with the application of rubber in asphalt and slurry seal [Michaut-2009]. Colas has poor experience with this and can not recommend the use of recycled tyres in bituminous products. This probably includes their Colsoft surface which contains a substantial amount of rubber, and which was initially claimed to provide significant noise reduction.
Figure 3. View of rural road with new Nanosoft at Vejle, Denmark, August 2009.

Figure 4. Detail of the new Nanosoft pavement at Vejle, Denmark, August 2009. The coin diameter is 24 mm and the diameter of the hole in the coin is 4.4 mm.
**Denmark**
Testing the general properties of asphalt modified with Road+, an additive developed by Degussa AG, Germany, DRI and the Danish asphalt contractor NCC Roads in September 2009 laid an asphalt binder course modified with Road+. This test showed that the Road+ was well mixed into the asphalt and no problems were observed with emission or smell of rubber. Road+ is similar to additives used in warm mix asphalt and the asphalt mix temperature was 140 °C. Road+ properties are described on the company website [Road+-2009].

### 6.3.2 PROPRIETARY PRODUCTS
A review was made of the proprietary products shown in Table 4. They are bituminous wearing course systems known to have noise reducing properties.

Table 4. Reviewed proprietary products from various companies.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Company Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB K SRS Whisper</td>
<td>Micropave</td>
</tr>
<tr>
<td>SMR SRS Whisper</td>
<td>Colsoft</td>
</tr>
<tr>
<td>SMA SRS Whisper</td>
<td>Accoduit</td>
</tr>
<tr>
<td>AB å SRS Whisper</td>
<td>Viagrip</td>
</tr>
<tr>
<td>Novachip</td>
<td>Dubofalt</td>
</tr>
<tr>
<td>SkanTop</td>
<td>Combifalt-SR</td>
</tr>
<tr>
<td>SkanDrain</td>
<td>Pangrip SRS</td>
</tr>
<tr>
<td>Skangrip</td>
<td>Pankas SMA SRS</td>
</tr>
<tr>
<td>Decipave</td>
<td>Pankas AB SRS (AB 6å SRS)</td>
</tr>
</tbody>
</table>

**Danish product**
Of these noise reducing proprietary products one is near to provide innovative noise reduction, namely the Pankas AB SRS (AB 6å SRS) from the Danish asphalt company Pankas [Pankas-2008]. The product is 0/6 mm modified asphalt and the noise reduction according to the Danish SRS-system [Kragh-2007a] is 7.9 dB at 80 km/h, corresponding to 7 dB noise reduction Dutch scale, see “Annex A – Reference values”.

**British product**
The literature search revealed a product from Associated Asphalt Ltd, an asphalt contractor primarily based in the UK, allegedly with noise reducing properties: Safepave 10 mm and 14 mm Thin Surfacing System For Highways [Safepave-2001]. The report shows a noise reduction characterized by the index for Road Surface Influence on High speed roads, $R_{SI_H} = -9.57$ dB, according to the British HAPAS procedure. This is estimated to correspond to 8.5 dB noise reduction Dutch scale, see “Annex A – Reference values”.

**Note 1:** Eq. (1) in Annex A implies the index $R_{SI_H}$ to presume a traffic mix of 83 % light vehicles, 6 % dual-axle and 11 % multi-axle vehicles.

**Note 2:** Values given with two decimals indicate that reporters are unfamiliar with noise measurements - or that the value is intended for use in a noise calculation scheme.
6.4 ONGOING NATIONAL AND INTERNATIONAL PROJECTS

6.4.1 LEISTRA2
In the German project „LeiStra2“, experiments were initiated amongst others to introduce

a) Nanotechnology into asphalt mix and
b) Helmholtz resonators inside porous asphalt concrete.

Test sections were built in June 2009 on a motorway and the first results concerning their noise reducing capacities are expected by spring 2010 [Bartolomaeus-2009].

DVS sent DRI a presentation given at the “Abschlussveranstaltung Leiser Strassenverkehr 2” of a product denoted “resonor” having Helmholtz resonators built into porous asphalt, see Figure 5 [Reuter-2009]. These resonators are expected to give an extra 2 dB of noise reduction [Beckenbauer-2009] but as mentioned, the first results will not be available until 2010.

6.4.2 DEUFRAKO
In the French-German cooperation "DEUFRAKO", LCPC in France and BASt in Germany have carried out a project that included the development of pavements optimized for low noise emission. Some results were presented during the Inter-Noise 2008 conference [Auerbach-2008a]. The SPERoN (Statistical Physical Explanation of Rolling Noise) model was used to predict traffic noise levels at pavement surfaces assumed to be associated with low tyre/road noise emission.

One such solution comprised the structuring of a surface with a moulding tool, perforated metal sheet structured with a negative of the texture to be printed into a resin surface, see Figure 6. The resulting surface should have a totally dense and flat structure. In this surface the metal sheet should “print” a lattice with a grid size of approximately 7 mm. The lattice lines are at 45 degrees to the vehicle driving direction. The width and the depth of the lattice cavities of the pavement were 1-2 mm and 2 mm, respectively. SPERoN prediction had this pavement type to yield approximately 1 dB lower noise levels than two-layer porous asphalt (at 80 km/h), see at the bottom of Figure 6. This prediction result corresponds to a light vehicle pass-by noise reduction of about 6 dB DK-scale or about 5 dB Dutch scale.

A test section with such a special artificial texture was produced on a test track [Auerbach-2009a]. Measurements showed, however, that the predicted low noise properties were not achieved. This was explained by the producer of the surface failing to shape the surface in exactly the intended way.
There were imperfections in the texture which created noise. Nevertheless, the BAST-LCPC team still believes that a surface produced without imperfections would provide approximately the predicted noise properties [Auerbach - 2009b].

Figure 5. Extract from [Reuter-2009] showing the construction of a motorway section with Helmholtz resonators built into porous asphalt.
6.4.3 MODIFIED RUBBER PLATES USED AT RAILWAY CROSSINGS

The authors have noted that a surface similar to the surface shown in the upper part of Figure 6 exists in rubber plates of a commercial material called STRAIL used at railway crossings, see [Bendtsen-2007] and Figure 7. This material is widely used in railway or tramway crossings in many countries.
The pattern of these plates is 3 or 4 times as large as the DEUFRAKO lattice. The STRAIL material has a well-made moulded geometrical pattern and may have the additional benefit of being relatively soft. If the STRAIL material were used with a pattern scaled down by a factor of 3 or 4 (but manufactured in the same way), even better results might be obtained than expected in the DEUFRAKO project, see Figure 6.

By further modifying the rubber carpet by adding vertical drainage holes with their upper openings in the grooves, and with horizontal grooves at the bottom, the surface might even become absorptive and yield additional noise reduction.

Figure 7. Rubber plate used at railway crossings. These plates are made of solid rubber but also has some stones in them, probably to increase skid resistance. The coin diameter is 25 mm.

The STRAIL material, with a pattern scaled down to the size of the DEUFRAKO pattern might give nearly 10 dB of noise reduction. If the DEUFRAKO modelling is right, one might obtain 8 dB by the pattern, and the elasticity might add a couple of dB. If needed one might drill – as mentioned above - vertical holes through the material (in the grooves) to introduce sound absorption and drainage combined with horizontal drainage in the bottom course.
6.4.4 DANISH PROJECT ON THIN LAYER WEARING COURSE SYSTEMS

The Danish Nanosoft pavement at Vejle has been mentioned in the section titled “Industry contacts and proprietary products”.

The Herning-II experiment

A number of thin layer test sections were built in 2008 on a rural road South of Herning [Kragh-2009]. The test section providing the lowest vehicle noise levels was denoted DA 6. It is open graded asphalt concrete with 6 mm nominal maximum aggregate size, 6.6 % bitumen and 9.5 % air voids. The results of SPB measurements carried out one month after opening the road to traffic are given in Table 5.

For light vehicles at 80 km/h this pavement provided 9.2 dB of noise reduction compared to the reference in the Nordic prediction method for road traffic noise, Nord2000, a nine years old asphaltic concrete with 11 mm nominal maximum aggregate size. For heavy vehicles (5-axle trucks) at 80 km/h the corresponding noise reduction was 4.3 dB.

With 85 % light and 15 % heavy vehicles at the speeds mentioned the traffic noise reduction was 6.2 dB relative to Nord2000_DK and 5 dB relative to the Dutch reference, see “Annex A – Reference values”.

Table 5. Results of pass-by measurements at a newly laid DA 6 thin layer, Nord2000 reference values and resulting noise reduction [Kragh-2009], cf. text.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>85</td>
<td>90</td>
<td>71.3</td>
<td>80.5</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>15</td>
<td>80</td>
<td>83.5</td>
<td>87.8</td>
</tr>
<tr>
<td>Traffic</td>
<td>100</td>
<td>88.5</td>
<td>76.5</td>
<td>82.7</td>
</tr>
</tbody>
</table>

6.4.5 PERSUADE

A European project called PERSUADE was launched on 1 September 2009. The acronym stands for "PoroElastic Road SUrface: an innovation to Avoid Damages to the Environment". The project is coordinated by BRRC in Belgium, and the 12 partners include VTI and DRI. The project has two partners from the pavement contracting industry in Europe, one Dutch and one Danish.

Much of the project takes advantage of previous and recent Swedish and Japanese experience with poroelastic road surfaces (PERS). In 2002-2005, VTI conducted a national project aiming at developing PERS, including several laboratory studies and a limited full-scale test on a Stockholm street [Sandberg-2005]. Cooperation with Japan was significant in this project. Part of the EU project SILVIA also contributed to this Swedish project.
PERSUADE aims at developing durable, cost-effective PERS, mainly based on rubber from scrap tyres, which would benefit the environment by contributing to abating traffic noise and vibration, but also helping to solve the problem of more than 3 million tons of tyres being dumped or burned every year in the European Union. The aim is not clearly expressed as a noise reduction value, but the project is an attempt to obtain up to 12 dB of tyre/road noise reduction, related to DAC 0/16, while at the same time solving durability and safety problems causing failure of previous projects.

Five countries will host experimental sites and test various mixes and construction methods. Current plans include prefabricated rolls (like Rollpave), prefabricated panels, and prefabricated covers glued on interlocking blocks. One will also analyze the global, possibly positive impact on CO2 emission. The project duration is six years.

The general goal is to remove doubts about the technical and economical feasibility of the PERS solution for abating road traffic noise by demonstrating successful full-scale applications. The strategy involves the following five steps (quoted from the Contract).

Step 1: In order to maximize the chances of technical success, the following preliminary works will be carried out:
- Laboratory tests with a view to optimizing the material mix with respect to mechanical properties (complex elastic modulus, flexural fatigue, hysteresis), acoustic properties (sound absorption), adhesion (to different sub-base materials), workability, porosity / drainage, resistance to tear and wear, resistance to rutting and resistance to fuel spillage:
- Small-scale field tests of resistance to emergency braking by heavy vehicles and behaviour in case of fire.

Step 2: Once an optimum mix design has been chosen, the material will be produced by specialized partner factories in different types of conditioning with a view to different laying/construction methods, namely delivery of batches of bulk material, application of PERS on paving blocks for urban streets, pre-fabrication of sheets or mats and laying in long stretches followed by rolling the surface around a drum for subsequent transport and unrolling on site where it will be bound to the basecourse by a special technique.

Step 3: The conditioned material will be delivered to the five countries that will build test sections on real roads (B, DK, S, PL, SI) in order to study the behaviour of different variants of PERS under different traffic and climate conditions. The tested solutions will differ somewhat from country to country. The full scale sections will be built in two phases; the second phase following twelve months after the first one. The aim of the staggering is to be able to learn from the experiences with the first phase for the second phase.
Step 4: The test sections will then be followed up by means of initial and periodic measurements and monitoring regarding noise performance (SPB and/or CPX measurements), acoustic absorption, skid resistance, rolling resistance (to be converted into fuel consumption and greenhouse gases (GHG) emissions), drainage (to test possible clogging) and behaviour in winter (salting, snow removal). By the staggering of the construction of the test sections, steps 3 and 4 will be executed partly simultaneously.

Step 5: Finally, a global evaluation of the PERS technology will be performed and disseminated based on the technical results from the full-scale experiments and cost/benefit and Life Cycle Assessment (LCA) using the information gathered from the activities throughout the project, including consideration of waste management balance and global GHG emissions balance.

6.4.6 ONGOING PROJECTS IN JAPAN

Work by Public Works Research Institute (PWRI)

The Public Works Research Institute (PWRI) in Tsukuba City has worked with PERS since 1995 to test durability and friction properties, and no noise data are available. Figure 8 shows

- In-situ construction by Yokohama Rubber Company: 30 mm thick pavement of approximately 50% rubber and 50% (by volume) of sand grains 2.5-3 mm and a binder
- Precast 1x1 m panels made by Sumitomo Rubber Industries, fixed with epoxy resin to a semi-flexible base course
- Precast panels, probably also by Sumitomo, fixed with adhesive tape to new asphalt (not polished).

At the time of visit, 100,000 passages had been made by a 30 ton truck, including (unintentional) braking with locked wheels. There were plans to construct a new 100-300 m long PERS test section on a suburban road in Tokyo.

The main reason for the failure of a previous PWRI experiment with PERS on a highway is believed to be that the surface the adhesive tape was to stick on was not totally clean. Even some dust may create a problem.

Sumitomo is now the major producer of precast PERS. A new producer, named “Okusho” or similar, also tries to master the technology.
Work by Yokohama Rubber Company and Nippon Road Company

In December 2006, the Yokohama Rubber Company laid its first PERS test section on a trafficked street in Zama City. The subjective impression at this new surface was that it "almost completely" reduced noise from cars while it had little effect on truck noise [Sandberg-2006/09]. The surface left the same impression in May 2007 and also in April 2009, when the surface displayed a few minor defects.

The Yokohama version of PERS is a mix of rubber and stone/sand aggregate. Previous versions with 90 % rubber gave low skid resistance when new, and loss of skid resistance with time. The following details were revealed, though the exact information is patented company secret:

- Air void content: 30 %.
- Silica sand, max aggregate size: 5 mm (but 2.5-3.6 mm dominates)
- Rubber granules diameter: approximately 1 mm
- Rubber/aggregate proportion: secret, probably 40/60 by weight
- Binder: polyurethane
- Tack coat under PERS: polyurethane (0.2 kg/m²)
• Base course: semi-flexible surface, polished to get rid of the cement and expose the aggregate

• Carbon black is added to give a darker surface.

Other information obtained at meetings with Yokohama and Nippon Road companies were:

• PERS is not yet considered to have any structural strength, due to missing data, but they are trying to estimate it

• In Zama they used continuous mixing and a paving machine supplying 4 m³/h

• Curing time is 5 h at or above 20 °C and exceeds 8 h at lower temperatures

• The average sound absorption coefficient over the important frequency is 35 % and the spectrum shape is similar to that of porous asphalt

• The tack coat is applied just before paving

• The E-modulus is 25 MPa for the Yokohama PERS, and 250 MPa for the DAC, but one cannot feel that the surface is soft

• Ravelling is only a problem along joints between screeds

• The pavement cost – excl. the semi-flexible surface – corresponding to 150 EUR/m² is considered by the Japanese company to be competitive to noise barrier cost.

About 20 test sections of Yokohama PERS have been built, most in non-trafficked areas or on test tracks. By April 2009 three field tests were ongoing:

• Zama City: a 30 m long section laid in one lane, downhill at a moderate slope, ADT 8000, with 500 heavies, see Figure 9 - Figure 10. It was 29 months old in April 2009 and still in good condition. The PERS thickness is 30 mm and the base course is semi-flexible porous asphalt\(^8\). This was polished to obtain a smooth texture

• Hiratsuka: a 28 m and a 26 m long section laid in March 2009 in one approximately 4 m wide lane on a level street with 50 km/h posted speed. One section is 25 mm, the other 20 mm thick. ADT is higher than in Zama City. See Figure 11 - Figure 12

• On northern Kyushu (the south-western island of Japan), laid in March 2009.

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\(^8\) Japanese semi-flexible porous asphalt is porous asphalt with its pores filled by a cement mixture, similar to what is used frequently on bus stops in Europe. This is a strong surface with flexibility between that of asphalt and cement concrete.
Noise measurements have been made in Zama City where the reference surface is a DAC 0/20 which in 2006 was 12 years old and had some cracks. The results are shown in Figure 13 [Nippon-2009]. Measurements were made at 50 km/h, probably with the SPB method at the new PERS.

Figure 9. Zama City PERS section by Yokohama and Nippon Road, November 2006.

Figure 10. The 29 months old Zama City PERS in April 2009 (left) and a couple of weeks old in December 2006 (right). The coin diameter is approximately 22 mm.
The passenger car noise reduction was 12-13 dB. Translated to the Dutch reference, the reduction is probably 2-3 dB lower, i.e. about 10 dB. It was said that after 19 months, noise reduction had diminished by 1 dB.

**Note:** Read visually from the graph in Figure 13, the temperature dependence was 0.08 dB/°C (DAC) and 0.12 dB/°C (PERS).

Figure 11. The one month old Hiratsuka PERS by Yokohama and Nippon Road.

Figure 12. The one month old Hiratsuka PERS. The coin diameter is approx 22 mm.
Another noise measurement result is shown in Table 6 [Yokohama-2009]. Measurements were made with a CPX-like method (with microphone a few tenths of a metre behind a tyre of a car). The maximum aggregate size probably was 13 mm since this is Japanese standard. Negative values for the old DAC 0/20 mean that it was noisier than the new DAC 0/13. Translated to the Dutch reference the PERS reduction probably will be 1-2 dB higher, i.e. 10 - 11 dB. This is consistent with the SPB results mentioned above, because a 1 dB lower SPB noise reduction compared to tyre/road noise alone is a reasonable effect of the power unit noise on SPB results measured at 50 km/h on a site with a slight downhill slope.

Table 6. Results of CPX-like noise measurements at three speeds.

<table>
<thead>
<tr>
<th>Pavement type and location</th>
<th>Noise reduction in dB (overall A-weighted values)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 km/h</td>
</tr>
<tr>
<td>DAC 0/20 in Zama City (12 years old)</td>
<td>-6.3</td>
</tr>
<tr>
<td>DAC 0/13 in Atsugi City (new)</td>
<td>ref</td>
</tr>
<tr>
<td>PA 0/13 in Atsugi City (new)</td>
<td>3.5</td>
</tr>
<tr>
<td>PERS in Zama City (new)</td>
<td>8.6</td>
</tr>
</tbody>
</table>
6.4.7 QUIET CITY TRANSPORT (QCITY)

Introduction
Qcity is a European project being carried out during 2005-2009. Besides two-layer porous asphalt - the results for which are not dealt with in the present report - Qcity comprised the development of noise reducing road surfaces by adding fine rubber granulate [Ulmgren-2006], [Malker-2007]. These surfaces were denoted "poroelastic" in Qcity.

The first Qcity test section with rubber asphalt
The first test section in the project with rubber added was similar to open-graded rubber asphalt applied in Arizona/USA and tried in Sweden, except for higher rubber content (8 % by weight compared to 2 %). Another difference is that rubber was added in the dry process (i.e. as a supplementary aggregate) rather than the wet process (i.e. rubber is added to the binder and mixed with it). The 0/2 mm rubber granulate was pre-treated with emulsion (SBS modified bitumen). The binder was polymer-modified bitumen (about 8 %) and the maximum aggregate size was 8 mm. The air void content was 15 %. The cost of such a surface is estimated to be twice that of conventional SMA, mainly as a result of the complex and expensive binder and the rubber processing [Ulmgren-2008].

In the autumn of 2006 a test section of this high-rubber-content surface was laid in one lane of a 50 km/h street, “Tagenevägen” in Gothenburg, Sweden. Pass-by noise was measured from one Volvo passenger car cruising-by at different speeds when the pavement was new, see Figure 14. The noise reduction was between 3.5 dB at 30 km/h and 5.6 dB at 70 km/h compared to a new SMA 0/11 on the same road, estimated to correspond to 5 dB and 7 dB, respectively, relative to new Dutch SMA 0/16.

Using a CPX-like measurement method (the tyre is unknown) with microphones in front of and behind a tyre on a car, 5.8 dB of noise reduction was measured as an average over the 30-70 km/h range compared to the new SMA 0/11, which is approximately 7 dB relative to new Dutch SMA 0/16.

The frequency spectra measured on the two surfaces (see Figure 15) show noise reduction at higher frequencies indicating reduced air pumping noise, presumably caused by the open structure of the pavement. There was no significant reduction at low frequencies to indicate that less noise was generated by tyre vibration. The typical dip in the spectrum on a porous surface due to sound absorption, in particular seen in SPB measurement results, is rudimentary, if present at all.
CHAPTER 6 RESULTS

Figure 14. Passenger car pass-by noise levels on road surface denoted poroelastic in Qcity and on SMA 0/11, [Malker-2007].

Figure 15. Measured CPX frequency spectra on "Tagenevägen" in Gothenburg, cf. text. Diagram from [Malker-2007].

One month after the measurements mentioned above the surface was replaced by a conventional wearing course. The durability was too low, probably because the binder was inappropriate for this type of surface [Ulmgren-2008].
Second Qcity test section with rubber asphalt

In September 2007 a new surface of essentially the same type was laid on “Eklandagatan”, Gothenburg, a 2-lane 50 km/h street with an ADT of 13,000, including 4 % heavy vehicles, mainly buses; see Figure 16 and Figure 17. This street has a moderate longitudinal grade. Parking along the street requires frequent turning of wheels at standstill or at very low speeds and this causes stress on the surface. Noise reductions relative to the former old pavement (type unknown) were approx. 5.5 dB measured in new condition as a before-after measurement of $L_{Aeq,24}$ (A-weighted equivalent noise level over 24 hours) from regular traffic [Brandberg-2007]. In relation to new SMA 0/16, the reduction must be expected to be around one dB lower. The reduction appeared to be essentially the same over the frequency range from 160 Hz to 5000 Hz, which suggests impact on both the vibration generation and the air pumping mechanisms.

To avoid durability problems as encountered in the first trial, the binder was substantially improved in this second experiment. After 15 months, the wearing course in the uphill lane had separated from the base course at some spots. Lack of adhesion between wearing course and base course caused the problem; not ravelling or rutting.

Figure 16. The second Qcity test section with rubber added, 8 months old, Eklandagatan in Gothenburg, Sweden, in the uphill lane.
Figure 17. Surface of the test section in Figure 16 after 8 months in service. The coin diameter is 22 mm. Black parts contain high proportions of rubber.

**Third Qcity test section with rubber asphalt**

A third trial with high-rubber-volume asphalt was made in 2008. On a 50 km/h local street in Gothenburg a new test pavement was laid, applying the same concept as for the previous trials, but the void content was reduced to 8-10 % and the rubber content was a bit lower: 6 % by weight. Maximum aggregate size was 8 mm and the thickness 40 mm. Noise was measured at 50 km/h with the CPX method variant used in Qcity. The result was a noise reduction for the new pavement of 2.5 dB compared to a DAC 0/11 and 5.1 dB compared to a SMA 0/16 [Nilsson-2009]. There is no information given as to the age or condition of the conventional DAC and SMA reference surfaces.

**6.5 LITERATURE REVIEW**

**6.5.1 NORTH AMERICA**

Many references found in the literature review deal with asphalt pavement modified by the addition of tyre rubber, and claim to obtain up to 10 dB noise reduction. However, closer review shows, that the reference pavement is Portland cement concrete; a pavement which in North America usually is extremely noisy. Most asphalt pavements should provide substantial noise reduction relative to this type of pavement. Such results are not innovative and they were not listed.
Similar results were found for “normal” quiet asphalt pavements where the "normal" noise reduction is 3-4 dB. Again, when the reference pavement is Portland cement concrete the stated noise reduction is much higher. Such results were not listed.

The project team considered to review data from the USA on Californian thin layers and drainage asphalt, Arizona rubberized asphalt concrete and longitudinally tined cement concrete pavement in various states. However, our overall conclusion was that the high noise reduction numbers often quoted in American references are related the use of noisy reference pavements.

6.5.2 NORWAY

The following conclusions from [Berge-2009] and [Statens Vegvesen-2009] indicate that little experience of direct interest for Danish or Dutch climate conditions was gained in the Norwegian project “Environmentally friendly pavement”.

The Norwegian project concluded, that

- New dense asphalt concrete pavement yields 4 – 8 dB lower CPX noise levels than those at a Norwegian SMA 0/11 reference pavement aged 2 years, but after one winter of service time exposed to studded tyres the noise levels seem to have increased by 3 – 4 dB
- Dense asphalt concrete pavement with small aggregate size (6 – 8 mm) yields higher initial noise reduction but is more sensible to winter conditions and traffic exposure than pavement with 11 – 16 mm nominal maximum aggregate size
- The thin layer wearing course systems tested behaved similarly to dense asphalt concrete with small maximum aggregate size
- Porous pavement tested in the project initially gave a noise reduction of 5 – 9 dB but after 2 or 3 years of exposure to traffic only 1 or 2 dB of this noise reduction remained
- The Norwegian project concluded that further research is needed before pavements are available to provide 3 dB or more noise reduction over a “normal” 6 – 7 years lifetime in a Nordic climate with the use of studded tyres.

6.5.3 FRANCE

We are aware that the LCPC in France has polished or ground an open graded thin layer wearing course to obtain an even surface, see Figure 18 [Bendtsen-2005b] but so far we have been unable to obtain information on its noise characteristics.
Figure 18. The surface of a new thin layer open pavement with a maximum aggregate size of 6 mm which has been diamond ground in order to get a more even surface texture.

6.5.4 SILENCE

During the European project SILENCE, BASt made an experiment with prearranged chippings for surfaces of mastic asphalt. The objective was to have chippings arranged with their “flattest” side facing upwards. Chippings were temporarily fixed on a “self adhesive aluminium foil”. This assisted in getting an optimum position of chippings which were then rolled on hot mastic asphalt, see [Ripke-2008]. Laboratory samples were produced with maximum aggregate size 5 mm or 8 mm and over/under-sizes removed. The chippings adjust themselves with a flat side to the adhesive layer, see Figure 19. So far we have been unable to obtain information on its noise characteristics.
Figure 19. Comparison between standard chippings applied on mastic asphalt and chippings temporarily adhered to a foil from [Ripke-2008].

Table 7 shows the data obtained: data for the new type of texture is compared with those for at test section of noise reducing mastic asphalt (Gussasphalt) on a German Federal Trunk Road. Noise reducing mastic asphalt is conventional mastic asphalt with smaller chippings. The effect on traffic noise is unknown.

Table 7. Shape factors GF, wavelength Wmax of amplitude-maximum and shape length GL of flat top chippings and noise reducing mastic asphalt, from [Ripke-2008].

<table>
<thead>
<tr>
<th>Surface</th>
<th>Shape Factor GF</th>
<th>Wmax [mm]</th>
<th>Shape Length GL [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Noise Gussasphalt on B56 near Dueren/Germany Chippings 2/3 mm</td>
<td>46</td>
<td>16</td>
<td>736</td>
</tr>
<tr>
<td>Flat Top Chippings 8 mm aggregate size</td>
<td>74</td>
<td>8</td>
<td>592</td>
</tr>
<tr>
<td>Flat Top Chippings 5 mm aggregate size</td>
<td>70</td>
<td>6</td>
<td>420</td>
</tr>
</tbody>
</table>
Table 8 summarises data on the best candidates.

Table 8. Summary of results for the potentially most quiet pavement candidates.

<table>
<thead>
<tr>
<th>Category</th>
<th>Country</th>
<th>Source or type of &quot;pavement solution&quot;</th>
<th>Reference</th>
<th>Stated noise reduction</th>
<th>Conversion into Dutch reference level (Engineering judgement)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[dB]</td>
<td>[dB]</td>
</tr>
<tr>
<td>Project</td>
<td>Denmark</td>
<td>DA 6</td>
<td>[Kragh-2009]</td>
<td>6.2 1)</td>
<td>5 1)</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>Leisser Verkehr</td>
<td>[Reuter-2009]</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>European/Sweden</td>
<td>Rubber asphalt</td>
<td>[Malker-2007]</td>
<td>5-7 2)</td>
<td>5-7 2)</td>
</tr>
<tr>
<td></td>
<td>European/Sweden</td>
<td>Rubber asphalt</td>
<td>[Brandberg-2007]</td>
<td>5.5 1)</td>
<td>4 - 5 1)</td>
</tr>
<tr>
<td></td>
<td>Japan</td>
<td>PERS (Zama)</td>
<td>[Sandberg-2006/09]</td>
<td>12-13 2)</td>
<td>10 2)</td>
</tr>
<tr>
<td>Literature</td>
<td>Norway</td>
<td>DAC; Thin layers; PAC</td>
<td>[Berge-2008]</td>
<td>up to 9 2)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>UK</td>
<td>Associated Asphalt / Safepave</td>
<td>[Safepave-2001]</td>
<td>9.5 1)</td>
<td>8.5 1)</td>
</tr>
<tr>
<td></td>
<td>Denmark</td>
<td>Pankas/AB SRS</td>
<td>[Pankas-2008]</td>
<td>7.9 2)</td>
<td>7 2)</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>Colas/Nanosoft</td>
<td>[Colas-2009d]</td>
<td>9 2)</td>
<td>8 – 10 2)</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td>Primarily rubber particles and polyurethane binder</td>
<td>[Fukuda-1999]</td>
<td>5.6-7.0 2)</td>
<td>9 – 10 2)</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td>Primarily rubber particles and polyurethane binder</td>
<td>[Satoru-2000]</td>
<td>6.4-9.8 2)</td>
<td>5.5 – 9 2)</td>
</tr>
<tr>
<td>Trademark</td>
<td>France</td>
<td>Colas/Microville</td>
<td>[Colas-2009a]</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>Eurovia/Viaphone</td>
<td>Eurovia-2009</td>
<td>&gt; 4 2)</td>
<td>5.5 2)</td>
</tr>
<tr>
<td></td>
<td>The Netherlands</td>
<td>Heijmans/Twinlay</td>
<td>[Masonda-2001]</td>
<td>8.5 2)</td>
<td>8.5 2)</td>
</tr>
</tbody>
</table>

1) “mix vehicle” noise; 2) light vehicle noise only
8. EXPECTED IMPROVEMENT POTENTIAL

8.1 HIGHER VOID CONTENT OF TLPA

If the void content of two-layer porous asphalt (TLPA) can be increased from the present 20 - 25 % to 30 %, predictions indicate that this may yield 1-2 dB extra noise reduction. At least newly constructed pavements of this type will be candidates to reach the target of 10 dB noise reduction. Trials in Sweden have shown that high void content is obtainable in both PAC and TLPA with 16 mm nominal maximum aggregate size (NMAS). 16 mm was chosen in order to improve resistance to wear from studded tyres, but this problem will not exist in most European countries, including The Netherlands and Denmark, so there is a potential to reduce NMAS to 8 mm or perhaps 6 mm and still maintain an increased void content.

To obtain the desired void content without endangering the structural durability, focus must be on binders to optimize both adhesion and cohesion. Candidates may be:

- Polymer modified binder with high content of SBS (e.g. 100/150-75: conclusion of the Danish HOLDDA-project [Nielsen-2004])
- Polyurethane (a conference on this took place in October 2009 in Washington)
- Polyurethane modified epoxy resin
- Epoxy (already under trial in New Zealand)
- Something new (will require basic research).

Some binders are very expensive and may involve special evaluation and application procedures. Also HSE issues (Health, Safety and Environment) need to be solved in addition to REACH documentation (the European Community Regulation on chemicals and their safe use) [REACH-2006].

With a more cohesive binder, combined with lower NMAS, one can reduce the thickness of the top layer of TLPA, which may make it easier to achieve high void content, as the bottom layer with larger aggregate gets a larger part of the total pavement and higher void content is easier to obtain with the larger aggregate. For example, try 25 % voids in a 15 mm top layer and 30 % in a 55 mm bottom layer with stronger binder in both layers.
There may exist an upper limit for the porosity even though increased porosity could be beneficial from a noise reduction perspective. The aggregate skeleton of porous asphalt needs a sufficient number of contact points so it will not be crushed by dynamic loads from heavy vehicles.

8.2 SMALLER AGGREGATE IN THE TOP OF TLPA
If the nominal maximum aggregate size in the top layer is decreased from 8 mm often used today to 6 mm, the expectation is that this will provide 1-2 dB extra noise reduction. 4 mm will perhaps be too small for the “filter” layer to have sufficient hydraulic permeability under heavy rain fall. Though such small NMAS is not common today, experience from proprietary products with surfaces that resemble porous asphalt concrete with small NMAS give some confidence in the structural durability of such a surface. Binders with good cohesive properties must be applied.

Note that small aggregate is not so effective against truck tyre/road noise, only against car tyre/road noise, cf. page 29.

8.3 BINDERS LESS AFFECTED BY OXIDATION
In porous pavement, oxidation of material due to exposure to air is an important durability-reducing mechanism. By using a binder making the material more resistant to oxidation, durability increases. Bituminous binders degrade like any organic material exposed to oxidation. After the initial mixing and compaction, the hardening of the bitumen part is more or less a linear function of time depending on the accessibility to oxygen in air. Polymers are relatively inert to oxidation under normal climatic road conditions. By stabilizing a thicker binder film on the aggregate surface in porous asphalt, polymer modified binders can contribute to slow down the average hardening of the binder film. The HOLDDA project concluded that an optimum strategy for extending the structural lifetime of porous asphalt with bituminous binders would be to use a soft base binder as polymer and then modify it with a high percentage of SBS elastomer. According to the European product standard for modified binders (EN 14023) a 100/150-75 binder could be a possibility.

8.4 ADD RUBBER TO BINDER, WET OR DRY PROCESS, IN TPLA
Using ground tyre rubber for modifying bituminous binders is just one way of modifying the binder, but the reference is often US experience where the application may be driven by other issues such as waste management of scrap car tyres.

Rubber addition can be made by two processes; either wet or dry. In the wet process the binder is just modified like any other polymer modified binder. In the dry process – depending on the size of the ground rubber – the binder is modified but some granular rubber particle structures may remain to add an elastic element to the asphalt aggregate skeleton.
First, adding rubber to the binder in the wet process will provide extra protection against oxidation in the material and provide stronger bonds. It has been difficult to achieve void contents exceeding 18% in rubber asphalt having 2% rubber, and experiments with 10% rubber so far have failed in short time. However, future research on better binders may solve this.

Furthermore, a combination of the wet and the dry process ought to be tested, in particular modified ground tyre rubber used in the wet process combined with ordinary ground tyre rubber in the dry process. Ground tyre rubber can be purchased in at least three different sizes (gradings). An optimum grading curve designed using two or more sizes and used in the dry process is also recommended for testing.

If one can achieve 20 - 25% voids in a TLPA or PA having 10% rubber, the noise reduction due to the combined effect of porosity and increased elasticity of the surface, may amount to 10 dB. In addition, the rubber should provide protection against oxidation. One may consider trading the high rubber content for increased void volume. It is unknown where the optimum lies. 2% rubber and 30% voids might give the same results? Activities in this area are high on the agenda in Sweden with VTI as a focal point.

Some PERS sections currently under test in Japan use the principle mentioned above, although the rubber content is much higher, namely 40-50%. Nevertheless, in Japan it has been shown that it is possible to combine small aggregate (4 mm) and high void content with high rubber content and yet (probably) get acceptable durability. Thus, it should be possible to achieve this also for the void/rubber proportions discussed above.

8.5 STEEL SLAG IN AGGREGATE

Certain steel slag has excellent adhesive properties towards bituminous binders. Steel slag also exhibits high strength. This makes such aggregate a good choice for surface layers to improve friction etc.

Good adhesion between bituminous binders and steel slag can have a positive impact on surface durability because the large surface area of bituminous mortar in open textured asphalt materials and porous asphalt concrete is not only exposed to oxygen but also to water (or moisture). In Sweden and Denmark successful testing has been carried out of steel slag in dense bituminous pavement. Widespread use of steel slag in porous asphalt concrete has not yet been tested, but a potential advantage exists.

There are steel slag materials which are expected to be approved in REACH (the European Community Regulation on chemicals and their safe use).
9. CONCLUSIONS AND RECOMMENDATIONS

The main conclusion from the review of patents, patent applications and trademarks is that no commercially available type of pavement is foreseen for the near future to bring us further than the present level of noise reduction.

The exception might be the poroelastic road surfaces developed in Japan and presently subject to full-scale road tests. Such pavement appears to provide 10 dB of noise reduction in new condition for cars (probably significantly less for trucks). Ongoing road tests suggest that durability after three years is satisfactory and that the deterioration of noise reduction with time is within reasonable limits. However, the cost of such pavement is high and more testing is needed, but this type of pavement cannot be excluded to be - after further development - a potentially super quiet road surface.

The impression from the round of industry contacts is that among proprietary products which are not already used in the Netherlands or Denmark, thin layer open graded wearing courses with 4 mm nominal maximum aggregate is probably the most powerful solution concerning traffic noise reduction. However, its applicability on Dutch or Danish motorways needs verification. Its ability to reduce passenger car noise is up to 9 dB while its ability to reduce heavy vehicle noise has not been documented, and the authors believe such a thin layer to be significantly less efficient in this than optimized two-layer porous asphalt.

The world-wide review of literature and ongoing projects also indicated that no solution is available to provide the wanted 10 dB of traffic noise reduction.

To obtain 10 dB of noise reduction, a possibility could be to add more porosity to porous pavement and to build an elastic wearing course skeleton. The application of special slag and binders, perhaps with the addition of rubber, could lead to progress in this direction. Considerations of a speculative nature on such product development are given in Annex B.

It also seems worthwhile to further investigate the potential of “polishing” the surface of open graded or porous surfaces and it is advisable to closely observe the progress of the European project PERSUADE.
Finally, it is advised to follow the DEUFRAKO project and to try the optimized rubber plates used at railway crossings in realizing the optimum texture according to DEUFRAKO while at the same time achieving substantial elasticity.

It is yet to be proved that the solutions mentioned will work well on high-speed roads (110 km/h) as most of them have relatively small aggregate and have been tried only at lower speeds.


See: www.roadinstitute.dk.


[Michaut-2009] Personal communication, Jean Paul Michaut, Colas France.


[Tarmac-2009a] product sheet MasterFlex from company website,

[Tarmac-2009b] product sheet MasterPave from company website,


ANNEX A
– REFERENCE VALUES

GENERAL
The joint DVS – DRI research project is looking for pavements providing high noise reduction values according to “the Dutch scale”. To determine a noise reduction a reference value is needed. Our interpretation of the Dutch system for characterizing the noise reduction properties of road surfaces is as follows.

The Dutch prediction schemes for road traffic noise contain “emission numbers” (emissiegetal) which characterize the sound power emitted by various categories of vehicles. To calculate an equivalent continuous noise level using these emission numbers is a straightforward process while there is no explicit procedure for the calculation of maximum vehicle pass-by noise levels.

Road surface noise characteristics are based on measurements of maximum vehicle pass-by noise levels with time weighting F. According to the CROW procedure [CROW-2009] a road surface correction \( C_{\text{road}} \) (\( C_{\text{wegdek}} \)) is derived for application in noise exposure calculations.

In the Netherlands traffic noise measurements are most often carried out at a height of 5 m above the road surface, although in many cases measurements have been made also at 1.2 m and/or at 3 m height. In most other European countries, pass-by noise levels are measured at a height of 1.2 m above the road surface. The comparison of Dutch results with results from other countries often involves “translation” between these heights. In the Dutch-Danish pavement noise translator worked out in the IPG-project [Kragh-2007b], the pass-by noise level measured at 1.2 m height was assumed as an average to be 1.5 dB higher than the pass-by level measured at 5 m height.

The difference between pass-by noise levels measured at 5 m and 1.2 m height, respectively, depends on the noise attenuation during propagation from source to receiver. Dutch measurements made at dense asphalt pavements indicate that the difference may be as high as 2.6 dB, see Table 9 based on [Vliet-2009]. These results are average results of measurements made in 1995 at 11 sites with new DAC 0/16.

Table 10 shows similar data derived by the authors from a report with results of measurements made in 2002 -2003 at a variety of Dutch sites with DAC or SMA pavements with an average age at the time of measurement of approximately four years [Peeters-2004]. The difference between results measured at 1.2 m and 5 m height is in the order of 2 dB ± 0.4 dB.
Where a translation between 1.2 m and 5 m is needed in the present report, we decided to presume 2 dB higher noise levels at 1.2 m than at 5 m height. This difference may be too high by 1 dB or so at (unclogged) porous pavement.

Table 9. Average results of measurements made in 1995 at 11 Dutch sites with new DAC 0/16, based on [Vliet-2009].

<table>
<thead>
<tr>
<th>Measurement height [m]</th>
<th>Constants</th>
<th>Speed v [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a + b·log(v)</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Light</td>
<td>5</td>
<td>12,0 33,0</td>
</tr>
<tr>
<td>1.2</td>
<td>8,8 35,7 69,5 77,7 82,4</td>
<td></td>
</tr>
<tr>
<td>Difference 1.2 m – 5 m [dB]</td>
<td>1,4 2,0 2,4</td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td>5</td>
<td>41,5 22,8</td>
</tr>
<tr>
<td>1.2</td>
<td>31,9 29,1 81,3 88,0</td>
<td></td>
</tr>
<tr>
<td>Difference 1.2 m – 5 m [dB]</td>
<td>1,1 2,6</td>
<td></td>
</tr>
</tbody>
</table>

COMPARISON OF REFERENCE VALUES
The Dutch reference values defined in the CROW Publication 200 [CROW-2002] correspond to the values shown in Table 9. Table 11 shows the Dutch CROW reference values together with the Danish and British reference values and the average measurement results from Dutch dense surfaces aged 4 years on the average (from Table 10).

Note: Measurement results in Table 10 marked with ° have been excluded from the average values given in Table 11.

Values in Table 11 are shown for light and heavy vehicles and for a “mixed vehicle” corresponding to the traffic composition specified on page 14 as Dutch reference traffic.

For the reference “mixed vehicle” a noise reduction declared in Denmark (based on SPB or CPX) related to the Danish Nord2000 reference is 1.0 dB higher than when related to the Dutch reference DAC. The British reference value is practically the same as the Danish reference value, that is 1.1 dB higher than the Dutch reference DAC, but the British reference is related to a new HRA 20 while the Danish reference is 8 or 9 years old DAC 0/11.
The average of the Dutch measurement results collected at averagely 4 year old dense pavements is 0.9 dB higher than the Dutch CROW reference value. Most often DAC pavement - all else like - are associated with slightly lower noise levels than SMA pavement. The difference between the Dutch and Danish reference noise levels can be explained by the different age of the pavements and by the difference in maximum aggregate size, as discussed below based on the data in Table 11.

Table 10. Results of SPB measurements 2002-2003 at Dutch DAC or SMA pavements of different age, based on [Peeters-2004].

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Meas. Year</th>
<th>Built Year</th>
<th>Age [yrs]</th>
<th>Light 115 km/h</th>
<th>Heavy 85 km/h</th>
<th>Light 115 km/h</th>
<th>Heavy 85 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[yr]</td>
<td>[yr]</td>
<td>[dB]</td>
<td>[dB]</td>
<td>[dB]</td>
<td>[dB]</td>
<td>[dB]</td>
</tr>
<tr>
<td>DAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2002</td>
<td>1998</td>
<td>4</td>
<td>87,9</td>
<td>86,3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2002</td>
<td>1999</td>
<td>3 (^)</td>
<td>80,6</td>
<td>80,6</td>
<td>85,2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2002</td>
<td>1999</td>
<td>3</td>
<td>82,4</td>
<td>86,0</td>
<td>79,5</td>
<td>(^) 84,1</td>
</tr>
<tr>
<td>4</td>
<td>2003</td>
<td>1999</td>
<td>4</td>
<td>82,6</td>
<td>88,5</td>
<td>80,8</td>
<td>85,7</td>
</tr>
<tr>
<td>5</td>
<td>2002</td>
<td>1997</td>
<td>5</td>
<td>83,3</td>
<td>87,8</td>
<td>81</td>
<td>85,2</td>
</tr>
<tr>
<td>6</td>
<td>2003</td>
<td>1994</td>
<td>9 (^)</td>
<td>84,9</td>
<td>87,9</td>
<td>81,5</td>
<td>85,4</td>
</tr>
<tr>
<td>7</td>
<td>2002</td>
<td>1993</td>
<td>9</td>
<td>84,3</td>
<td>89,3</td>
<td>81,3</td>
<td>86,5</td>
</tr>
<tr>
<td>8</td>
<td>2003</td>
<td>2000</td>
<td>3 (^)</td>
<td>83,9</td>
<td>83,9</td>
<td>(°) 83</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2003</td>
<td>2000</td>
<td>3</td>
<td>82,3</td>
<td>87,7</td>
<td>80,2</td>
<td>85,5</td>
</tr>
<tr>
<td>10</td>
<td>2002</td>
<td>2001</td>
<td>1</td>
<td>82,4</td>
<td>89,0</td>
<td>80,5</td>
<td>86,4</td>
</tr>
<tr>
<td>11</td>
<td>2003</td>
<td>1999</td>
<td>4</td>
<td>82,7</td>
<td>88,8</td>
<td>80,5</td>
<td>86,2</td>
</tr>
<tr>
<td>12</td>
<td>2003</td>
<td>1993</td>
<td>10</td>
<td>82,7</td>
<td>88,1</td>
<td>80,2</td>
<td>85,8</td>
</tr>
<tr>
<td>13</td>
<td>2003</td>
<td>2000</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>2003</td>
<td>2001</td>
<td>2</td>
<td>82,5</td>
<td>88,2</td>
<td>81,7</td>
<td>85,9</td>
</tr>
<tr>
<td>15</td>
<td>2003</td>
<td>2001</td>
<td>2</td>
<td>84,3</td>
<td>89,5</td>
<td>82</td>
<td>86,8</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>82,9</td>
<td>87,9</td>
<td>80,8</td>
<td>85,6</td>
</tr>
<tr>
<td>1.2 m re 5 m</td>
<td></td>
<td></td>
<td></td>
<td>1,2</td>
<td>2,3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| SMA     |             |            |           |                |               |                |               |
| 1       | 2002       | 1999       | 3         | 84,8           | 88,6          | 81,7           | 85,5          |
| 2       | 1996       |            |           |                | 86,8          | 84,5           |               |
| 3       | 2003       | 2000       | 3         |                | (°) 82,9      | 83,9           |               |
| 4       | 2002       | 2000       | 2         |                | (°) 86,0      | 83,2           |               |
| 5       | 2002       | 1999       | 3 (^)     | 79,4           | (°) 82,9      | (°) 82,8       |               |
| 6       | 1993       |            |           |                | (°) 86,0      | 85,3           |               |
| 7       | 2003       | 2000       | 3         | 84,8           | 88,3          | 81,7           | 86,0          |
| 8       | 1997       |            |           | 83,4           | 87,8          | 81,1           | 85,4          |
| 9       | 2003       | 1994       | 9         | 87,0           |               | 85,8           |               |
| 10      | 2003       | 1999       | 4 (^)     | 89,3           | (°) 89,3      | (°) 88,0       |               |
| Average |            |            |           | 83,1           | 87,1          | 81,5           | 85,0          |
| 1.2 m re 5 m | | |          | 1,6 | 2,0 |

Note: Results marked with (^) are considered outliers by DVS.
The variations in reference values looked at here are all in all in a reasonable range considering the differences in basic assumptions. A noise reduction in the Danish or British classification system may be translated into an approximately 1 dB smaller noise reduction according to the Dutch system.

Table 11. Dutch CROW $L_{A\text{Fmax}}$ reference values, Dutch measurement results at 4 years old dense pavements and Danish and British reference values, all at a height of 1.2 m.

<table>
<thead>
<tr>
<th>Vehicle category</th>
<th>Composition</th>
<th>Speed</th>
<th>$L_{A\text{Fmax}}$ at 1.2 m height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CROW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass. car</td>
<td>85</td>
<td>115</td>
<td>82.4</td>
</tr>
<tr>
<td>Heavy veh.</td>
<td>15</td>
<td>85</td>
<td>88.0</td>
</tr>
<tr>
<td>&quot;Mixed vehicle&quot;</td>
<td>100</td>
<td>110.5</td>
<td>83.8</td>
</tr>
</tbody>
</table>

Notes:  
1) M+P 1995, new DAC 0/16, measured at 1.2 m  
2) 8 - 9 years old DAC 0/11  
3) [Peeters-2004]: 4 years old DAC 0/16  
4) [Peeters-2004]: 4 years old SMA 0/16  
5) TRL HRA 20 soon after open to traffic

There is no international consensus on the influence of pavement ageing on traffic noise emission, and research on this topic is in progress, amongst others in the DVS-DRI research project. DRI has recently carried out two projects on the acoustic effect of pavement ageing. As part of the EU project SILENCE, DRI conducted a study [Kragh-2008]. The overall result was that at dense pavements the traffic noise level increases by 0.1 dB per year for both light and heavy vehicles. This was mainly based on European time series of noise measurements at dense pavements with 16 mm nominal maximum aggregate size.

As part of cooperative research with the Californian road administration, DRI carried out a pilot study [Bendtsen-2009]. Four long-term measurement series on dense asphalt concrete with maximum aggregate size 11 mm were included. The noise level increase was 0.4 dB per year for passenger cars and 0.2 dB per year for heavy vehicles or 0.3 dB as an average. This is a steeper slope than the 0.1 dB per year found in the SILENCE study. A hypothesis could be that in relation to noise, pavements with large aggregate are more resistant to wear than pavements with small aggregate.
The noise emission from “a mixed vehicle” on 8 year old dense Danish DAC 11 in Nord2000 is 85.4 dB, Table 11. By subtracting 0.3·8 = 2.4 dB the level 83.0 dB is found for a new Danish DAC 11. The Dutch CROW reference value for a new surface is 83.8 dB. This is 0.8 dB higher than the Danish reference for a new pavement. The aggregate sizes are 16 mm and 11 mm, respectively. An increase in maximum aggregate size is considered to correspond to an increase in noise level of about 0.25 dB per mm. The Dutch 16 mm reference should then yield 5·0.25 = 1.3 dB higher noise level than the Danish 11 mm reference. This is close to the above calculated difference of 0.8 dB.

The noise level at average four years old Dutch DAC 16 is 84.4 dB, Table 11. By subtracting 0.1·4 = 0.4 dB we can estimate the noise level at a new Dutch DAC 16 to 84.0 which is nearly the same as the 83.8 dB CROW reference for new pavement.

The UK reference for new hot rolled Asphalt is 85.5 dB which is 2.5 dB higher than for the new Danish DAC 11 reference. This is to be expected, since HRA is considered to yield 2 - 3 dB higher traffic noise levels than dense asphalt concrete.

All in all the differences in reference values looked at here are in a reasonable range considering the differences in basic assumptions.

A noise reduction in the Danish or British classification system may be translated into a 1 dB smaller noise reduction according to the Dutch system, due to differences in type and age of the reference pavements.

NOTES ON THE HAPAS PROCEDURE

The British HAPAS procedure characterizes the traffic noise reducing ability of a pavement by its index for Road Surface Influence [HAPAS-2004]. For High speed roads this index $R_{SIH}$ is defined as

$$R_{SIH} = 10\log_{10}(7.8 \times 10^{-10} + 0.578 \times 10^{-10} + 10^{-10}) - 95.9$$  \hspace{1cm} (1)

Note 1: Light (L) vehicles at 110 km/h; trucks with two axles (H1) and trucks with more than two axles (H2) at 90 km/h.

Note 2: British reference values are noise levels measured at hot rolled asphalt (HRA 20) having been open to traffic for at least 12 months, with 20 mm max aggregate and with an aimed texture depth (sand patch) in the wheel track of 1.5 mm.

Note 3: The numbers below were measured in 2001 by TRL for the Highways Agency when collecting data to obtain generic SPB values for different types of surfaces “soon after they were open to traffic” [Abbott-2008]. The results given for HRA 20 are based on 12 surfaces at 6 different sites. The corresponding value of $R_{SIH}$ is not zero and this indicates that Equation (1) is based on a slightly different set of results.
<table>
<thead>
<tr>
<th>Speed [km/h] / ( L_{\text{veh}} ) [dB]</th>
<th>( L_{\text{veh-light}} )</th>
<th>( L_{\text{veh, dual-ax}} )</th>
<th>( L_{\text{veh, multiax}} )</th>
<th>( RSI_H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Speed</td>
<td>110 / 84.6 dB</td>
<td>90 / 86.6 dB</td>
<td>90 / 89.1 dB</td>
<td>-0.7 dB</td>
</tr>
</tbody>
</table>
ANNEX B – FUTURE POROUS ASPHALT

The following rather speculative considerations on potential future development of poroelastic pavements were noted by VTI after reviewing Qcity results.

The poroelastic surface failed after a few months and subsequent tests with similar surfaces (supposedly improved) also failed. Therefore, the results are of no immediate use. Nevertheless, interesting lessons can be learnt, even though they are mainly of academic interest:

- There is a potential for a certain noise reduction by the elasticity of asphalt surfaces into which a significant but not very high amount of rubber has been mixed
- The rubber amount needs to be around 8 %, by weight of the total mass, in order to obtain 2-3 dB extra noise reduction (by elasticity alone)
- To achieve such effects, the surface probably needs to be "semi-porous", with around 15 % voids, although also smaller void content may give a (smaller) noise reduction
- The above combination of elasticity and porosity might give 6-7 dB noise reduction compared to an old SMA 0/16; which is not very useful, though, to replace normal PA or TLPA surfaces, except that even after the deterioration due to clogging there may be some noise reduction may remain due to elasticity
- Higher void content is likely to add more noise reduction, due to the added effect of sound absorption and the elimination of air pressure gradients
- By using a mix of (say) 50 % rubber and 50 % sand and stones, it is probable that the elasticity effect can be substantially higher than 2-3 dB; perhaps up to 5 dB. This is used in new PERS in Japan
- It is possible and even probable that the effects of elasticity and porosity might be essentially additive since they affect different mechanisms
- It is difficult to obtain a high void content, as the rubber "absorbs" binder and creates a substance which tends to narrow the pores
- It is worth trying to combine high void content porous asphalt with 7-10% of rubber content (by weight of total mix). It could be suggested to try PA with 6 mm max aggregate size as the basis. One might aim at 25-30% voids in the mix without rubber, which is likely to result in 20-22% in the ready mix when rubber is included. This way it should be possible to get about 10 dB of noise reduction.

- The same effect should be achievable with a 50-50 mix of rubber and sand/stone and something like 15-20% voids; i.e. a surface similar to the new PERS in Japan.

- The above might be achieved without needing a thick surface; 30 mm might be sufficient (for passenger car noise at least).

- A surface where part of its noise reduction comes from high elasticity will not be as sensitive to clogging as a surface which relies totally on porosity. Elasticity might also improve “self-cleaning” of the pores.

- The crucial thing will be durability; trials have so far resulted in rapid failure.

- This does not mean that it will be impossible to get a sufficient strength of the mix; the new PERS in Zama and Hiratsuka in Japan indicate that it is possible to get a reasonable structural durability of a rubber and sand mix, albeit with about 50% of rubber and with much smaller aggregate.

- The Qcity results may be seen as taking further the principle of “asphalt rubber”, as used in USA and in Europe, by multiplying the rubber content by a factor of four or so, in which case a clearer effect of the rubber on noise emission is obtained.
<table>
<thead>
<tr>
<th>Nr. No.</th>
<th>Titel/Title</th>
<th>Forfatter/Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>Thin Asphalt Layers for Highways - Optimised for low tyre / road noise</td>
<td>Bent Andersen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>161</td>
<td>Road Surfacings - Noise reduction time history</td>
<td>Jørgen Kragh</td>
</tr>
<tr>
<td>162</td>
<td>Optimized thin layers for urban roads - Paper for Acoustics '08 in Paris</td>
<td>Bent Andersen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>163</td>
<td>Råstofforsyning i Danmark</td>
<td>Caroline Hejlesen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Michael Larsen</td>
</tr>
<tr>
<td>164</td>
<td>Livscyklusvurdering af vejbefæstelser - Projekt Bording - Funder MV</td>
<td>Knud A. Pih</td>
</tr>
<tr>
<td></td>
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<td>Jørn Raaberg</td>
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<td>Helle Blæsbjerg</td>
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Road Directorate has local offices in Aalborg, Fløng, Herlev, Herning, Middelfart, Næstved, Skanderborg and a head office in Copenhagen.

Find more information on roaddirectorate.dk.

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