Noise reducing pavements

- Evaluation workshop

Danish Road Institute
Technical note 45
2006

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Ministry of Transport and Energy

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Contents

Preface

The DRI-DWW Noise Abatement Programme [1] is a joint cooperation between the Road and Hydraulic Engineering Institute (DWW) in the Netherlands and the Danish Road Institute (DRI) for research and development in issues related to abatement of road traffic noise. The cooperation is carried out within the framework of the Dutch Noise Innovation Programme [2] (the IPG programme).

In October 2005, an invited workshop was held in Copenhagen where the international research community evaluated the first findings and reviewed the programme [3]. Based on the good experiences of this workshop, it was agreed to follow up and implement the findings of the research in an evaluation workshop one year later.

The Evaluation Workshop in Copenhagen in November 2006 presented the main findings of the research and asked the international scientific community to evaluate the results obtained to date. This provided the opportunity to adjust or extend data analysis and conclusions. The main aim was to share and discuss knowledge among FEHRL members (Federation of European Highway Research Laboratories) and participants from USA and Japan.

The workshop was divided into five parts; main results and recommendations, a general introduction and three technical sessions dealing with the following topics of the DRI-DWW cooperation:

- Structural durability (ravelling).
- Acoustical durability (clogging).
- Noise reducing thin layer pavements.

The introduction featured an opening speech by FEHRL and international outlook by four internationally recognized speakers from USA, Japan and Europe. In the technical sessions, the results obtained within the DRI-DWW co-operation programme was presented and evaluated by a panel of three international specialists followed by an open discussion of the relevance and perspectives of the findings. The workshop was closed with a summary and conclusions by DWW.

The Danish Road Institute would like to acknowledge the evaluators for the big effort which they have made in connection with the evaluation of our research work on noise reducing pavements, the four international experts for the international outlook upon road traffic noise abatement and all participants for the active and constructive attendance in the workshop.

Forord

Vejteknisk Institut og Road and Hydraulic Engineering Institute (DWW) i Holland samarbejder under det Hollandske Noise Innovation Programme (IPG) [2] i en række projekter relateret til støjbekæmpelse [1]. I oktober 2005 blev der afholdt en workshop i København, hvor det internationale forskningsmiljø blev inviteret til at evaluere forskningsprogrammet og de første resultater [3]. På grundlag af de gode erfaringer fra denne workshop blev det besluttet at præsentere resultaterne af forskningen ved en workshop et år senere.

I november 2006 blev resultaterne af arbejdet derfor præsenteret og evalueret af det internationale forskningsmiljø indenfor området ved en workshop i København. Det gjorde det muligt at tilpasse analyser og konklusioner. Hovedformålet var at dele og diskutere viden blandt FEHRL (Federation of European Highway Research Laboratories) medlemmer og forskere fra USA og Japan.

Workshoppen var delt op i fem dele; hovedresultater og anbefalinger, en generel in introduktion og tre tekniske sessioner, der omhandlede følgende emner indenfor forskningssamarbejdet:

- Strukturel holdbarhed (stentab).
- Akustisk holdbarhed (tilstopning).
- Støjreducerende tynde asfaltbelægninger.

Introduktionen indeholdt et indlæg fra FEHRL, og fire internationalt anerkendte eksperter fra USA, Japan og Europa gav et overblik over forskningsområdet. I hver af de tre tekniske sessioner blev resultaterne opnået gennem samarbejdet præsenteret og efterfølgende vurderet af et panel med tre internationale specialister Derefter fulgte en åben diskussion af relevansen og perspektiverne af resultaterne. Workshoppen blev afsluttet med en sammenfatning af DWW.

Vejtekniks Institut vil gerne takke de internationale specialister for deres store indsats med vurdering af forskningsresultaterne, de fire internationale eksperter for deres præsentationer af den internationale scene i relation til bekæmpelse af trafikstøj og alle deltagerne for deres aktive og konstruktive indsats i workshoppen.

Summary and conclusions

The DRI-DWW Noise Abatement Programme is a joint cooperation between the Road and Hydraulic Engineering Institute (DWW) in the Netherlands and the Danish Road Institute (DRI) for research and development in issues related to abatement of road traffic noise. The cooperation is carried out within the framework of the Dutch Noise Innovation Programme (the IPG programme).

The Evaluation Workshop in Copenhagen in November 2006 presented the main findings of the research and asked the international scientific community to evaluate the results obtained to date. This provided the opportunity to adjust or extend data analysis and conclusions. The main aim was to share and discuss knowledge among FEHRL members (Federation of European Highway Research Laboratories) and participants from USA and Japan. The nine evaluators were:

Structural durability (ravelling)

- Seishi Meiarashi, Public Works Research Institute (PWRI), Japan.
- Manfred Partl, Eidgenössische Materialprüfungs- und Forschungsanstalt, (EMPA), Switzerland.
- Johann Litzka, , Technische Universität, Vienna (TU Vienna).

Acoustical durability (clogging)

- Ulf Sandberg, Transport Research Institute (VTI), Sweden.
- Luc Goubert, Belgian Road Research Centre (BRRC), Belgium.
- Thomas Beckenbauer, Müller-BBM, Germany.

Noise reducing thin layer pavements

- Judith Rochat, Volpe Acoustics, USA.
- Fabienne Anfosso, Laboratoire Central des Ponts et Chaussées (LCPC), France.
- Oliver Ripke, Federal Highway Research Institute (BASt), Germany.

The three evaluators found the work presented on **structural durability** good and very detailed, but also suggested both general and more specific improvements. They found it is a very valuable study that could serve as an example for future studies and an interesting and advanced quantitative analysis of wearing courses. Generally, the goal of the study was achieved and the people involved in this part of the study must be acknowledged for their remarkable work. However, there is still more work to be done.

The final reports will consider the suggested improvements and adjust or extend data analysis and conclusions. In addition, the study is part of the IPG research on structural durability of porous pavements also including ageing studies, mechanical tests and modelling of the physical processes. The evaluation during the workshop therefore elucidates the importance of a co-ordinated evaluation of all IPG projects on durability of porous pavements. The general advice was given to “observe the tree and see the whole forest”. Specifically, it is recommended to make available all mix-design data and road section related performance data.

The three evaluators found that the work presented on **acoustical durability** added new and valuable information to existing knowledge. The work had a high scientific quality and at the same time produced results that can be used for practical noise abatement.

All topics included in the programme for the project on CPX measurements were found to be well justified and well chosen and the work seems to have been conducted very well. It was suggested to include texture data, if available, as a factor to explain the CPX results. A good correlation between CPX and SPB is found, but it is not considered sufficient for sensible SPB prediction. The assessment of IPG test sections by the use of CT scanning as well as thin and plane section analyses was considered well conducted pioneering work with a well justified and well chosen research programme. The Øster Søgade Experiment on two layer porous pavements for urban roads was considered a well designed research project, where the time history (age effect) was very well studied. It was found good that this experiment was continued for so many years by using funds from various projects and the comprehensive measurement programme was acknowledged.

The three evaluators found that the work presented on **noise reducing thin layer pavements** was of a high scientific quality and produced results for practical use by road administrations. The comprehensive approach of the research which addressed both acoustical parameters and parameters describing the structural performance of the pavements was highlighted as valuable, though seldom seen in such projects. The goal of the study was achieved and the people involved in this part of the study must be acknowledged for their remarkable work. However, there is still further work to be done in optimizing the acoustical and structural durability of thin layers. An important point is to perform long time full scale experiments in order to obtain real performance data for these types of noise reducing pavements.

1. Programme

1.1 Thursday 23rd November, 2006

10:00 **Opening and Introduction**

Chairman: Wim Hoevers, DWW.

- Welcome, Wim Hoevers, DWW.
- Implementation of the IPG program, Ruud Nijland, DWW.
- Relevance and perspective of the DRI-DWW noise abatement program, Mr. Bojan Leben, Executive Committee officer, Environment, Energy and Resources (EER), Forum of European National Highway Research Laboratories (FEHRL).

11:00 **Results and Recommendations**

Chairman: Gert Ahé, DRI.

- Structural durability, Carsten Bredahl Nielsen, DRI.
- Acoustical durability, Jørgen Kragh, DRI.
- Noise reducing thin layer pavements, Hans Bendtsen, DRI.
- Relevance and perspective, Rob Hofman, DWW.

13:00 **International Outlook**

Chairman: Gert Ahé, DRI.

- European Research on Road Traffic Noise Abatement, Chairman of the IPG Scientific Board Johan Litzka, Technische Universität, Vienna (TU Vienna).
- Innovations in noise reducing pavements in Japan, Seishi Meiarashi, Public Works Research Institute (PWRI), Japan.
- Trends in the US development of quieter pavements, Judith Rochat, Volpe Acoustics, USA.
- The future of tyre/road noise reductions, Ulf Sandberg, Swedish National Road and Transport Research Institute (VTI), Sweden.

15:30 **Session 1: Structural Durability of Porous Asphalt**

Chairman: Rob Hofman, DWW.

- Development of prediction tool LOT using knowledge from structural analysis and aging research, André Molenaar, TU Delft.
- Assessment of IPG test sections, Carsten Bredahl Nielsen, DRI.
- Effects of ageing processes, Jan Voskuilen, DWW.
- Evaluation of results – relevance and perspective
  Seishi Meiarashi, PWRI / Manfred Partl, Eidgenössische Material-prüfungs- und Forschungsanstalt, (EMPA) / Johan Litzka, TU Vienna.
- Discussions and summary.

17:30 End of first day.

1.2 Friday 24th November, 2006

09:00 **Summary of Day 1**
Hans Jørgen Ertman Larsen, DRI.

09:30 **Session 2: Acoustical Durability of Porous Asphalt**
Chairman: Martijn van den Brink, DWW.

- IPG research on acoustical durability, Rob Hofman, DWW.
- Experiences with CPX measurements, Jørgen Kragh, DRI.
- Assessment of IPG test sections, Carsten Bredahl Nielsen, DRI.
- The Øster Søgade experiment, Hans Bendtsen, DRI.
- Evaluation of results – relevance and perspective
  Ulf Sandberg, VTI / Luc Goubert, Belgian Road Research Centre (BRRC) / Thomas Beckenbauer, Müller-BBM.
- Discussions and summary.

13:00 **Session 3: Noise Reducing Thin Layer Pavements**
Chairman: Hans Jørgen Ertman Larsen, DRI.

- IPG research on Thin Layer Pavements, Maya Sule, DWW.
- Assessment of Danish highway test sections, Hans Bendtsen, DRI.
- Evaluation of results – relevance and perspective
  Judith Rochat, Volpe Acoustics /
  Fabienne Anfosso, Laboratoire Central des Ponts et Chaussées (LCPC) /
  Oliver Ripke, Bundesansatlt für Strassenwesen (BASt).
- Discussions and summary

15:30 **Summary and Conclusions**
Ruud Nijland, DWW

16:00 **End of Workshop**

2. Evaluation of findings

The idea of the evaluation workshop was to have the international research community evaluate the results obtained to date of the projects in the DRI-DWW noise abatement programme. For this purpose all material for evaluation was sent to the evaluators three weeks in advance of the workshop to give them time to prepare the evaluation. The material was intended for evaluation and corrections where still possible after the evaluation. It was recognized that the evaluators are all busy international experts and therefore could not spend too much time on reading reports for evaluation and it was therefore decided to limit the amount of material for evaluation.

For each of the three sessions, three evaluators were asked to give oral comments on the material and the preceding presentations and contribute to discussions at the end of the session. The comments of each evaluator were given within 5-10 minutes and in total comments and discussion was within 30-45 minutes. Below is given the summary of the evaluation for the three sessions.

2.1 Structural durability

The evaluation of the work on structural durability in the DRI-DWW noise abatement programme was based on a paper submitted for review at the International Conference on Advanced Characterization of Pavement and Soil Engineering Materials (Athens-'07) entitled 'Micro-structural characterization of porous pavements' by Carsten Bredahl Nielsen, Jørn Raaberg and Dave van Vliet. The paper covers the work performed on structural durability in the DRI-DWW noise abatement programme and therefore gives the necessary background for discussions during the session. The work was presented in detail during the presentations at the session. The three evaluators were:

- Seishi Meiarashi, PWRI
- Manfred Partl, Eidgenössische Materialprüfungs- und Forschungsanstalt, (EMPA)
- Johann Litzka, TU Vienna

In general, the three evaluators found the work presented good and very detailed, but also suggested both general and more specific improvements. They found it to be a very valuable study that could serve as an example for further studies and an interesting and advanced quantitative analysis of wearing courses. Generally, the goal of the study was achieved and the people involved in this part of the study must be acknowledged for their remarkable work. However, there is still further work to do.

- This is a phenomenological study on cores. Hence the results are only valid for the pavements investigated and for the specific loading and climatic situation. Generalization is limited. It would have been beneficial to combine this study with some mechanical tests. One has to understand that the set of sections investigated reflects a **limited** specific set of porous asphalt. One would have to confirm the findings for **other cases**. Conclusions are in some cases too conclusive, because they are not supported by an objective result.

- Information on mix-design (aggregate size and gradation as well as the aggregate and binder type) and exact location of drill cores are missing. The evaluators found this information very important to be able to draw significant conclusions from the work.

- No fundamental study was made regarding the influence of water, temperature and ageing, i.e. no **modelling** and **theoretical** investigation and physical explanation. This is risky in the sense that there is no check if the findings are general enough. It is claimed that the investigation allows understanding the **mechanism** of ravelling. The study produces some **nice interpretations** of effects. However, **recording and monitoring** a process without trying to model and simulate the effects in the laboratory means stopping halfway in the attempt to understand the mechanism. It is recommend to focus not only on the age of the roads, but in particular on the **ageing** of the mastic (binder), including fundamental studies of the influence of oxygen, water, frost, UV and chemical agents (deicing agents and windshield washer agents). **Combined testing** under water is strongly encouraged. Since adhesion and cohesion are **mechanical properties,** it is strongly recommended to back up the findings also by appropriate **mechanical tests**. Here, technical development is needed.

- The evaluated **parameters**: adhesion, cohesion, aggregate and clogging grades and the other parameters determined in CT appear to produce valuable information about the state of the cores. Unfortunately, the paper does not explain **how** these parameters were determined. The authors should clearly explain the different "grades". In addition, it would have been helpful to learn about **errors and confidence range**. In particular, only average values are given without any basic statistical information. 3D and statistical analysis including basecourse will give more interesting and perspective results.

- **CT scanning** is a valuable method, however with **limited resolution** (0.3 mm, as indicated in the text). It is therefore of limited use to study binder – aggregate interface (and cracks) and fine capillary pores that might go as low as 0.1 mm. These **capillary pores** may still play a role in absorbing water.

- In the paper it is found that **adhesion grade increases with age and clogging grade**. From that it is concluded that the overall deterioration mechanism is related to mastic-aggregate adhesion. **Clogging** cannot only result from a deterioration mechanism, but also from other effects (external dust, dirt, salt). Hence, the conclusion that the overall deterioration mechanism is related to the adhesion between mastic and aggregate is not completely justified, but of course, very plausible. **Top and bottom zones** were investigated. However, since ravelling is a surface defect that occurs basically on the top, conclusions regarding **ravelling** are hard to establish. The other findings regarding the microstructural parameters are valid, of course.

- From a practical point of view, the findings are **relevant** and in many ways confirm findings by other researchers. The finding that it is necessary improving the adhesion between aggregate and mastic in order to avoid ravelling is certainly valid. However, improving materials requires an appropriate set of laboratory **test and assessment methods** that reflect and simulate the behaviour in the field.

The work discussed will be reported as part of the DRI-DWW noise abatement programme in two reports:

- Danish Road Institute (2006). Microstructure of porous pavements – Experimental procedures. DRI technical note 47 (to be published).
- Danish Road Institute (2006). Ravelling of porous pavements – assessment of test sections. DRI technical note 48 (to be published).

These reports will consider the suggested improvements and adjust or extend data analysis and conclusions. In addition, the study is part of the IPG research on structural durability of porous pavements also including ageing studies, mechanical tests and modelling of the physical processes. The evaluation during the workshop therefore elucidates the importance of a co-ordinated evaluation of all IPG projects on durability of porous pavements. The general advice was given to “observe the tree and see the whole forest”. Specifically, it is recommended to make available all mix-design data and road section related performance data.

2.2 Acoustical durability

The evaluation of the work on research in acoustical durability of porous asphalt in the DRI-DWW noise abatement programme was based on two DRI reports entitled:

- Acoustical characteristics of Danish road surfaces. Danish Road Institute. Technical note 38, 2006.
- Traffic noise at two-layer porous asphalt -Øster Søgade, Year No. 6. Danish Road Institute. Technical note 30, 2005.

These reports cover parts of the work carried out by DRI on acoustical durability and therefore give the necessary background for the discussions at the session. In three presentations, further results and details were presented:

- Experiences with CPX measurements by Jørgen Kragh, DRI.
- Assessment of IPG test sections by Carsten Bredahl Nielsen, DRI.
- The Øster Søgade experiment by Hans Bendtsen, DRI.

The three evaluators were:

- Ulf Sandberg, Transport Research Institute (VTI), Sweden.
- Luc Goubert, Belgian Road Research Centre (BRRC), Belgium.
- Thomas Beckenbauer, Müller-BBM, Germany.

The three evaluators presented their evaluations and comments. Besides this, some of the other attendees of the workshop also took part in the discussion with comments and suggestions.

In general, the three evaluators found that the work presented added new and valuable information to existing knowledge. The work had a high scientific quality and at the same time produced results that can be used for practical noise abatement.

All topics included in the programme for the project on CPX measurements were found to be well justified and well chosen and the work seems to have been conducted very well. The acoustical ageing effect was very well studied together with the clogging effect on a porous pavement monitored by continuous CPX measurements.
A similar study of the potential clogging variation in the transverse direction of a porous pavement would be valuable. It was suggested to include texture data, if available, as a factor to explain the CPX results. A good correlation between CPX and SPB are found, but it is not considered sufficient for sensible SPB prediction.

The assessment of IPG test sections by the use of CT scanning as well as thin and plane section analyses was considered well conducted pioneering work with a well justified and well chosen research programme. It was pointed out that it was very good to show void profiles over the lateral and vertically position. It is important to note that ”mastic” seen in the CT scanning actually is the original mastic plus the dirt as well as some of the aggregate that might have been turned into ”dirt”!

The Øster Søgade Experiment on two layer porous pavements for urban roads was considered a well designed research project where the time history (age effect) was very well studied. The project was found to be unique for the posted speed and the work seems to have been conducted very well. It was found good to follow this experiment over so many years, by using funds from various projects and the comprehensive measurement programme was acknowledged. All topics included in the comprehensive measurement programme are well justified and well chosen. Results of acoustic measurements fit experiences found in other projects. It is fine that such high void contents were actually achieved in the porous pavements. The conclusion that the surface type which has the lowest initial noise reduction may well be the best seen over the lifecycle was emphasized. As a concluding remark one of the evaluators suggested that the Øster Søgade Experiment should be awarded a prize!

Some more detailed comments and discussions are highlighted in the following:

- The question was raised whether the increase of SPB levels on the DAC 8 reference section was due to deterioration of the road surface or due to a change in vehicle noise over time.

- An evaluator questioned whether the leaves of the chestnut trees in the western lane of Øster Søgade clogged the pavement and therefore influenced the noise, but concluded that this does not seem to be the case.

- In a German experiment, the general result on the effect of cleaning was that one dB is lost per year due to clogging and 0.5 dB gained per year due to cleaning.

- The measured MPD values do not indicate ravelling at the end of the lifetime. It might be promising to use spectral analyses of the measured texture data.

- One evaluator would have liked to see an updated version of the original study comparing the cost-benefit of the two layer porous pavements vs. noise barriers and improved windows, with real values for noise reduction vs. time and lifetime replacing the projected ones. He also would have like to see the original study of how the residents perceived the noise effect of the surface change.

- The lateral and vertical voids profiles measured on the CT scanning pictures do not seem to confirm the hypothesis of clogging occurring preferentially in the top layer of TLPA; except for the Copenhagen test section. Therefore it can be asked if the two-layer principle for porous pavements is justified on high-speed roads.

- One evaluator missed some kind of quantification of ravelling as a function of time; even if only subjectively estimated.

- The projects show a relation between the measured water penetration and the noise reduction.

- On the background of the Øster Søgade data and data from a Belgian experiment, a rule of thumb was derived saying that average annual noise reduction loss for two layer porous pavements is about 1,0 dB(A)/ year ± 0,3 dB(A)/year.

- The use of a backboard microphone position at Øster Søgade was discussed. The conclusion was that the used 6 dB correction was reasonably correct.

- The measurement distances at Øster Søgade are for practical reasons different from the 7.5 m stated in the SPB standard. It was evaluated that the uncertainty introduced in the SPB measurements were hardly noticeable in measured SPB spectrum and totally negliable in global dB-level.

- It was mentioned that there is no global temperature correction, but that the temperature correction depends on the kind of pavement and on frequency.

- The acoustical behaviour of different road surfaces is hard to compare without considering civil engineering properties!

- Porous road surfaces are still forward-looking approaches for highly efficient noise reducing road pavements!

- Porous road surfaces with favourable properties are multilayer porous road surfaces!

- Understanding water mechanics in porous asphalts will help to keep soil out.

- Innovative substances and materials can help to reduce innovative structures to practice!

The work discussed will be reported as part of the DRI-DWW noise abatement programme in a final report on acoustical durability. This report will consider the suggested improvements and adjust or extend data analysis and conclusions. These results will be a part of the overall IPG work on acoustical durability porous pavements.

2.3 Noise reducing thin layer pavements

The evaluation of the work on research in noise reducing thin layer pavements in the DRI-DWW noise abatement programme was based on a paper submitted for the Inter-Noise 2006 conference entitled “Noise reducing thin layers for highways” by Hans Bendtsen and Sigurd Thomsen. This paper covers parts of the work carried out by DRI on thin layers and therefore gives the necessary background for the discussions at the session. In the presentation entitled “Assessment of the Danish highway test sections, Noise reducing thin layer pavements” by Hans Bendtsen, the work was presented with additional details. The three evaluators were:

- Judith Rochat, Volpe Acoustics, USA.
- Fabienne Anfonsso, Laboratoire Central des Ponts et Chaussées (LCPC), France.
- Oliver Ripke, Federal Highway Research Institute (BASt), Germany.

The three evaluators presented their evaluations and comments. In addition, some of the other attendees of the workshop also took part in the discussion with comments and suggestions.

In general, the three evaluators found that the work presented was of a high scientific quality and produced results for practical use by road administrations. The comprehensive approach of the research which addressed both acoustical parameters and parameters describing the structural performance of the pavements was highlighted as valuable, though seldom seen in such projects. It was recommended also to use this comprehensive approach in the newly started project on further optimization of the noise reduction on thin layers, the so called “Herning Experiment”. The new “Herning Experiment” was seen as a good continuation of the project on the M10 test sections.

Generally, the goal of the study was achieved and the people involved in this part of the study must be acknowledged for their remarkable work. However, there is still further work to be done in optimizing the acoustical and structural durability of thin layers. An important point is to perform long time full scale experiments in order to obtain real performance data for these types of noise reducing pavements. Both the Danish M10 test sections, the new “Herning experiment” and the new test sections with thin layers in the Netherlands are important for the performance of long time investigations.

Some more detailed comments and discussions are highlighted in the following:

- It was appreciated that a good description of the mix design of the different tested pavements was available, and that this data was not kept secret.

- The noise reductions are seen in the high frequency domain over 1000 Hz indicating that the openness of the thin layers reduces the noise generated from air pumping.

- The results from the M10 test sections were compared to similar German and French results. The same tendencies for noise reduction are seen in this comparison even though the Danish absolute noise levels seem to be a little higher.

- It was discussed whether to use SPB or CPX (or the US version using sound intensity) measurements for registration of the acoustical properties of the pavements. It was suggested to use both methods in parallel.

- It was suggested to perform measurements of acoustical absorption, especially on the very open and semi-porous thin layers.

- In order to perform better analyses of the pavement textures it was recommended to perform spectral analyses of the laser texture measurements and DRI is planning to do so in the near future. Especially the rather high noise level of the SMA8 pavement might be explained by such analyses.

- The use of rather long test sections at the M10 highway was appreciated.

The work discussed will be reported as part of the DRI-DWW noise abatement programme in a final report on the thin layer project. This report will consider the suggested improvements and adjust or extend data analysis and conclusions. These results will be a part of the overall IPG work on noise reducing thin layers which will also include results from the new Dutch test sections etc.

3. References

[1] Danish Road Institute (2005). The DRI-DWW Noise Abatement Program - Project description. DRI technical note 24.

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[3] Danish Road Institute (2005). Workshop on optimization of noise reducing pavements. DRI technical note 32.

[4] C. B. Nielsen, J. Raaberg and D. van Vliet (2007). Micro-structural characterization of porous pavements. Paper submitted for review at he International Conference on Advanced Characterization of Pavement and Soil Engineering Materials (Athens-'07).

[5] Acoustical characteristics of Danish road surfaces. Danish Road Institute. Technical note 38, 2006.

[6] Traffic noise at two-layer porous asphalt -Øster Søgade, Year No. 6. Danish Road Institute. Technical note 30, 2005.

[7] H. Bendtsen and S. Thomsen (2006). Noise reducing thin layers for highways. Paper submitted for the INTER-NOISE 2006 conference, 3-6 December 2006 Honolulu, Hawaii, USA.

4. Participants

Name	Institute	Country
A.A.A. Molenaard	TU Delft	Holland
Bent Andersen	Danish Road Institute	Denmark
Bojan Leben	FEHRL	Slovenia
Carsten B. Nielsen	Danish Road Institute	Denmark
Erik Nielsen	Danish Road Institute	Denmark
Erwin Kohler	University of California	USA
Fabienne Anfosso	Laboratoire Central des Routes et Chaussées	France
Flemming Berg	Danish Road Institute	Denmark
Gerbert van Bochove	Heijmans NV	Holland
Gert Ahé	Danish Road Institute	Denmark
Guy Descornet	Belgian Road Research Centre	Belgium
Hans Bendtsen	Danish Road Institute	Denmark
Hans Jørgen Ertman Larsen	Danish Road Institute	Denmark
Helen Hasz-Singh	Danish Road Institute	Denmark
Ingunn Milford	Vegdirektoratet	Norway
J. Hooghwerff	M+P Radgevende ingenieurs bv	Holland
Jakob Fryd	Miljøkontrollen	Denmark
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Jan Voskuilen	Dienst Weg- en Waterbouwkunde	Holland
Johann Litzka	TU Wien	Austria
Jostein Aksnes	Norwegian Public Roads Administration	Norge
Judith Rochat	Volpe Acoustics	USA
Jürgen Haberl	TU Wien	Austria
Jørgen Kragh	Danish Road Institute	Denmark
Jørn Bank Andersen	NCC Roads	Denmark
Jørn Raaberg	Danish Road Institute	Denmark
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Manfred Partl	EMPA	Switzerland
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Michael Rasmussen	Municipality of Copenhagen	Denmark
Ole Grann Andersson	Skanska	Denmark
Oliver Ripke	Federal Highway Research Institute (BASt)	Germany
Philip A Morgan	Transportation Research Laboratory	UK
Richard Stait	Transportation Research Laboratory	UK

Rob Hofman	Dienst Weg- en Waterbouwkunde	Holland
Ruud Nijland	Dienst Weg- en Waterbouwkunde	Holland
Seishi Meiarashi	Public Works Research Institte	Japan
Sigurd N. Thomsen	Danish Road Institute	Denmark
Svein Storeheier	SINTEF	Norway
Thomas Beckenbauer	Müller-BBM	Germany
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Wim Hoevens	Dienst Weg- en Waterbouwkunde	Holland
Wolfram Bartolomaeus	Federal Highway Research Institute (BASt)	Germany

5. Presentations

Opening and introduction

Chairman: Wim Hoevers, DWW.

Results and recommendations

Chairman: Gert Ahé, DRI.

International outlook

Chairman: Gert Ahé, DRI.

Structural durability

Chairman: Rob Hofman, DWW.

Acoustical durability

Chairman: Martijn van den Brink, DWW.

Noise reducing thin layer pavements

Chairman: Hans Jørgen Ertman Larsen, DRI.

Welcome

Denmark, Rungstedgaard, 23/24 November 2006

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Why a IPG?

Traditional noise measures cost over:

- € 4.0 billion for high way and rail
- € 2.2 billion for high way, because:
  - Over 400 km new noise barriers are needed
  - in many other cases higher barriers are needed
- Space
- Visual hindrance

A new approach was needed

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IPG

IPG approach

Cost effectiveness by source oriented measures

Cooperation between Ministry of Transport and Ministry of Environment

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IPG goals

Goal

Cheaper noise reduction in the Netherlands

Main focus on source oriented measures

Pavement types like:
- Two layer Porous Asphalt
- Thin Silent Asphalt Layers
- Rollpave, Modieslab

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Biggest achievement

Approval of two layer porous Asphalt

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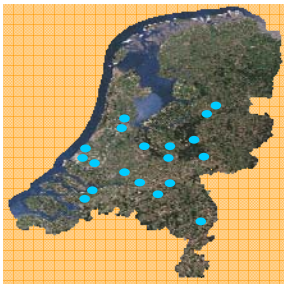
IPG

Biggest achievement

Approval of two layer porous Asphalt



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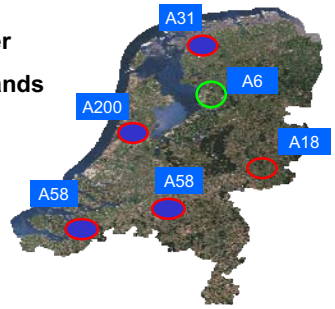
Another achievement

Thin layers:

pilots all over

The Netherlands



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Achievement 3

Rollpave

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Achievement 4

Modieslab (silent concrete plates)

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Pavement Goals

Pavements studied within IPG have to be:

Silent	4 – 9 dB(A)
Safe	Comparable to current pavement types
Availability	Not later than 2007
Cheap	Longer lifetime (9 –13 year)

Current issue **structural** lifetime,
but also **acoustical** lifetime

Both are main topics of DWW/DRI programme and the workshop these days

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Implementation of the IPG program

Ruud Nijland
DWW

Road and Hydraulic Engineering Institute

IPG approach

Cost effectiveness by source oriented measures

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IPG-Innovations

- **Silent Pavements**
  - Two Layer Porous Asphalt
  - Thin Asphalt Layers
  - Third generation silent pavements
- **Silent tires**
  - Kopenhagen Workshop
  - International Lobby
- **Noise barriers**

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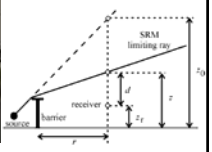
Another achievement

T-Top in Dutch noise legislation

$$D_l = \begin{cases} A & \text{for} \quad d \le d_l \\ A\dfrac{d-d_0}{d_l-d_0} & \text{for} \quad d_l < d < d_0 \\ 0 & \text{for} \quad d \ge d_0 \end{cases}$$

with $d_l = -5$ m, $d_0 = +5$ m, and $A = 4$ dB



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What are we doing?

Bridging the gap between invention and implementation

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Implementation

Pavements studied within IPG have to be:

Silent	4 – 9 dB(A)
Safe	Comparable to current pavement types
Available	Not later than 2007

Implementation

Pavements like:
- Twin layered Porous Asphalt
- Thin Silent Asphalt Layers

-ready for use in 2008
- Rollpave
- Modieslab

-demonstrated for use in 2008

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Still to be done

Goals

Improve **Structural** lifetime:
- Lifetime Optimisation Tool (LOT)

Improve **Acoustical** lifetime:
-Acoustical Optimisation Tool (AOT)

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Also to be done

- Test a potential –9 db(A) surface (poro-elastic pavement)
- Describe clogging and cleaning of porous pavements
- Describe ravelling process

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Relevance and perspective of the DRI-DWW noise abatement program

Bojan Leben

Executive Committee officer

Forum of European National Highway Research Laboratories (FEHRL)

FEHRL Background

- 15 years as the European Centre of Excellence in Road Research
- Formed as the organisation of European National Road Research Centres
- Currently consists of 29 institutes – all with a public service orientation – employing over 5,000 staff
- Facilitates cooperative research projects for European Road Directorates, European Commisson and other clients
- Maintains contacts with EC and other international associations
- Prepares strategic documents (vision, SERRP → TP documents)

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FEHRL's statutory objectives

Through research collaboration, FEHRL's main objectives are to:

- **Provide scientific input to EU and national government policy on highway engineering and road transport matters**.
- Create and maintain an efficient and safe road network in Europe.
- **Increase innovation in European road construction and road-using industries.**
- Improve the energy efficiency of highway engineering and operations.
- **Protect the environment and improve quality of life**.

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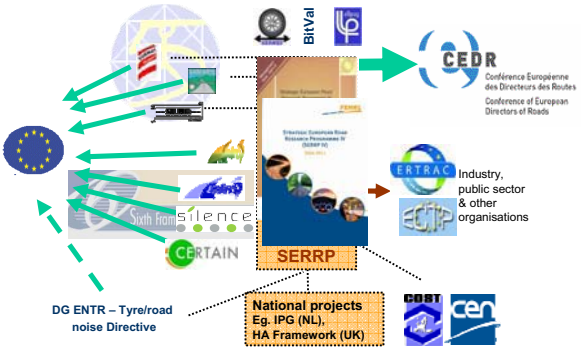
SERRP – to be a part of European Strategy



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Process for new SERRP programmes

- Get priorities of stakeholder
  - Input strategies (visions) of external drivers
  - Consultation with individual industry partners
- Develop strategic research plan
  - Action plan, not a wish list
- Select instruments
- Put results into practice

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The external drivers for SERRP

- CEDR
  - Top 15 priorities
  - ERA-NET ROAD
- Industry
  - Implementation of innovation
  - Regulations and Directives
  - Holistic research
- Commission
  - EU Council – Lisbon agenda
  - Competitiveness
  - Reducing management requirements

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External driver - Industry

- Biggest funders of research in Europe
  - DaimlerChrysler €5 Billion per year
  - Bouygues €89 Million per year
- Implementation of innovation
  - global competitiveness
- Dealing with Regulations and Directives
  - Overcoming problems for 'narrow' legislation
- Holistic research
  - eg EUCAR interest in congestion

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SERRP Instruments – project types

- FEHRL Internal projects
- CEDR-FEHRL projects
- National projects
- Joint Industry-FEHRL projects
- COST actions
- EC Framework RTD projects
- EC Study contracts

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The SERRP Technical Work Areas

- **Mobility, Transport & Infrastructure**
- **Energy, Environment & Resources**
- **Safety & Security**
- **Design & Production**

- ***Maintain strong link with ERTRAC & ECTP inputs***
- ***Appoint champions and create selected task forces***

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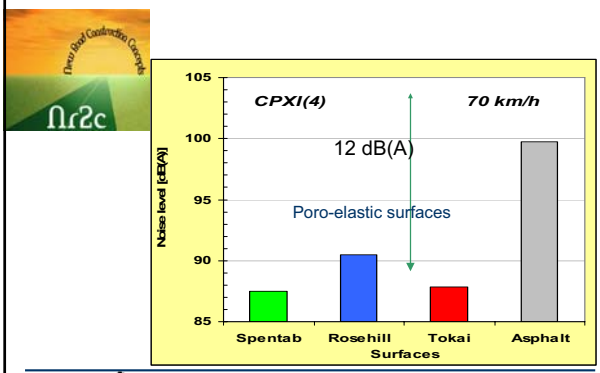
FEHRL projects



vti

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Projects with some noise elements

New Road Construction Concepts

SPENS Sustainable Pavements for New Member States with Noise elements

CALM Coordination of European Research for Advanced Transport Noise Mitigation

CERTAIN Central European Research in Transport Infrastructure

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INQUEST

Information Network on QUiet European road Surface Technology

- CA
- To foster the use of low-noise road surfaces throughout Europe
- To disseminate European research results through Workshops in EU MS that were not involved in the SILVIA project
- Setting up a group of users of the classification (including labelling and Conformity of Production) procedures developed by SILVIA

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Relevance

The co-operation is carried out within the framework of the Dutch Noise In-novation Programme (IPG).

Experience of organising workshop where the international research community evaluated the first findings and reviewed the programme is now at the second step.

Cooperation

This is to present the main findings of the research within the programme and ask the scientific community to evaluate the results obtained to date.

This will provide the opportunity to adjust or extend data analysis and conclusions.

Perspective programme

Address the following topics:

- Investigation of the possible noise reductions by road surfaces, tyres and vehicles and enhanced noise barriers;
- Scientific research into the knowledge needed to realize the reduction effects;
- Development of the technologies and products to a level of general application in the national main road and vehicle population.

Reduction programme

- *Silent roads*
- *Silent tyres and vehicles*
- *Enhanced noise barrier efficiency*
- *Assessment methods*

Perspective results

The contents of the research cluster are summarised:

Knowledge management and facilities

- setting up of a system that gathers and communicates technical/scientific results of research inside and outside the IPG;
- broadening and deepening of the basic knowledge on rolling noise generation, short distance propagation (including shielding) and active noise cancellation;
- building and maintenance of research facilities for vehicle/tyre testing in semi-trafficked conditions and real trafficked conditions.

Lessons and relevence

- Strong steering from policy department needed to cross the gap
- Create mutual interest to cross the gap from decision making organizations
- Effort in communication between science and policy

Need for a noise harmonisation

- Member states are developing their own systems for noise classification.
- It would be wasteful for further divergent activity to continue and reduce duplication and force the nergy in directions to topics that are not yet in research

- Understandable, practical & cost-effective
- Compatible with existing (national) methods of assessment
- Compatible with the EU HARMONOISE/ IMAGINE road traffic noise prediction model

- Properly defined Performance based specifications for road infrastructure and especially pavements will lead to better performance and increased innovation

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Instead of conclusion

IPG programme is showing a large range of:

- Cooperation
- Willingness and
- Excellence

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Welcome on:

www.fehrl.org

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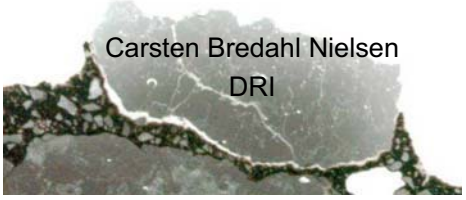
Results and recommendations Structural durability

Carsten Bredahl Nielsen
DRI



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IPG statements

"Improvement of lifetime is a major issue within the IPG-programme"

"Structural durability of a porous surface is mainly determined by its ravelling resistance"

"For Single layer porous asphalt about 80 % of failure is caused by ravelling "

"Improvement is to be found in improving size, shape and properties of the contact bridges between aggregate elements."

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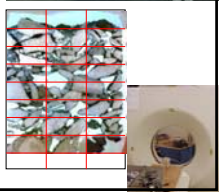
Research questions

Strategy 1: Prevent early failure

Which properties leads to early failure?

Strategy 2: Improve overall behavior

Which mechanisms cause failure?



- DRI microstructure research

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Microstructure research

Durability depends on design and quality of paving

- Performance under mechanical loading
- Influence of time and climate (aging and stripping)
- Cohesion failure and/or adhesion failure
- Identification of appropriate test methods

Goals

- Understanding the ravelling process
- Prediction of ravelling susceptibility
- Mixes with better resistance

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European Experiences

- Development towards finer mixes with high binder content and 22 - 30 % voids;
- Public demand for noise abatement leads to new developments;
- Avoid the expensive use of high quality aggregate due to the applied thickness of porous asphalt;
- The use of modified binders are generally recommended;

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Research techniques

CT-scanning

- Overview of the micro-structure
- Quantify the cause of ravelling
- Useful in the design of new, durable porous asphalt pavements

Thin sections

- Detailed visual information - explain the cause of ravelling
- Quantifying visual observations - correlate with CT-scanning
- Useful in modelling of porous asphalt deterioration mechanisms

Recommended for the assessment of road sections

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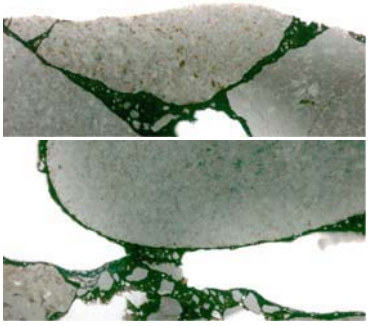
Good performance – 1 year



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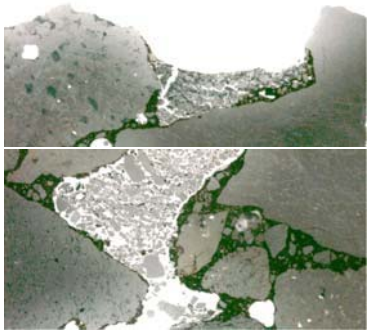
Clogging of surface – 7 years



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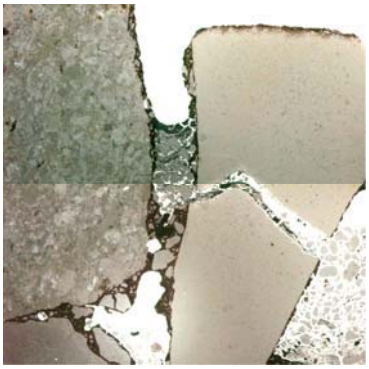
Poor performance – 12 years



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Conclusions

- The main overall deterioration mechanism is related to the adhesion between mastic and aggregate and mastic cohesion
- Clogging correlates with adhesion
- The bituminous mastic deteriorates in pavements with poor adhesion and leaves clogging in the voids
- Narrow voids have been formed in the top zone for poorly performing roads

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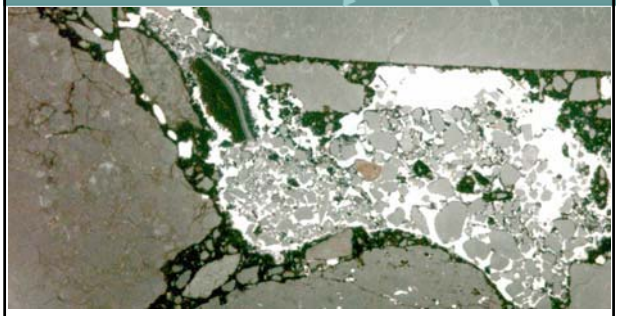
A15: Section F, fast lane



12 years old. Poor performance. Layer 2 (5-10 mm)

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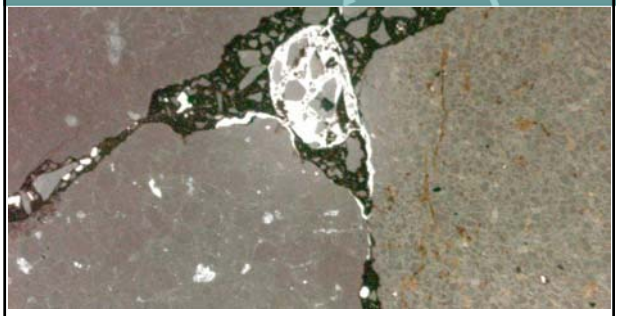
A15: Section E, shoulder



12 years old. Good performance. Layer 6 (25-30 mm)

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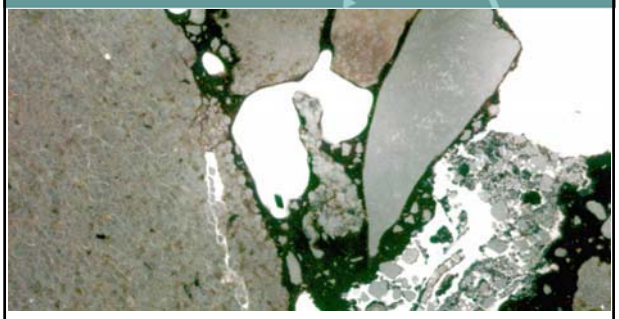
A15: Section D, fast lane



7 years old. Poor performance. Layer 2 (5-10 mm)

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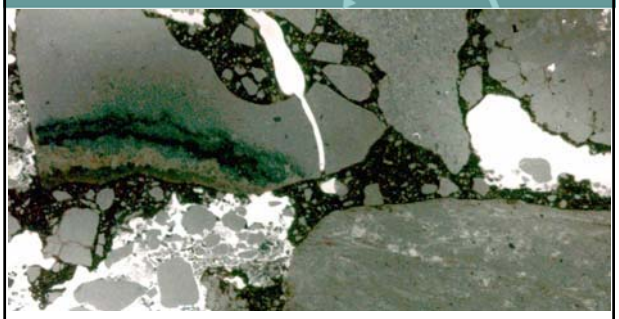
A15: Section C, shoulder



7 years old. Good performance. Layer 2 (5-10mm)

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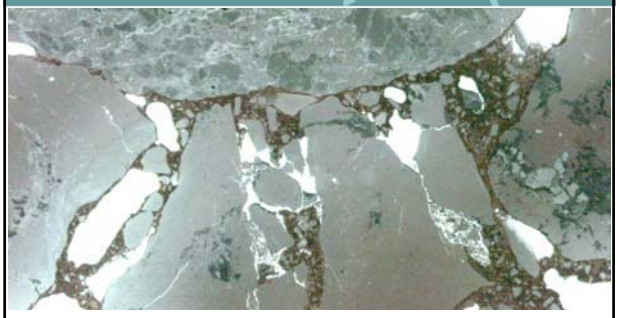
A15: Section B, slow lane



3 years old. Good performance. Layer 2 (15-10 mm)

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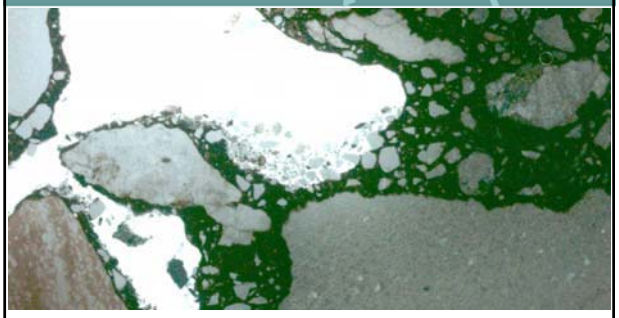
A15: Section A, shoulder



1 year old. Good performance. Layer 3 (10-15 mm)

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Acoustical durability – Conclusions and Recommendations

Jørgen Kragh
Danish Road Directorate
Danish Road Institute

Overview

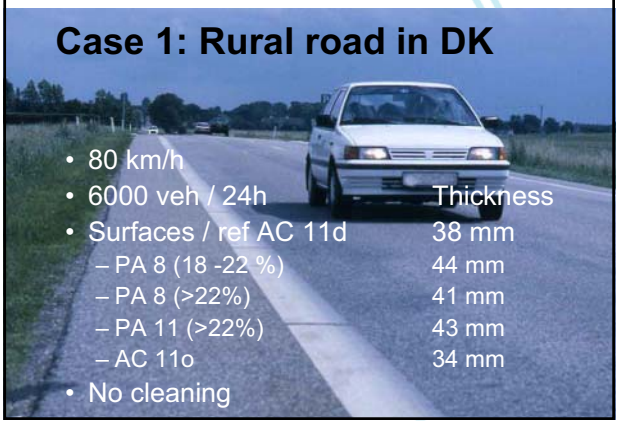
Porous asphalt
- Rural road – DK
- Motorways – NL
- City Street – DK
- Collection – SILVIA/SILENCE

Thin layers: Next speaker

Proposed conclusions

Rel. DAC of same age
- Porous asphalt: Initial 4 - 6 dB reduction
- Gradual clogging => loss of noise reduction
- Terminal state: still 1 – 3 dB reduction
  - Motorway 8+ mm: duration 10 - 12 years
  - City street with cleaning (+local situation)
    - 8 mm: 8+ yrs; 5 mm: 4 – 6 yrs (structural: 8yrs)
- Rel. "standard surface" ≈ 2 dB more red. until reference > standard

Case 1: Rural road in DK

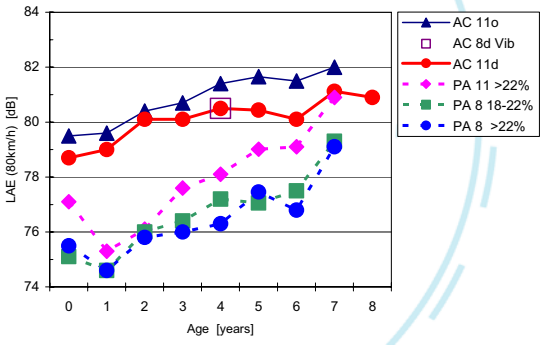


- 80 km/h
- 6000 veh / 24h
- Surfaces / ref AC 11d

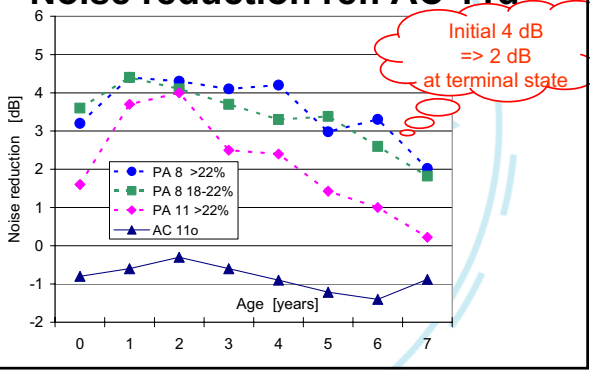
Thickness
38 mm
– PA 8 (18 -22 %) 44 mm
– PA 8 (>22%) 41 mm
– PA 11 (>22%) 43 mm
– AC 11o 34 mm

- No cleaning

Noise levels - rural



Noise reduction ref. AC 11d

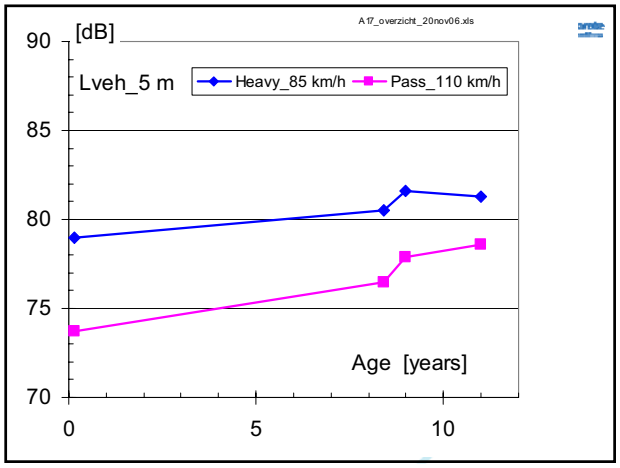


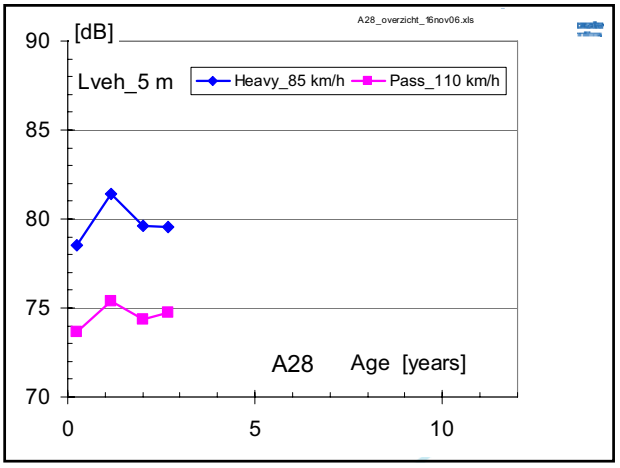
Part 2: Motorways - NL

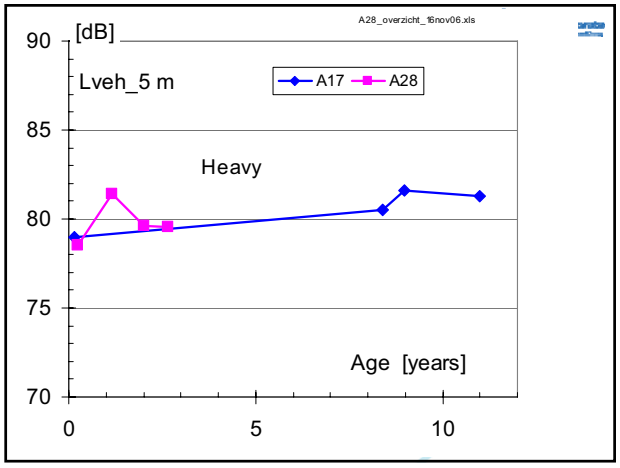
SPB; CPX; Alpha
Air & Water drain
Skid; Brake; Tex
Vis

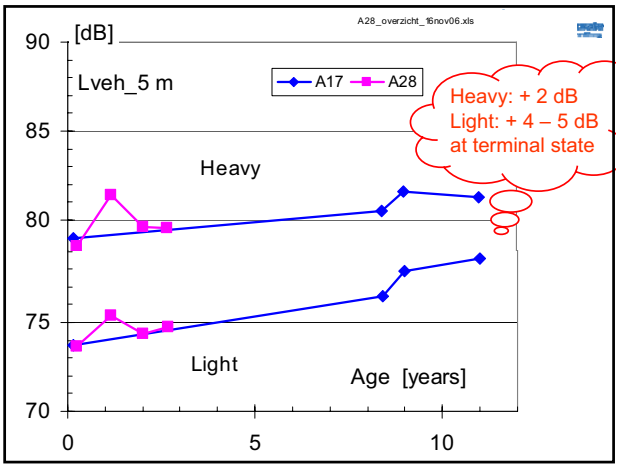
DWW database

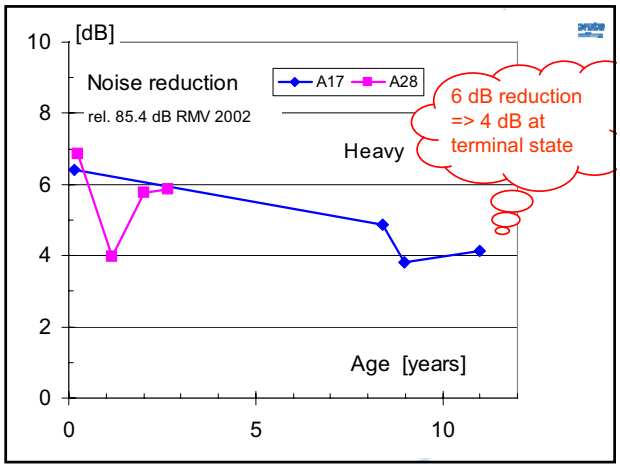
- Two-layer PA 8 / PA 16 built
  - A17: Nov 94: Twinlay
  - A28: Aug 02: Dura Vermeer
  - Clean emergency lane – unknown how often

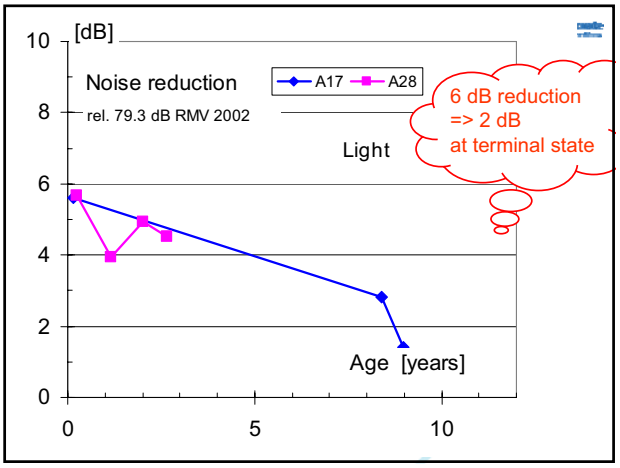


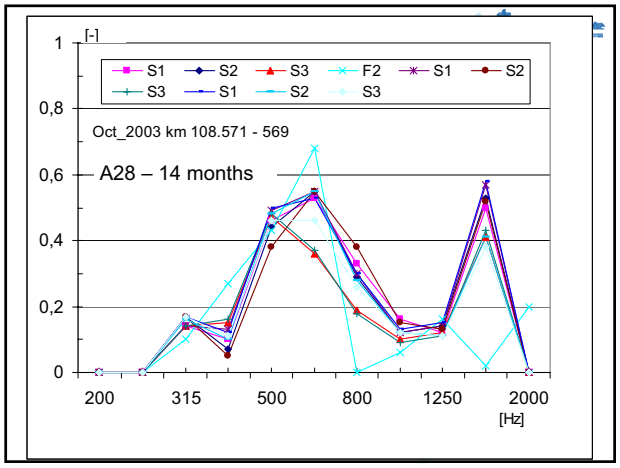


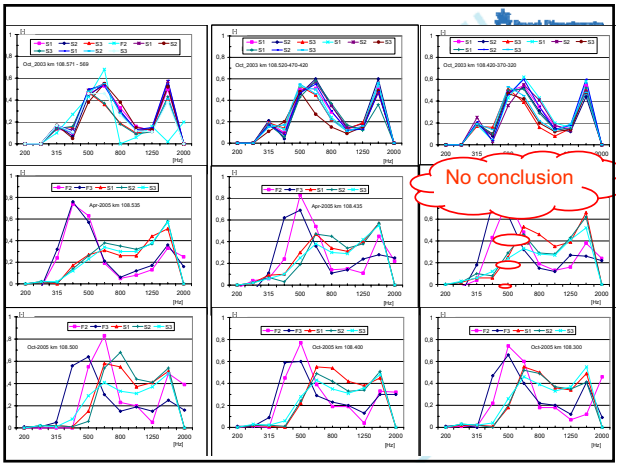






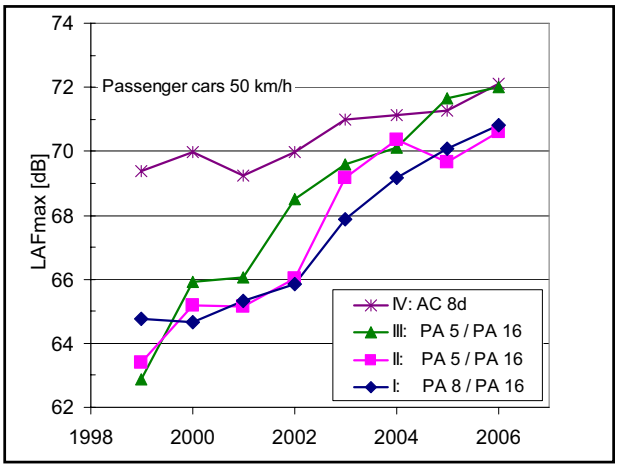


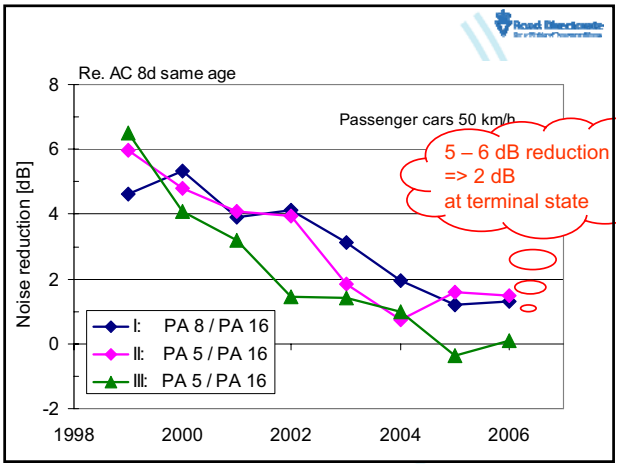


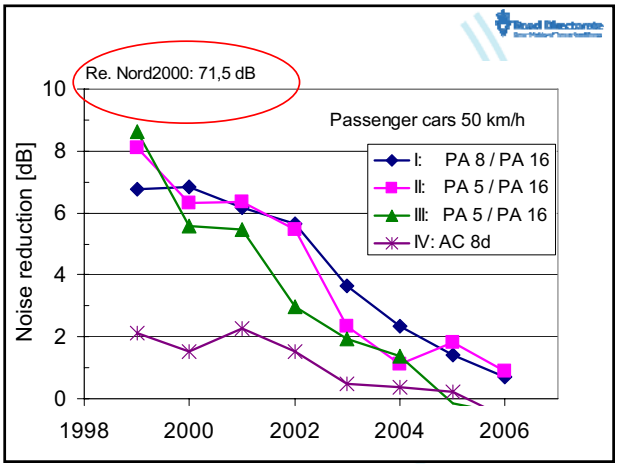


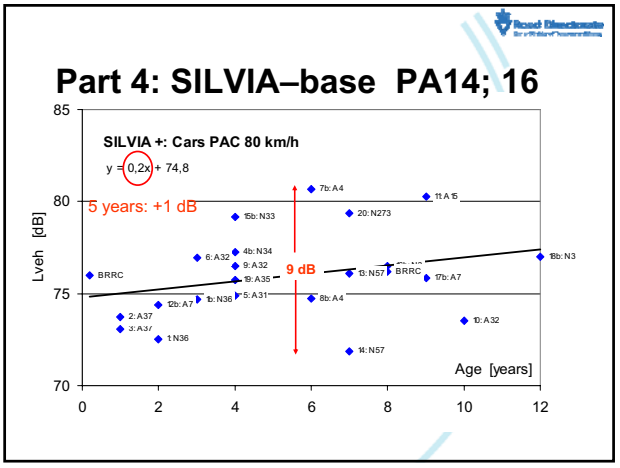
Case 3: City Street - DK

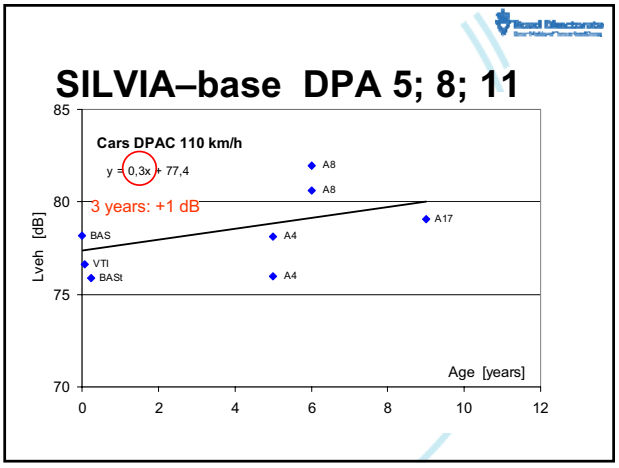
- 50 km/h
- 7000 / 24h
- Surfaces
  - PA 8 / PA 16 - 90 mm
  - PA 8 / PA 16 - 55 mm
  - PA 8 / PA 16 - 70 mm
- 2*Cleaning/year
- Reference: AC 8d


Passenger cars 50 km/h
LAFmax [dB]
74
72
70
68
66
64
62
1998
2000
2002
2004
2006
IV: AC 8d
III: PA 5 / PA 16
II: PA 5 / PA 16
I: PA 8 / PA 16

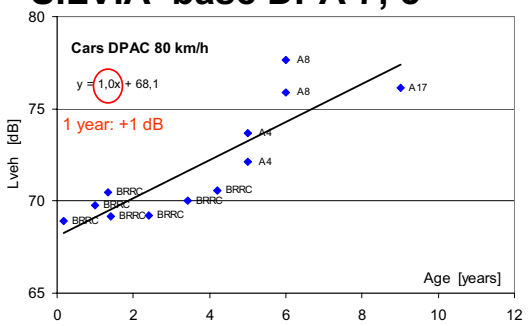

Re. AC 8d same age
Passenger cars 50 km/h
Noise reduction [dB]
8
6
4
2
0
-2
1998
2000
2002
2004
2006
5 – 6 dB reduction
=> 2 dB
at terminal state
I: PA 8 / PA 16
II: PA 5 / PA 16
III: PA 5 / PA 16


Re. Nord2000: 71,5 dB
Passenger cars 50 km/h
Noise reduction [dB]
10
8
6
4
2
0
1998
2000
2002
2004
2006
I: PA 8 / PA 16
II: PA 5 / PA 16
III: PA 5 / PA 16
IV: AC 8d

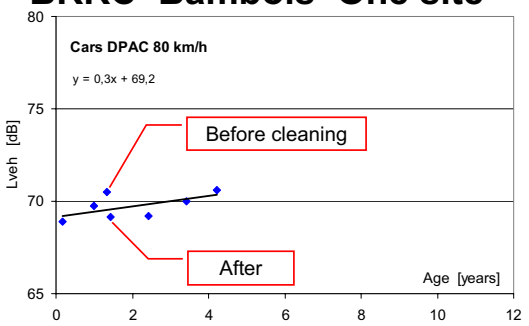

Part 4: SILVIA–base PA14; 16
SILVIA +: Cars PAC 80 km/h
y = 0,2x + 74,8
5 years: +1 dB
9 dB
Lveh [dB]
85
80
75
70
0
2
4
6
8
10
12
Age [years]
BRRC


SILVIA–base DPA 5; 8; 11
Cars DPAC 110 km/h
y = 0,3x + 77,4
3 years: +1 dB
Lveh [dB]
85
80
75
70
0
2
4
6
8
10
12
Age [years]
A8
A8
A17
A4
A4
BAS
VTI
BASt

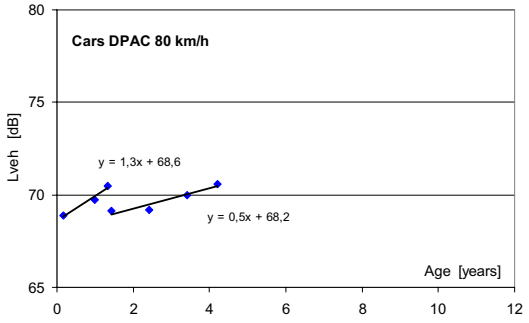
SILVIA–base DPA 7; 8



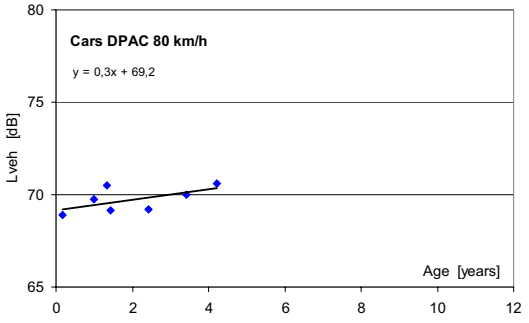
BRRC–Bambois One site



BRRC - Bambois



DPA – One site



Proposed conclusions

Rel. DAC of same age

- Porous asphalt: Initial 4 - 6 dB reduction
- Gradual clogging => loss of noise reduction
- Terminal state: still 1 – 3 dB reduction
  - Motorway 8 mm: duration 10 - 12 years
  - City street with cleaning (+local situation)
    - 8 mm: 8+ yrs; 5 mm: 4 – 6 yrs (structural: 8yrs)
- Rel. ”standard surface” ≈ 2 dB more red. until reference > standard

Noise reducing thin layer pavements
Results and Recommendations

Hans Bendtsen
Senior researcher
Road Directorate
Danish Road Institute

DRI-DWW noise abatement program Workshop November 23rd to 24th 2006

The thin layer project

Task to develop and test thin layers for highways with:

- Long time acoustical effect
- Long time structural effect
- Good traffic safety

Activities:

- International literature study
- Study tour to France, Japan and USA
- Development of optimized mixes
- Measurements on Danish test section from 2004
- New test sections Denmark the Netherlands (2006)

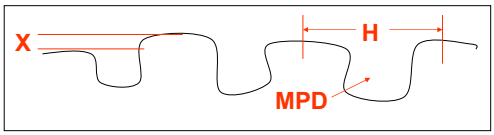
History

- Thin layers were introduced in the beginning of the 1990´th in France and other European countries
- Purpose was to achieve a durable wearing course with a good friction at a relatively low price
- The idea of modifying the surface structure of thin layers to achieve a noise reduction introduced in the late 1990´th in the Netherlands, France and other countries
- Noise reducing pavements without a porous structure for urban roads
- Now IPG research and development on highway application

Influence of surface texture
Fujikawa et. al. Japan

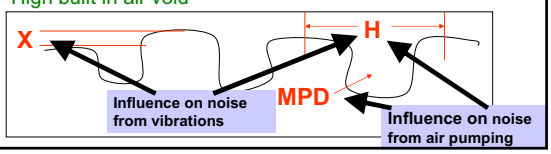
- Unevenness (X) the difference in height between the highest points on surface
- (H) average distance between the highest points in the road profile
- Medium Profile Depth (MPD)

$L = 1.07*H + 0.33*X - 0.22*MPD + 91.1$ (dB)



Optimizing of noise reduction:

- The highest points of a road surface must have the same height (reduce X)
- Cubic aggregate and good compaction
- The distance between these high points must be minimized (reduce H)
- Small aggregate
- The “holes” between the top points shall be as deep as possibly (increase MPD)
- High built in air void



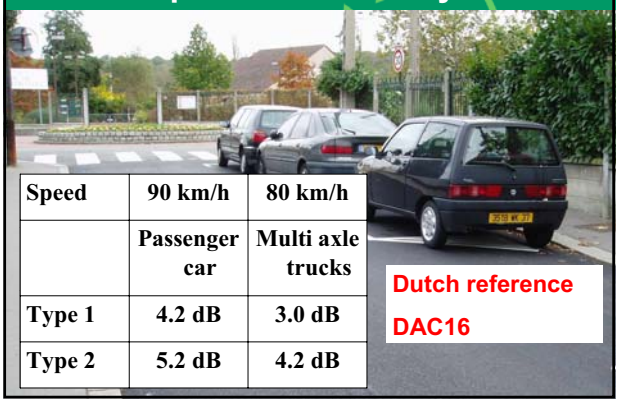
Noise reducing thin layers ?

- Pavements with a very open surface structure (reduces noise from air pumping)
- Small max. aggregate size (even surface structure reduces noise from tire vibrations)
- Thickness typically 20-30 mm
  Rule of thumb 3 times max. aggregate size

Built in air void

- Dense layers (4-9 %).
- Semi dense layers (9-14 %).
- Semi open (14-19 %).
- Open layers (over 19 %) porous.

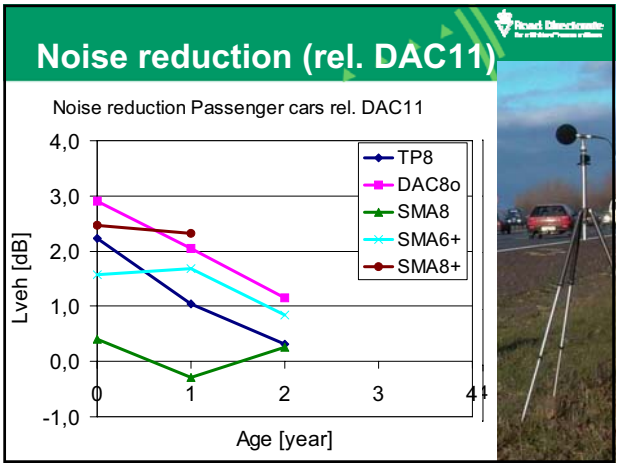
French experiences thin layers



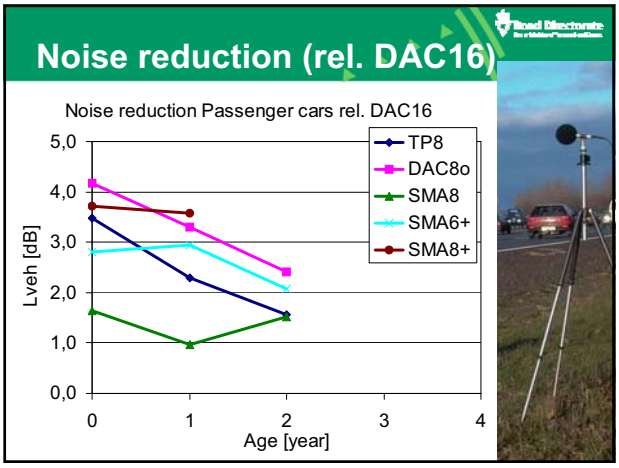
Speed	90 km/h	80 km/h
	Passenger car	Multi axle trucks
Type 1	4.2 dB	3.0 dB
Type 2	5.2 dB	4.2 dB

Dutch reference
DAC16

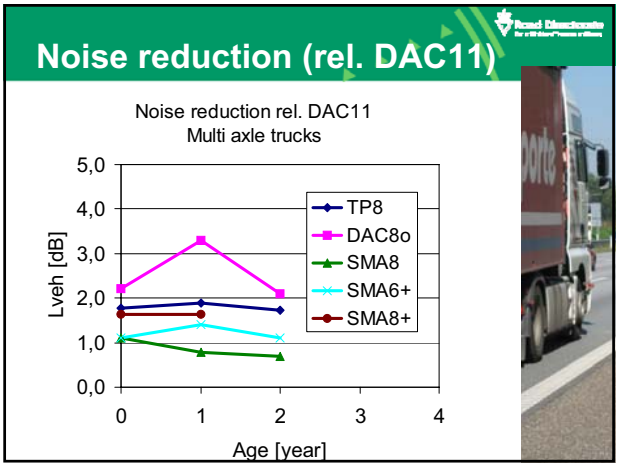
Noise reduction (rel. DAC11)



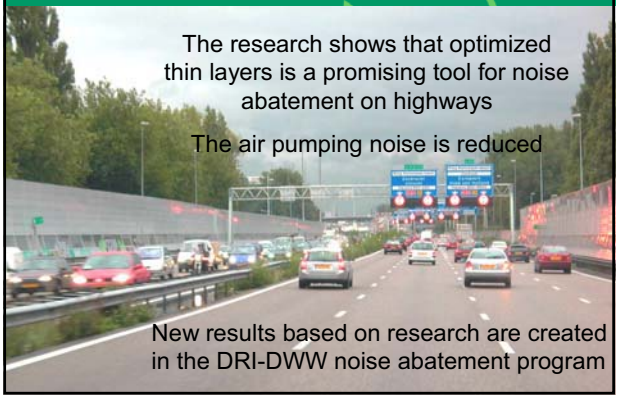
Noise reduction (rel. DAC16)



Noise reduction (rel. DAC11)



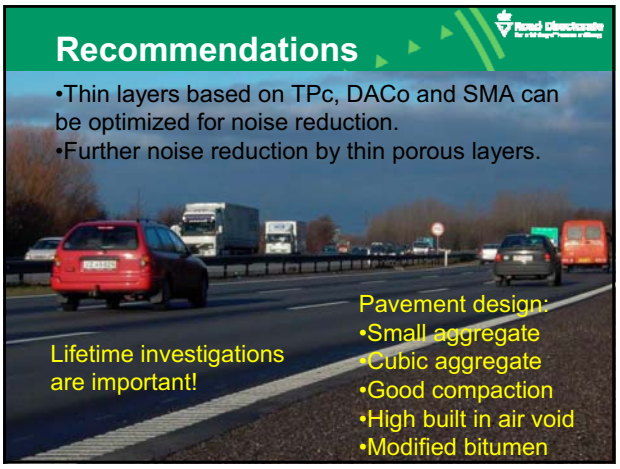
Conclusion



The research shows that optimized thin layers is a promising tool for noise abatement on highways

The air pumping noise is reduced

New results based on research are created in the DRI-DWW noise abatement program


Recommendations
•Thin layers based on TPc, DACo and SMA can be optimized for noise reduction.
•Further noise reduction by thin porous layers.
Lifetime investigations are important!
Pavement design:
•Small aggregate
•Cubic aggregate
•Good compaction
•High built in air void
•Modified bitumen


END

Silent Pavements

Relevance and Perspective

24 November 2006
DRI-DWW Workshop, Rungsted Kyst
Program

IPG
Noise Innovation

Dutch Perspective

Current Dutch Perspective/Expectations influenced by:

Yesterday's Elections

Santa Claus

Santa Claus

Children make a :

List with desired presents

IPG-List

Two Layer Porous Asphalt with:

- Better Durability
- Better Noise Reduction during Lifetime
- Longer Construction Season
- Higher Safety

Silent Thin Layer Asphalt with:

- Lower Life Cycle Cost (compared to PA)

Techniques for better assessment of Noise Reducing Properties after construction

Perspective

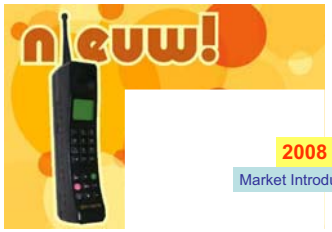
Two Layer Porous Asphalt

2005
Market Introduction

2008
Improved Product

Perspective

Silent Thin Layer Asphalt



2008
Market Introduction

From List to Products 2006

IPG has one year to go….

and

…knows (exactly) which products fulfils its wishes

Towards products…

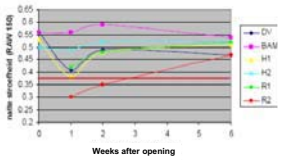
Political/U…

Two Layer Porous Asphalt

Targeted Products

Asphalt Mixture which exhibits superior initial skid resistance

2005: Test with several additives



Two Layer Porous Asphalt

Targeted Products

Tested Mixture Improvements:

DV	**Added glass slag (0/1)**
BAM	Added mineral material (Europium fluoride)
H1	Added fine sand
H2	Added 2/6 aggregate (Belgian sandstone) & fine sand
R1	H2 + added synthetic fibres
R2	R1 + bitumen replaced with standard bitumen 70/100

See: www.innovatieprogrammageluid.nl

Two Layer Porous Asphalt

Targeted Products

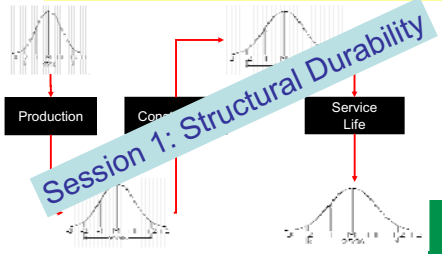
Construction Method that allows Construction at low Temperatures, i.e. during Spring and Autumn but also during night time

Test in 2006 and in 2007

Two Layer Porous Asphalt

Targeted Products

A model that allows contractors to develop more durable mixtures



Two Layer Porous Asphalt

Targeted Products

A cleaning method for longer lasting noise reduction

Session 2: Acoustic Durability

Test in in 2007

Silent Thin Layer Asphalt

Targeted Products

A Silent Thin Layer Pavement which is cheaper than PA

Session 3: Thin Silent pavements

Test in in 2006 and 2007

Noise Assesment

Targeted Products

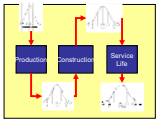
New reference tyres for CPX-method

Special session: CPX-tyres

Test in in 2006 and 2007

DRI Knowledge

Two Layer Porous Asphalt

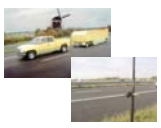


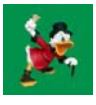
DRI → DWW/IPG → End-User

Knowledge — Improvement — Desired Effect

DRI Knowledge

Silent Thin Layer Asphalt





DRI → DWW/IPG → End-User

Knowledge — Product — Desired Effect

This Event

Presentation recent knowledge obtained by DRI and DWW

Enjoy/join our ideas

but

- Be Critical
- Stimulate us by sharing your Experience and Knowledge

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European Research on Road Traffic Noise Abatement

Johann Litzka, TU Vienna
supported by
Jürgen Haberl
Phil Morgan

Workshop „Optimization of Noise Reducing Pavements“, Copenhagen, 23.-24.11.2006

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Europe:

Much Noise About Noise

„European noise climate“ (IPG strategy document)

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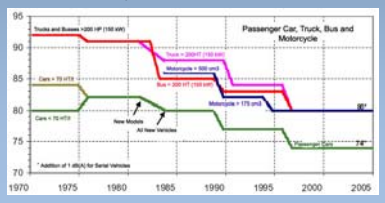
EU noise regulations

- Directive 2002/49/EC relating to the assessment and management of environmental noise, 2002
- Directive 2001/43/EC relating to tyres for motor vehicles and their trailers and to their fitting, 2001
- Directive 96/20/EC relating to the permissible sound level and the exhaust system of motor vehicles, 1996



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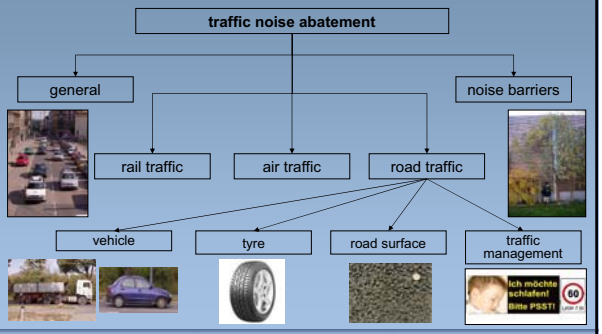
research topics



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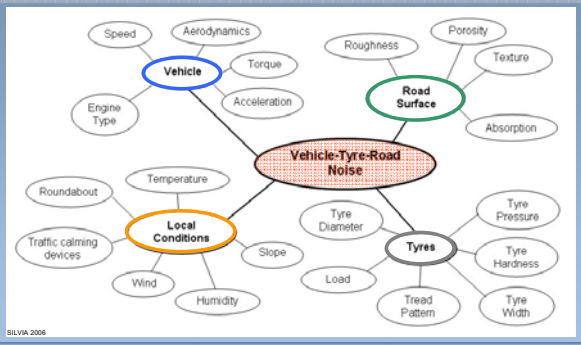
influence factors on road traffic noise



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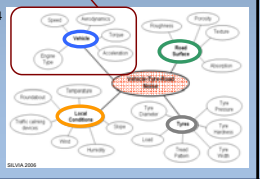
European research projects on road traffic noise abatement

(extract)

- FLODAC – Modelling Sound Generation and Propagation in Fluid Machinery Systems, 1997-2001
- DOLCE – Development of Innovative Low Pollutant, Low-Noise, Low Fuel Consumption Two-Spark Ignition Engines for Future Vehicles for Individual Urban Mobility, 1997-2000
- ELCIDIS – Electric Vehicle Goods Distribution Systems, 1998-2002
- BRAKE NOISE – Methods and Tools to Address Friction-Induced Noise and Vibration in Brakes and Wheels, 199-2002
- CASCO – Consistent Semiactive System Control, 2000-2003
- SVEN – Sound Quality of Exterior Vehicle Noise, 2000-2003
- VISPER – Vehicle Integral Simulation for Pass-By Noise Reduction, 2001-2004
- ARTEMIS – Acoustic Research on Turbocharged Engine Modelling of Exhaust and Inlet Systems, 2001-2004
- AROMA – Acoustic Radiation of Small Turbo-Machines, 2001-2003
- ACES – Optimal Acoustic Equivalent Source Descriptors for Automotive Noise Modelling, 2002-2005
- FURORE – Future Road Vehicle Research – A Roadmap for the Future, 2002-2003
- EFFNOISE – Effectiveness of Noise Mitigation Measures, 2003-2004



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European research projects on road traffic noise abatement

(extract)

- TINO – Analysis, Measurement and Suppression of Tyre Noise, 1996-1999
- RATIN – Road and Tyre Interaction Noise, 2000-2003
- ROTRAMO - Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures, 2002-2004
- SILVIA – Sustainable Road Surfaces for Traffic Noise Control, 2002-2005
- FEHRL – Study about technical possibility to apply the tyre/road noise emission levels of Directive 2001/43/EC without compromising vehicle safety, 2005

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European research projects on road traffic noise abatement

(extract)

- TINO – Analysis, Measurement and Suppression of Tyre Noise, 1996-1999
- SIRUUS – Silent Road for Urban and Extra-Urban Noise, 1998-2001
- RATIN – Road and Tyre Interaction Noise, 2000-2003
- HARMONOISE – Harmonised, Accurate and Reliable Prediction Methods for the EU-Directive on the Assessment and Management of Environmental Noise, 2001-2004
- ROTRAMO – Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures, 2002-2004
- Integrated assessment of noise reduction measures in the road transport sector (IntAss), 2002-2003
- SILVIA – Sustainable Road Surfaces for Traffic Noise Control, 2002-2005
- IMAGINE – Improved Methods for the Assessment of the Generic Impact of Noise in the Environment, 2003-2006
- ITARI – Integrated Tyre and Road Interaction, 2004-2007
- SILENCE – Quieter Surface Transport in Urban Areas, 2005-2008
- INQUEST – Information Network on Quiet European road Surface Technology, 2006

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European research projects on road traffic noise abatement

(extract)

- UDC - Urban Drive Control, 1996-1998
- SYLVIE – Systematic Implementation of Low-Noise Measures in Urban Residential Areas in Vienna, 1999-2002
- SUTRA – Sustainable Urban Transportation, 2000-2002
- CALM – Community Noise Research Strategy Plan, 2001-2004
- TELLUS – Transport and Environment Alliance for Urban Sustainability, 2002-2006
- Integrated assessment of noise reduction measures in the road transport sector (IntAss), 2002-2003
- SILVIA – Sustainable Road Surfaces for Traffic Noise Control, 2002-2005
- EFFNOISE – Effectiveness of Noise Mitigation Measures, 2003-2004
- SIPTRAM – Sustainability in the Public Urban Transport Market, 2003-2005
- SILENCE – Quieter Surface Transport in Urban Areas, 2005-2008
- QCITY – Quiet City Transport, 2005-2009

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European research projects on road traffic noise abatement

(extract)

- FLODAC (1997-2001)
- DOLCE (1997-2000)
- ELCIDIS (1998-2002)
- BRAKE NOISE (1999-2002)
- CASCO (2000-2003)
- SVEN (2000-2003)
- VISPER (2001-2004)
- ARTEMIS (2001-2004)
- AROMA (2001-2003)
- ACES (2002-2005)
- FURORE (2002-2003)
- EFFNOISE (2003-2004)
- .....

- UDC (1996-1998)
- SYLVIE (1999-2002)
- SUTRA (2000-2002)
- CALM (2001-2004)
- TELLUS (2002-2006)
- IntAss (2002-2003)
- SILVIA (2002-2005)
- EFFNOISE (2003-2004)
- SIPTRAM (2003-2005)
- SILENCE (2005-2008)
- QCITY (2005-2009)
- ....

- TINO (1996-1999)
- SIRUUS (1998-2001)
- RATIN (2000-2003)
- HARMONOISE (2001-2004)
- ROTRAMO (2002-2004)
- IntAss (2002-2003)
- SILVIA (2002-2005)
- IMAGINE (2003-2006)
- ITARI (2004-2007)
- SILENCE (2005-2008)
- INQUEST (2006)
- ....

- TINO (1996-1999)
- RATIN (2000-2003)
- ROTRAMO (2002-2004)
- SILVIA (2002-2005)
- FEHRL tyre study (2005)
- ....

→ in addition: many national projects

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national research projects on road traffic noise abatement

(examples)

- Lärmarme Straße, 1994 – *Austria*, test section, several low noise road surfaces, different tyres & vehicles, vehicle-tyre-road surface combinations
- Øster Søgade project, 1999 – *Denmark*, double layer porous asphalt
- Leiser Verkehr (quiet traffic), 1999 – *Germany*, several low noise road surfaces, noise- optimised tyres, joints, …
- HILJA, 2001 – *Finland*, several test sections, double layer porous asphalt
- IPG, 2002 – *Netherlands*, Noise Innovation Program for road and rail traffic, double layer porous asphalt, innovative low noise road surfaces, ….
- Roads To The Future, 2003 – *Netherlands*, innovative low noise road surfaces
- SILVIA.DK, 2003 – *Denmark*, noise reducing thin layer pavements (urban street)
- DRI/DWW Noise abatement programme, 2004 – *Denmark, Netherlands* double layer porous asphalt, thin surfacing
- …….

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CALM project database

overview of European and selected national research projects:

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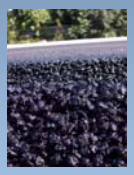
low noise road surfaces

problems to solve:



- improvement of existing noise reducing solutions
- development of innovative noise reducing road surfaces (laboratory tests and implementation under real traffic conditions)
- acoustical durability of silent road surfaces
- structural durability of silent road surfaces
- life-cycle costing
- traffic safety (early skid resistance)
- road operation and maintenance
- harmonisation of noise measurements (e.g. CPX)
- noise calculation, noise prediction models
- ……..

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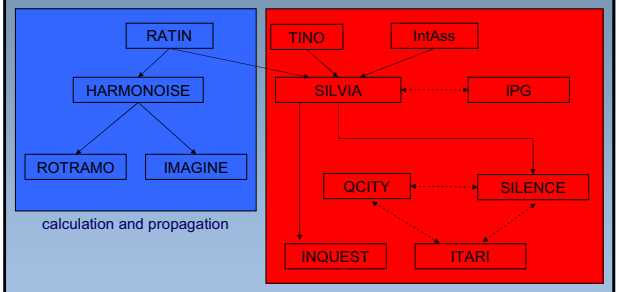
recent European projects on low noise road surfaces

(excerpt)



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project SILVIA [1]

SILVIA — Sustainable Road Surfaces for Traffic Noise Control

- **objectives:**
  - develop a classification procedure for noise reducing road surfaces combined with a conformity-of-production testing method
  - test and specify road construction and maintenance techniques
  - develop a procedure for cost/benefit analysis of noise abatement measures
  - "European Guidance Manual on the Utilisation of Low-Noise Road Surfaces"
- **duration:** 2002-2005
- **budget:** > €2.0 Million
- **parties involved:** 15 partners
- **website:** www.trl.co.uk/silvia

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project SILVIA [2]

content:

- overview current state of the art
- improvement of performance
- experimental surfaces under development
- integration of low noise surfaces with other noise mitigation measures
- classification system for low noise surfaces

www.trl.co.uk/silvia

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project SILVIA [3]

assessment of new low noise road surface types:

double (twin) layer porous asphalt ⇒ IPG

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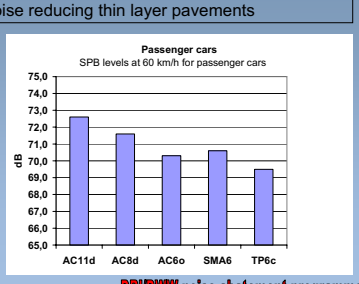
project SILVIA [4]

assessment of new low noise road surface types:

noise reducing thin layer pavements



AC 6o
thickness: 20mm
void content: 8-14 V-%

SMA 6
thickness: 20mm
void content: 4-8 V-%

TP 6c
thickness: 17mm
void content:17 V-%

⇒ DRI/DWW noise abatement programme

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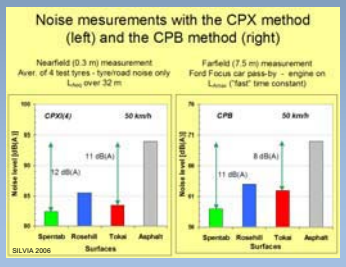
project SILVIA [5]

assessment of new low noise road surface types:

poroelastic road surface



European Research on Road Traffic Noise Abatement slide 19

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project SILVIA [5]

assessment of new low noise road surface types:

poroelastic road surface

European Research on Road Traffic Noise Abatement slide 20

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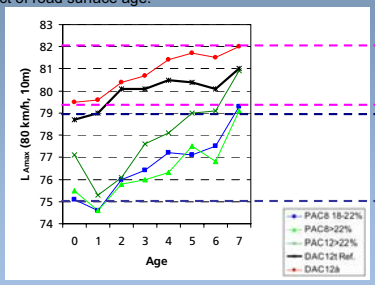
project SILVIA [6]

effect of road surface age:



European Research on Road Traffic Noise Abatement slide 21

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project SILVIA [6]

effect of road surface age:

IPG

Definition of noise reduction for ROAD SURFACES

In the IPG, the acoustical performance of a road surface will be expressed as a reduction value, based on the average performance over its technical life time. The reduction value is defined as the traffic noise level on the reference pavement (DAC 0/16) minus the corresponding traffic noise level on the silent road surface. The noise levels are based on SPB measurements using a 5 m microphone height (rather than the 1.2 m height stated in the associated ISO standard). The corresponding road traffic vehicle composition used to determine these noise levels consists of 80% passenger cars at a speed of 110 km/h and 20% heavy traffic (category 3) at a speed of 85 km/h. This composition will be referred to in the document as the "IPG traffic composition".

Notes: For the reference surface noise levels, see Appendix A
For the noise reductions on individual types of surfaces, see Table 2.1

Age

DAC12a

European Research on Road Traffic Noise Abatement slide 22

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project SILENCE [1]

silence

Quieter surface transport in urban areas

- **objectives:**
  - develop an integrated methodology and technology for improved control of surface transport noise in urban areas
  - develop innovative strategies for action plans for urban transport noise abatement and practical tools for their implementation
  - reach significant reduction of people's exposure to noise
  - overall outcome: reduction of noise emission in urban areas of up to 10 dB(A)
- **duration:** 2005-2008
- **budget:** > €15.8 Million (EU funding: €8.9 Million)
- **parties involved:** 45 partners
- **website:** www.silence-ip.org

European Research on Road Traffic Noise Abatement slide 23

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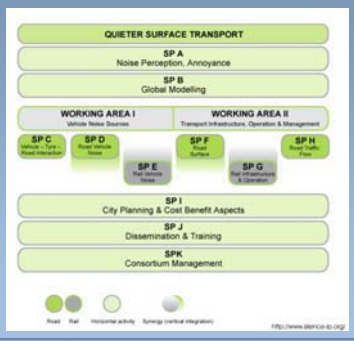
project SILENCE [2]

research topics:



European Research on Road Traffic Noise Abatement slide 24

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project SILENCE [3]

Sub-Project F: Road Surface

objectives:

- design and maintenance of lower noise road surfaces in urban areas
- develop new low-noise surfacing techniques and processes (speeds of 50 to 100 km/h)

The innovative part of sub-project F is to develop, monitor, classify and maintain pavements to be used in urban areas (looking at their whole lifetime and cost/effectiveness)

sub-projects:

- F1: surfaces on urban streets
- F2: surfaces on urban main roads
- F3: improved systems for maintenance of quieter surfaces
- F4: noise classification methods for urban road surfaces
- F5: testing of new road surfacing materials

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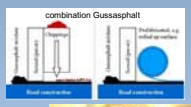
project SILENCE [4]

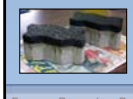
sub-project F: road surface

new low-noise surfacing techniques and processes

- **F1:** surfaces on urban streets
  - surfaces for cultural areas
  - texture optimised surface dressings
  - noise reducing technologies for low-noise street utilities

- **F2:** surfaces on urban main roads
  - optimised construction techniques
  - use of existing materials in new combinations
    - thin layers
    - single & double layer porous asphalt
  - new construction technologies
    - combination Gussasphalt
    - dense asphalt with high content of polymer-modified binder (ARFC)
    - block pavement improved by a cover of quiet poroelastic surface





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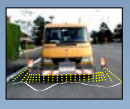
project SILENCE [5]

sub-project F: road surface

monitoring, maintenance and noise classification

- **F3:** improved systems for maintenance of quiet surfaces
  - acoustic monitoring
  - detection systems for discontinuities
  - systems for preventative maintenance
  - rejuvenation & fast repair systems



- **F4:** noise classification methods for urban road surfaces
  - measurement methods
  - models for predicting noise performance over time
  - classification
  - corrections for discontinuities

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project SILENCE [6]

sub-project F: road surface

laboratory tests

- **F5:** testing of new road surfacing materials

Focus on testing SILENCE-developed materials and technologies with regard to noise emission from passenger car tyres

- consultation and workshops on promising materials
- testing of new materials on drum facilities
- measurement of rolling resistance

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project ITARI [1]

ITARI Integrated Tyre and Road Interaction

- **objectives:**
  - supply knowledge, methodologies and insight to enable the research community to develop sustainable road transport for the future
  - provide the necessary design, test and measurement tools to investigate new road surfaces
- **duration:** 2004-2007
- **budget:** €1.7 Million (EC, DG Research)
- **parties involved:** 7 partners
- **website:** None

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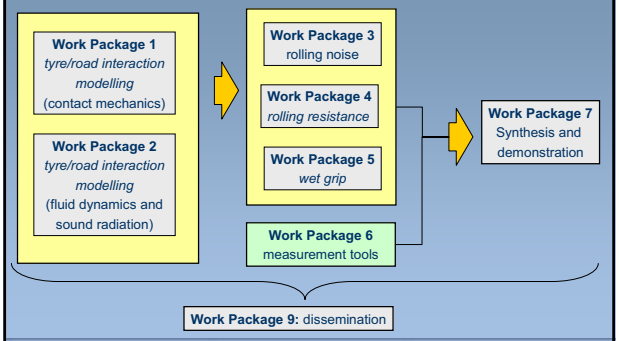
project ITARI [2]



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project ITARI [3]

- measurement methods to be used or developed:
  - in-situ measurement of normal and oblique sound incidence (also used for measuring 3D texture)
  - in-situ measurement of air-flow resistance within the contact of the tyre/road contact patch
  - mechanical impedance of surfaces
  - measurement procedures for grip
- construction of test sections will be done on "laboratory-scaled test patches which are unsuited to vehicle coast-by or rollover measurements

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review of the European situation [1]

- noise from road traffic is a big problem
- realised by administrations and politicians
- many projects on European level
- numerous important results
- voluminous reports

but:

- some parallel work with suboptimal use of synergies
- wide spread distribution and implementation of results on national level often neglected or missing

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review of the European situation [2]

reasons for this gap:

- too little connection between research groups, contractors and administrations (users, applicants)

although stakeholder advisory boards at some projects

- administrations, who are to implement results need well prepared guidelines for implementation

positive examples:

- INQUEST: presentation of results from SILVIA- project at workshops in several European countries
- IPG: national project based on international research with implementation as main target

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project IPG [1]

Noise Innovation Program for road and rail traffic

- the Dutch Government has defined strategic goals for noise reduction extending to 2030
- achieving these goals using conventional noise measures would be costly (€4 Billion by 2010) and require higher/longer noise barriers

MISSION

deliver noise reduction measures which are *ready to implement*, and allow traffic noise in the Netherlands to be reduced in an *affordable way*

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project IPG [2]

Noise Innovation Program for road and rail traffic

- **objectives:**
  - introduction of a coherent range of new measures and methods for the reduction of the noise caused by road and rail traffic
  - implementation of technical measures, which are already available
  - adaptations of technical measures to legislation and ways of working
  - reduce the costs of noise reduction measures by half
- **duration:** 2002-2007
- **budget:** Roads > €50.0 Million
- **parties involved:** Dutch project
- **website:** www.innovatieprogrammageluid.nl

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project IPG [3]

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project IPG [4]

- development of low noise road surfaces:
  - two layer porous asphalt
  - thin layers
  - next generation surfaces
    - Rollpave
    - Modieslab
    - Silent Transport

- improved noise barrier efficiency
  - T- profile tops, guidelines for construction and calculation
  - position of noise barriers
  - modular barriers

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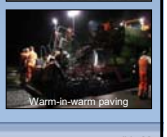
project IPG [5]

development of new low noise road surfaces:

TLPA – wide application and improvement

- **aim:** wide application of TLPA on the network
  - *current specification:* 6dB(A) noise reduction when new, 4 dB(A) average over lifetime, 7 year structural lifetime
  - guidance and advice note issued in May 2005
  - functional specifications for TLPA (2006)
- **aim:** extend the structural lifetime, improve the acoustic performance, extend laying period
  - optimisation of mix designs, research into ravelling resistance, early life skidding resistance, cleaning and clogging
  - assessment of warm-in-warm paving techniques
  - European contractors contest, improved homogeneity
  - recommendations for improved ravelling resistance, 2007



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project IPG [6]

development of new low noise road surfaces:

thin layers

- **aim:** define specifications for the design, construction and maintenance of thin layers (2007)
  - specification:

    4-5 dB(A) noise reduction when new depending on type,
    3 dB(A) average over lifetime,
    7-13 year structural lifetime depending on type
  - review of Dutch and international experiences, pilot studies on highways, desktop studies for low/medium speed roads
  - DWW/DRI cooperation project

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project IPG [7]

development of new low noise road surfaces:

next generation surfaces (ex WnT- project)

- **aim:** to define specifications for the design and construction of (porous) road surfaces with an average noise reduction of 6-8 dB(A) and an average lifetime of 8-10 years via feasibility studies and pilot projects
- **Rollpave:**
  rollable porous asphalt bonded to an adhesive support layer;
  6 dB(A) when new
- **Modieslab:**
  prefabricated two-layer porous concrete slabs on piles (modular system); 6-7 dB(A) when new
- draft functional specifications for Rollpave and Modieslab expected by the end of 2006
- **Silent transport (discontinued):**
  acoustically dense membrane between two porous asphalt layers; 6-7 dB(A) when new

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summary [1]

- the problem of road-traffic noise is one that is recognised at different levels of national and European administration
- a wide range of national and European projects are either in progress or have been completed which aim to reduce the scale of this problem
- more focus on implementation of results necessary
- European legislation can support this implementation by setting levels und thus intensify wider use of new techniques

but:

- adaptation to national preconditions necessary
- national demonstration projects to be promoted and executed

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summary [2]

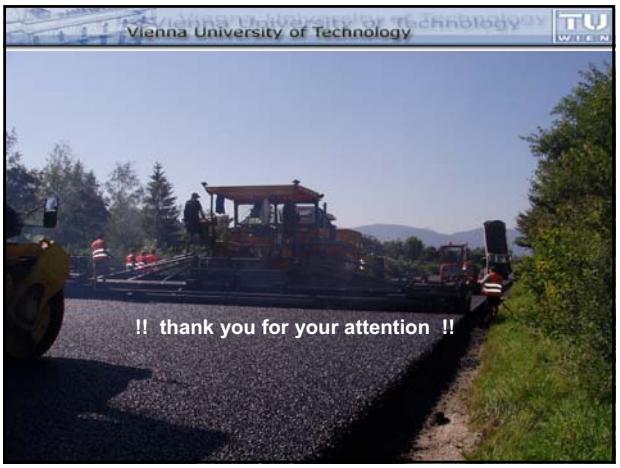
problems obviously well recognised, e.g.:

Mission of TRA 2008

- support of the alignment of European, national, regional and private research on road transport
- based on a shared European Strategic Research Agenda (SRA) it should bring together all stakeholders, researchers, policy makers and end users
- these common activities should result in better implementation of research results

important task for e.g. CEDR (Conference of European Directors of Roads)

- TG Research
- Project group noise abatement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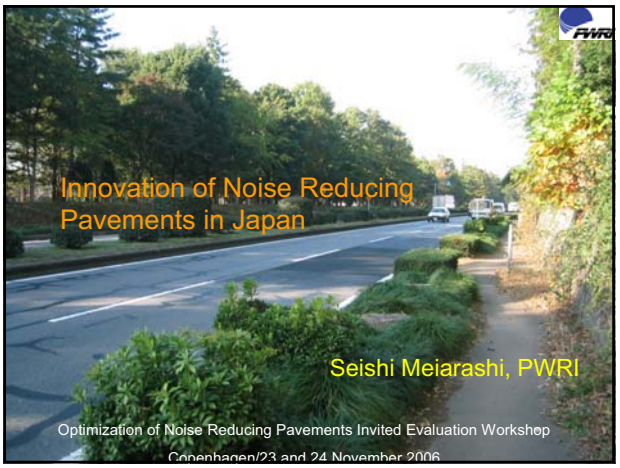
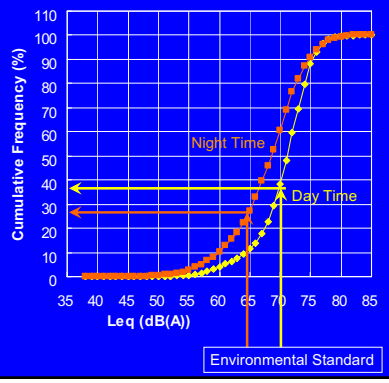
!! thank you for your attention !!



Outline

1. Background & Object
2. R&D in Lab and Test Course
3. R&D in Test Construction Sites
4. Future R&D Plan

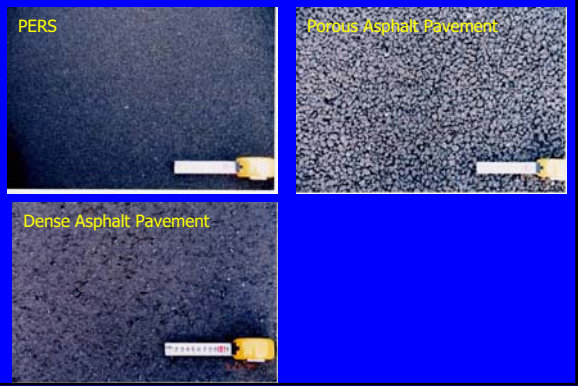
Noise Level in Urban Arterial Highway



Noise Barriers
-Access Controlled Highway-

Access-uncontrolled Highway

Pavement Surface Texture

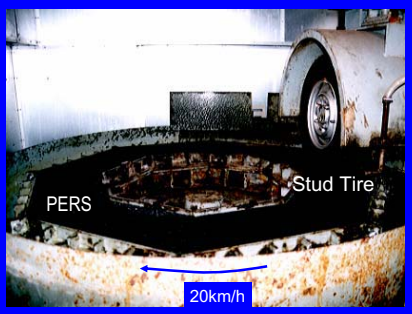


Accelerated Pavement Test

Pavement test field

Loading vehicle

Abrasion Test



Fire Test

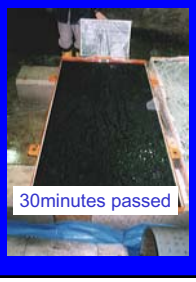
PERS

Dense asphalt pavement

Fuel : Gasoline,
Fuel volume : 36L for PERS, 10L for dense asphalt pavement
Sample size : 5m×5m

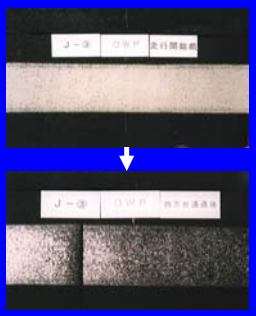
Rainfall Test

Rain hardly penetrates into PERS because of Its small size of porosity and water surface tension.
(Sample size:1×2m,t=3cm, Gradient: 2%, Rainfall intensity: 10mm/h)

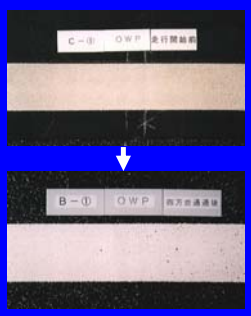


Lane Marking Durability Test

40,000times passes of loading vehicle



Acrylic resin



Polyurethane resin

Test Construction Site

PERS in Test Track

Skid Resistance Test

Test Construction Sites

Test Construction Site 3

R4 0 8 national road (4 lanes)
Traffic volume : 30,713 vehicles per day
Heavy tracks ratio : 11.9%
Limited speed : 60km/h
Base Course: SMA

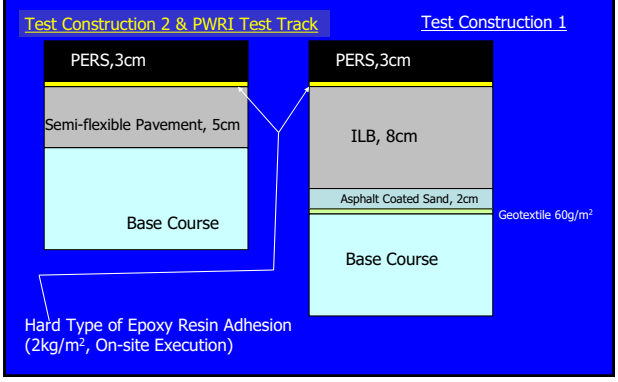
Test Construction Site 1

R46 national road (2 lanes)
Traffic volume : 10,120 vehicles per day
Heavy tracks ratio : 20%
Limited speed : 60km/h
Base Pavement: Interlocking Concrete Block

Test Construction Site 2

R23 national road (2 lanes)
Traffic Volume: 7,305 vehicles per day
Heavy tracks ratio: 13.1%
Limited Speed: 60km/h
Base Pavement: Semi-flexible Pavement

Pavement Structure



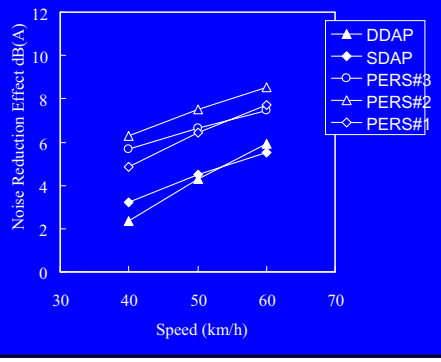
Construction Site 1 (20m)

Interlocking Concrete Block Pavement Damage in Wheel Path

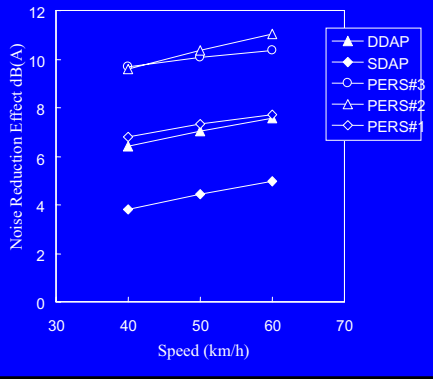
Pavement Specification

Pavement	Base Course (thick-ness: cm)	Surface						Note
		Thick-ness (cm)	Binder (%)	Aggregate (mm)	Porosity (%)	Age (year)	MPD (mm)	
DENAP	Coarse-graded asphalt mixture (5+5=10)	5	Asphalt (5%)	20-0	-	1	0.20	
SDAP		5	High Viscosity Modified asphalt (5%)	13-5	20	1	0.35	
DDAP		2 (upper) + 3 (lower)		5-3 (upper) + 13-5 (lower)	25 (upper) + 20 (lower)	1	0.70	
PERS #1	Semi-flexible Pavement (5cm) +Coarse-graded asphalt mixture (5+5=10)	3	Poly-urethane (15%)	3-1	40	0.25	0.44	On-site construction
PERS #2		3		3-1	40	0.25	0.35	Prefabrication Type
PERS #3		3		3-1	40	0.25	0.32	Prefabrication Type

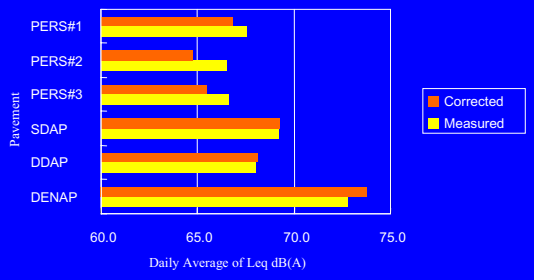
Noise Reduction Effect of PERS on Large Vehicles



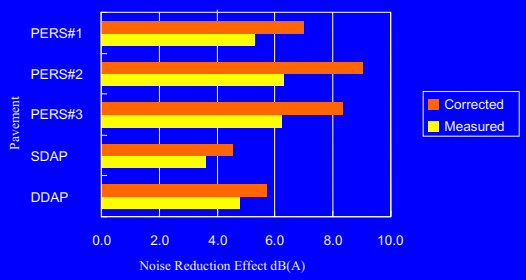
Noise Reduction Effect of PERS on Small Vehicles



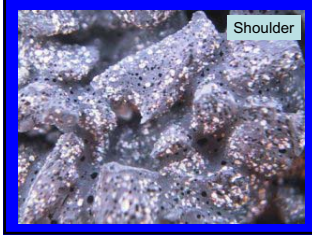
Measured and Corrected Equivalent Continuous A-weighted Sound Pressure Level



Noise Reduction Effect of PERS & DAP in Equivalent Continuous A-weighted Sound Pressure Level



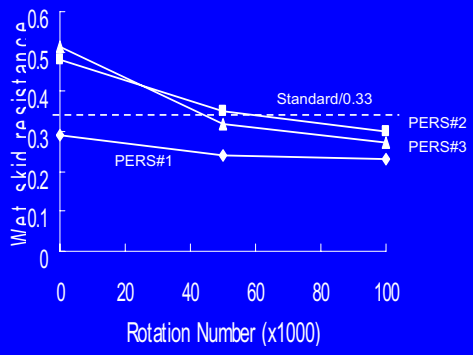
Reduction of Wet Skid Resistance at 8 Months after Test Construction



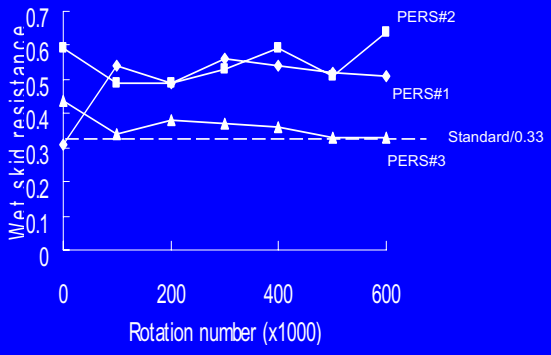
Lab Test for Improving Performance of Wet Skid Resistance

Dynamic Friction Tester ASTM E-1911-98

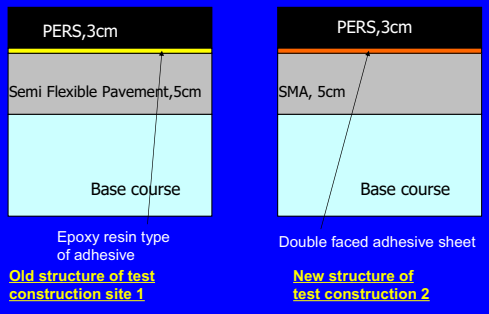
Product of Test Construction Site 2



Improved Products



New Pavement Structure



Old structure of test construction site 1

New structure of test construction 2

Braking Test by Full-loaded Truck

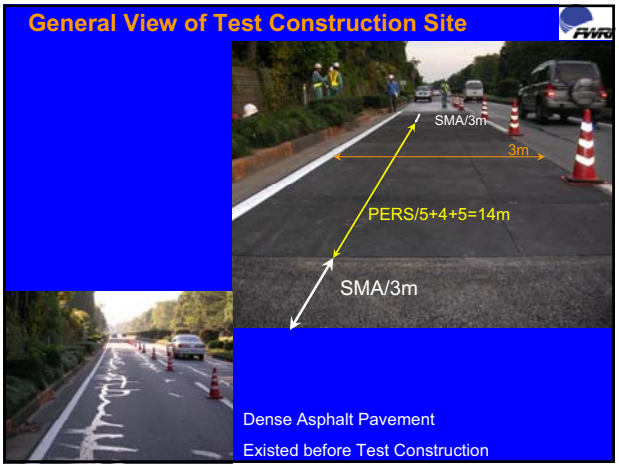

Test Construction Site 3

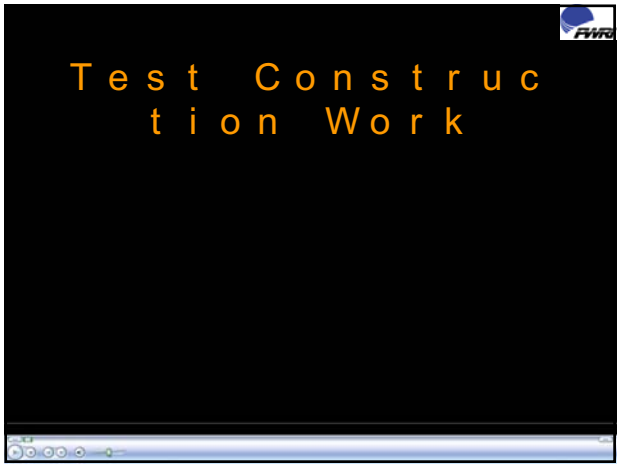

I
II
III
Surface Removing Work by Milling Machine

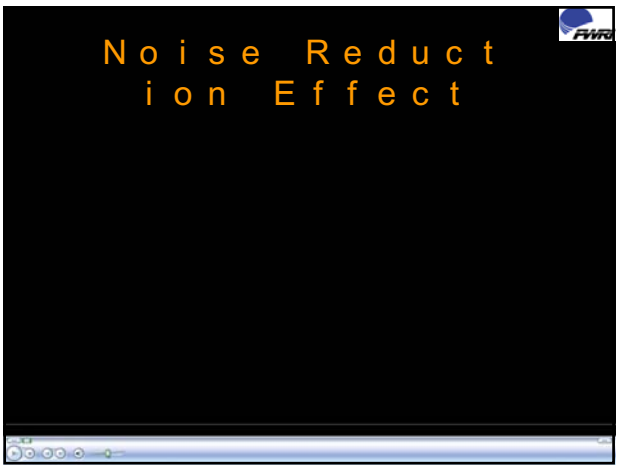

Binder Course of SMA
I
II
III
IV


PERS laying on SMA
I
II
III
IV


I
II
III
Spacing & Compacting

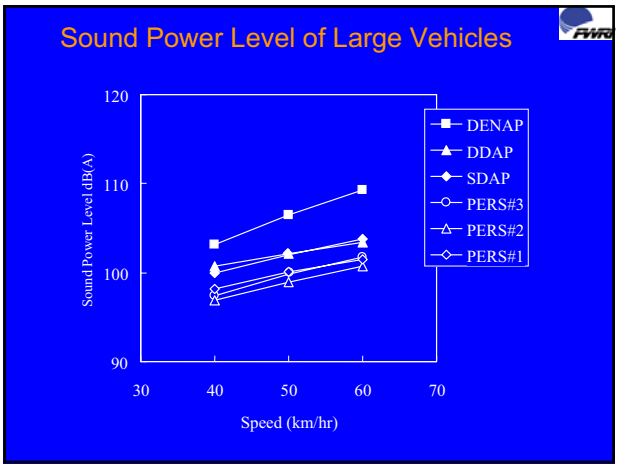


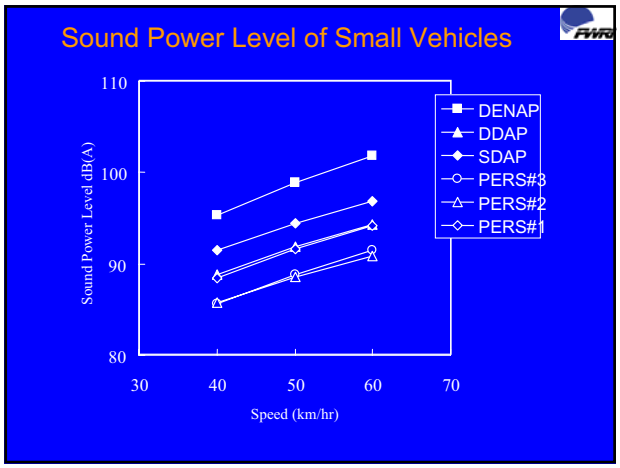




Future R&D Plan

- Larger scale of test construction in Japan from October/2007
- Test construction in Netherlands from 2007
  a) Test section at a location with no traffic (about 100 meter)
  b) Test section on a exit on a parking area on a highway (few hundred meter trafficked)
  c) Test location on the highway (maximum 500 meter)
  d) Full scale demonstration section (a few kilometers)


Sound Power Level of Large Vehicles
Sound Power Level dB(A)
120
110
100
90
30
40
50
60
70
Speed (km/hr)
DENAP
DDAP
SDAP
PERS#3
PERS#2
PERS#1


Sound Power Level of Small Vehicles
Sound Power Level dB(A)
110
100
90
80
30
40
50
60
70
Speed (km/hr)
DENAP
DDAP
SDAP
PERS#3
PERS#2
PERS#1

Trends in the U.S. Development of Quieter Pavements

Judith L. Rochat, Ph.D.
U.S. DOT / RITA / Volpe Center
Environmental Measurement and Modeling Division

IPG Workshop – Optimization of Noise Reducing Pavements
Copenhagen, Denmark
November 23-24, 2006

Volpe Acoustics

What has been driving tire/pavement noise research and quieter pavement research in the U.S.?

Background

- States want an additional tool for noise mitigation
  - To reduce the tire/pavement source noise
  - For use in conjunction with other tools
  - For use in projects where other tools are not feasible

  … pushed by public awareness


Hush hour on the highway

Driven mad by traffic noise? Unroll the quiet road or try a revolutionary new tyre on your car and you won't have to put up with the roar of passing vehicles much longer, says **Max Glaskin**

Background

- In the U.S. around 2000, the number of studies for tire/pavement noise and quieter pavement research started to increase
- These studies motivated a scan of quieter pavement systems in Europe (May 2004, supported by FWHA & AASHTO)
- European projects, information, and results stimulated dramatic increase in U.S. studies and workshops, conducted by …
  - Federal Department of Transportation (DOT)
  - State DOTs
  - Pavement industry (Asphalt and PCC)

Looking to the Future

- Eventually, results of studies will likely support use of quieter pavements for noise mitigation purposes
- When results are sufficient and verified, Federal policy will need to be modified to allow for use of quieter pavements for noise mitigation
- As part of modifying federal policy, noise effects of pavements will need to be implemented into the Federal Highway Administration (FHWA) Traffic Noise Model® (TNM)

Using Quieter Pavements for Noise Mitigation

- **Responsibility**

  When noise mitigation is determined to be necessary, the applicable mitigation tools must provide a known minimum reduction in noise and must be maintained
- **Current noise policy**

  If receiving federal funds for a highway project
  - Must use TNM with "Average" pavement for all noise predictions (Federal program exceptions – discussed later)
  - Until the noise benefits quantified and longevity determined,
    - cannot use specific pavement types or surface textures as noise abatement measures
    - cannot make adjustments for pavement type in the prediction of highway traffic noise levels
    - noise policy will not change

Using Quieter Pavements for Noise Mitigation

Local governments can self fund the cost of quieter pavements but should do so with caution

- Cautionary noise mitigation issues to consider:
  - *Have the noise benefits been properly quantified?*
    - How much benefit is the community receiving?
    - How much is it for each pavement type or surface treatment?
    - How much is it for each vehicle type or for a mix of traffic?
    - Is it region or material dependent?
    - Is it contractor or paving process dependent?
  - *Risk deterioration of noise benefits over time*
    - How long does the benefit last?
    - Is repaving at regular intervals an option?
  - *Public perception*
    - If using quieter pavements as a replacement for noise barriers …
    - Will they accept pavement as a substitute?
    - Will they lose the out-of-sight, out-of-mind advantage of barriers? ("reduces" noise impact)

Moving forward

FHWA Tire/Pavement Noise Strategic Planning Workshops

- Workshops to date: September 2004, April 2006
- Purposes of workshops
  - Share information
  - Identify gaps in knowledge
  - Identify how to fill gaps
  - Form a national plan, a roadmap to quieter highways
- Participants
  - Federal DOT (including FHWA and Volpe Center)
  - State DOTs
  - Private industry (including construction companies, automotive and tire industry, and pavement and materials associations)
  - Consultants
  - Universities
  - International participants in 2006

FHWA Tire/Pavement Noise Strategic Planning Workshops

- Key discussion items
  - Web-based clearinghouse to share information
  - Identify goal-based noise measurement methodologies
  - Noise policy and guidelines
  - Optimization of quieter pavement designs
  - Construction, monitoring, and maintenance of pavements
  - Education for the tire/pavement noise community and public
  - Cost/benefit analysis
- Continuing progress (following the roadmap)
  - Expert Task Group (ETG)
  - Tire/Pavement Noise Research Consortium (pooled fund program)

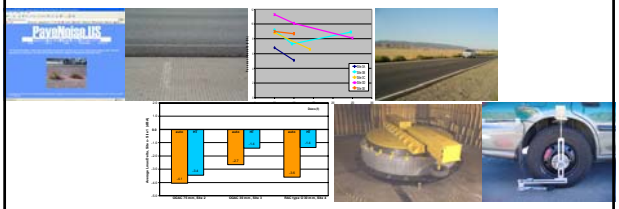
Expert Task Group

- Purpose: to advance tire/pavement noise measurement standards and practice in the U.S.
- High priority tasks – write or adapt provisional standards for
  - source measurements
    - On-Board Sound Intensity (OBSI) – Currently working on draft
    - Close Proximity (CPX)
  - wayside measurements
    - Statistical Pass-By (SPB)
    - Time-Averaged
  - sound absorption measurements

Tire/Pavement Noise Research Consortium

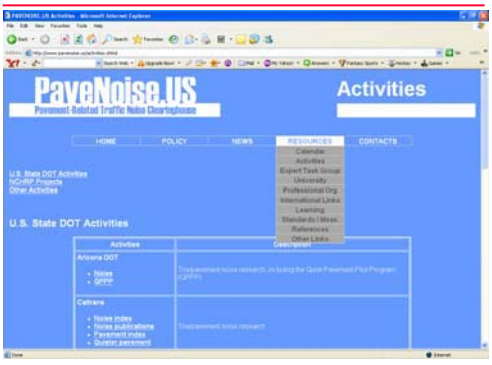
- Transportation Pooled Fund Program
  http://www.pooledfund.org/projectdetails.asp?id=1104&status=1
- Objectives
  - Provide a forum for states to discuss issues and develop a research plan
  - Pool resources and efforts of multiple state agencies, FHWA, and industry to perform research and share data
- Technical Advisory Committee (TAC)
  - Participants
    - Noise and pavement representatives from contributing states
    - Invited experts
  - Will provide guidance and technical input

Progress



U.S. Tire/Pavement Noise Website

U.S. Tire/Pavement Noise Website



Tire/Pavement Noise 101

Federal Highway Administration

THE TRANSTEC GROUP

Tire-Pavement Noise 101

A Federal Highway Administration Workshop

WORKSHOP OBJECTIVES

- To educate noise practitioners on the fundamentals of pavements.
- To educate pavement practitioners on the fundamentals of noise.
- To understand tire-pavement noise and how it fits into the bigger picture.
- To understand the fundamentals of measuring and interpreting noise.
- To examine current practices for designing and constructing quieter pavements.
- To learn of research and policy directions related to tire-pavement noise.

Quiet Pavement Pilot Program (QPPP)

- **Key aspects**
  - Voluntary program for a U.S. state (or a group of states) to demonstrate the effectiveness of quieter pavement strategies
  - Allows for use of quieter pavements for noise mitigation purposes (exception to current Federal policy)
  - Focuses on specific pavement type(s) as multiple sites
  - Agreement to quantify, achieve, and maintain noise reduction
  - Monitoring required
  - State(s) work with FHWA to achieve goals
- **Current participant**
  - Arizona Department of Transportation (ADOT)

www.quietroads.com

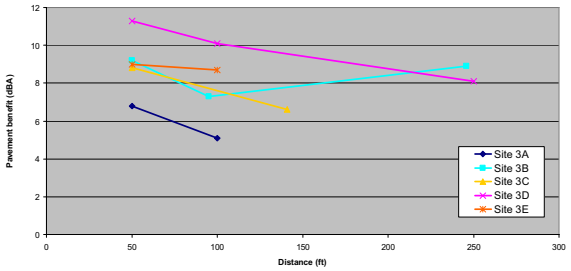
Arizona's QPPP

- **Project area: 115 miles of Phoenix area freeways receiving overlay**
  - New pavement: 1 inch Asphalt Rubberized Friction Course (ARFC) 3/8" (9.5 mm) minus aggregate, open-graded
  - Old pavement: Transversely tined PCC random or uniform spacing

- **Types of noise measurements**
  - Source: CPX and OBSI
  - Wayside: time-averaged near road and in communities

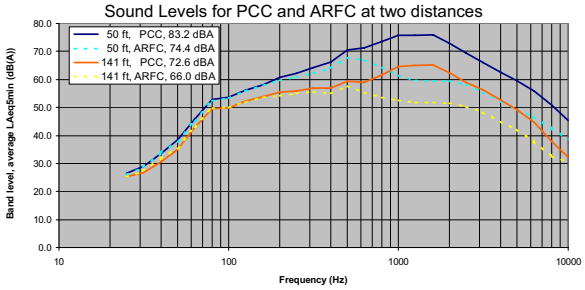
Arizona's QPPP – initial wayside results

Pavement benefit (PCC – ARFC) over distance



Arizona's QPPP – initial wayside results (spectral)

Sound Levels for PCC and ARFC at two distances



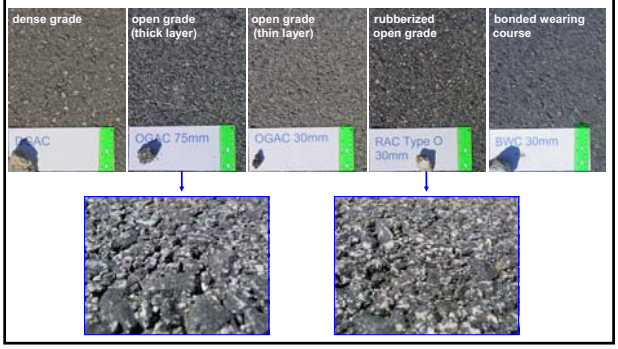
Quieter Pavement Research (QPR)

- State research programs are being conducted to help substantiate future noise policy changes
- Several states are currently conducting research, including California, Colorado, Florida, Kansas, Ohio, Texas, and Washington
- California research
  - http://www.dot.ca.gov/hq/oppd/pavement/qpavement.htm
  - Research includes PCC surface treatments and two long-term AC projects (LA138, I-80)

California LA 138 Site

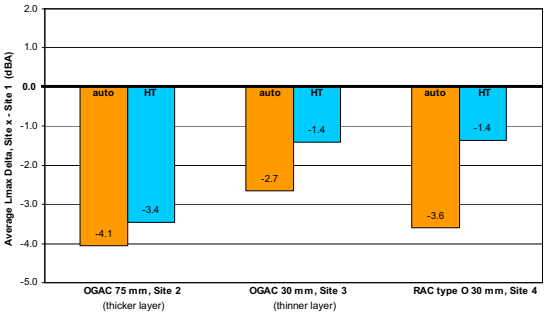
LA138 Study – pavement types

Estimated maximum aggregate size for all pavements: ~1/2 in (~13 mm)



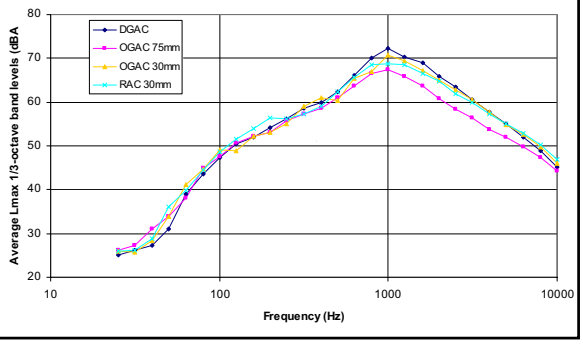
LA138 Study – broadband noise reduction by vehicle type (pavement age = 16 months)

(comparing each of the quieter pavements to DGAC, 25 ft or 7.5 m from road, SPB-type measurement)



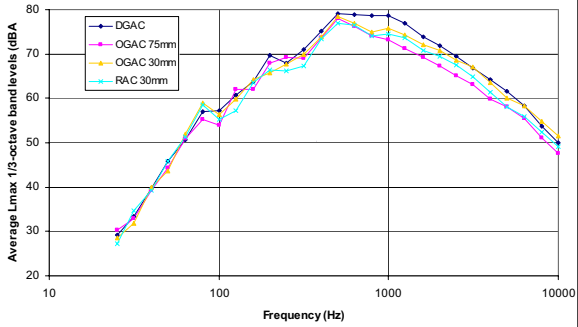
Results for Autos – spectral data by pavement type (pavement age = 16 months)

(25 ft or 7.5 m from road)

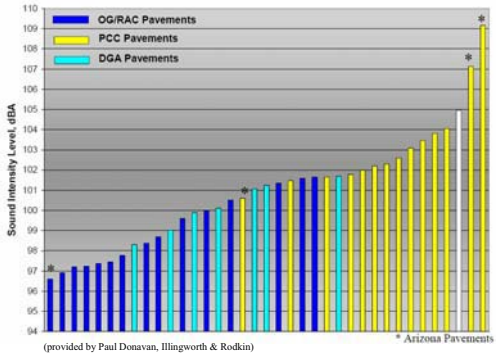


Results for Heavy Trucks – spectral data by pavement type (pavement age = 16 months)

(25 ft or 7.5 m from road)



California OBSI Database

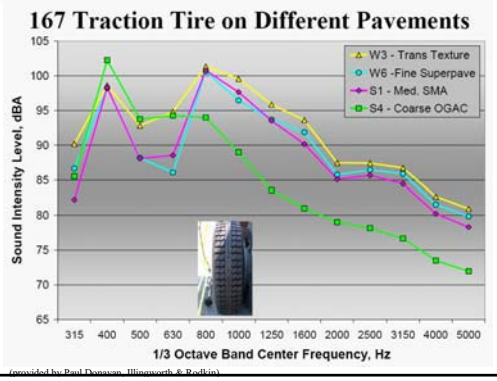


(provided by Paul Donavan, Illingworth & Rodkin)

Comparing Heavy Truck Tires and one Auto Tire

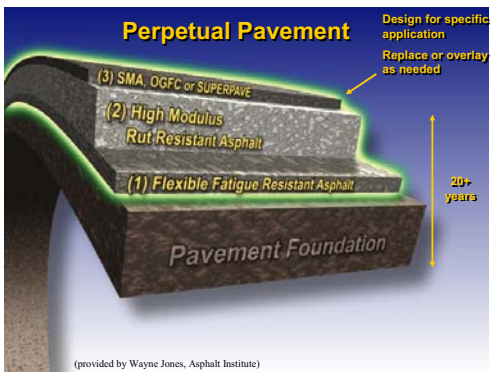
(provided by Paul Donavan, Illingworth & Rodkin)

Comparing One Heavy Truck Tire on Four Pavements



(provided by Paul Donavan, Illingworth & Rodkin)

Asphalt Industry Research

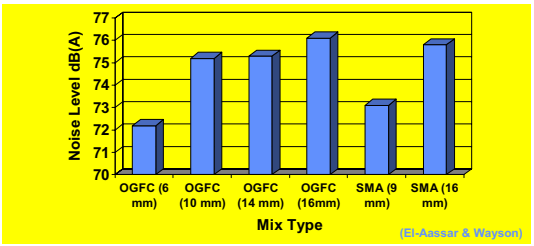


(provided by Wayne Jones, Asphalt Institute)

Asphalt Industry Research

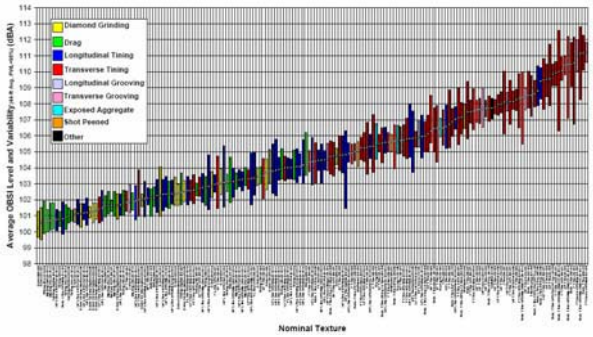
OGAC: Open-Graded Friction Course
SMA: Stone-Matrix Asphalt

Noise at 50 ft & 55 mph



(provided by Dave Newcomb, National Asphalt Pavement Association)

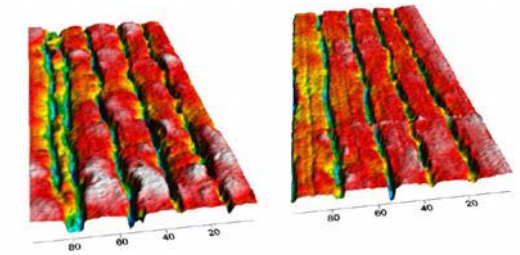
Concrete Industry Research



(provided by Rob Rasmussen, The Transtec Group)

Concrete Industry Research

Noise in relation to PCC surface texture (texture measured with RoboTex, advanced line laser technology)



Distance ~ 147 ft.
OBSI Level ~ 107 dBA

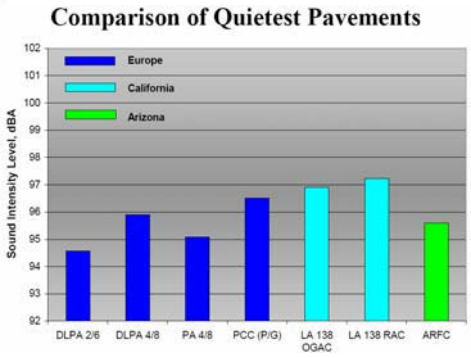
Distance ~ 259 ft.
OBSI Level ~ 102 dBA

(provided by Rob Rasmussen, The Transtec Group)

Other Investigations

- Tire/Pavement Noise Intensity Testing in Europe (NITE)
- Laboratory drum (Purdue University)
- FHWA TNM trends with pavements
- FHWA investigating change in noise policy
- FHWA investigating the implementation of pavement effects in FHWA TNM

NITE Study



(provided by Paul Donavan, Illingworth & Rodkin)

Laboratory Drum at Purdue University

(provided by Bob Bernhard, Purdue University)

FHWA TNM Trends with Pavements
(using general pavement types currently in TNM: OGAC, PCC)

- Investigation to dispel common misunderstanding:

  "Turning down the volume" at the source equates to the same "volume adjustment" throughout an area adjacent to a highway

  (NOT TRUE!)

- The effect of pavement on noise levels is …
  - Distance dependent
  - Site dependent

    Ground type, intervening objects, and site geometry will affect the noise reduction due to pavement

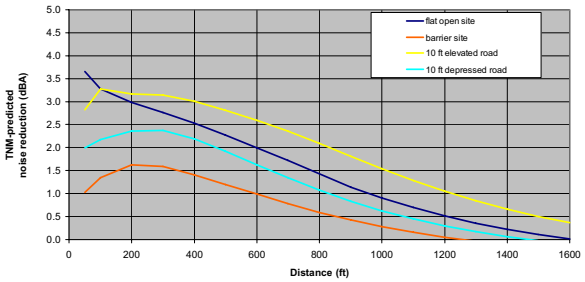
- At farther distances, low frequencies …

  … are contributing more to overall sound level

  … are affected very little by pavement type

FHWA TNM Trends with Pavements
(using general pavement types currently in TNM: OGAC, PCC)

- For predicting sound levels, the effect of pavement should be accounted for at or near the source to allow for propagation effects



FHWA Investigating Change in Noise Policy

- Short term
  - Validating use of general pavement types currently in the TNM (OGAC, DGAC, PCC) using data from the TNM Validation Study
  - Draft text for change in policy

    Using pavement type other than TNM "Average" is optional

    Strict requirements (includes: knowing project pavement type when noise impact analysis is performed and requires a reanalysis if pavement type is ever changed)
- Long term
  - More inclusive policy (more pavement types) on hold

    Waiting for answers to "How much?" and "How long?"
  - Conducting TNM Pavement Effect Implementation Study

FHWA TNM Pavement Effect Implementation Study (TNM PEI)

- If policy changes regarding use of quieter pavements, it is necessary to include the effects of quieter pavements into noise predictions
- Many questions need to be answered concerning noise predictions, including …
  - What measurement type should be used to quantify pavement effects?
  - What type of data can be most effectively implemented into TNM?
  - Should new data be added to the TNM vehicle noise database?
  - Can an adjustment be made from a reference pavement to account for the pavement effects?
  - What should be used as the reference pavement?
  - Does spectral data obtained with current measurement methods satisfy the needs of TNM calculations?
  - Is an adjustment to the road sound absorption necessary? If so, how should it be accomplished?
  - Is there a simple way to incorporate new pavements as pavement technology advances?

FHWA TNM Pavement Effect Implementation Study (TNM PEI)

- Phase 1 of TNM PEI
  - Investigating effective flow resistivity (EFR) measurements

    (ANSI S1.18 – 1999)

To obtain data for a direct adjustment to road sound absorption in TNM

Currently determining sensitivity to pavement types

So far, determined that the standard method needs to be modified to allow for the possibility of extracting proper EFR values

Will examine other data collection methods if necessary (extended surface method, guard tube, impedance tube, etc.)

FHWA TNM Pavement Effect Implementation Study (TNM PEI)

- Phase 1 of TNM PEI (continued)
  - Accounting for change in source noise by adding new data to TNM vehicle noise database ("REMEL light")

    Conducting small set of field measurements to collect data

    Initially focusing on 4 pavement types: rubberized AC, dense grade AC, longitudinally tined PCC, transversely tined PCC

    Will insert analyzed data directly into TNM database

    Will determine necessary GUI changes

    Will conduct validation study using wayside data to assess accuracy with this method

    Will assess ease of implementation in consideration of large-scale pavement database

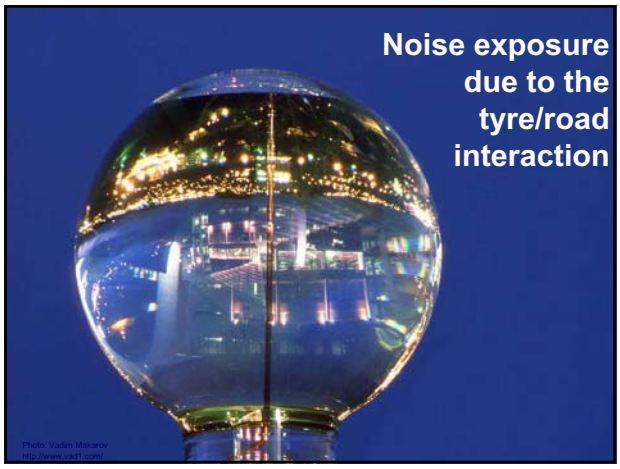
FHWA TNM Pavement Effect Implementation Study (TNM PEI)

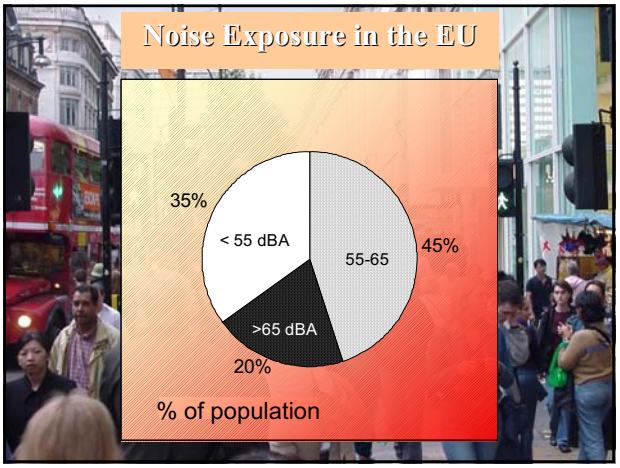
- Phase 1 of TNM PEI (continued)
  - Accounting for the change in source noise by adjusting the tire/pavement noise sub-source
    - Acquired OBSI data from Illingworth & Rodkin (Caltrans and ADOT studies) and from The Transtec Group (FHWA/ISU PCC study)
    - Initially focusing on 4 pavement types: rubberized AC, dense grade AC, longitudinally tined PCC, transversely tined PCC
    - Calculated energy adjustments from reference pavement (currently using DGAC as the reference)
    - Located place in TNM source code where adjustment is possible
    - Will determine necessary GUI changes
    - Will conduct validation study using wayside data to assess accuracy with this method
    - Will assess ease of implementation in consideration of large-scale pavement database

Conclusions

- There are many investigations currently being conducted across the U.S. on the national and state levels

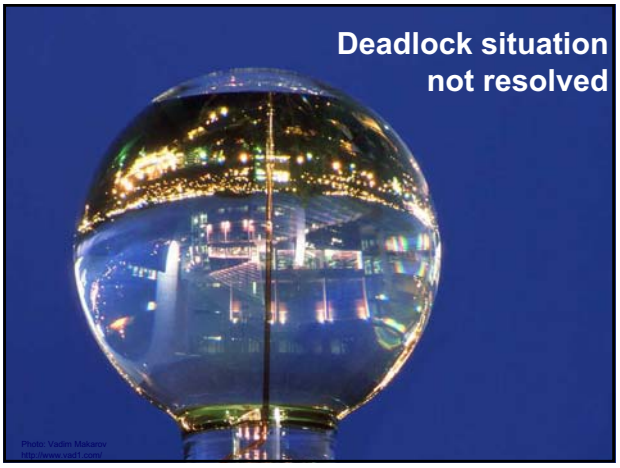
  Trends:
  - Many studies examining noise properties of existing pavement types (rubberized asphalt, open-graded asphalt, quieter PCC surface textures such as burlap drag), ones that have already proven to be safe and durable
  - Still assessing measurement methodologies – many studies are using multiple types (OBSI becoming widespread for source measurements, SPB and time-averaged for wayside measurements)
- There has been substantial advancement in the knowledge base over the last few years
- Results are helping to promote and guide future changes in federal noise policy and noise predictions

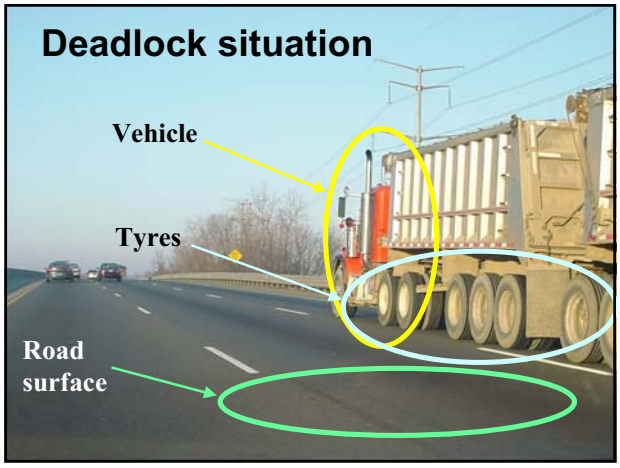




Noise exposure trends

- The grey area will increase, mainly due to traffic increase
- The black spot area will stay constant, mainly due to local measures counteracting increasing trends
- Traffic noise pollution will shrink quiet areas dramatically
- Tyre/road noise relative contribution will first continue to increase, later become reduced (due to noise limits, congestion)
- Increased use of electric operation of vehicles will increase the tyre/road contribution on a relative scale





Noise generation and propagation models

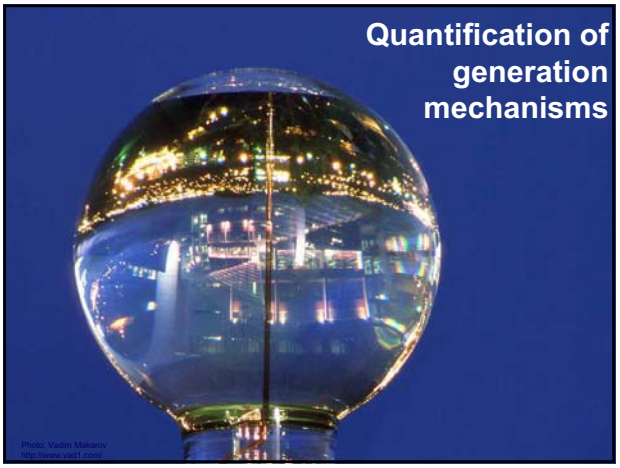
Winkler bedding

$$-\frac{ES}{a^2}\left(\frac{\partial v}{\partial \varphi}+u\right)-\frac{B}{a^4}\left(\frac{\partial^4 u}{\partial \varphi^4}+\frac{\partial^2 u}{\partial \varphi^2}\right)$$

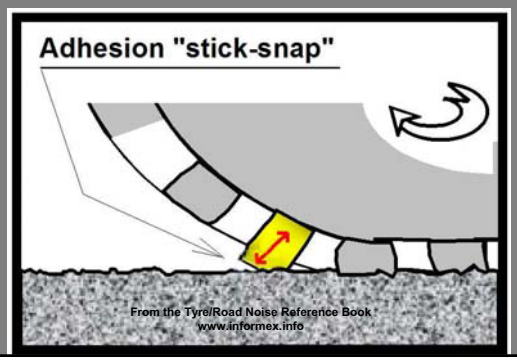
Illustrations from Chalmers Univ of Technology, Dept of Applied Acoustics

State-of-the-art models are
- quite OK at low frequencies
- limited at medium frequencies
- poor at high frequencies
- not yet good for truck tyres

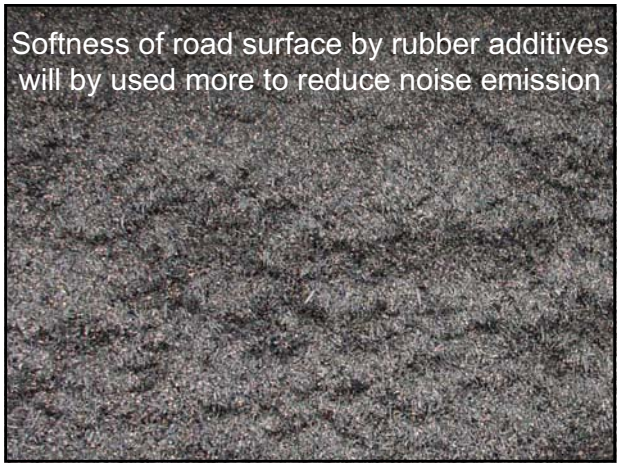
EU Projects ITARI, SILENCE and the IPG AOT will provide better tyre and road surface modelling



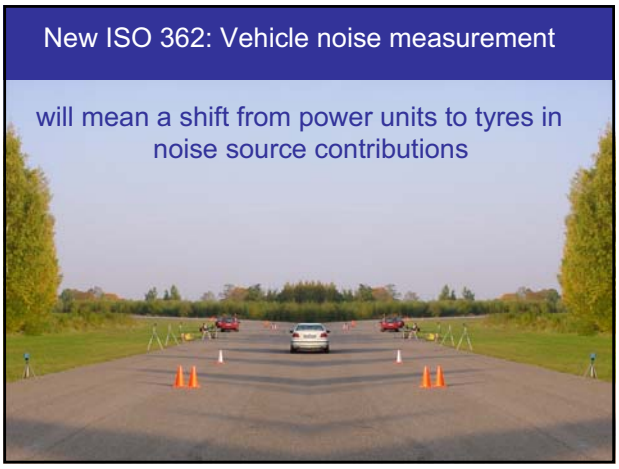
Stick-snap mechanism likely to show-up as important



Softness of road surface by rubber additives will by used more to reduce noise emission



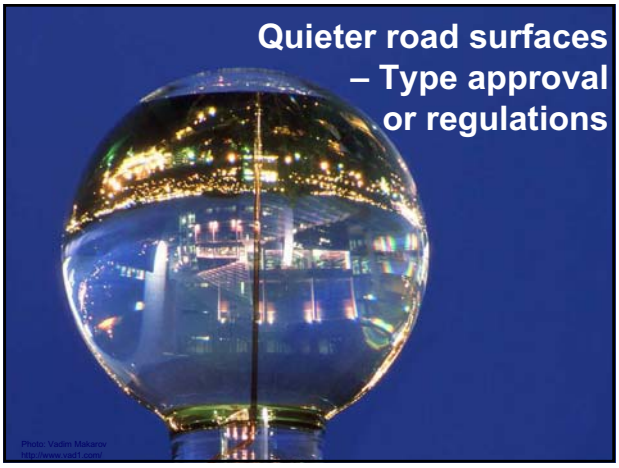

Improved and new measurement methods


New ISO 362: Vehicle noise measurement
will mean a shift from power units to tyres in noise source contributions


SPB method:
Backing board will be allowed and frequently used


The Close-Proximity (CPX) Method
Standard published by ISO
VTI test


Photo: Ulf Sandberg, VTI, June 1999
Reference tyres for the CPX method
.... 4 old tyres replaced
by 2 new tyres

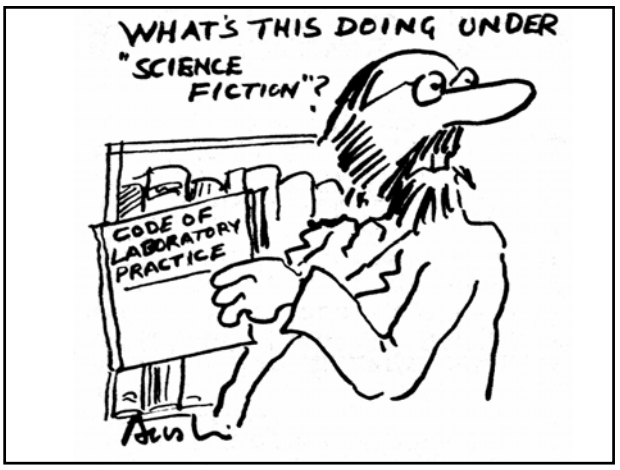

Quieter road surfaces
– Type approval
or regulations


Class A: High noise
Class B: Normal
Class C: Almost low noise
Class D: Really low noise
Class E: Super-duper low noise
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung
European classification system for road surfaces


Type approval of road surfaces
74 dB


> 100 CPX trailers worldwide
VTI test


Lab. drum method (new)
Drum facility at the Techn. Univ. of Gdansk, Poland


WHAT'S THIS DOING UNDER "SCIENCE FICTION"?
CODE OF LABORATORY PRACTICE

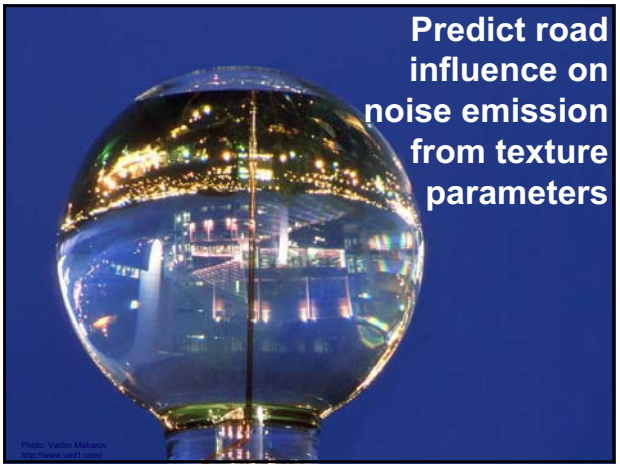

Necessary to use replica road surfaces on the drum
Laboratory drum facility at Dunlop Tyres, Birmingham, U.K.
Laboratory drum segments of replica road surfaces at Dunlop Tyres in Birmingham, U.K.

Temperature correction

$$L = a + bT$$

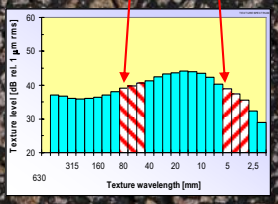
Where: L - sound level [dB]
T - temperature [°C]
a,b - constants

The slope b called ”temperature coefficient”



Calculate the ”Estimated Road Noisiness Level (ERNL)” of all pavements

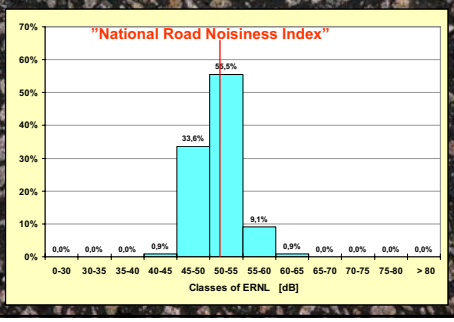
$$ERNL = a \cdot L_{80} - b \cdot L_5 + c$$



Part of Environmental Quality Assessment

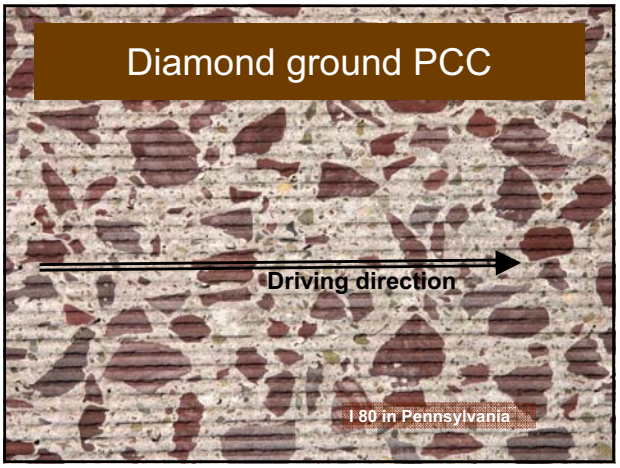
Survey macro- and megatexture of the entire road network

Statistical distribution of ERNL on the entire road network




Avoid the
“noisy”
pavements


Avoid transversely tined or grooved cement concrete
For example, the UK is replacing such pavements;
Hong Kong has a comprehensive program to replace these in the urban areas


Diamond ground PCC
Driving direction
I 80 in Pennsylvania


Exposed Aggregate Cement Concrete
(preferably < 8 mm chippings)


Avoid large-aggregate SMA
(the dominating pavement type in Sweden)
Approx. penalty for increasing max. aggregate size = 0.25 dB/mm

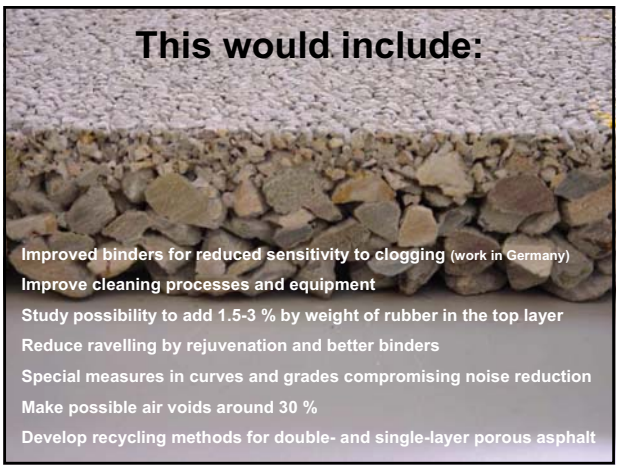

Use “quieter”
pavements

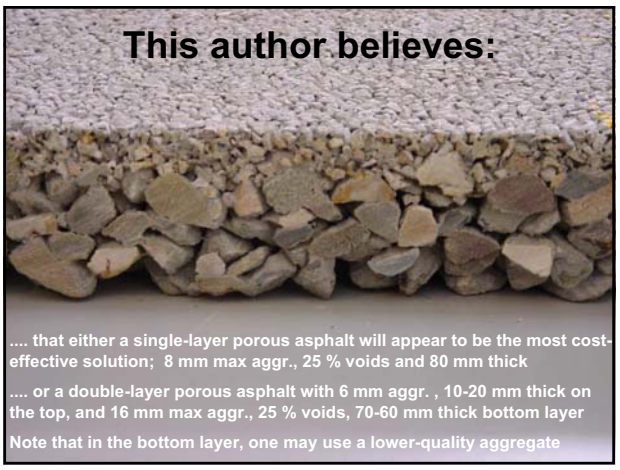

Use negative profile (skew)


Grind off the positive texture
..... and gain 1-4 dB(A)

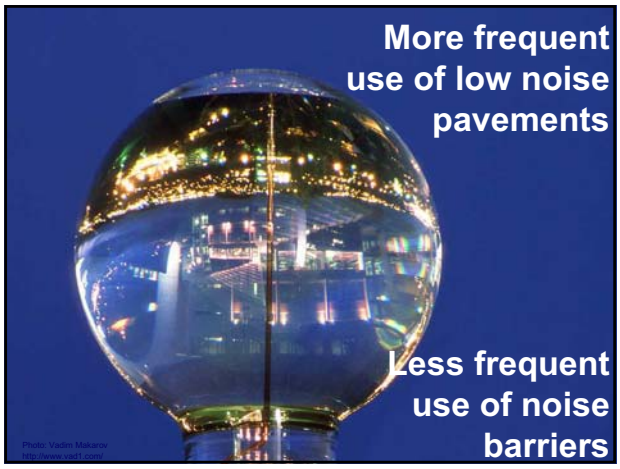

International Experiences with Thin Layer Pavements
Dramatic increase in the use of thin layers

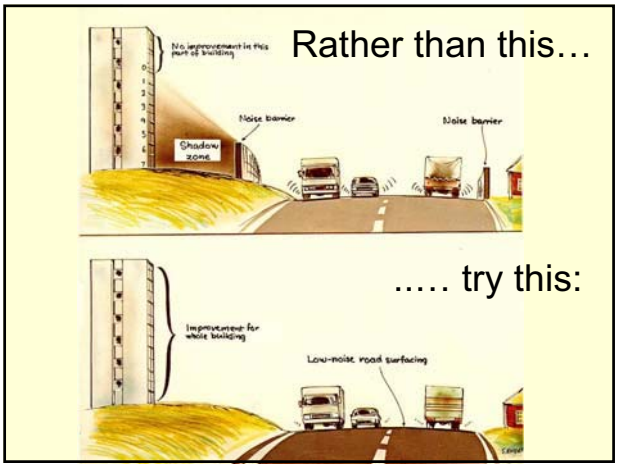

Develop and improve the porous pavements further

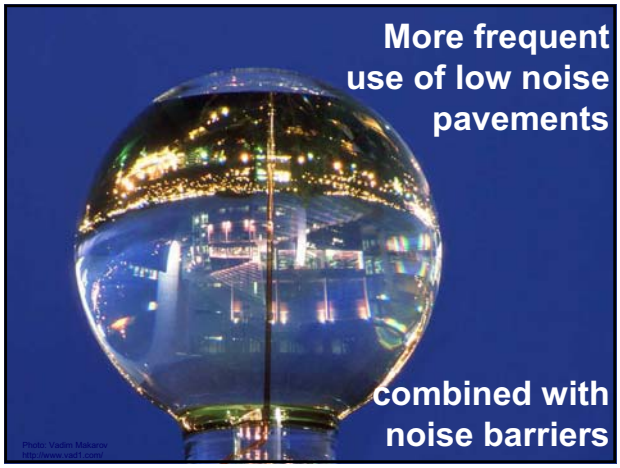

This would include:
Improved binders for reduced sensitivity to clogging (work in Germany)
Improve cleaning processes and equipment
Study possibility to add 1.5-3 % by weight of rubber in the top layer
Reduce ravelling by rejuvenation and better binders
Special measures in curves and grades compromising noise reduction
Make possible air voids around 30 %
Develop recycling methods for double- and single-layer porous asphalt


This author believes:
.... that either a single-layer porous asphalt will appear to be the most cost-effective solution; 8 mm max aggr., 25 % voids and 80 mm thick
.... or a double-layer porous asphalt with 6 mm aggr. , 10-20 mm thick on the top, and 16 mm max aggr., 25 % voids, 70-60 mm thick bottom layer
Note that in the bottom layer, one may use a lower-quality aggregate

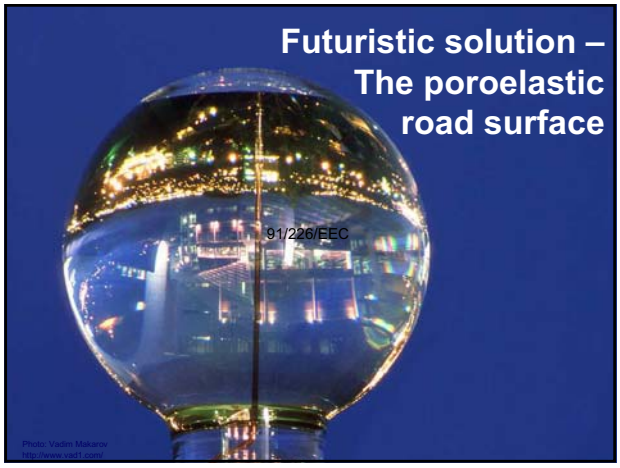

Wider application,
for example in urban streets
Hibiya dori Avenue in central Tokyo


More frequent
use of low noise
pavements
Less frequent
use of noise
barriers


Rather than this…
Noise barrier
Noise barrier
Shadow zone
….. try this:
Improvement for whole building
Low-noise road surfacing


More frequent
use of low noise
pavements
combined with
noise barriers


Tokyo Outer Ring Road


Futuristic solution –
The poroelastic
road surface
91/226/EEC

Picture from Mr Jan Hooghwerff at M+P raadgevende ingenieurs bv, the Netherlands

Vision: Production of lane-wide 100 m rolls

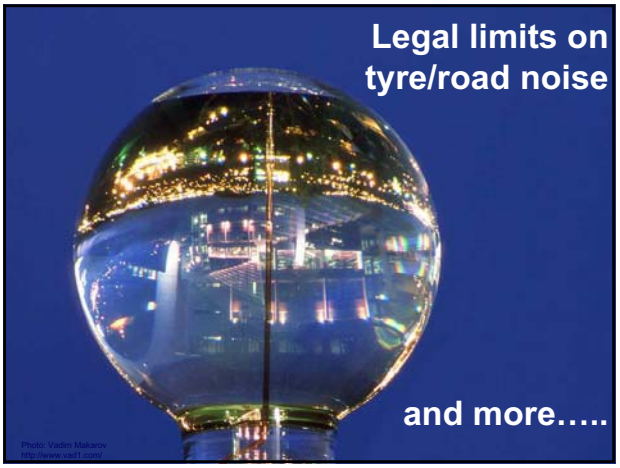


Table 5.3: Proposed tyre noise limits for C1 tyres
(rounding to nearest integer)
Note: Darkness of shade is proportional to the expected number of tyres in the category around 2010

New tyre category	Nominal section width (mm)	First step (2008)	Relative decrease compared to current limit value	Second step (2012)	Relative decrease compared to current limit value
C1a_new	≤ 185	73	0.5 - 2.5	71	2.5 - 4.5
C1b_new	> 185 ≤ 215	74	2.5	72	4.5
C1c_new	> 215 ≤ 245	74	3.5	72	5.5
C1d_new	> 245 ≤ 275	75	2.5	73	4.5
C1e_new	> 275	77	0.5	75	2.5

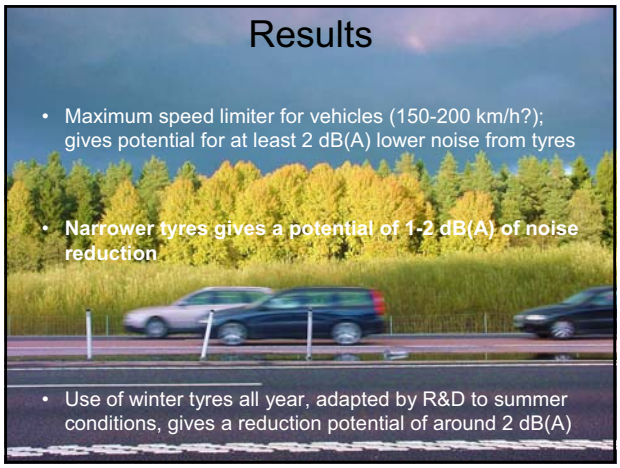
Data from the FEHRL report to the Commission; table made by Ulf Sandberg, VTI

Table 5.4: Proposed tyre noise limits for C2 and C3 tyres
(rounding to nearest integer)

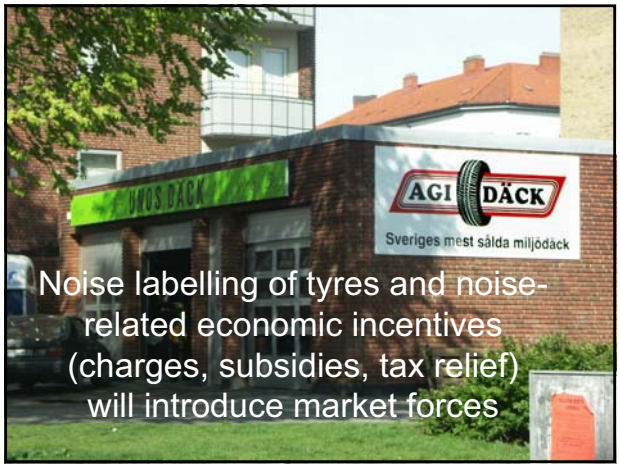
Tyre category	Nominal section width (mm)	First step (2008)	Relative decrease compared to current limit value	Second step (2012)	Relative decrease compared to current limit value
C2	Normal	73	3.5	71	5.5
	Snow (M+S)	74	4.5	72	6.5
	Special	76	3.5	74	5.5
C3	Normal	73	4.5	71	6.5
	Snow (M+S)	75	4.5	73	6.5
	Special	77	3.5	75	5.5

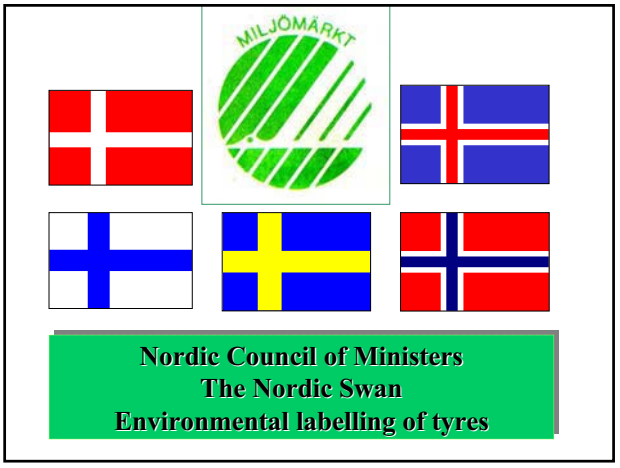
Data from the FEHRL report to the Commission; table made by Ulf Sandberg, VTI


Trends to turn around
• Glorification of extreme power and speed must stop
• The absurd maximum speed race continues a couple of more years, but will be broken due to climate change problems
• Speed limit on all European roads within 10 years ?
• Trend for wider tyres continues a couple of more years, but will be broken due to climate change problems


Results
• Maximum speed limiter for vehicles (150-200 km/h?); gives potential for at least 2 dB(A) lower noise from tyres
• Narrower tyres gives a potential of 1-2 dB(A) of noise reduction
• Use of winter tyres all year, adapted by R&D to summer conditions, gives a reduction potential of around 2 dB(A)


Quieter tyres – market mechanisms


AGI DÄCK
Sveriges mest sålda miljödäck
Noise labelling of tyres and noise-related economic incentives (charges, subsidies, tax relief) will introduce market forces


MILJÖMÄRKT
Nordic Council of Ministers
The Nordic Swan
Environmental labelling of tyres


The first Nordic Swan awards

Eine runde Sache

Lärmarme und kraftstoffsparende Fahrzeugreifen

RAL-UZ 89

RAL e.V., Bonn, Germany

”Blauer Engel - Blue Angel”

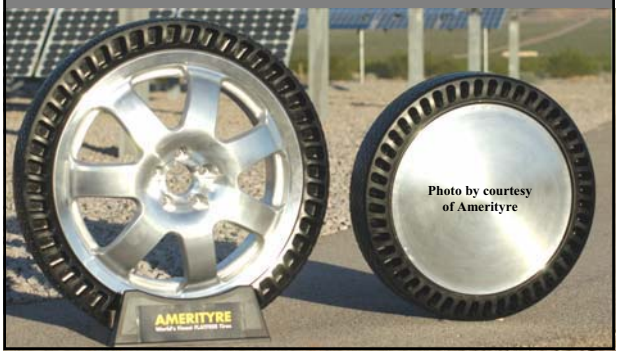
Low-Noise and Fuel-Saving Automobile Tyres

Tyre innovations

Photo: Vadim Makarov
http://www.vad1.com/

Solid polyurethane (filled) tyre

Spare tyres already approved and offered on the market from Amerityre in USA



Our contribution – The Composite Wheel and the Porous Tread Tyre

Photo: Vadim Makarov
http://www.vad1.com/

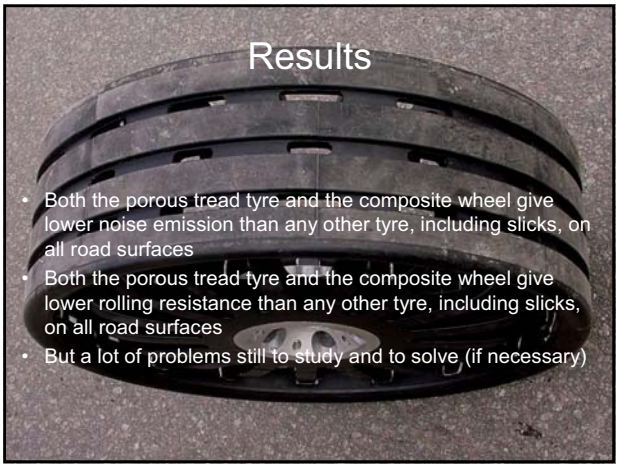
The first 4 porous tread tyres produced in the project led by VTI, 19 May 2004

Dr B Kalman, VTI Dr A.R Williams (retired) Mr D Bengmark, Fighter AB Dr U Sandberg, VTI


The ”Composite wheel”, version of 2000


The Michelin TWEEL
Presented in 2005 by Michelin in USA
Photo by
Dr Lin Kung,
Kumho Tires, USA


Composite wheel - version of 2006


Results
• Both the porous tread tyre and the composite wheel give lower noise emission than any other tyre, including slicks, on all road surfaces
• Both the porous tread tyre and the composite wheel give lower rolling resistance than any other tyre, including slicks, on all road surfaces
• But a lot of problems still to study and to solve (if necessary)


Let us work in order to make the visions come true !
THE END
The author at the poroelastic test section at Public Works Research Institute in Japan

LOT for PAC

Lifetime Optimisation Tool for Porous Asphalt Concrete

Rien Huurman
Andre Molenaar

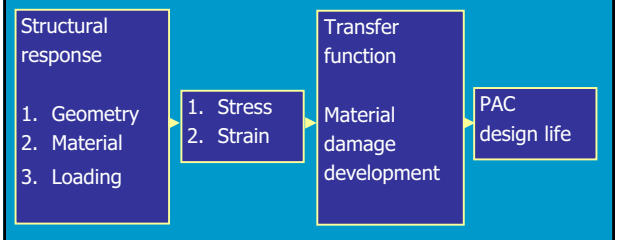
What is ravelling

What is ravelling

Purpose of LOT

- Relative predictions of lifetime.
- Influence factors
  - aggregate size
  - film thickness
  - adhesive strength (stone and bitumen type)
  - cohesive strength (bitumen, filler and sand type)
  - aging
  - traffic
  - volumetric composition

Straight forward engineering

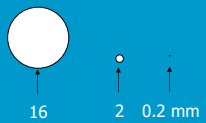


Response, geometry

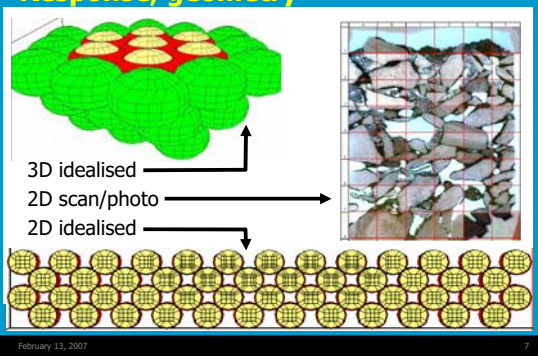
PAC, a complex 3D structure.
Larger stones held together by bituminous binder.
Distinction in scale between binder and stones.

Components in idealised PAC:

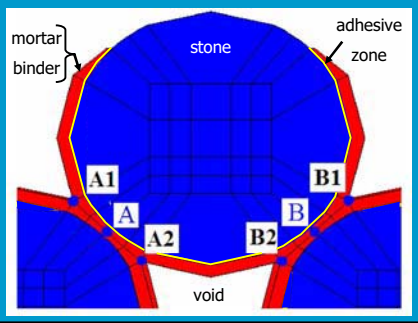
- Stone
- Stone-mortar adhesive layer
- Mortar (bitumen+filler+sand)
- Voids



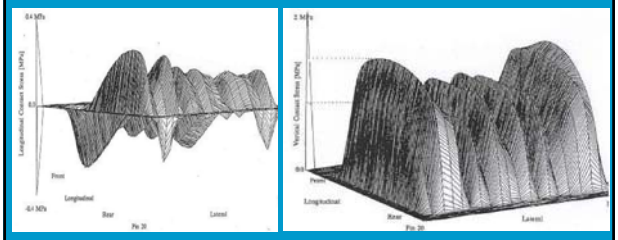
Response, geometry



Response, geometry

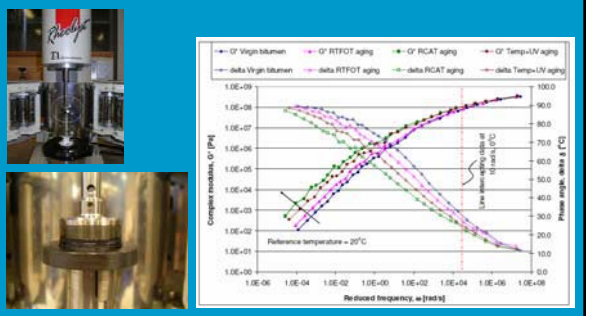


Response, loading



lateral stress vertical stress

Response, mortar stiffness

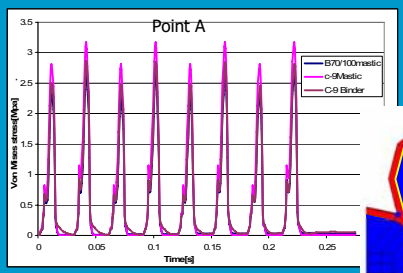


Aging is important factor !

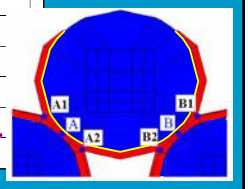
- Treatment A simulates aging during production
- A + 1000 h weatherometer (UV + temp)
- A + water
- A + water + weatherometer

Weatherometer for aging of bituminous materials

Response, stresses in the mortar



We get stresses in the mortar....



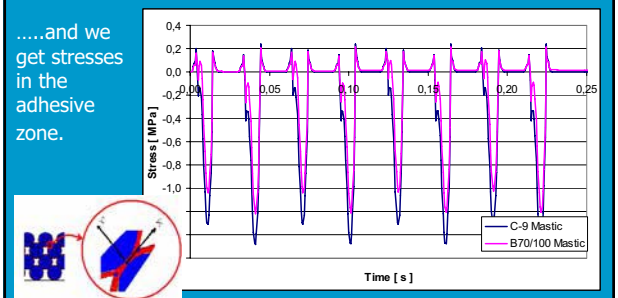
February 13, 2007 13

Algemeen / Geometrie / Materiaalgedrag / Sprieding / Niets nieuws / Conclusies

TUDelft

Response, stresses in the adhesive zone

.....and we get stresses in the adhesive zone.



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Algemeen / Geometrie / Materiaalgedrag / Sprieding / Niets nieuws / Conclusies

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Material damage

- Cohesive fatigue
- Adhesive fatigue

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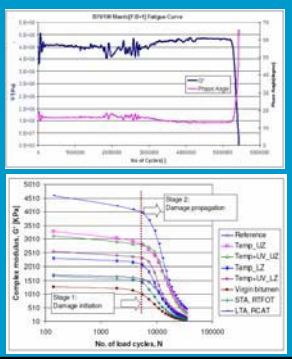
Cohesive fatigue



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Modified DSR specimen for fatigue

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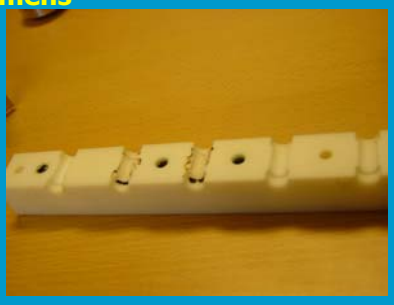
TUDelft

Mold to produce DSR fatigue specimens



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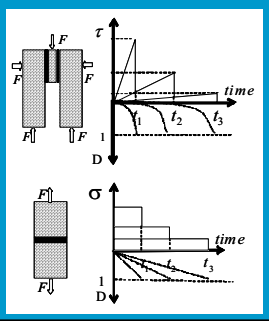
Detail of clamping device to DSR

TUDelft

Adhesive fatigue in shear and tension



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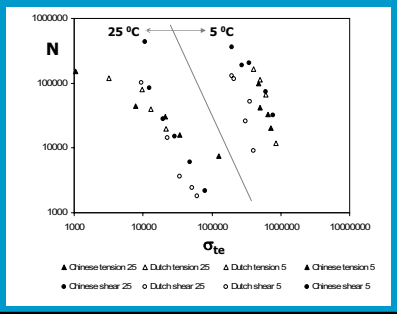
Greywacke ready to be cut

TUDelft

First results



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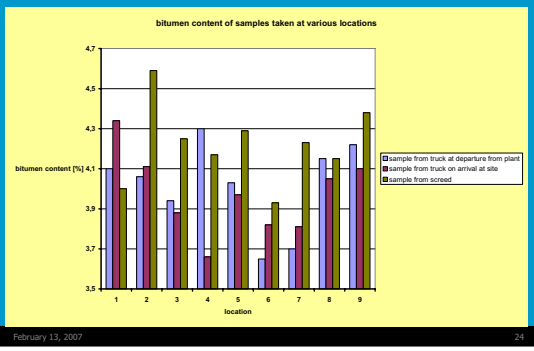
Variability is an important issue

- Variability in composition is large.
- Must be taken into account in lifetime analyses.
- Variations in characteristics due to:
  - variation in material
  - variation induced by production and laying
- Spot measurements cannot give a full picture.

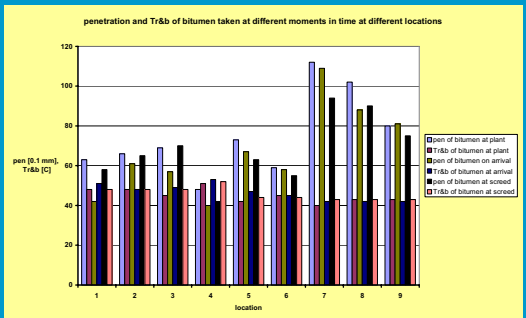
TUDelft

Variation in bitumen content



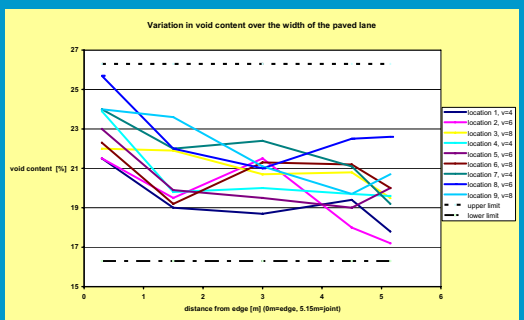
TUDelft

Variation in bitumen characteristics



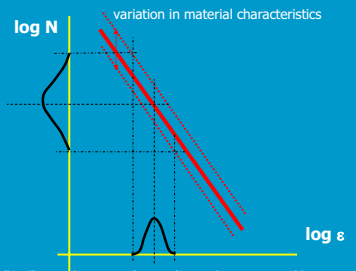
TUDelft

Variation in void content



TUDelft

Variation in fatigue life



Var ε = f (var {load}, var {geometry}, var {mat. characteristics})

TUDelft

After one year

- Computer model that allows effects of changing variables to be analysed.
  - bitumen content
  - void content
  - aggregate size
  - etc
- Probabilistic analyses with fem can be done but is at least cumbersome.

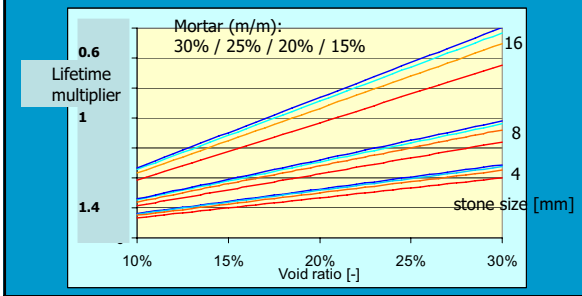
TUDelft

Possible future developments

- Design charts ?
- ANN based user's tool ?
- Such simplified models are better suited for probabilistic analyses.

TUDelft

Possible design chart ?

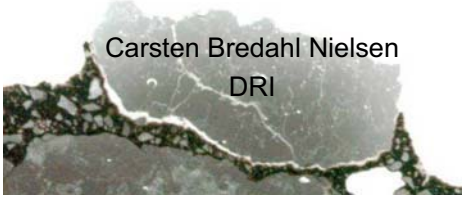


TUDelft


Thank you for
your attention
27 11 2004
February 13, 2007
31
TUDelft

Assessment of IPG test sections

Carsten Bredahl Nielsen
DRI



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Research aims

1. Understand the ravelling process from the microstructure of porous pavements
2. Correlate the microstructure with the performance of road sections

Research techniques:
- Drilling cores
- CT-scanning
- Thin and plane sections

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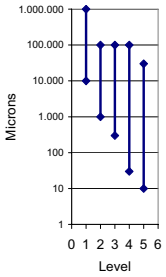
Levels of detail

1. The characteristics of the pavement surface [meter – millimetre]
2. The properties of the drill cores [centimetres – millimetres]
3. The micro-structure in CT-scanning [millimetres – 300 microns]
4. The micro-structure in plane sections [millimetres – 30 microns]
5. The micro-structure in thin sections [millimetres – 10 microns]



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Techniques for different levels

- Pavement (level 1)
  - Performance, ravelling (good, poor)

- Asphalt cores (level 2)
  - Asphalt composition (binder, aggregate fractions, density)

- CT-scanning (level 3)
  - Height and diameter
  - Voids and mastic content profiles
  - Micro-structure parameters (voids and mastic)

- Thin- and plane sections (level 4 and 5)
  - Visual assessment (adhesion, cohesion, aggregate, clogging)

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Hypothesis

The microstructural condition is related to
- the age of the pavement
- the vertical position in the pavement
- the thickness of mastic
- the volume distribution of voids and mastic
- the number of crushed aggregate

Failure mechanism
- Adhesion failure
- Cohesion failure
- Homogeneity failure

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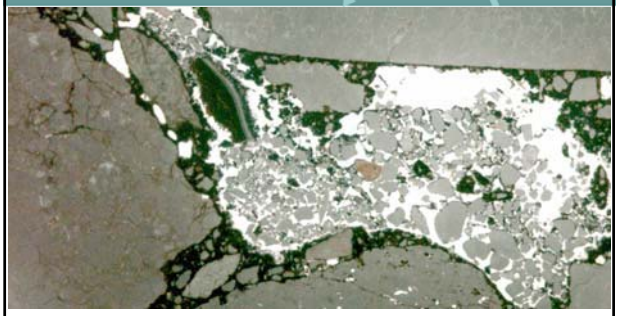
A15: Section F, fast lane



12 years old. Poor performance. Layer 2 (5-10 mm)

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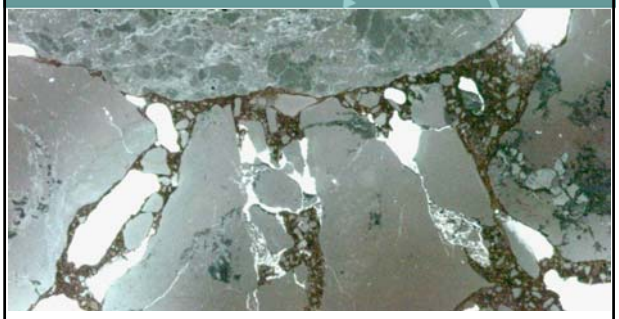
A15: Section B, slow lane



3 years old. Good performance. Layer 2 (15-10 mm)

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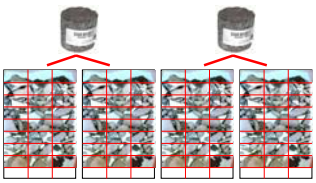
Experimental design

Asphalt composition



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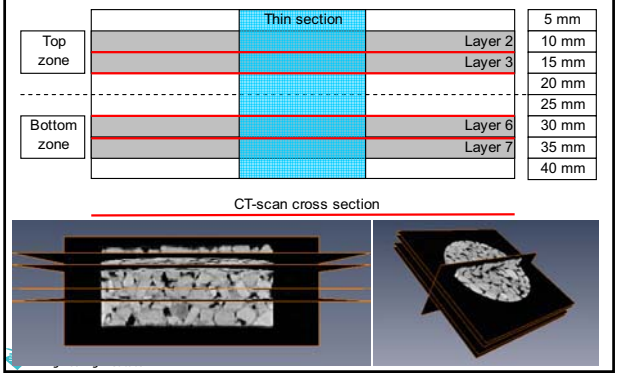
Top and bottom zones



Experimental design

Age, years	Performance, ravelling	Traffic	Location	Section
0	Good	Shoulder	A13, km 7.5 – 7.7	G
1	Good	Shoulder	RW15, km 38.8 – 39.0	A
		Slow lane		
3	Good	Shoulder	RW15, km 45.6 – 45.8	B
		Slow lane		
7	Good	Shoulder	RW15, km 52.8 – 53.0	C
		Slow lane		
		Fast lane		
	Poor	Slow lane	RW15, km 52.1 – 52.3	D
		Fast lane		
12	Good	Shoulder	RW15, km 71.7 – 71.9	E
		Slow lane		
		Fast lane		
	Poor	Shoulder	RW15, km 71.3 – 71.8	F
		Slow lane		
		Fast lane		

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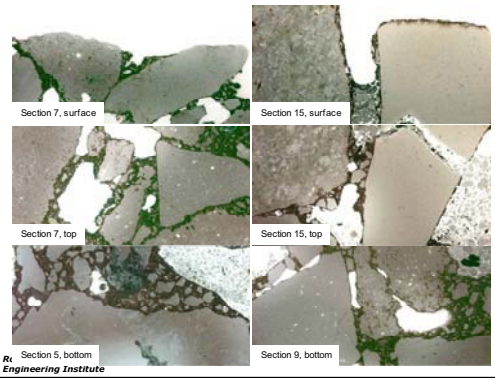
Good and poor performance



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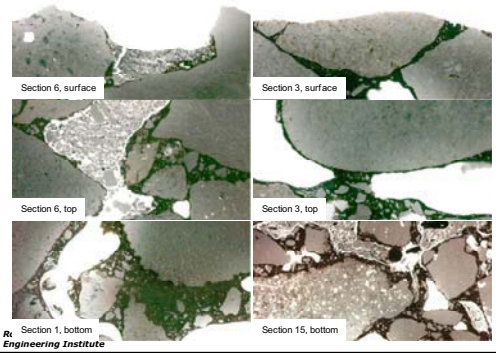
Shoulders and slow lane



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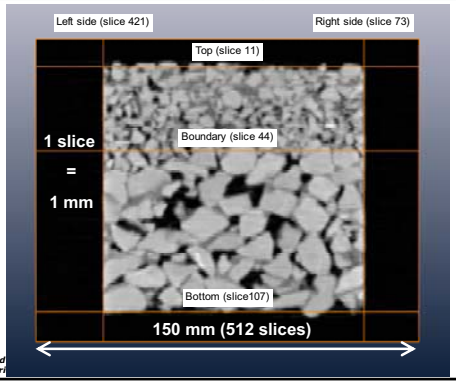
CT-scan volumetrics



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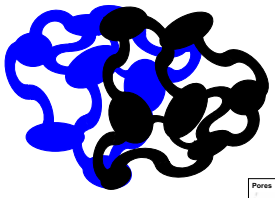
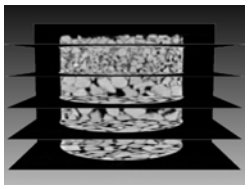
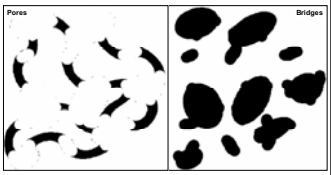
CT-scan parameters





- Small-size voids (pores)
- Large-size voids
- Small-size mastic
- Large-size mastic (bridges)



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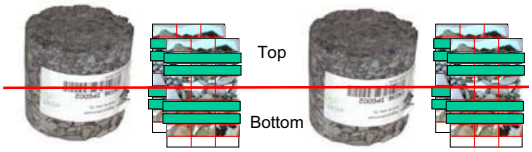
Test samples – thin sections

- Thin section parameters is the average of eight test samples from two cores with each two thin sections and two layers in each zone



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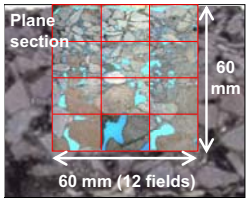
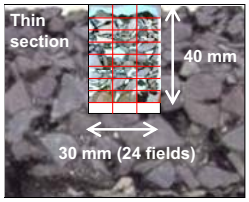
Classification of sections





Parameter	Class 0	Class 1
Adhesion	No cracks between mastics and aggregate	Cracks between mastics and aggregate
Cohesion	No cracks in mastics	Cracks in mastics
Aggregate quality	No crushing	Crushing
Clogging	No clogging in voids	Clogging in voids

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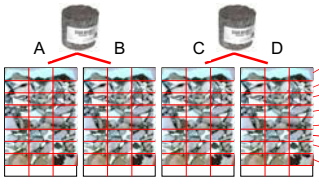
Calculating the grade

24 fields for each layer

=>

Grade 0-10



	A	B	C	D	Σ	G
L1	4	3	5	2	14	5.8
L2	1	3	0	0	4	1.7
L3	0	0	0	1	1	0.0
L4	1	1	0	0	2	0.1
L5	2	5	2	3	12	5.0
L6						
L7						
L8						

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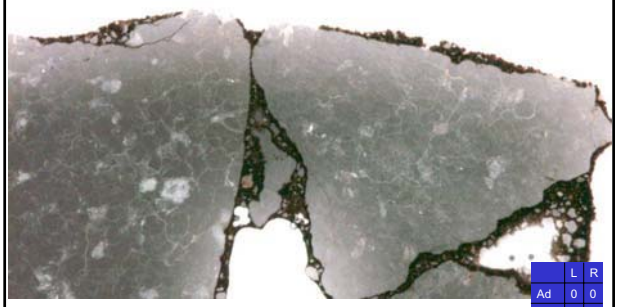
Adhesion - class 0



1 year old. Good performance. Layer 1 (0-5 mm)

	L	R
Ad	0	0
Co	0	0
Ag	0	0
Cl	0	0

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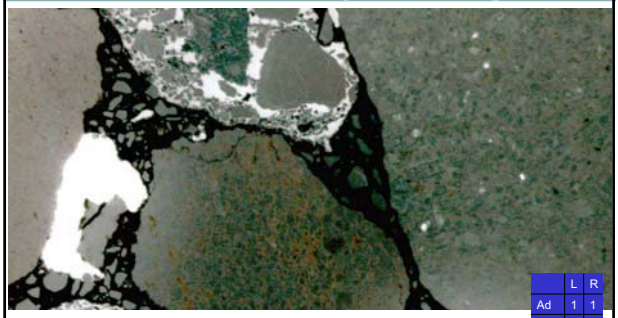
Adhesion – class 1



	L	R
Ad	1	1
Co	1	0
Ag	0	0
Cl	1	1

12 years old. Good performance. Layer 2 (5-10 mm)

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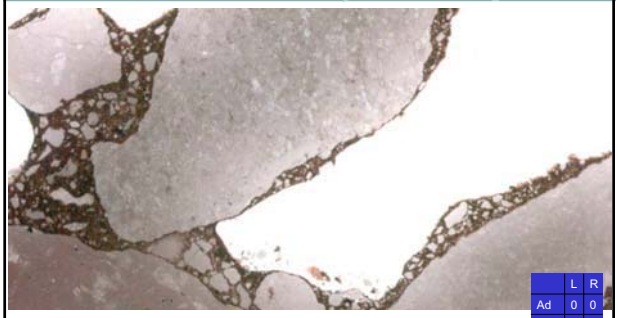
Cohesion – class 0

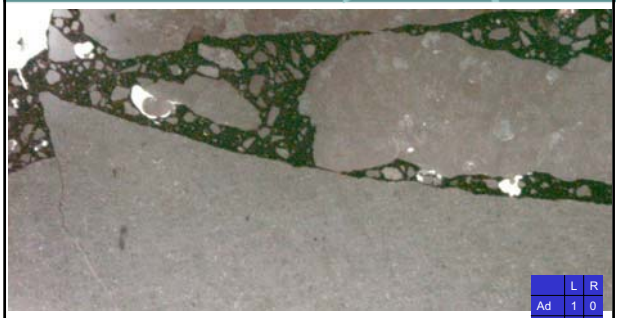


	L	R
Ad	0	0
Co	0	0
Ag	0	0
Cl	1	0

1 year old. Good performance. Layer 2 (5-10 mm)

Road and Hydraulic Engineering Institute

Cohesion – class 1

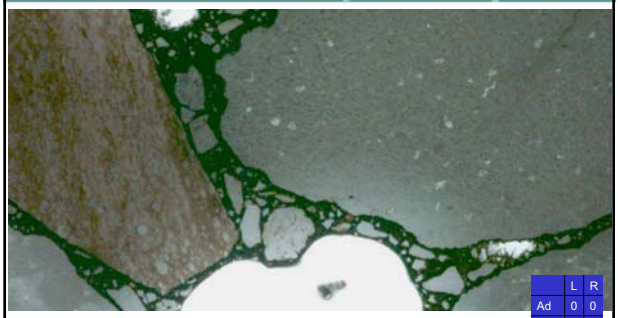


	L	R
Ad	1	0
Co	1	1
Ag	0	0
Cl	0	0

12 years old. Good performance. Layer 6 (25-30 mm)

Road and Hydraulic Engineering Institute

Aggregate – class 0



	L	R
Ad	0	0
Co	0	1
Ag	0	0
Cl	0	0

1 year old. Good performance. Layer 4 (15-20 mm)

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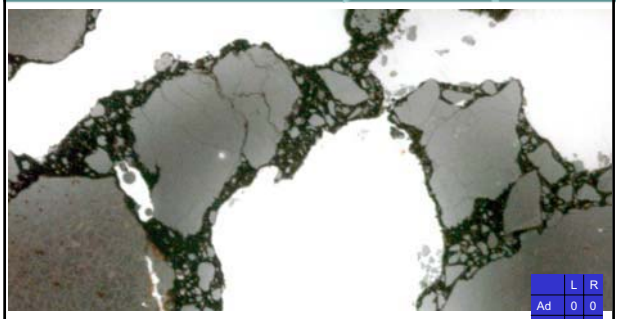
Aggregate – class 1



	L	R
Ad	0	0
Co	0	0
Ag	1	0
Cl	0	1

12 years old. Good performance. Layer 1 (0-5 mm)

Road and Hydraulic Engineering Institute

Clogging – class 0

	L	R
Ad	1	0
Co	0	0
Ag	1	1
Cl	0	0

1 year old. Good performance. Layer 6 (25-30 mm)

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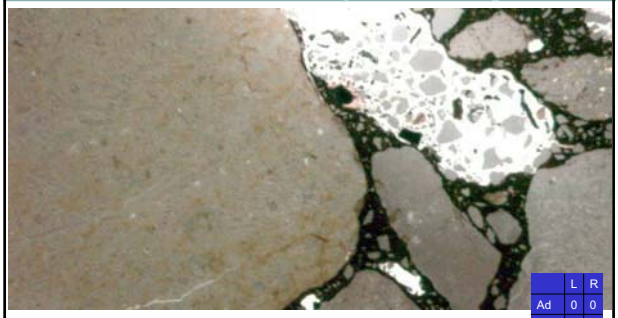
Clogging – class 1

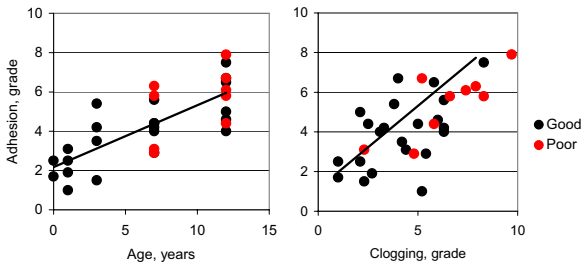


	L	R
Ad	0	0
Co	1	1
Ag	0	0
Cl	1	1

12 years old. Good performance. Layer 5 (20-25 mm)

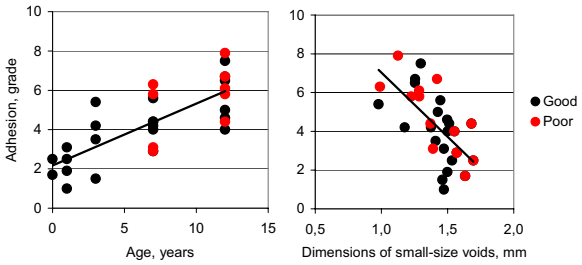
Road and Hydraulic Engineering Institute

Performance of road sections



Road and Hydraulic Engineering Institute

Performance of road sections



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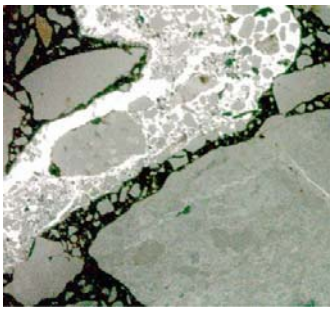
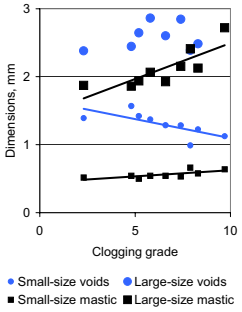
Clogging of microstructure



Poor performing road sections



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Top and bottom zones

Performance	Zone	Small-size			Large-size
		Voids	Mastic	Mastic dimensions, mm	Mastic dimensions, mm
Good	Top	9.6 %		0.537	
	Bottom	8.6 %	12.2 %	0.557	2.052
	Significance	0.8 %	No	3.6 %	No
Poor	Top	10.7 %	13.1 %	0.533	2.002
	Bottom	7.8 %	10.3 %	0.585	2.302
	Significance	0.0 %	0.3 %	0.02 %	1.3 %

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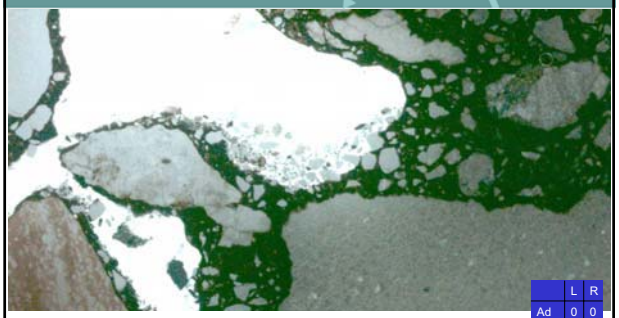
A15: Section A, shoulder



	L	R
Ad	0	0
Co	0	0
Ag	0	0
Cl	1	1

1 year old. Good performance. Top zone.

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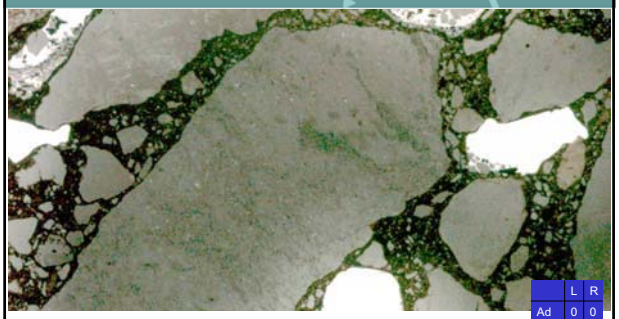
A15: Section A, slow lane



	L	R
Ad	0	0
Co	0	0
Ag	0	0
Cl	1	1

1 year old. Good performance. Bottom zone.

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A15: Section F, fast lane

	L	R
Ad	0	1
Co	0	0
Ag	0	0
Cl	1	1

12 years old. Poor performance. Top zone.

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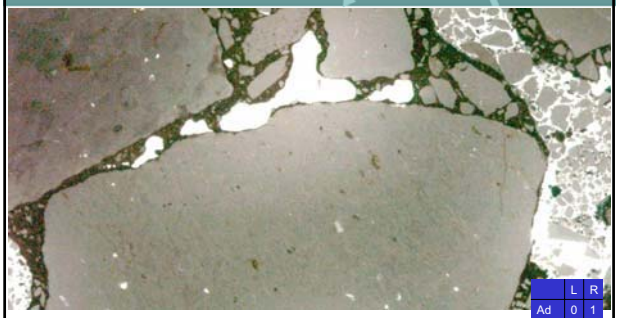
A15: Section F, slow lane



	L	R
Ad	0	1
Co	0	0
Ag	0	0
Cl	1	1

12 years old. Poor performance. Bottom zone.

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Visual assessment

Road lane	Zone	Adhesion	Cohesion	Aggregate	Clogging
Shoulder	Top	4.0	0.5	1.0	4.6
	Bottom	2.6	1.2		2.1
	Significance	2.1 %	1.2 %	No	0.0 %
Slow lane	Top	4.4	1.4	1.2	5.0
	Bottom	5.3			6.0
	Significance	11 %	No	No	9 %
Fast lane	Top	4.8	0.8	1.2	4.6
	Bottom				6.1
	Significance	No	No	No	4.5 %

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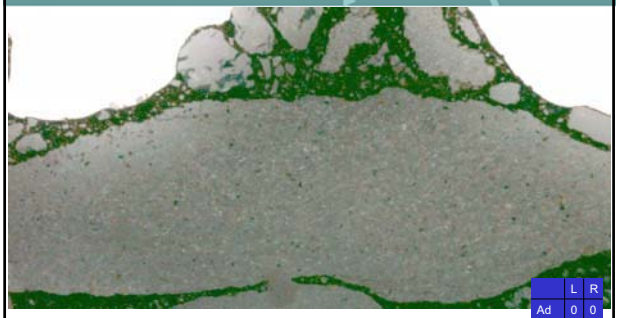
Shoulder - top zone



	L	R
Ad	0	0
Co	0	0
Ag	0	0
Cl	0	0

New. Good performance.

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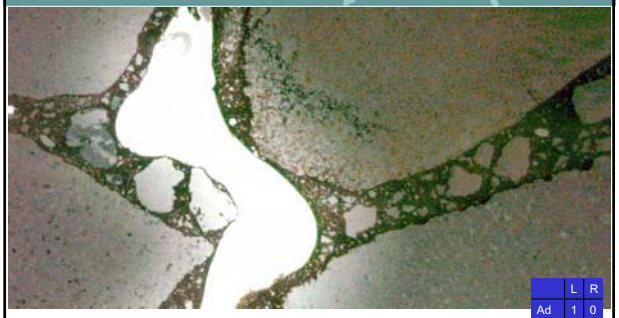
Shoulder - bottom zone



	L	R
Ad	1	0
Co	1	0
Ag	0	0
Cl	0	0

New. Good performance.

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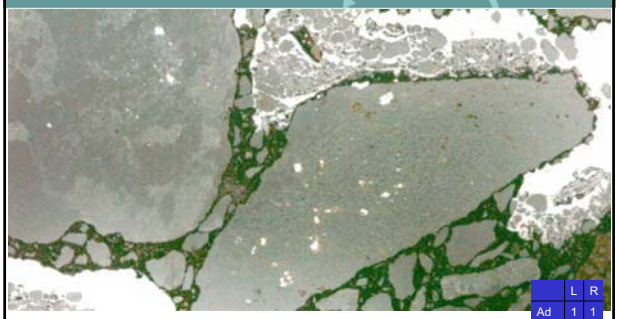
Shoulder – top zone



	L	R
Ad	1	1
Co	0	0
Ag	0	0
Cl	1	1

12 years old. Poor performance.

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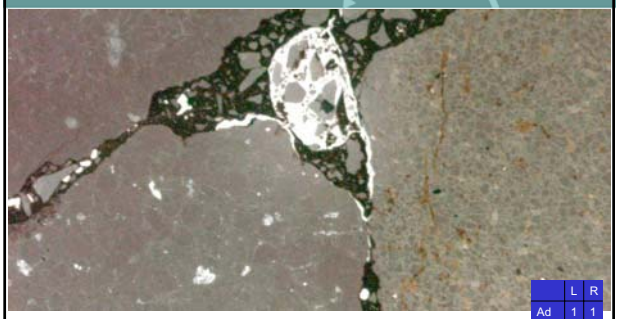
Shoulder – bottom zone



	L	R
Ad	1	1
Co	1	1
Ag	0	0
Cl	1	1

12 years old. Good performance.

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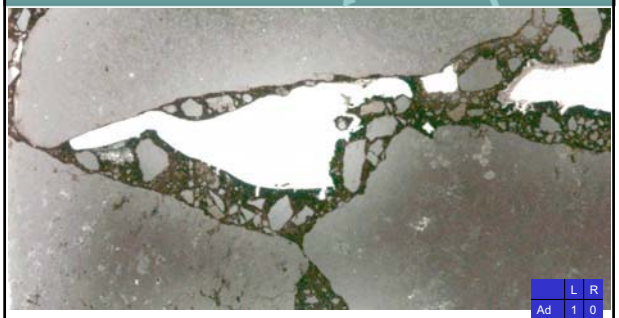
Slow lane – top zone



	L	R
Ad	1	0
Co	0	0
Ag	0	0
Cl	0	1

12 years old. Good performance.

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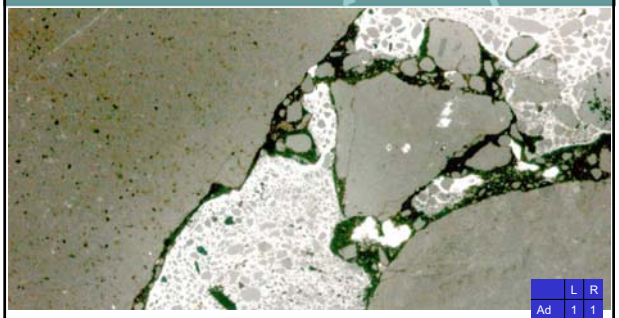
Slow lane – bottom zone



	L	R
Ad	1	1
Co	0	1
Ag	0	0
Cl	1	1

12 years old. Good performance.

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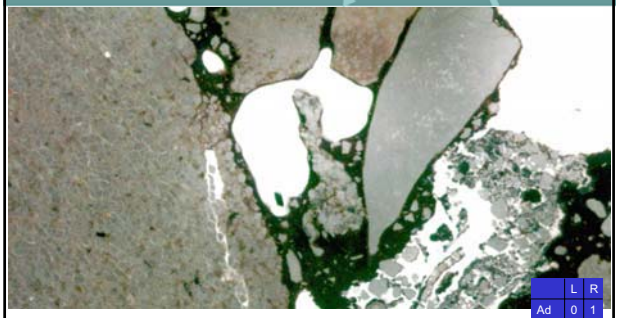
Fast lane – top zone



	L	R
Ad	0	1
Co	0	0
Ag	1	0
Cl	0	1

7 years old. Poor performance.

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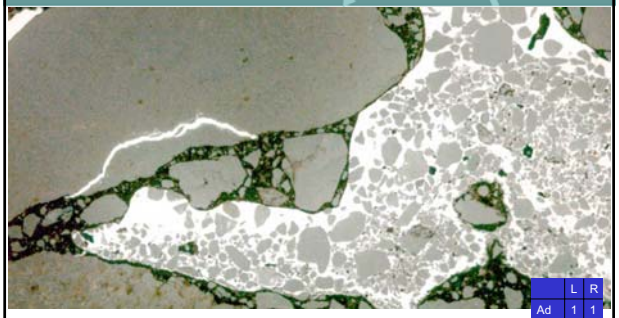
Fast lane – bottom zone



	L	R
Ad	1	1
Co	0	0
Ag	1	0
Cl	1	1

12 years old. Good performance.

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Conclusions

- The main overall deterioration mechanism is related to the adhesion between mastic and aggregate and mastic cohesion
- Clogging correlates with adhesion
- The bituminous mastic deteriorates in pavements with poor adhesion and leaves clogging in the voids
- Narrow voids have been formed in the top zone for poorly performing roads

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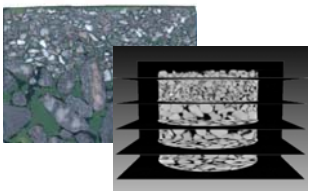
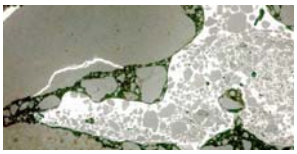
Implementation

- Input for modelling
- New instruments for assessing the lifetime of porous asphalt



- Assessment of the effectiveness of suggested mix designs and cleaning programmes in contract evaluation systems



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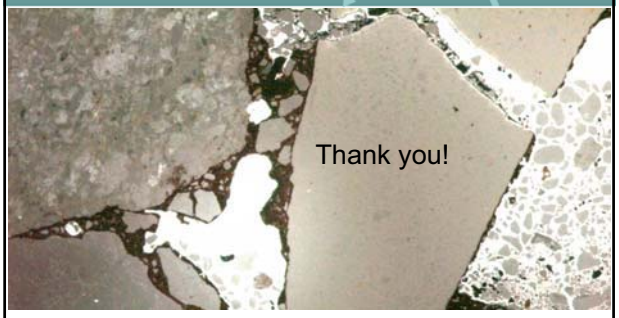

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DRI/DWW workshop 2006

Effect on aging processes of Porous Asphalt

Jan Voskuilen

Advisor Asphalt Mixtures

Road and Hydraulic Engineering Institute

Ministry of Transport, Public Works and Water Management

Rijkswaterstaat

TOPICS

1. History of Porous Asphalt (PA)
2. Service life of PA
3. Field model
4. Ageing of the bitumen
5. Effects of aging on ravelling
6. Learnig of the road
7. Conclusions and recommendations

Rijkswaterstaat

History of SLPA in the Netherlands

PA developed during 2nd world war for air fields

Rediscovered in the Netherlands in the seventies

Since 1987 limited application of PA for safety

Policy since 1990: application of PA on all motorways because of noise reduction

Single-layer PA 0/16

Rijkswaterstaat

History of TLPA in the Netherlands

25 mm fine graded PA as top layer

45 mm coarse graded PA as a bottom layer

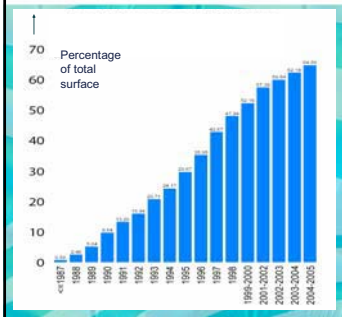
Early nineties first Two-layer PA test sites in the Netherlands (Twinlay)

Monitoring Two-layer PA by INP (Zebra test sites)

In 2005 TLPA was given free for motorways

Rijkswaterstaat

Increasing part of PA on motorways



End 2006 the total percentage of PA is almost 70%

Rijkswaterstaat

Important goal of Noise Innovative Progra

Increase the service life of TLPA!

(knowledge SLPA⟶ TLPA)

Projects based on experiences with SLPA:

•Ageing of bitumen in SLPA - PhD study of E.Hagos, Technical University of Delft

(Study of ageing of SLPA with 0, 1, 3, 7 and 12 years in service)

•Learning of the road – Technical University Aachen

(Investigation of 199 PA specimens at the end of service life)

Rijkswaterstaat

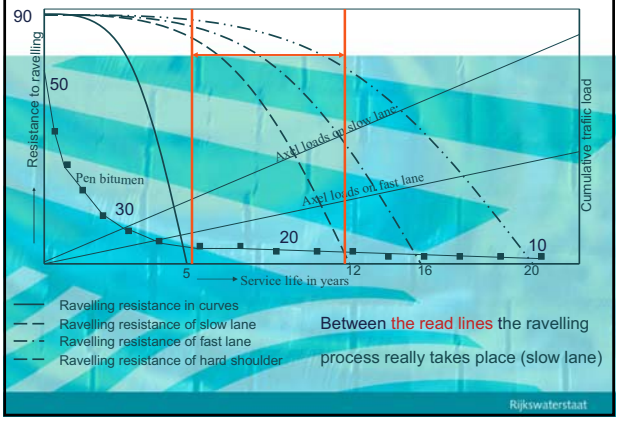
Mix composition of SLPA 0/16 (mass %)

On sieve	desired	max.	min.
16.0 mm		0.0	7.0
11.2 mm		15.0	30.0
8.0 mm		50.0	65.0
5.6 mm		70.0	85.0
2.0 mm	85.0		
0.063 mm	95.5		
Bitumen 70/100	4.5 (= on 100% aggregate)		

Hydrated lime in filler must be at least 25%

Rijkswaterstaat

Performance model for SLPA



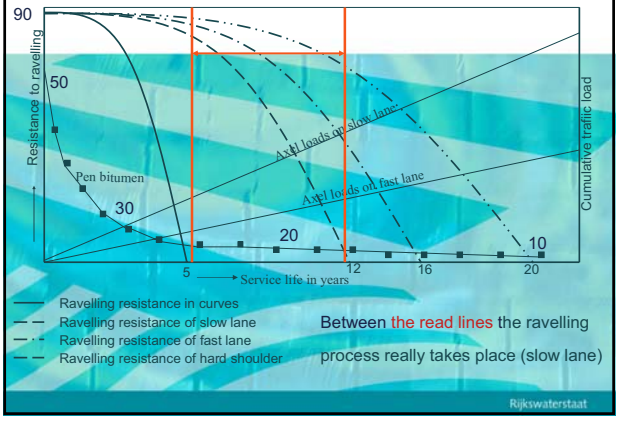
Between the read lines the ravelling process really takes place (slow lane)

Rijkswaterstaat

Short service life of PA on a parking place

Rijkswaterstaat

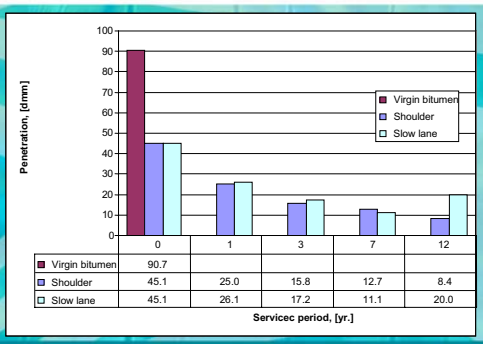
Performance model for SLPA



Between the read lines the ravelling process really takes place (slow lane)

Rijkswaterstaat

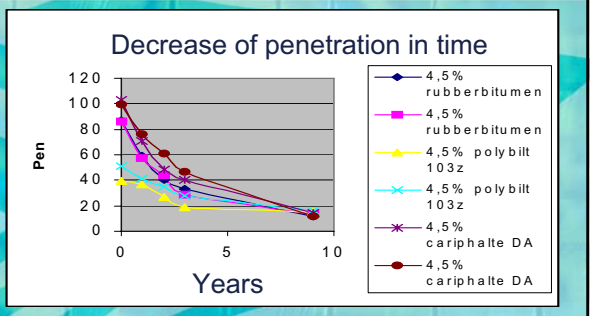
Ageing of bitumen (study Hagos)



	0	1	3	7	12
Virgin bitumen	90.7				
Shoulder	45.1	25.0	15.8	12.7	8.4
Slow lane	45.1	26.1	17.2	11.1	20.0

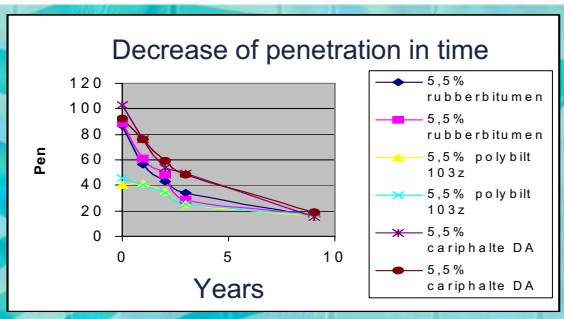
Rijkswaterstaat

Ageing of bitumen of SLPA with 4.5% binder (A10 test sites Amsterdam)



Rijkswaterstaat

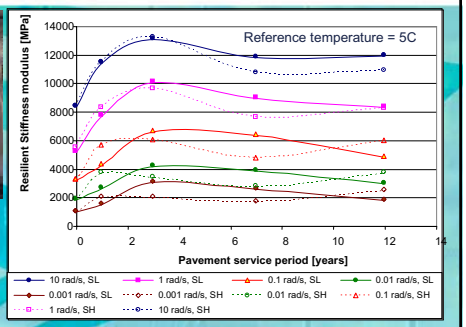
Ageing of bitumen of SLPA with 5.5% binder (A10 test sites Amsterdam)



Rijkswaterstaat

Indirect Tensile Strength on SLPA (Hagos)

ITT



SL = slow lane SH = hard shoulder

Rijkswaterstaat

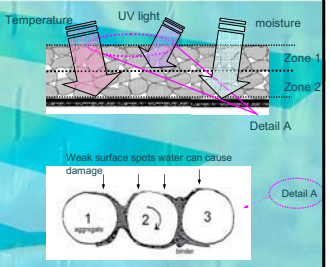
Ageing of bitumen has effect on the :

- Hardening of the bituminous binder of SLPA (mix of sand/filler/bitumen)
- Failure at lower strain levels
- Reduction in the ability to relax stress
- Reduction in healing ability
- Brittle behaviour leading to damage development
- Reduction of the bonding ability

Rijkswaterstaat

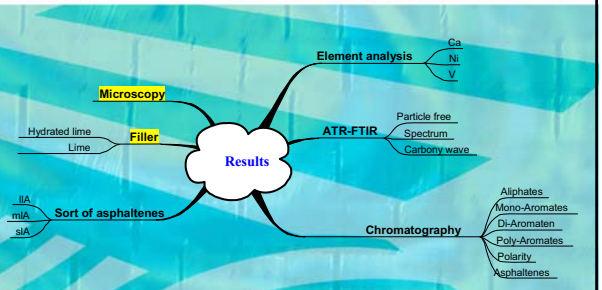
Facts until now

- Ageing influences the cohesive strength of PA
- Ageing is a complex process
- **Ageing is a high temperature occurrence**
- **Ravelling occurs mainly at low temperatures**
- **There is difference in ageing between the Upper Zone and Lower Zone**



Rijkswaterstaat

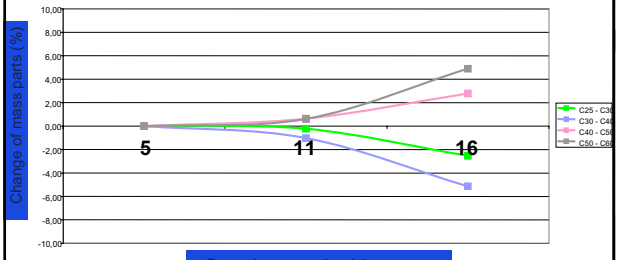
Overview of project: Learning of the Road (TU Aachen)



Rijkswaterstaat

Gas chromatography

Change in percentage of boil fractions



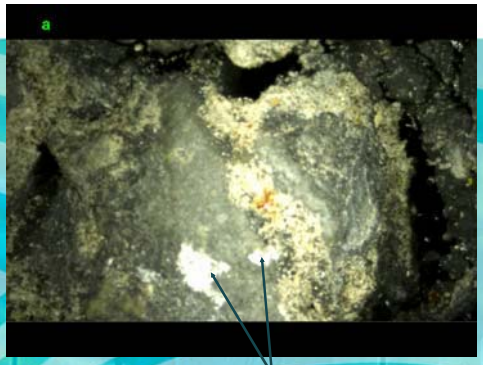
Service period in years

Rijkswaterstaat

Example of profile of a drilled SLPA core

Rijkswaterstaat

Example of the socalled “leaning“ zone

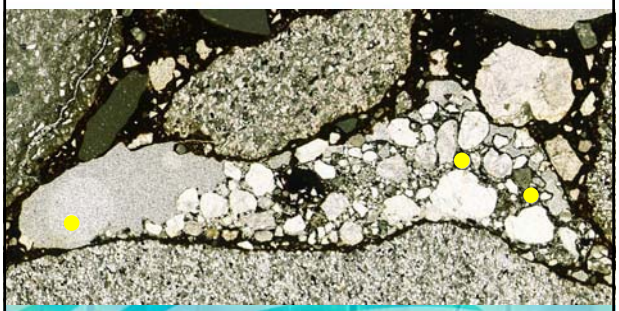


Rijkswaterstaat

Example of a coated particle

Rijkswaterstaat

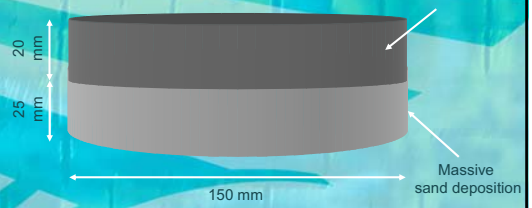
Example of o thin section



Rijkswaterstaat

Autopsy of a drilled SLPA core (upper zone)

Road section: A 8
Constructed: 1995
Location: wheel path



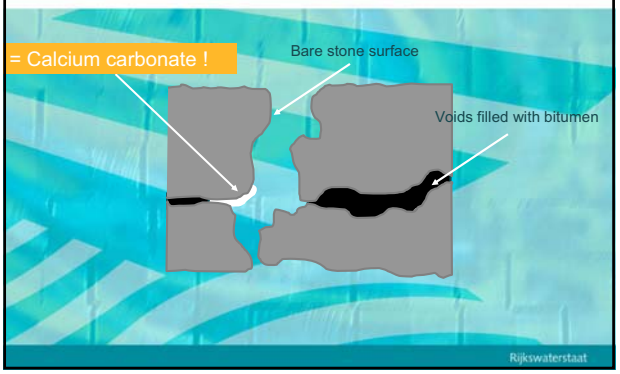
Rijkswaterstaat

Autopsy of a drilled SLPA core (upper zone)

Road section: A 8
Constructed: 1995
Location: wheel path

Rijkswaterstaat

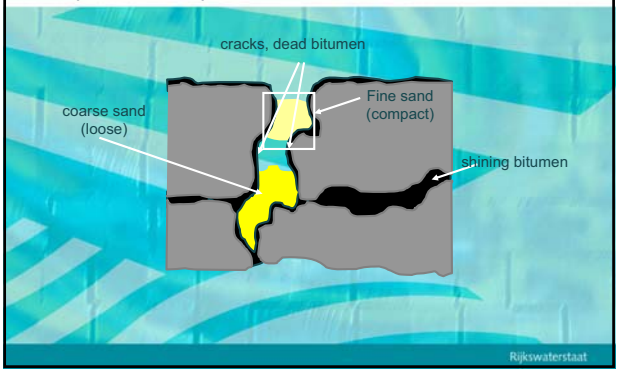
Lean making (upper zone)



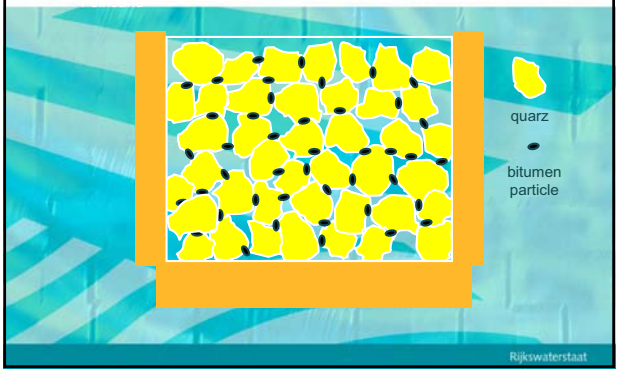
Autopsy of a SLPA core
(bottom zone)

Road section: A 8
Constructed: 1995
Location: wheel path

Enriching zone
(bottom zone)

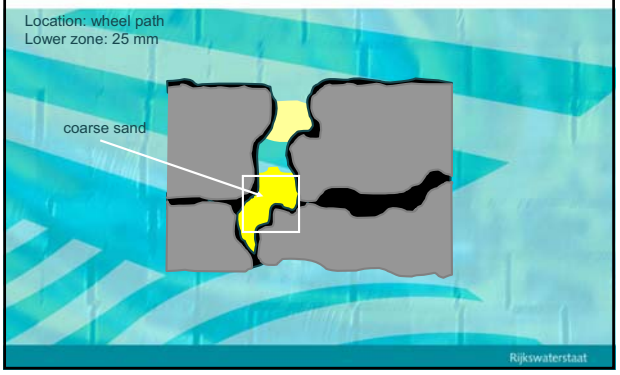


Point-to-point-bonding



Enriching zone

Location: wheel path
Lower zone: 25 mm



Composition of the coarse sand

Composition of coarse sand

1. Mostly large grains of quarz sand
2. High amount in acid soluble grains
3. Partly acid resistant **ferro magnetic steel** > Magnet Test
4. Partly **difficult soluble** organic parts (only soluble by heating in toluene)
5. No point-to-point-bonding as seen with the fine sand, but **„calcining“** by calcium carbonate
6. **The coarse sand consists partly of coarse sand from the mortar and partly of sand due to clogging (determined with petrographic research)**

Rijkswaterstaat

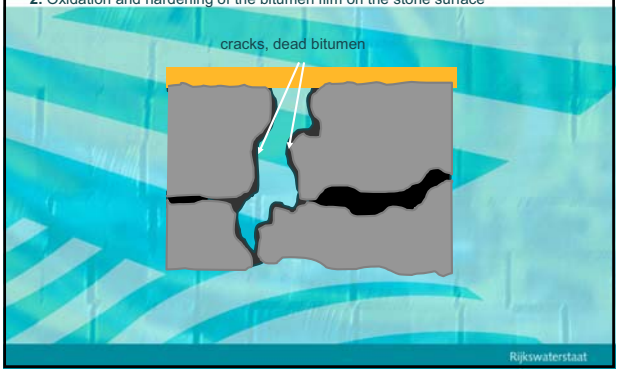
Ravelling mechanism (1)

1. Remove of the bitumen film from the surface

Rijkswaterstaat

Ravelling mechanism (2)

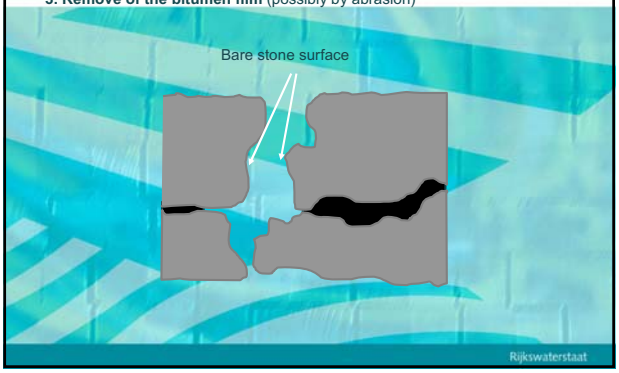
2. Oxidation and hardening of the bitumen film on the stone surface



Rijkswaterstaat

Ravelling mechanism (3)

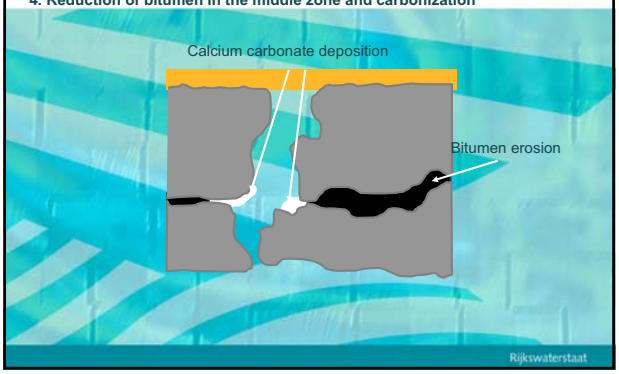
3. Remove of the bitumen film (possibly by abrasion)



Rijkswaterstaat

Ravelling mechanism (4)

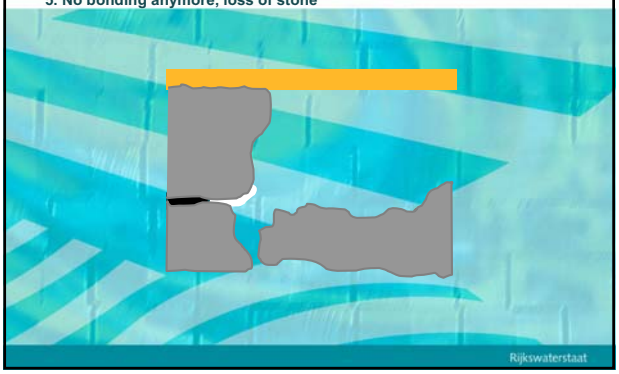
4. Reduction of bitumen in the middle zone and carbonization



Rijkswaterstaat

Ravelling process (5)

5. No bonding anymore, loss of stone



Rijkswaterstaat

Ravelling mechanism (6)

6. No bonding anymore, loss of stones

Rijkswaterstaat

Conclusions: Ravelling mechanism

1. Loss of stones (ravelling) due to **Bitumen erosion**.
2. The noise reduction of SLPA is decreased by coarse sand from degenerated mortar and fine sand from clogging.

Rijkswaterstaat

Conclusions ans recommendations (Bitumen)

Advantages:

- low bitumen content and choice of bitumen 70/100 are cost effective
- The low viscosity will take care of a good bonding with the coarse aggregate

Disadvantages:

- the thin bitumen film is accessible for oxyden (oxdation)

Recommendations:

- Use higher content of high viscous bitumen
- **Try to improve the resistance to ageing**

Rijkswaterstaat

Conclusions and recommendations (Filler)

Advantages:

- hydrated lime is positive for the durability and the bonding between bitumen and acid stone surfaces

Disadvantages:

- an overdose of hydrated lime increases the stiffness of the bitumen too much **(low temperature brittleness)**

Recommendations:

- keep using hydrated lime, but be careful with high viscous bitumen or PMB
- quality control of lime and hydrated lime is necessary

Rijkswaterstaat

You can compare your teeth with the coarse aggregate in PA

Rijkswaterstaat

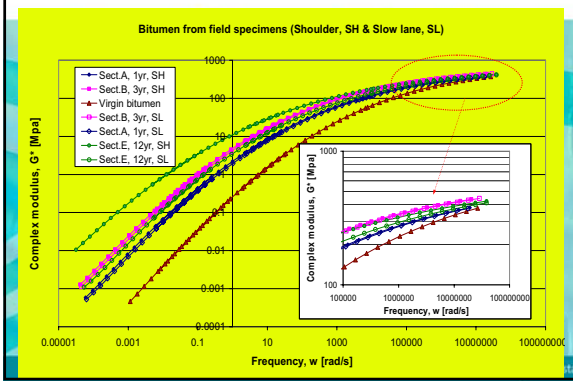
Due to parodontose you can loose some teeth

Rijkswaterstaat

Happy end, thank you!

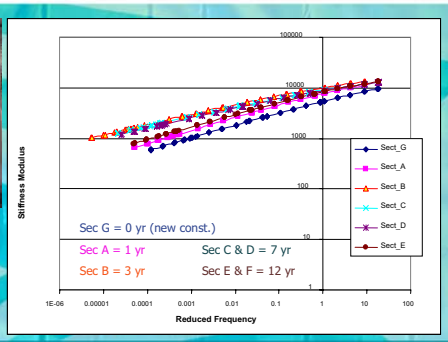
Rijkswaterstaat

Aging of bitumen (study Hagos)



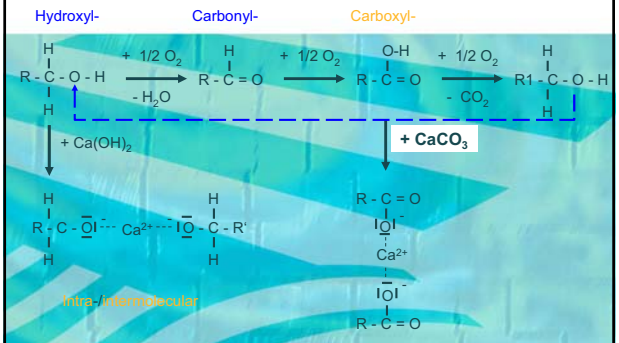
Indirect Tensile Strenght PA (Hagos)

ITT



Rijkswaterstaat

Chemical action of hydrated lime



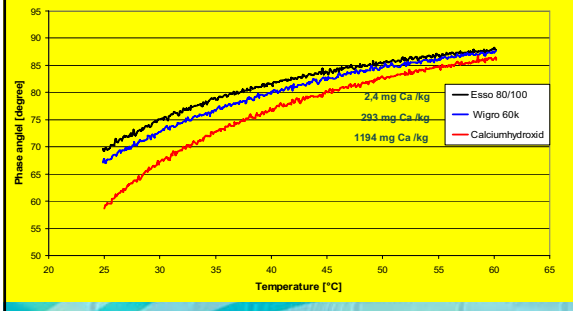
Rijkswaterstaat

Experiment

1. Strarting point is Bitumen 70/100
2. Addition of hydrated lime with calcium carbonite
3. One hour heating at 120°C
4. Extraction of the bitumen with Toluene
5. Research of the extracted bitumen

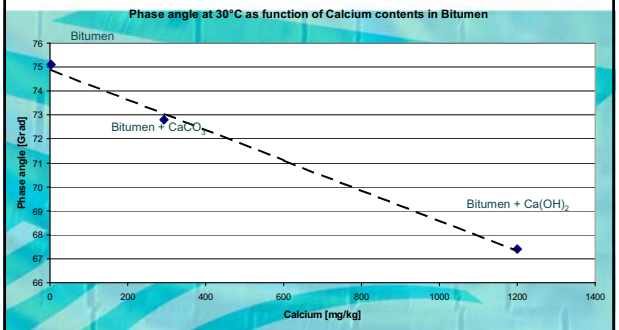
Rijkswaterstaat

Phase angle of the recovered bitumen

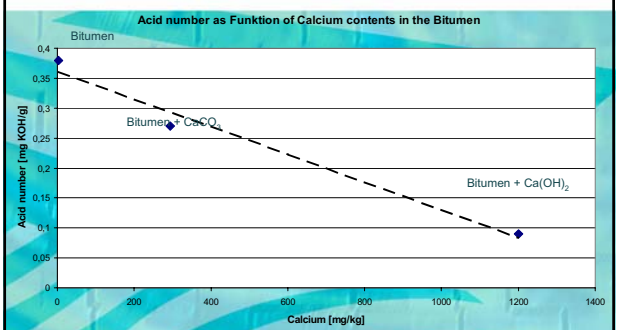


Rijkswaterstaat

Recovered bitumen



Recovered bitumen



How does hydrated lime works?

1. **Hydrated lime conserves the bitumen**
   - „Protects" the functional groups by Calcium ions (-OH, -COOH, -SH, NH_2)
   - Alkaline reduces the redox potential (improved environment -> „Vitamine C-Effect")
2. **Hydrated lime improves the bonding effect**
   - Acid groups are neutralised
   - Alkaline environment
3. **Hydrated lime increases the bitumen stiffness**
   - Inter molecular bonding of molecules
   - Bonding of Calcium ions in the structure
4. **Hydrated lime works better than Calcium Carbonate**

Rijkswaterstaat

Carbonization

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

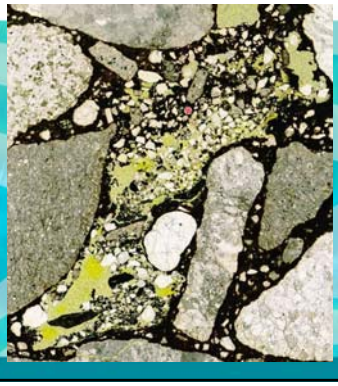
light water soluble

medium watter soluble

Rijkswaterstaat

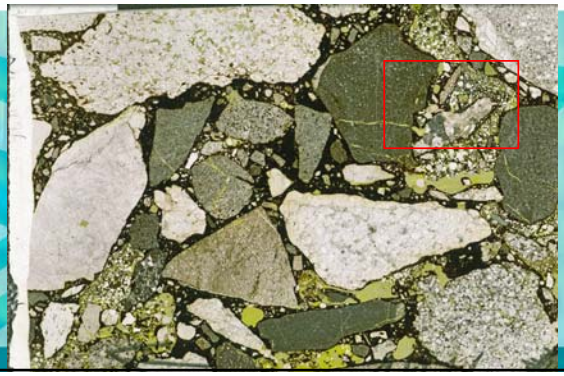
Examples of thin sections

Examples of thin sections



Rijkswaterstaat

Examples of thin sections



Examples of thin sections

Examples of thin sections

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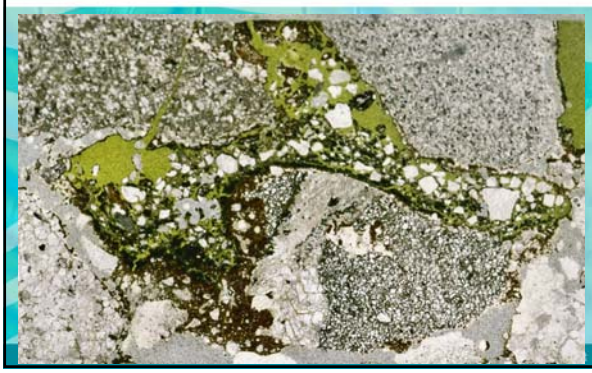
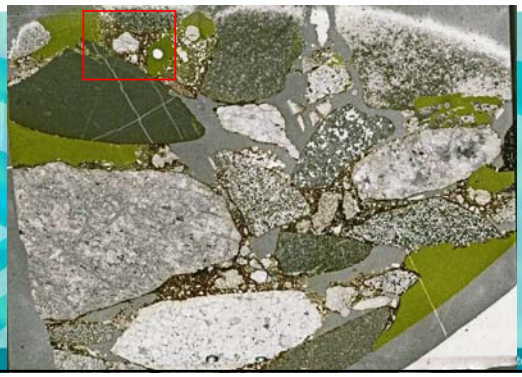
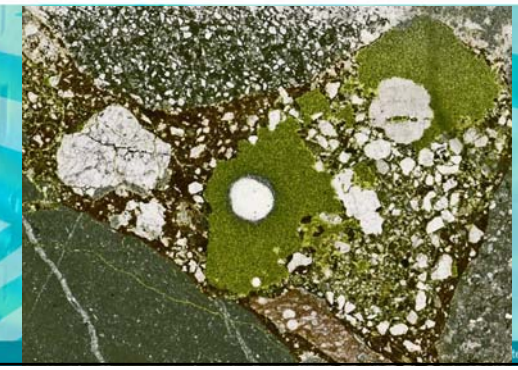


Examples of thin sections



Examples of thin sections



Two Layer Porous Asphalt

Acoustic Durability – Introduction: Dutch Outlook

24 November 2006
DRI-DWW Workshop, Rungsted Kyst

IPG
Noise Innovation

Acoustic Durability

The Problem

Opinion

TLPA (and other silent pavements) looses quite rapidly its Noise Reducing Capacity

Is It a Fear or Reality??

Dubbellaags zoab op A10 niet meer stil

Double Layer Porous Asphalt on A10 no longer silent

DRI-DWW Workshop 23 - 24 November 2006

Acoustic Durability

Content

1. Dutch Experience
2. DRI – DWW project on Acoustic Durability
   - Scanning Tour to Japan (This presentation)
   - Structural Observation (Carsten Bredahl Nielsen)
   - Relation Clogging-Acoustical Behaviour (Bent Andersen)
3. Modelling
4. Future Dutch Experiment on Cleaning

DRI-DWW Workshop 23 - 24 November 2006

Dutch Experience

Description Zebra Test Sections

High Lights

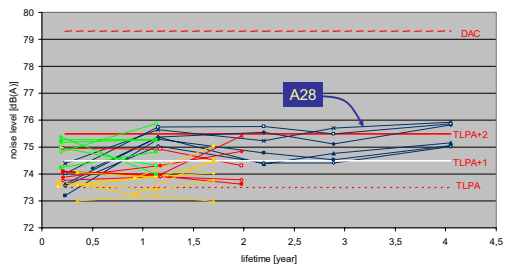
- Four Locations
- Eight Contractors
- i.e. 32 Different Test Sections/Measuring Points
- On each Location Same Mixtures
- Intensively Monitored after Construction and during Lifetime
- Construction during day time (>20°C) all lanes at same time

A28 Staphorst 2002

DRI-DWW Workshop 23 - 24 November 2006

Dutch Experience

Results Zebra Test Sections

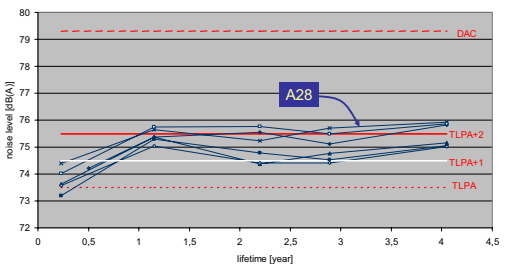


DRI-DWW Workshop 23 - 24 November 2006

SPB-value Light vehicles @ 110 km/h

Dutch Experience

Results Zebra Test Sections

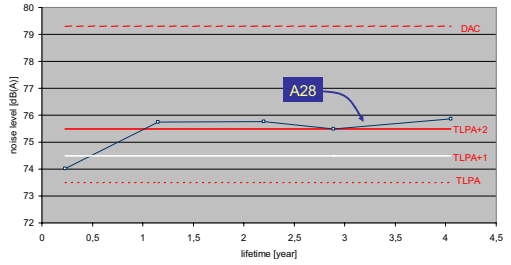


DRI-DWW Workshop 23 - 24 November 2006

SPB-value Light vehicles @ 110 km/h

Dutch Experience

Results Zebra Test Sections



SPB-value Light vehicles @ 110 km/h

Japanese Experience

Two Layer Porous Asphalt used on dense trafficked Roads with maximum speed of 60 km/h

Japanese Experience

Situation of clog in void

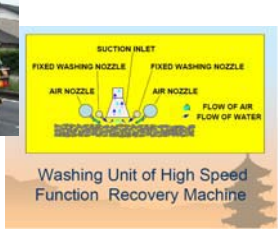
Japanese Experience

Japanese Experience

d Cleaning with Air

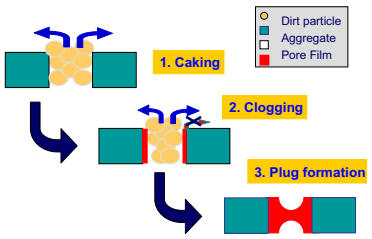
Japanese Experience

High Speed Cleaning with Water and Air



Acoustic Durability

Clogging Model



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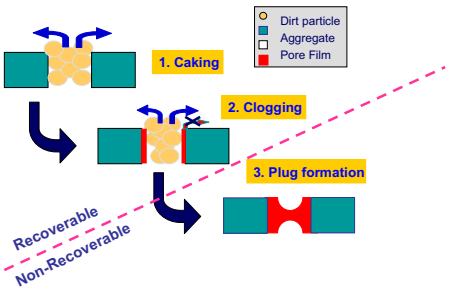
Acoustic Durability

From Model towards Behaviour



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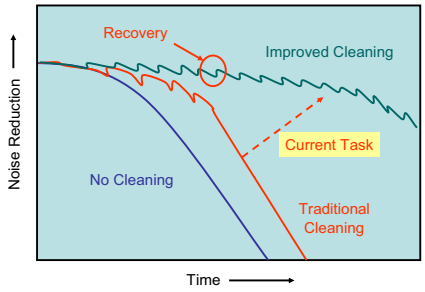
Acoustic Durability

Expected behaviour



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Acoustic Durability

"Beauty Contest"

Desired Product: Improved Cleaning Technique

Required Specification:

- Improved Cleaning Behaviour
- High Speed Equipment to prevent Congestion during cleaning
- Good Cost Effectiveness
- No effect on structural durability

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Acoustic Durability

Cleaning test 2006-2007

Idea Phase

August 2006

Development Phase

November 2006

Demonstration Phase

April 2007

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Acoustic Durability

Cleaning test 2006

1. Wet and Dry Cleaning

Wet: see drawing (1 km/h)
(not tested in 2007)

Dry: comparable to JP-equipment??
(80 km/h??)

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Acoustic Durability

Cleaning test 2006

2. Ultra Sonic Cleaning

Using ultra sonic waves to remove clogged particles

3. Steam Cleaner

Using steam to clean

Still unclear whether speed of cleaning vehicle is satisfactory

Experience with CPX measurements

Jørgen Kragh
Danish Road Directorate
Danish Road Institute

Overview

- Measured in DK with CPX trailer DGMR/JR:
  - September / October 2004
  - June / July 2005
- Variability of CPXL; typical DK-values
- Repeated measurements in DK
- Clogging Example CPX
- Relation CPX - SPB
- Compare two trailers

Conclusions

- Clogging discovered by CPX trailer

- Typical CPX-values for new surfaces
- Increase 1 dB after 6 – 9 yrs for DAC
- 8 -> 11 mm aggregate => + 1 – 2 dB
- ≈ 1/1-relation CPX - SPB pass. cars
- Similar results by two trailers

Selected surfaces

- Dense asphalt concrete AC 6, 8, 11, 16d
- Open graded asphalt concrete AC 6, 8, 11o
- Open graded soft asphalt SA 6o
- Stone mastic asphalt SMA 6, 8, 11
- Thin layer asphalt concrete BBTM 6, 8, 11
- Double-layer porous asphalt concrete PA 5 / PA 16, PA 5 / PA 22, PA 8 / PA 16
- Surface dressing SD 2/5, 5/8, 5/8 + 8/11
- Hot rolled asphalt HRA 11/16

170 · CPX: sections speed time (04/05) 44 · SPB

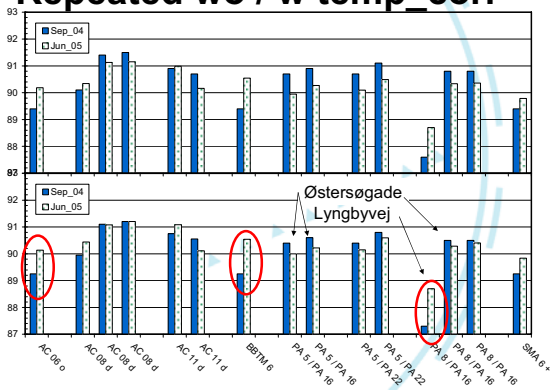
CPX-trailer used by DRI

In action

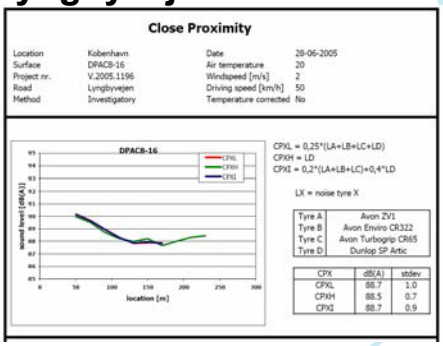
Typical DK-CPXL; ≤ 15 months

Speed [km/h]	AC or SMA	BBTM [dB]	PA [dB]	SD [dB]
110	102	103 - 105	-	-
80	98	96 – 99	-	97 - 100
50	90	89 - 82	88	91 - 92

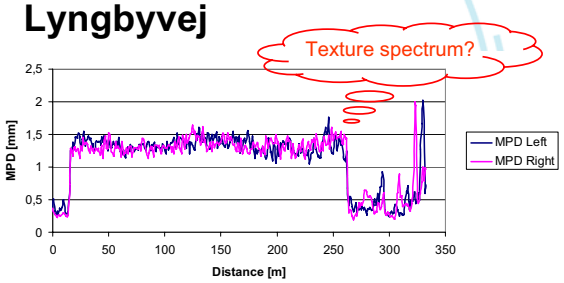
Repeated wo / w temp_corr



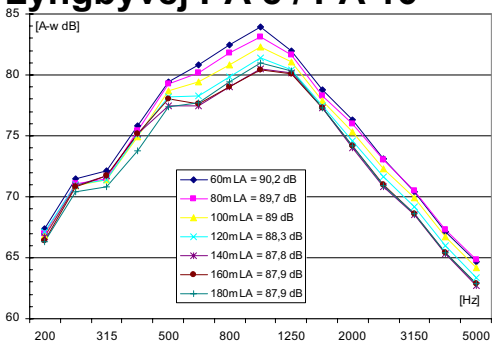
Lyngbyvej PA 8 / PA 16



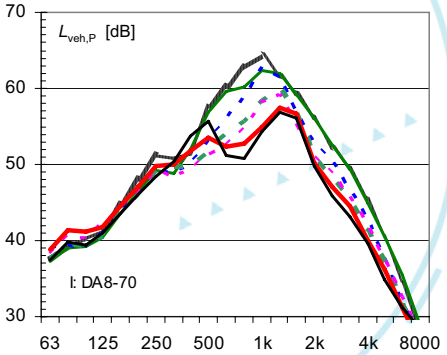
Mean Profile Depth – Lyngbyvej



Lyngbyvej PA 8 / PA 16



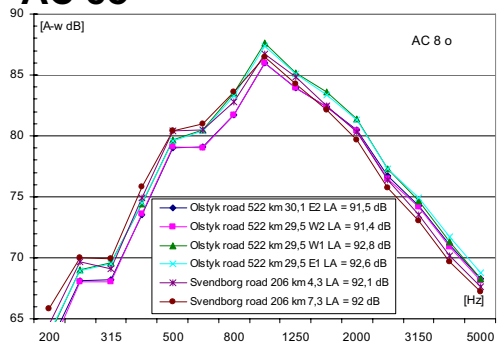
PA 8 / PA 16: Year 0–6 OSOGADE



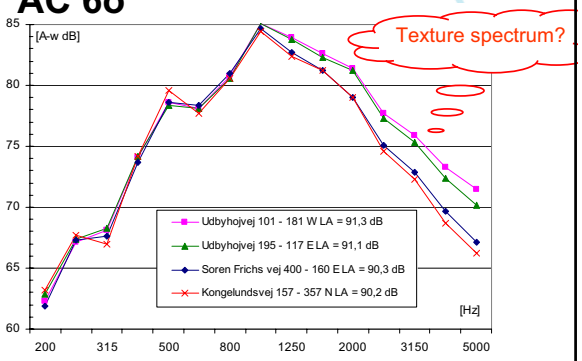
Drainage time [s/10 cm] in lane 3 of Lyngbyvej, June 2005

Distance [m]	Right wheeltrack	Between wheeltracks	Left wheeltrack
28	>75	58	>75
150	11.4	5.1	5.9

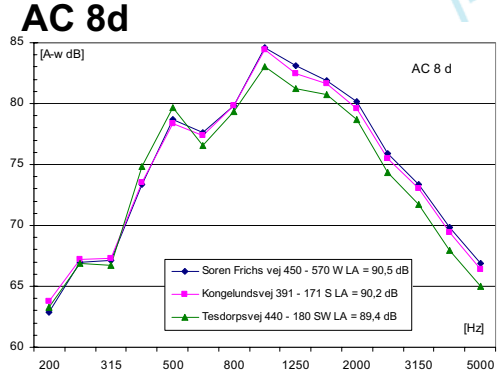
AC 8o



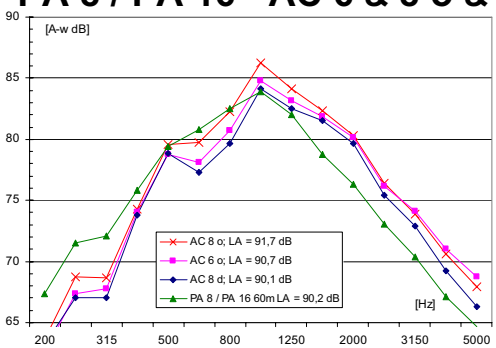
AC 6o



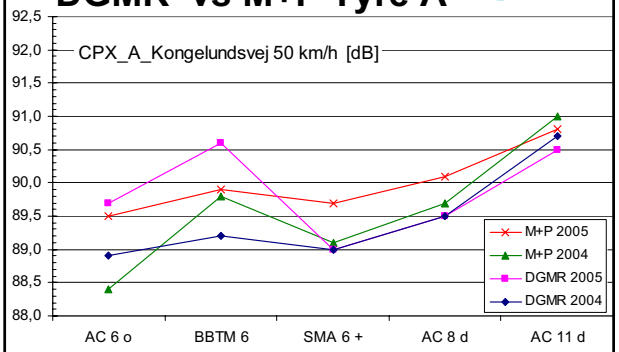
AC 8d

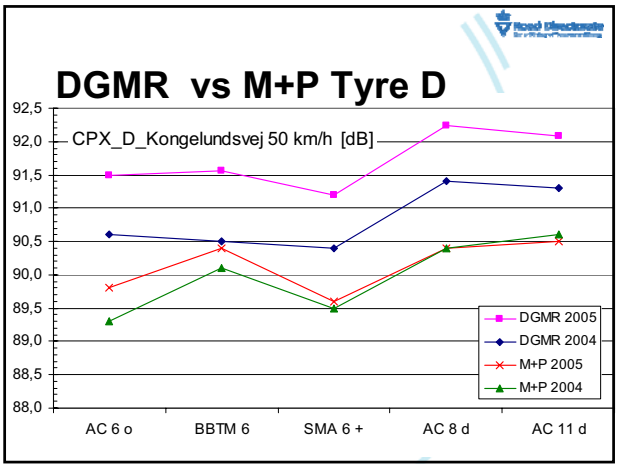


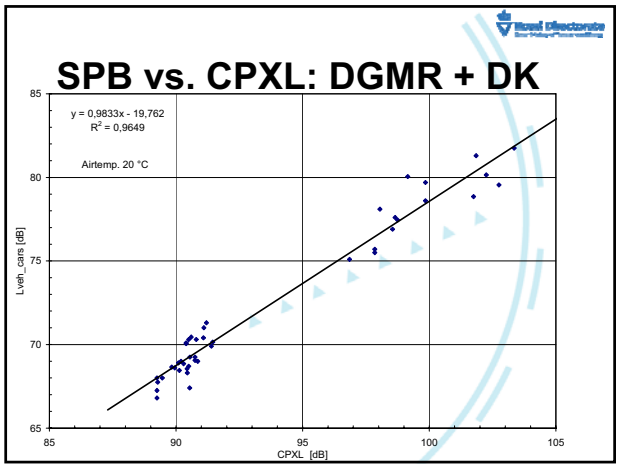
PA 8 / PA 16 - AC 6 & 8 o & d

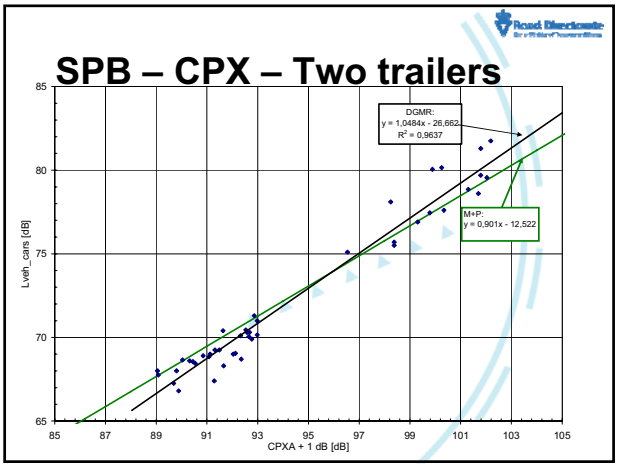


DGMR vs M+P Tyre A









Conclusions

- Clogging discovered by CPX trailer

- Typical CPX-values for new surfaces
- Increase 1 dB after 6 – 9 yrs for DAC
- 8 -> 11 mm aggregate => + 1 – 2 dB
- ≈ 1/1-relation CPX - SPB pass. cars
- Similar results by two trailers

Assessment of IPG test sections

Carsten Bredahl Nielsen
DRI

Road and Hydraulic Engineering Institute

Research aims

1. Understand the clogging process from the microstructure of porous pavements
2. Correlate the microstructure with the performance of road sections

Research techniques:
- Drilling cores
- CT-scanning
- Thin sections

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Hypothesis

Clogging
- increases with the age of the pavement
- is reduced by high speed traffic
- is more extensive in the shoulder
- concentrates between the wheel tracks
- initiates in the interface between the top and bottom layer
- initiates at the bottom of the porous asphalt

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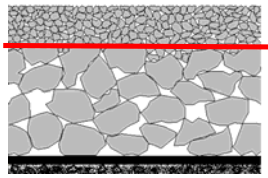
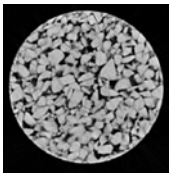
Two-Layer Porous Pavements

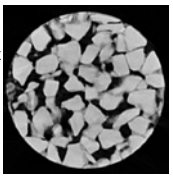
- Fine graded upper course prevents clogging in the coarse graded lower course



Top:
4/8 mm mix

Base:
11/16 mm mix





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IPG test sections

- Highway A28 in the Netherlands with a three years old two layer porous pavement.
- Highway A17 in the Netherlands with an eleven years old two layer porous pavement.
- Urban street in Denmark (Øster Søgade) with three different six years old two layer porous pavements

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Techniques for different levels

- Pavement (level 1)
  - Performance, ravelling (good, poor)

- Asphalt cores (level 2)
  - Asphalt composition (binder, aggregate fractions, density)

- CT-scanning (level 3)
  - Height and diameter
  - Voids and mastic content profiles
  - Micro-structure parameters (voids and mastic)

- Thin- and plane sections (level 4 and 5)
  - Visual assessment (adhesion, cohesion, aggregate, clogging)

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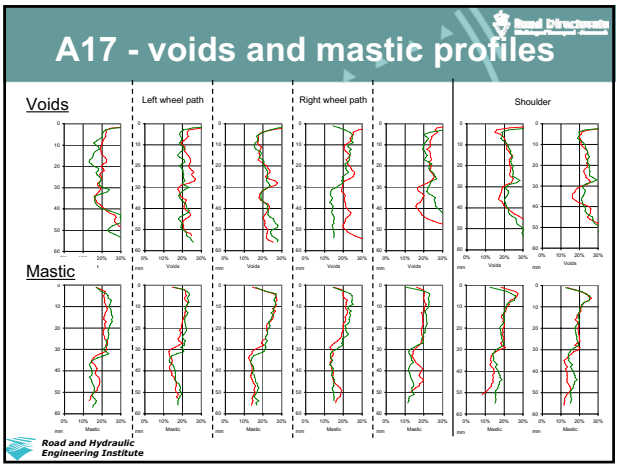
A17 - voids and mastic profiles
Voids
Left wheel path
Right wheel path
Shoulder
Mastic
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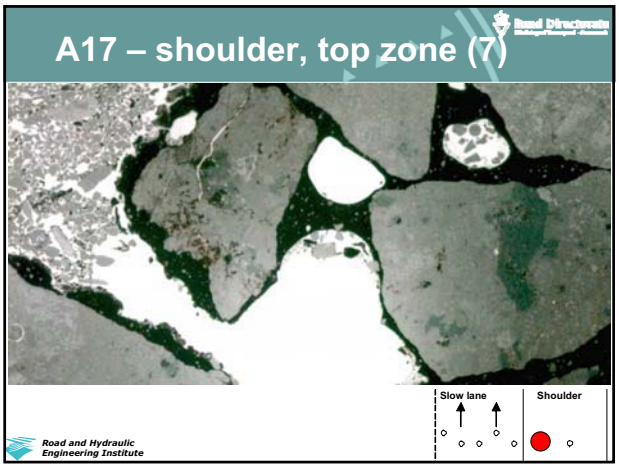
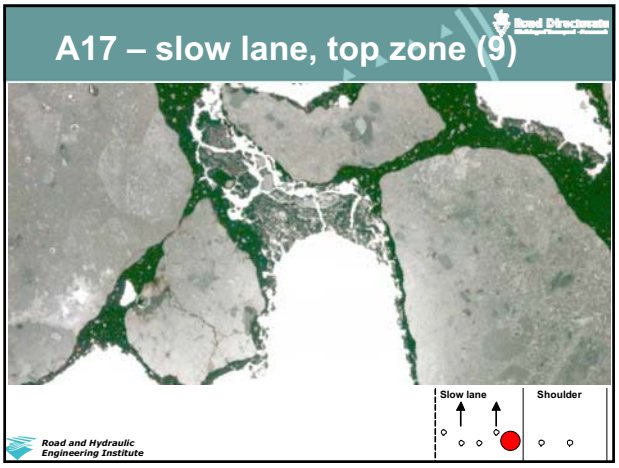

A17 – shoulder, top zone (7)
Slow lane
Shoulder
Road and Hydraulic Engineering Institute


A17 – slow lane, top zone (9)
Slow lane
Shoulder
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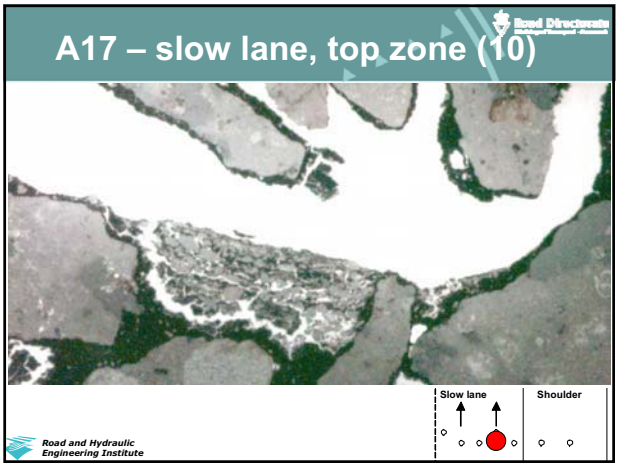
A17 – slow lane, top zone (10)
Slow lane
Shoulder
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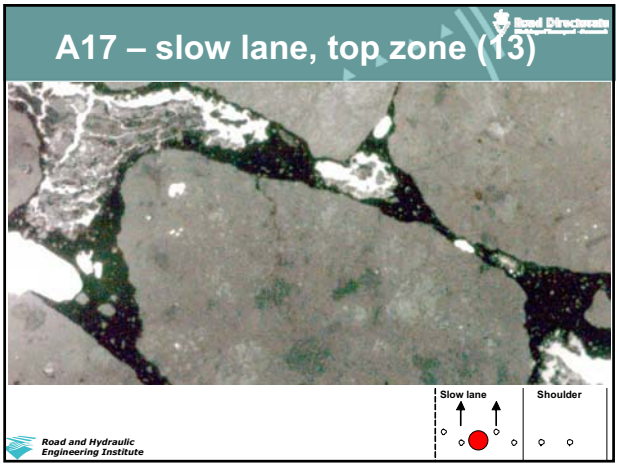
A17 – slow lane, top zone (13)
Slow lane
Shoulder
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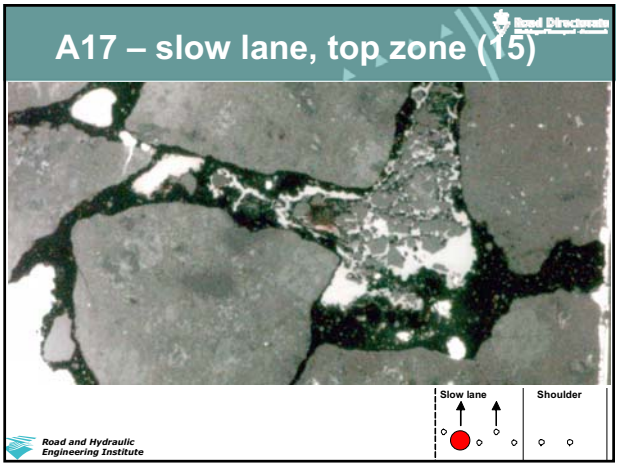
A17 – slow lane, top zone (15)
Slow lane
Shoulder
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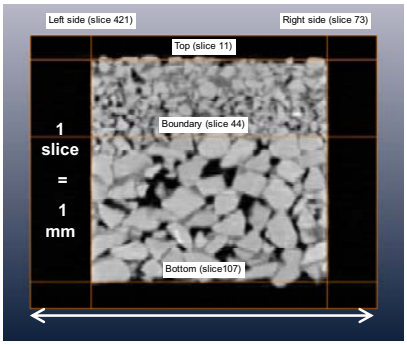
CT-scan volumetrics



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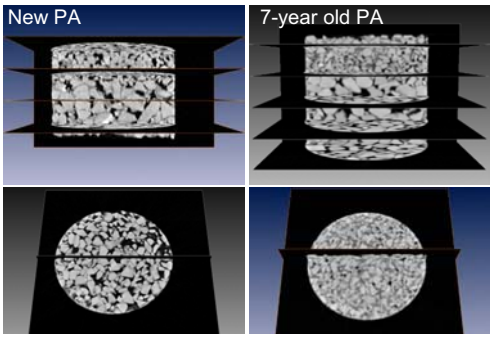
3D-models of Porous Asphalt



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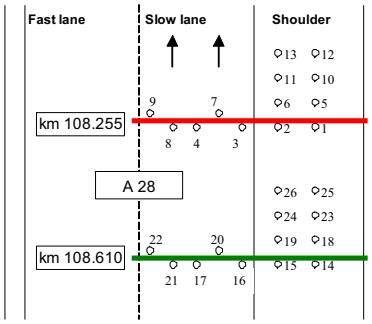
Drill core profiles on A28

Three years old
Two layer PA



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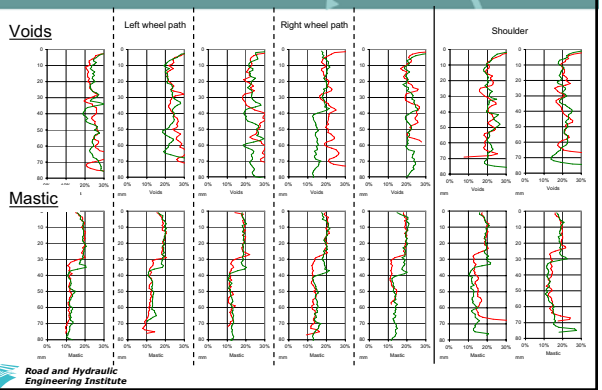
A28 - voids and mastic profiles



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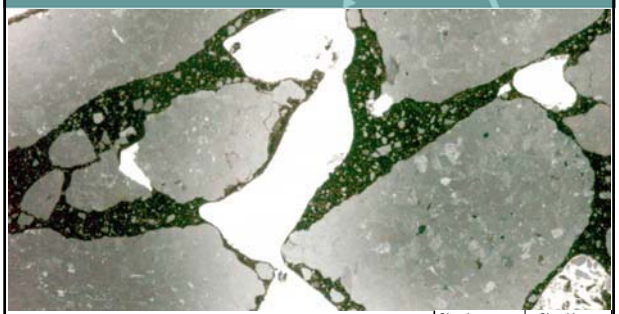
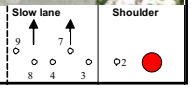
A28 – shoulder top zone (1)





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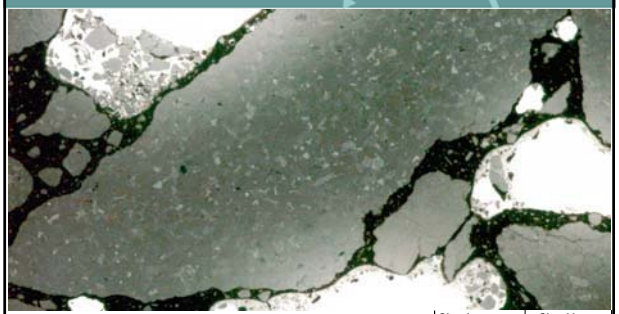
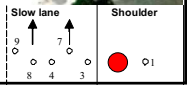
A28 – shoulder top zone (2)





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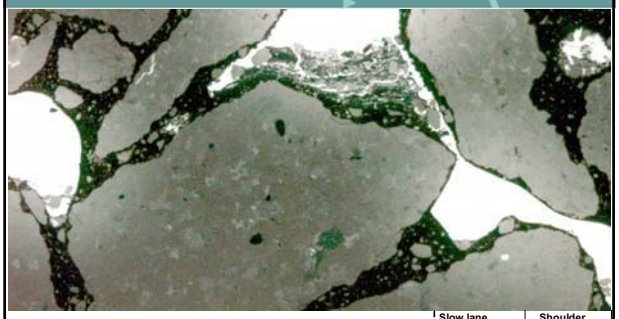
A28 – slow lane, top zone (3)



Slow lane Shoulder

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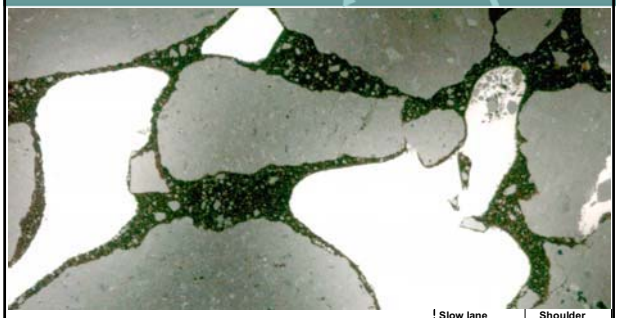
A28 – slow lane, top zone (7)

Slow lane Shoulder

Road and Hydraulic Engineering Institute

A28 – slow lane, top zone (4)



Slow lane Shoulder

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A28 – slow lane, top zone (8)

Slow lane Shoulder

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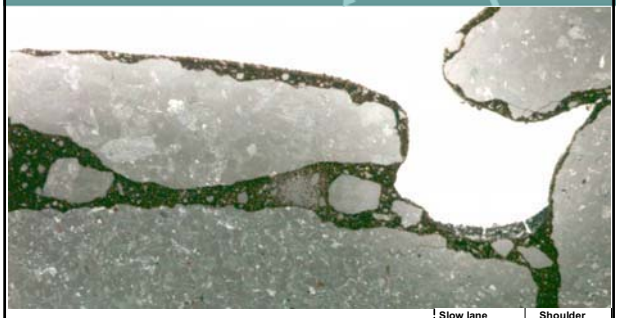
A28 – slow lane, top zone (9)



Slow lane Shoulder

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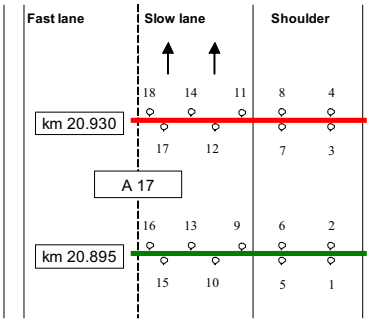
Drill core profiles on A17

Eleven years old
Two layer PA



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Drill cores - Øster Søgade

Road section	Position		IPG Core No.
1 / No. 52-54	Right side	Outer wheel path	1
		Centre	2
	Left side	Outer wheel path	3
		Centre	4
1 / No. 64	Right side	Outer wheel path	5
	Left side	Centre	6
2 / No. 76	Right side	Outer wheel path	7
	Left side	Outer wheel path	8
3 / No. 78	Right side	Outer wheel path	9
	Left side	Outer wheel path	10

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Øster Søgade

Voids

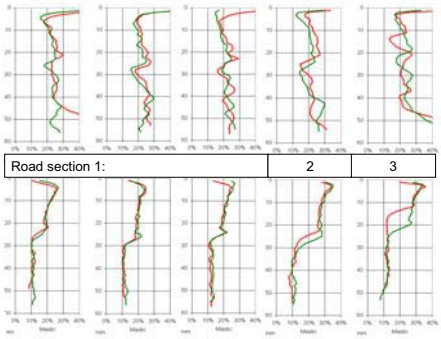
Voids and mastic profiles

Road section 1
25 mm PA 8
45 mm PA 16

Road section 2
20 mm PA 5
35 mm PA 16

Road section 3
25 mm PA 5
65 mm PA 22

Mastic



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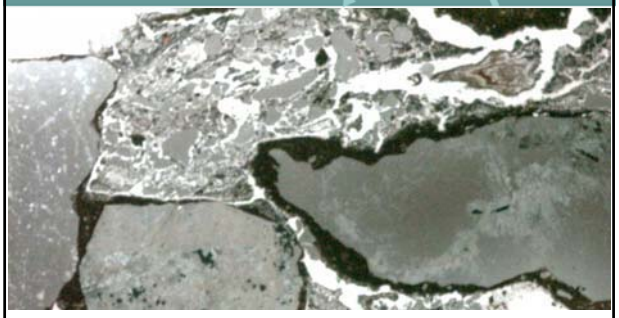
ØSG – section 1, top zone (5)



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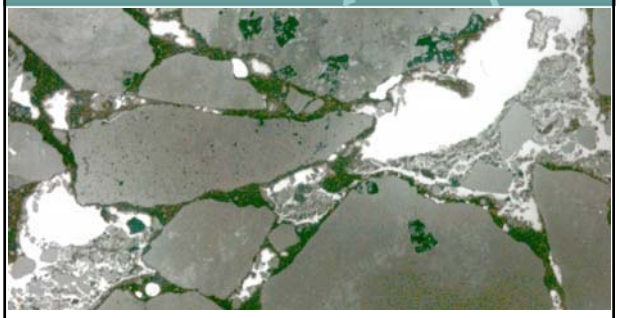
ØSG - section 2, top zone (7)



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Conclusions

- The CT-scan technique is unique in the identification and analysis of clogging
- The effect of different cleaning techniques could be documented by CT-scanning

CT-scanning
- Overview of the micro-structure – profiles of voids and mastic
  - Evaluate the homogeneity, structural problems and clogging.

Thin sections
- Very detailed visual information about the micro-structural condition
  - Explain the cause of clogging
  - Quantifying visual observations - correlate with CT-scanning

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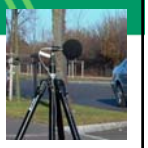
The Øster Søgade experiment Acoustical Durability of Porous Asphalt

Acoustical Durability of Porous Asphalt

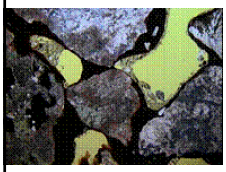
Hans Bendtsen
Senior researcher
Road Directorate
Danish Road Institute

DRI-DWW noise abatement program Workshop November 23rd to 24th 2006

Content



- The Øster Søgade experiment
- The test pavements
- Noise measurements
- Measurements on structural performance
- Conclusion



Project goals

- To develop and test noise reducing pavements for urban roads
- Applying and improving Dutch twin-lay concept for Danish conditions
- Investigate the clogging phenomenon of two-layer porous pavements
- Over the lifetime of the pavements to analyse:
  - The acoustical properties of the pavements
  - The clogging of the pavements
  - The structural properties of the pavements

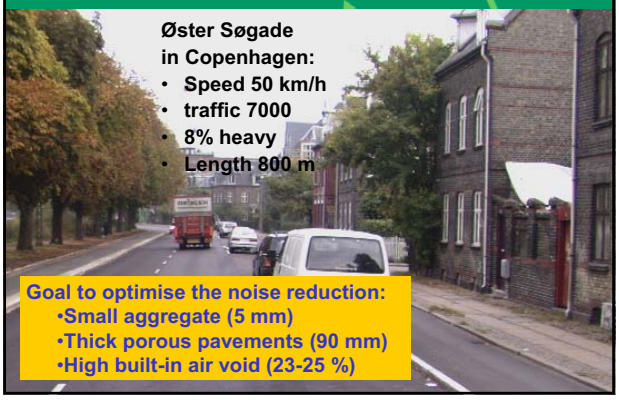
Organisation

Øster Søgade experiment originally financed by:
- Danish Ministry of Transport
- Ministry of Environment

Danish project group:
- Danish Road Directorate/DRI
- Municipality of Copenhagen
- Pavement Contractors Association /NCC

The clogging project:
- Now part of the DRI-DWW noise abatement programme
- Example of an old porous pavement with lifetime measurements

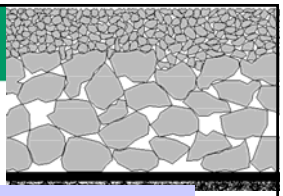
Test road



Øster Søgade in Copenhagen:
- **Speed 50 km/h**
- **traffic 7000**
- **8% heavy**
- **Length 800 m**

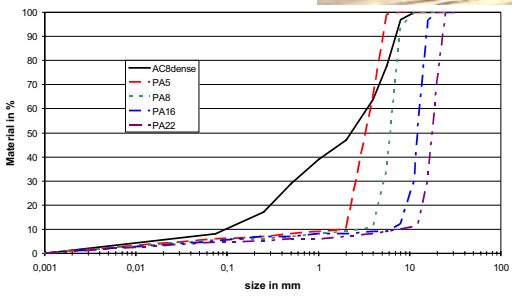
Goal to optimise the noise reduction:
- **Small aggregate (5 mm)**
- **Thick porous pavements (90 mm)**
- **High built-in air void (23-25 %)**

The porous pavements

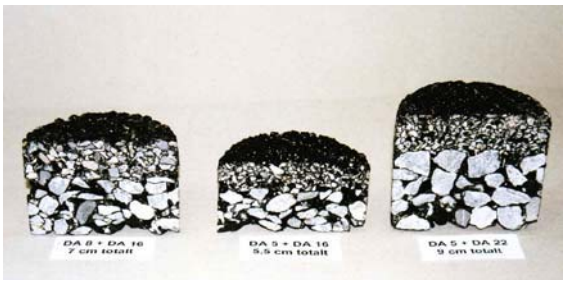


Name	Type	Total thick-ness	Top layer aggregate	Bottom layer aggregate

Grain-size curves



Drill cores new pavements



Built in air void

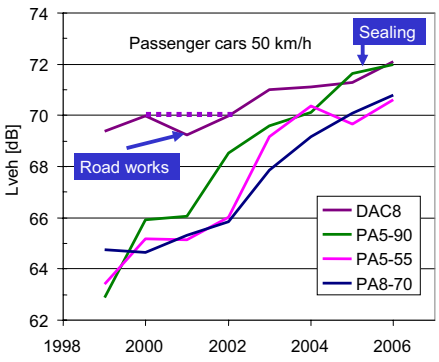
	Layer	Built-in voids (%)	Compaction degree (%)
PA8-70	PA8 (top)	26.5	99
	PA16 (bottom)	22.8	104
PA5-55	PA5 (top)	26.6	99
	PA16 (bottom)	25.2	100
PA5-90	PA5 (top)	23.7	102
	PA22 (bottom)	21.8	105
DAC8 (reference)		4.2	98

Measured on drill cores taken from test sections shortly after these were laid.

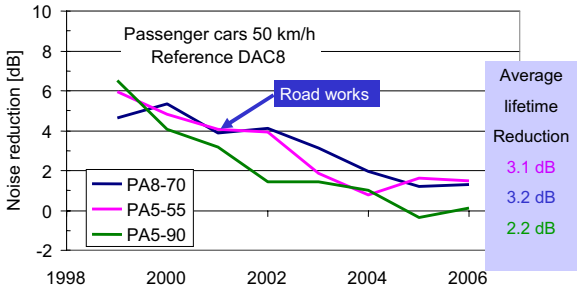
Maintenance

- High pressure water cleaning twice a year:
  - Before winter
  - After winter
- Summer 2005 sealing with bituminous emulsion (400 g/m2) on:
  - PA5-55
  - PA5-90

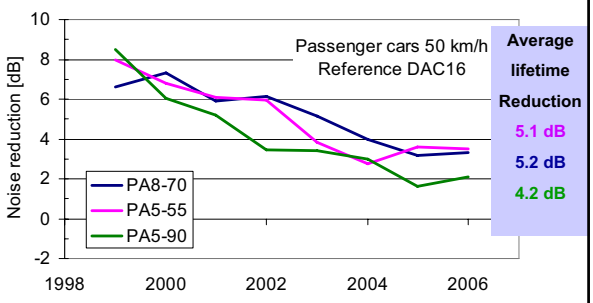
Passenger cars (SPB)



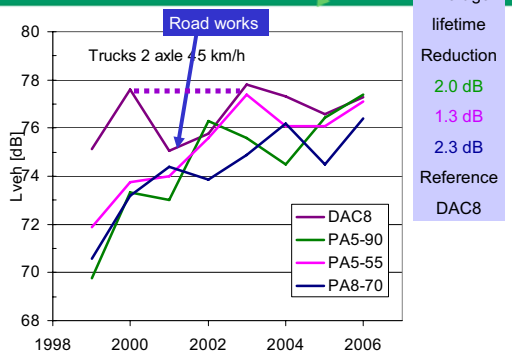
Noise reduction passenger cars



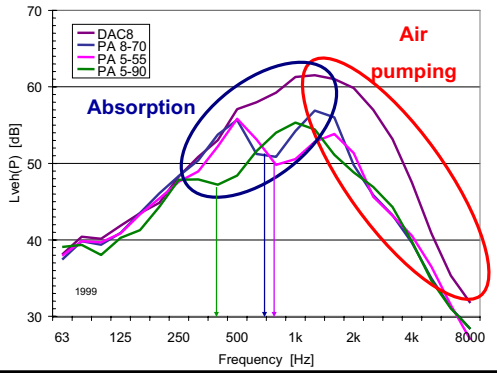
Reference DAC16



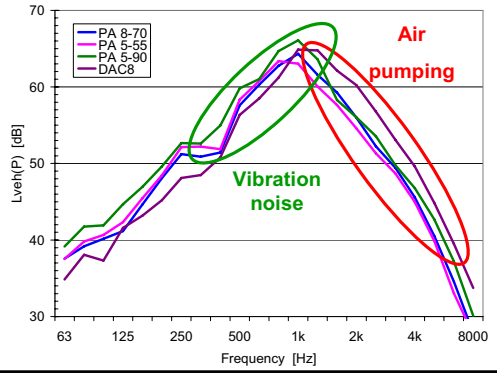
Trucks two axles (SPB)



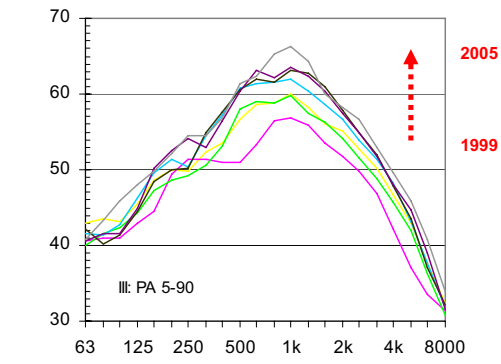
Spectra passenger cars 1999



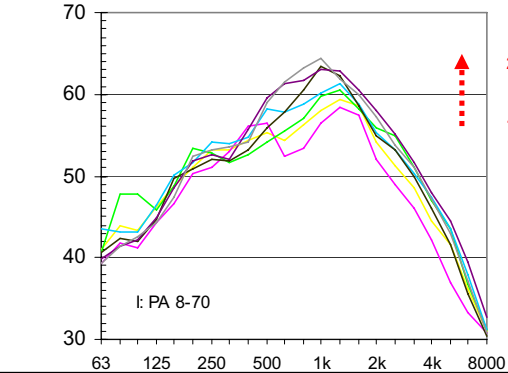
Spectra passenger cars 2005



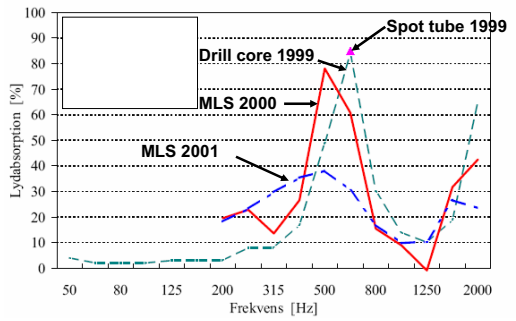
PA5-90 spectral development



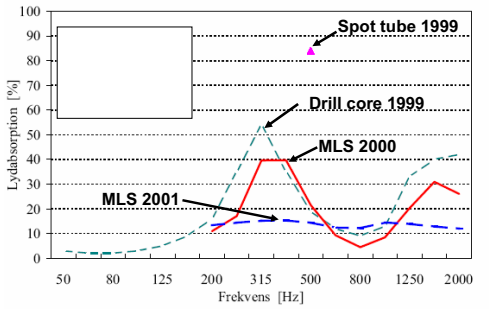
PA8-70 spectral development



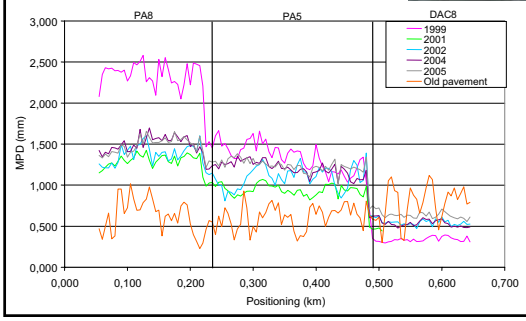
Absorption PA8-70



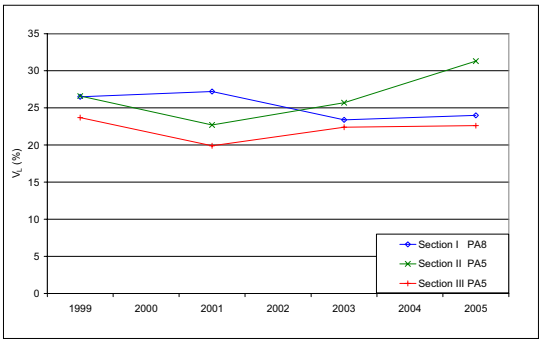
Absorption PA5-90



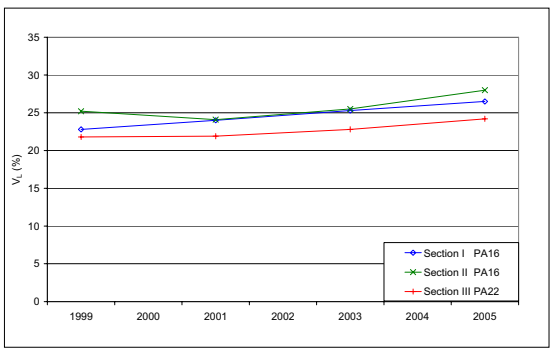
Measurements of MPD



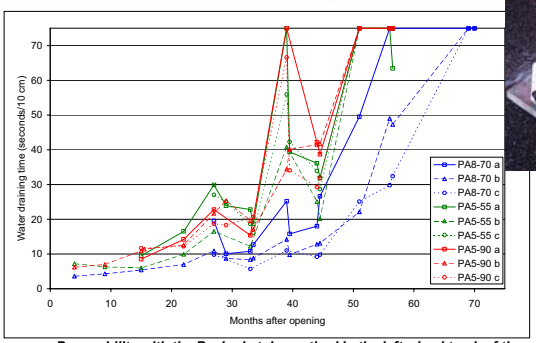
Built in air void top layer



Built in air void bottom layer

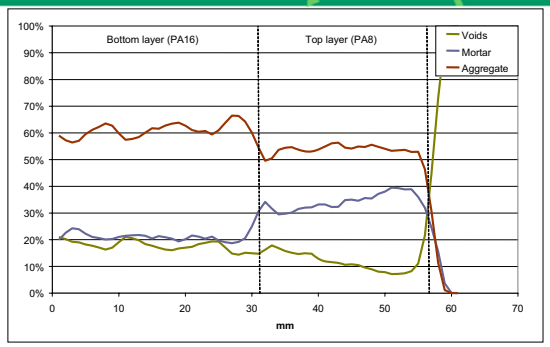


Permeability



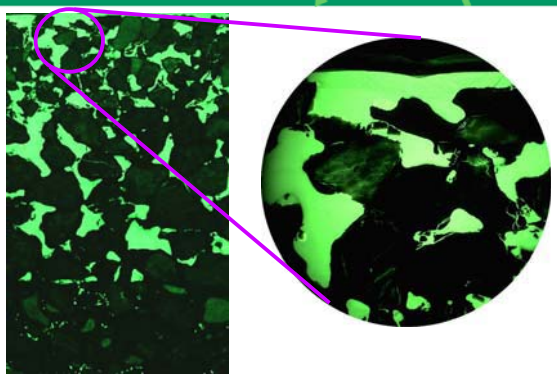
Permeability with the Becker's tube method in the left wheel track of the northbound lane

CT scanning 2005

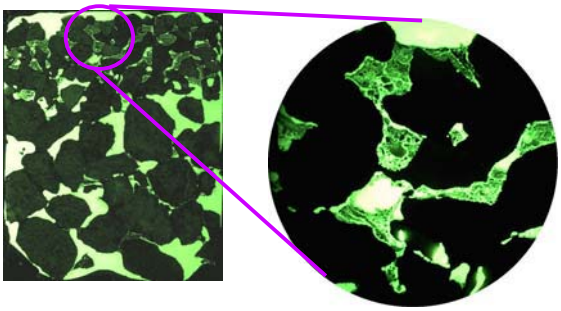


Result of CT-scan of a core from the PA8-70 pavement, drilled in 2005

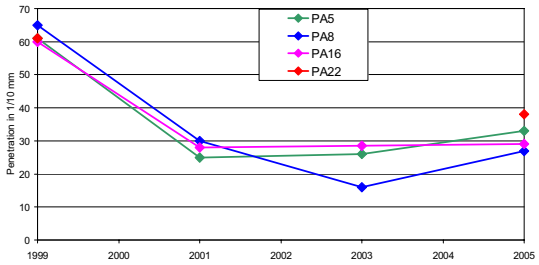
Plane section PA8-70 1999



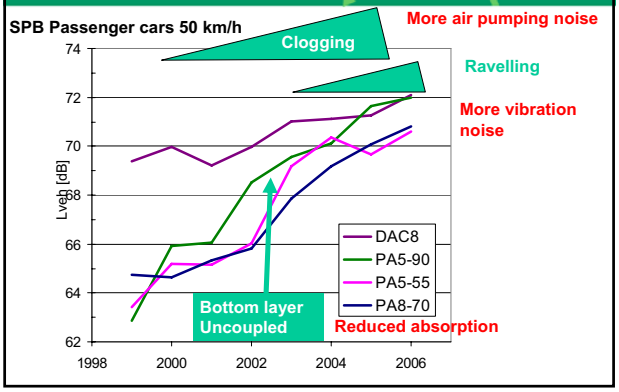
Plane section PA8-70 2003



Penetration in 1/10 mm



Square root of measurements



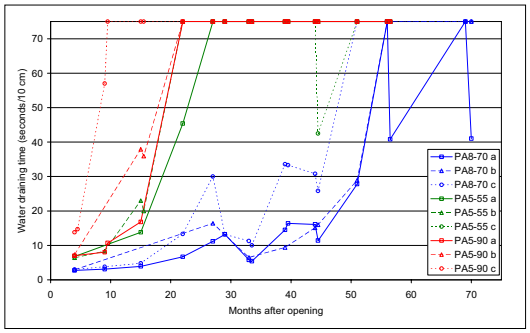
Conclusion

- Two layer porous asphalt with 8 mm aggregate gave 3.2 /5.2 dB lifetime noise reduction on urban road 50 km/h.
- Clogging occur.
- Development towards open not porous pavement.
- End of lifetime indicator is ravelling.
- Structural lifetime top layer 8 years.
- Sealing with bituminous emulsion increased lifetime.
- Best describer of clogging:
  - Permeability
  - CT scanning
  - Thin and plane sections

END

Extra

Permeability



Draining pipes at road side

Why research on noise reducing thin layer pavements?

- Other countries already use thin layers since a couple of decennia.
- In the 80's single layer porous asphalt was chosen as silent pavement in the Netherlands.
- It was only five years ago that the ministry of environment introduced a programme in order to stimulate the use of noise reducing thin layer pavement on the secondary road network.

Aim of IPG research

Research on the possibilities to use noise reducing thin layer pavements as alternative to single layer porous asphalt on Dutch highways.

Research questions

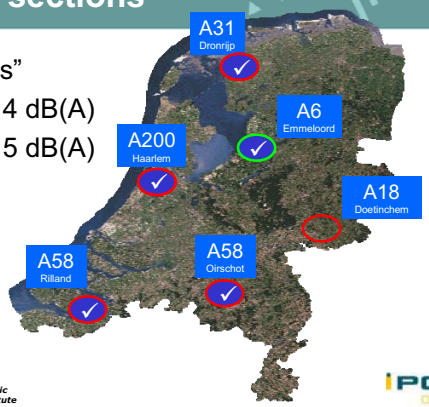
Are noise reducing thin layers

- safe and comfortable?
- cost-effective (life time, noise reduction)?
- ready to use?

Test sections

6 "pilots"

- > 4 dB(A)
- > 5 dB(A)



Functional specifications

- existing products with the ability to meet the requirements

Requirements on

- Ravelling, cracking, transversal and longitudinal evenness,
- Braking deceleration, Skidding resistance
- Noise reduction

Overview products

location	requirement	product	C-wegdek
Dronrijp	-4 dB(A)	Microville	-3.7 dB(A)
Haarlem	-4 dB(A)	Redufalt	-3.4 dB(A)
Rilland	-4 dB(A)	Redufalt	-3.4 dB(A)
Oirschot	-4 dB(A)	Decipave	-4.3 dB(A)
Doetinchem	-4 dB(A)	*Bruitville*	*-3,6 dB(A)*
Emmeloord	-5 dB(A)	Dubofalt	-5.0 dB(A)
		Nobelpave	-4.6 dB(A)
		ZSA 0/6 SD	-4.6 dB(A)
		Microflex 0/6	-4.3 dB(A)
		Microtop 0/6	-4.3 dB(A)

Requirement: 85% cars, 115 km/u en 15% trucks, 85 km/h

C-wegdek: 100% cars, 50 km/u

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Measurements

- Braking deceleration
- Skidding resistance
- Permeability (air/water)
- Absorption (alpha-in-situ)
- Noise (CPX/SPB)
- Run-off

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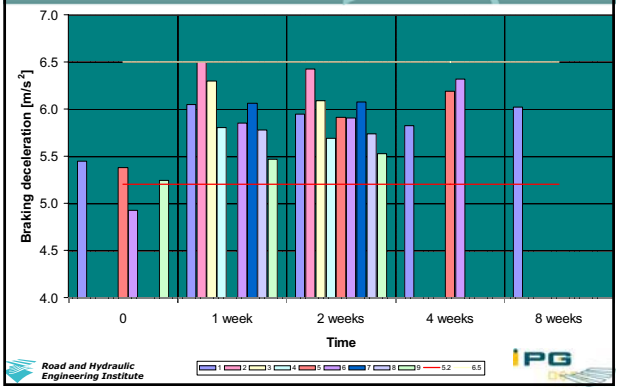
Braking deceleration



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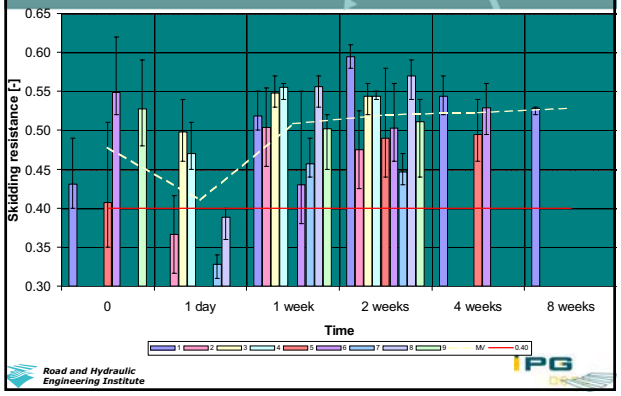
Skidding resistance



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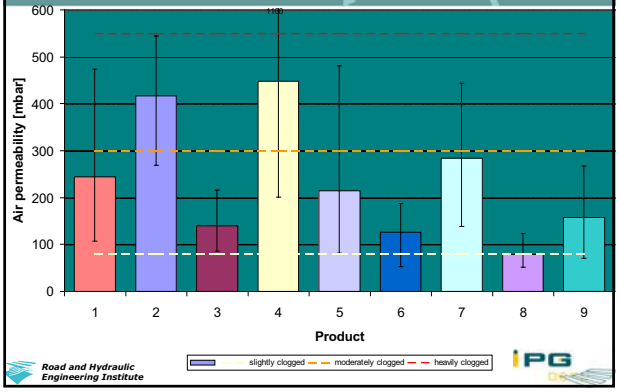
Air permeability



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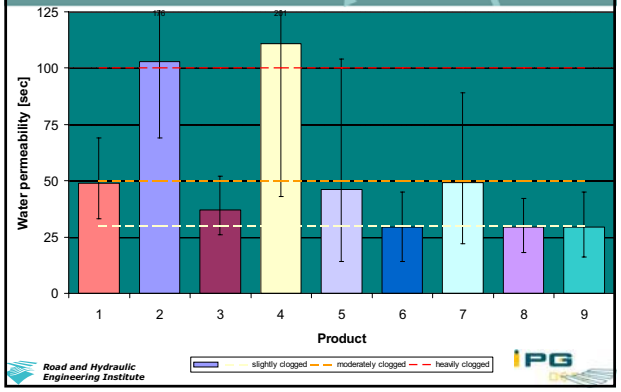
Water permeability



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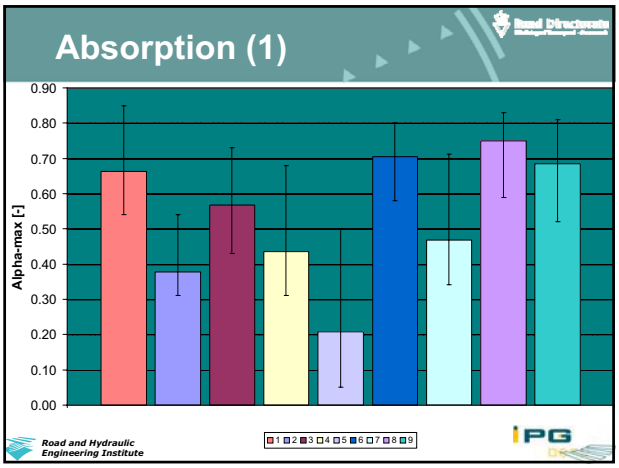
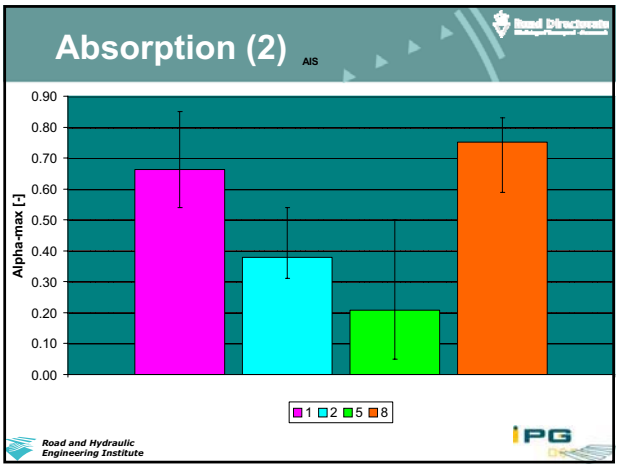
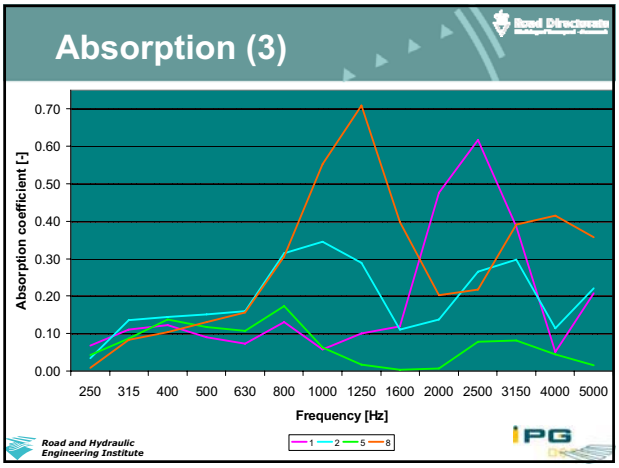
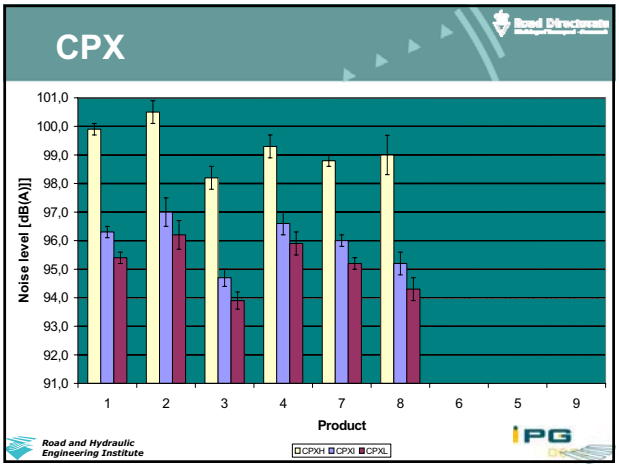

Absorption (1)
Alpha-max [-]
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9
Road and Hydraulic Engineering Institute
IPG


Absorption (2) AIS
Alpha-max [-]
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 5 8
Road and Hydraulic Engineering Institute
IPG


Absorption (3)
Absorption coefficient [-]
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000
Frequency [Hz]
1 2 5 8
Road and Hydraulic Engineering Institute
IPG


CPX
Noise level [dB(A)]]
101,0
100,0
99,0
98,0
97,0
96,0
95,0
94,0
93,0
92,0
91,0
1 2 3 4 7 8 6 5 9
Product
CPXH CPXI CPXL
Road and Hydraulic Engineering Institute
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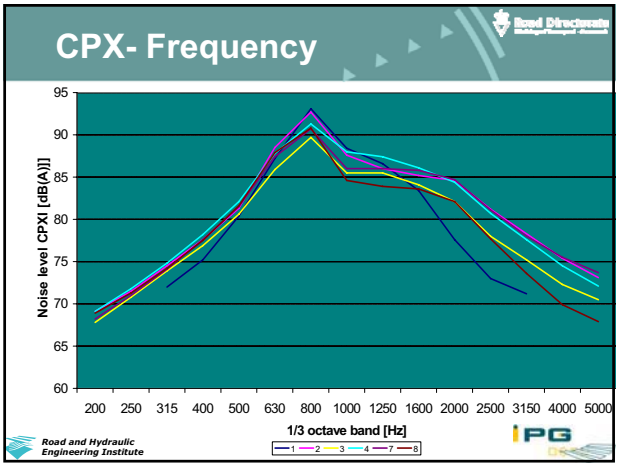
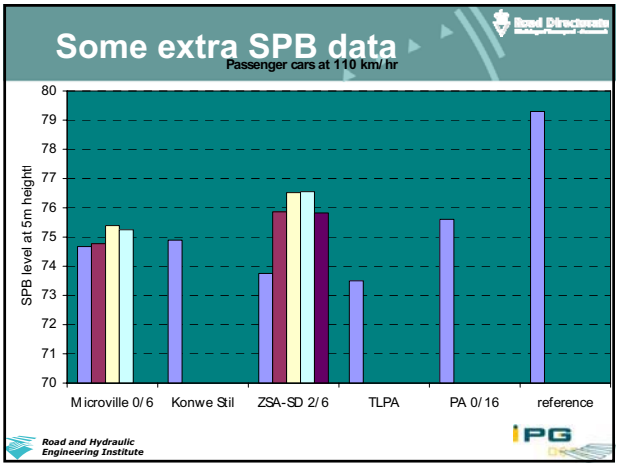

CPX- Frequency
Noise level CPXI [dB(A)]]
95
90
85
80
75
70
65
60
200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000
1/3 octave band [Hz]
1 2 3 4 7 8
Road and Hydraulic Engineering Institute
IPG


Some extra SPB data
Passenger cars at 110 km/ hr
SPB level at 5m height
80
79
78
77
76
75
74
73
72
71
70
Microville 0/6
Konwe Stil
ZSA-SD 2/6
TLPA
PA 0/16
reference
Road and Hydraulic Engineering Institute
IPG

Laboratory research

Ravelling
(Rotating Surface Abrasion Test)

Long term skidding resistance
(Wehner/Schulze)

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Laboratory research

- Adhesion (direct tensile test)
- Distribution air voids (CT-scan)
- Aggregate (petrographical research)
- Asphalt mixture (Grading, bitumen, etc.)

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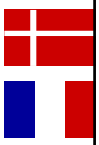
Further investigation

- Data-analyses (measurements/laboratory research)
- Other experiences (other countries and road authorities)
- Splash and Spray
- Run-off
- Evaluation functional specification
- Cost-effectiveness
  - Life time
  - Maintenance strategy



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Overview project

Dutch Pilots

Danish Test sections

Measurements
Laboratory research
Further investigation

Advice note 2007

Measurements
Laboratory research

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Conclusion

YES, NRTLS are an alternative for SLPA as they meet all requirements.

NRTLS are an alternative for SLPA in case…

Advice note 2007

NRTLS are not yet an alternative for SLPA and have to be improved.

NO, NRTLS are no alternative for SLPA because…

Road and Hydraulic Engineering Institute

Assessment of Danish highway test sections
Noise reducing thin layer pavements

Hans Bendtsen
Senior researcher
Road Directorate
Danish Road Institute

DRI-DWW noise abatement program Workshop November 23rd to 24th 2006

Danish test sections on a highway

Pavement types

- Reference DAC11

- Open graded asphalt concrete (DAC8-open)

- 3 Split Mastics Asphalt (SMA)

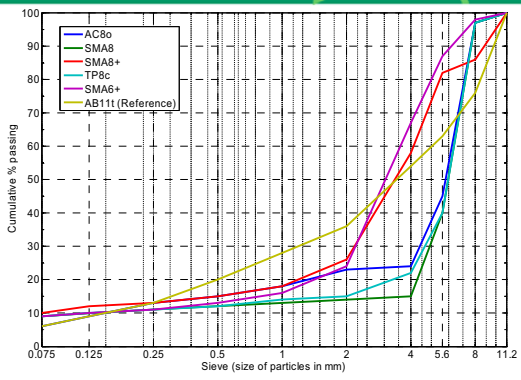
- A thin layer combination pavement (TP8c).

Data on test pavements

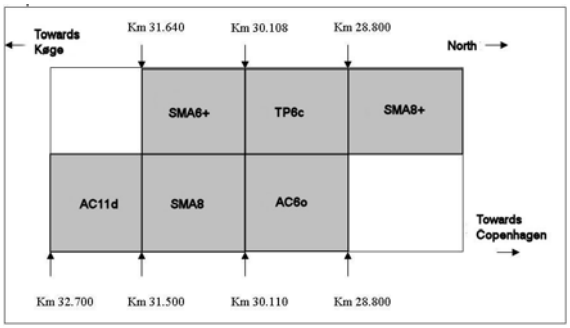
Test section	Max. aggregate size [mm]	Built in air void [%]	Thickness [mm]	Weight [kg/m²]
AC11d (reference)	11	2.8	33	80
SMA8	8	12.4	29	60
DAC8o	8	15.3	28	60
TP8c	8	14.4	22	45
SMA6+	6 + 5/8	3.0	26	60
SMA8+	8 + 8/11	5.7	33	60

SBS modified bitumen

Grain-size curves



Location of test sections



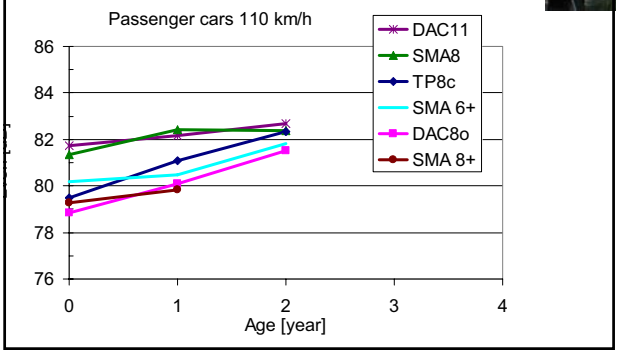
Texture measurements

MPD Year 0	Mean left wheel track	Mean right wheel track
DAC11 (reference)	0.39	0.47
SMA8	0.90	0.96
DAC8o	0.91	0.97
TP8c	0.92	0.87
SMA6+	0.51	0.62

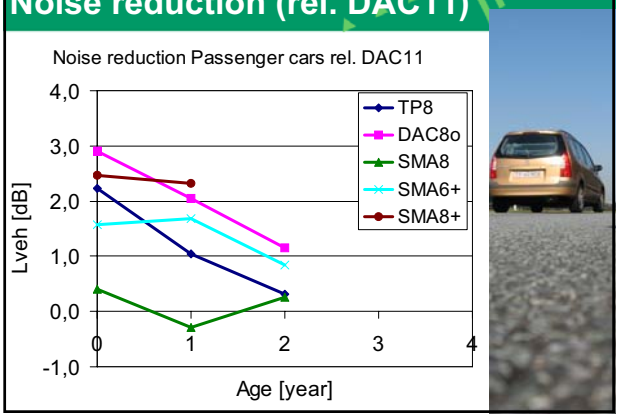
Friction

Year 0	Mean left wheel track	Mean right wheel track
DAC11 (reference)	0.65	0.63
SMA8	0.70	0.72
DAC8o	0.76	0.73
TP8c	0.77	0.74
SMA6+	0.66	0.72

SPB measurements

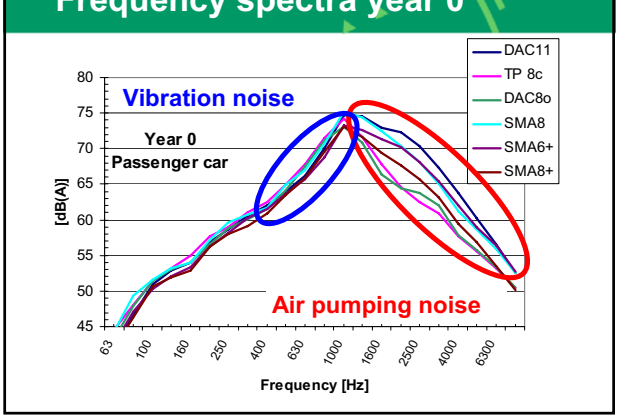


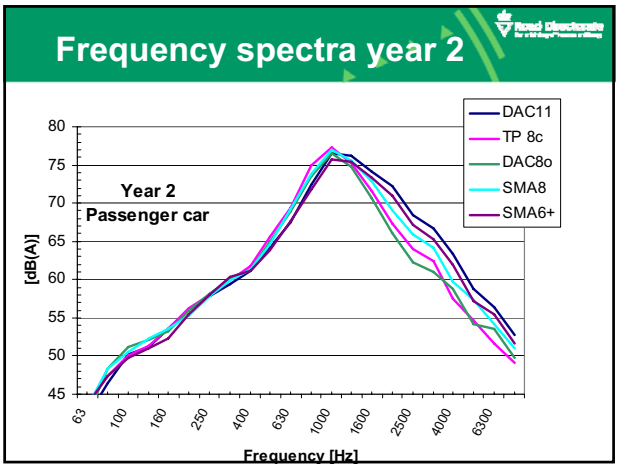
Noise reduction (rel. DAC11)

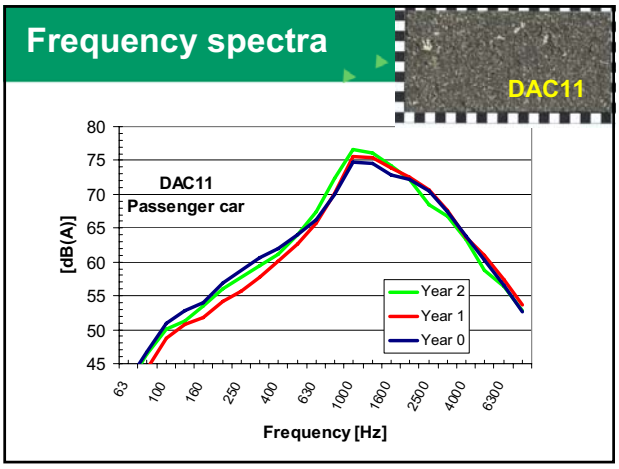


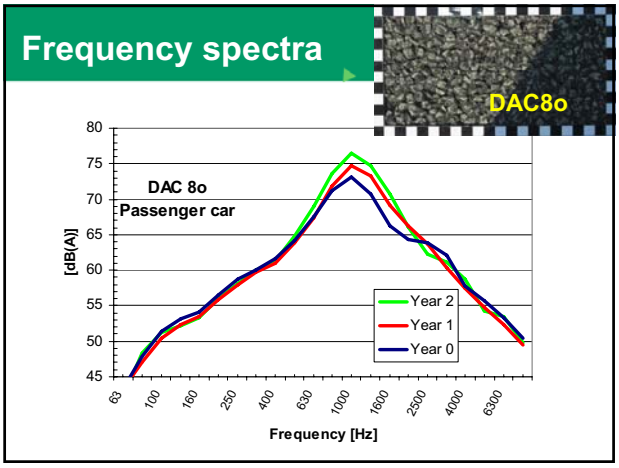
Noise reduction (rel. DAC16)

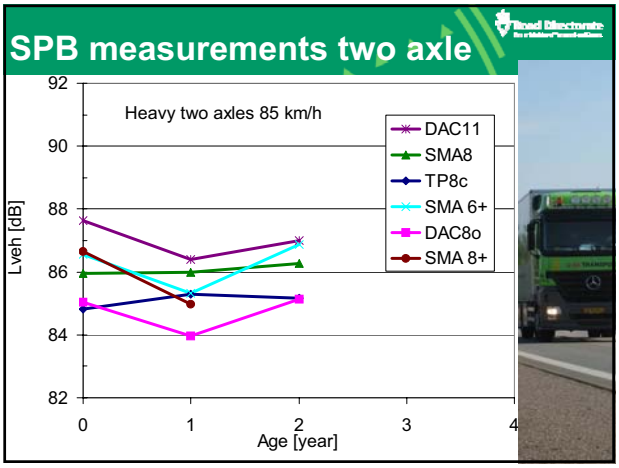
Frequency spectra year 0

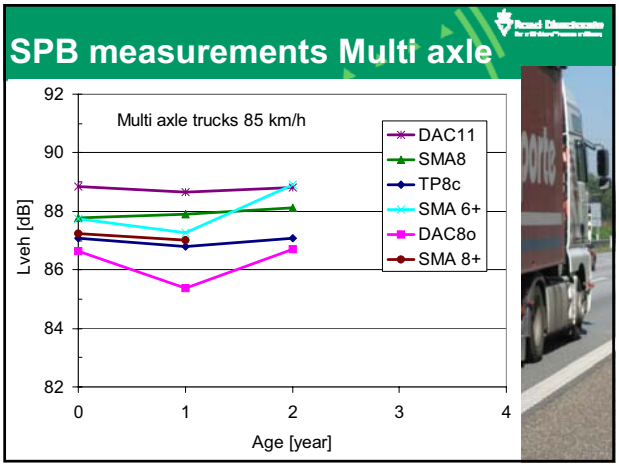


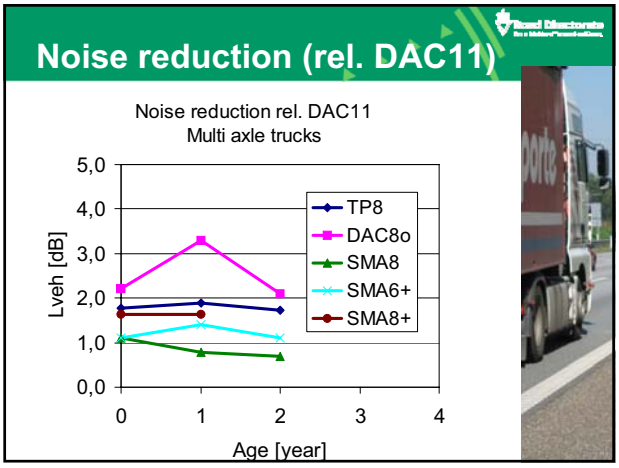

Frequency spectra year 2
DAC11
TP 8c
DAC8o
SMA8
SMA6+
Year 2
Passenger car
[dB(A)]
Frequency [Hz]


Frequency spectra
DAC11
DAC11
Passenger car
[dB(A)]
Year 2
Year 1
Year 0
Frequency [Hz]

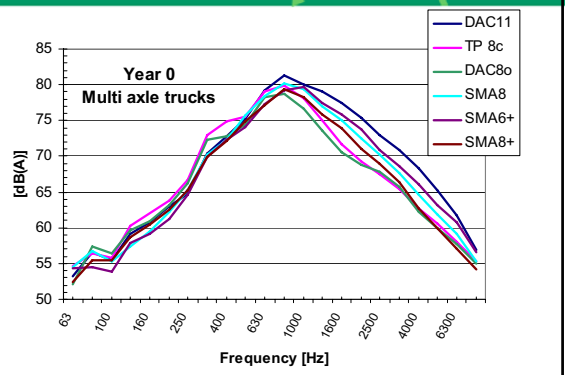

Frequency spectra
DAC8o
DAC 8o
Passenger car
[dB(A)]
Year 2
Year 1
Year 0
Frequency [Hz]


SPB measurements two axle
Heavy two axles 85 km/h
DAC11
SMA8
TP8c
SMA 6+
DAC8o
SMA 8+
Lveh [dB]
Age [year]


SPB measurements Multi axle
Multi axle trucks 85 km/h
DAC11
SMA8
TP8c
SMA 6+
DAC8o
SMA 8+
Lveh [dB]
Age [year]

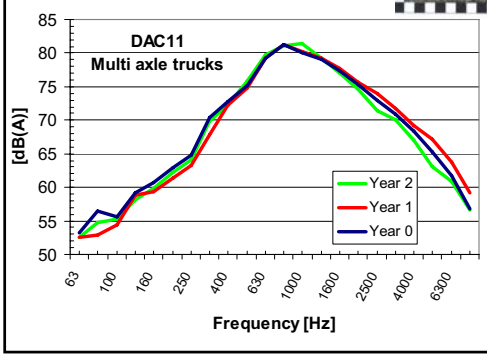

Noise reduction (rel. DAC11)
Noise reduction rel. DAC11
Multi axle trucks
TP8
DAC8o
SMA8
SMA6+
SMA8+
Lveh [dB]
Age [year]

Frequency spectra year 0



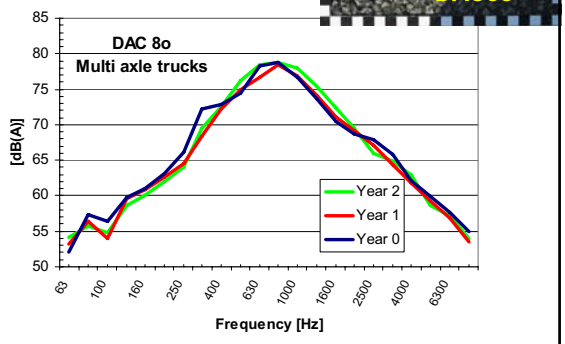
Frequency spectra

DAC11



Frequency spectra

DAC8o



Thin layers for urban roads

Results year 0 and year 2

Noise levels $L_{A,\,max}$ at 60 km/h for passenger cars, rel. to DAC11

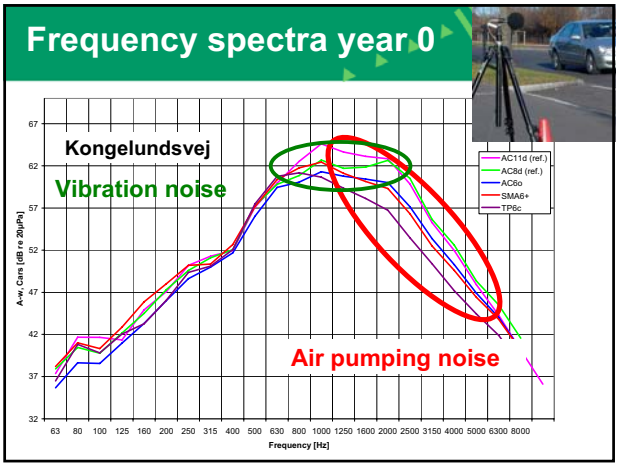
	DAC11d	DAC8d	DAC6o	SMA6+	TP6c
Cars, year 0	72.6	71.6	70.3	70.6	69.5
Noise reduction, year 0	*ref.*	*1.0*	*2.3*	*2.0*	*3.1*
Cars, year 2	72,8	71,5	71,3	70,9	70,1
Noise reduction, year 2	*ref.*	*1,3*	*1,5*	*1,9*	*2,7*
Increase, year 0 – 2	0,2	-0,1	1,0	0,3	0,6

Results year 0 and year 2

Noise levels $L_{A,\,max}$ at 60 km/h for passenger cars, rel. to DAC16

	DAC8d	DAC6o	SMA6+	TP6c
Noise reduction, year 0	2,3	3,6	3,3	4,4
Noise reduction, year 2	2,6	2,8	3,2	4,0

Frequency spectra year 0



New test sections in Denmark

The "Herning experiment"
Constructed August 2006.
Also new sections in the Netherlands

Experiment layout

- Optimized mixes on the background of international experience.
- Maximum aggregate size down to 6 mm
- Increased built in air void.
- 4 pavement families included.

Optimized noise reducing thin layers:

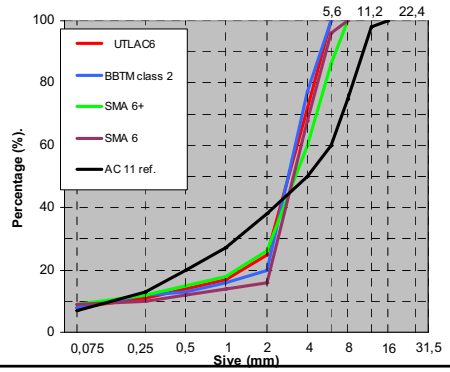
Reference pavement: -DAC 11
-SMA 11

- **SMA concept:**
  - **SMA 6**
  - **SMA 6+**
  - **SMA 8**
- **UTLAC concept (combination pavements, TPc):**
  - **UTLAC 6**
  - **UTLAC 8**
- **Based on French BBTM class 2, very thin asphalt concrete:**
  - **BBTM 6**
  - **BBTM 8-a**
  - **BBTM 8-b**
- **Open graded asphalt concrete with a surface texture optimised for noise reduction:**
  - **AC 6o**
  - **AC 8o**

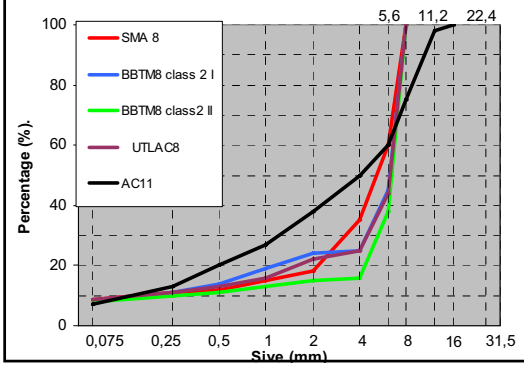
Data on test pavements

Type	Max. Aggregate in mm	Bitumen Content %	Marshall Air voids %	Built in Air voids %
UTLAC6	5.6	6.0	13	
UTLAC8	8	5.8	14	
SMA 6	5.6	8.2	10	12
SMA 6+	8	7.5	8	10
SMA 8	8	7.3	9	11
BBTM6 class 2	5.6	~6.5	16	18
BBTM8 class 2	8	~6.0	18	20

Grain-size curves 6 mm



Grain-size curves 8 mm



Measurement program

- Acoustical performance:
  - SPB
  - CPX
- Structural performance
  - The composition of the material
  - Texture by laser
  - sand patch method
  - RSAT durability by Heijmans, in Holland
- Traffic safety:
  - Friction

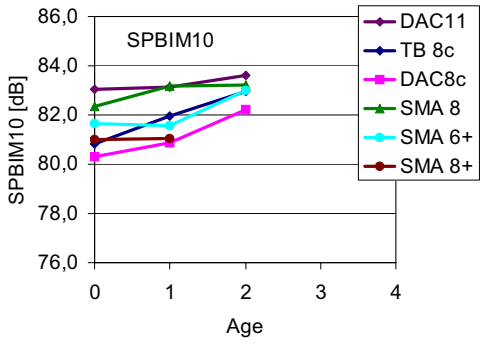
Conclusions

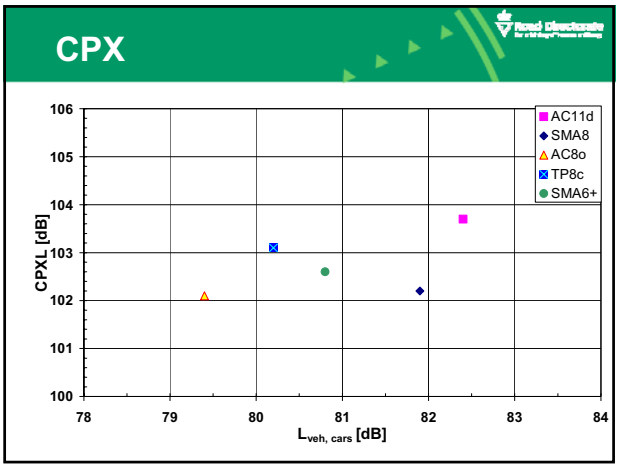
- On highways thin layers offer a 2-3 dB noise reduction rel. to DAC11 and 3-4 dB rel. to DAC16.
- Air pumping noise reduced.
- Also effective for heavy vehicles.
- Reduced effect for cars after two years.
- On urban road effect intact after two years.
- Good friction (traffic safety).
- TPc, DACo and SMA can be optimized for noise reduction.
- Test sections with further noise optimized thin pavements have been constructed, including thi porous layers.
- Measurements are ongoing.

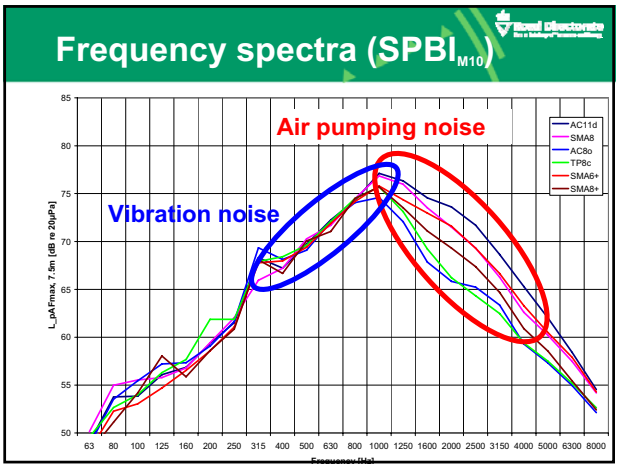
END

Extra

$SPBI_{M10}$




CPX
CPXL [dB]
106
105
104
103
102
101
100
78
79
80
81
82
83
84
$L_{veh, cars}$ [dB]
AC11d
SMA8
AC8o
TP8c
SMA6+


Frequency spectra ($SPBI_{M10}$)
Air pumping noise
Vibration noise
AC11d
SMA8
AC8o
TP8c
SMA6+
SMA8+
63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000 6300 8000

Eksternt notat / Technical notes		
Nr. No.	Titel/Title/Shortcut	Forfatter/Author
24/05	The DRI – DWW Noise Abatement Program - Project description	Hans Bendtsen H.J. Ertman Larsen Bent Andersen Carsten Bredahl Nielsen Jørn Raaberg Vibeke Wegan Bjarne Schmidt Karin Kool Ammitsøe
25/05	Holdbarhed af Drænasfalt – asfaltprøvning	Carsten Bredahl Nielsen
26/05	Thin layer Test Pavements in Denmark -Project description	Hans Bendtsen
27/05	Notes from Forum Acusticum in Budapest 2005	Hans Bendtsen Bent Andersen Lars Ellebjerg Larsen
28/05	French Experiences on Noise Reducing Thin Layers	Hans Bendtsen Jørn Raaberg
29/05	International Experiences with Thin Layer Pavements	Hans Bendtsen Jørn Raaberg Sigurd N. Thomsen
30/05	Traffic noise at two-layer asphalt – Øster Søgade Year no. 6	Jørgen Kragh
31/05	Noise reducing pavements in Japan - study tour report	Hans Bendtsen Carsten Bredahl Nielsen Bent Andersen H.J. Ertman Larsen
32/05	Workshop on Optimization of Noise Reducing Pavements	Hans Bendtsen Helen Hasz-Singh Carsten Bredahl Nielsen
33/05	Friktion og MPD-tal	Bjarne Schmidt Birger Roland Jensen
34/05	Trafikstøjmåling Tesdorpfsvej – September 2005	Sigurd N. Thomsen Bent Andersen Jørgen Kragh
35/06	Test of thin layers on highway - Year 1 measurement report	Sigurd N. Thomsen Hans Bendtsen Jørgen Kragh
36/06	Noise reducing thin layers - Promising concepts	Hans Bendtsen Erik Nielsen
37/06	Seminar on road noise abatement	Hans Bendtsen Carsten Bredahl Nielsen Helen Hasz Singh
38/06	Acoustical characteristics of Danish road surfaces	Jørgen Kragh
39/06	Noise reducing SMA pavements – Mix design for Silence – F2	Erik Nielsen Jørn Raaberg Hans Bendtsen
40/06	Ravelling of porous asphalt - Seletion of road sections	Carsten Bredahl Nielsen
41/06	Durability of porous asphalt - International experience	Carsten Bredahl Nielsen
42/06	Porous pavements with PMB – Selection of road sections	Carsten Bredahl Nielsen
43/06	Notes from INTER-NOISE 2006	Hans Bendtsen
44/06	Acoustic performance - low noise road pavements	Bent Andersen Jørgen Kragh Hans Bendtsen
45/06	Noise reducing pavements – Evaluation workshop	Carsten B. Nielsen Hans Bendtsen

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