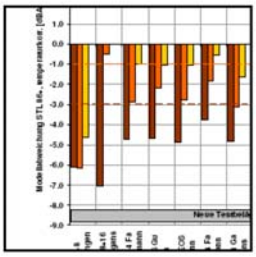
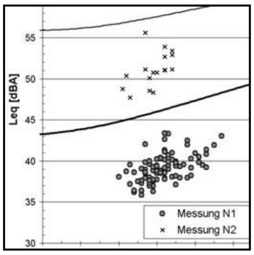
Low-noise road surfaces in urban areas

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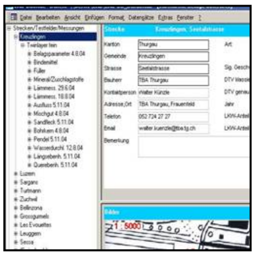
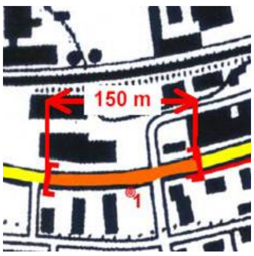



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Authors
Angst Christian, dr ès sc.techn., IMP Bautest AG, Oberbuchsiten
Beltzung Francoise, dr ès sc., IMP Bautest AG, Oberbuchsiten
Bosshardt Dieter, ing. civ. dipl. ETS/SIA/usic, Frey + Gnehm Olten AG, Olten
Grolimund Hans-Jörg, ing. civ. dipl. EPF/SIA/SGA, Grolimund & Partner AG, Berne
Pestalozzi Hansueli, dr ès sc. nat., Grolimund & Partner AG, Bern

Project Commission
Mariotta Carlo, Project Commision Chairman, FoKo Chairman; Jörg Urs, FOEN, Noise Protection Division; Schguanin Gregor, FOEN, Noise Protection Division; Beyeler Hans-Peter, FOEN, Infrastructure Division; Gloor Hanspeter, Construction, Transport and Environment Department. Ct. Aargau, Noise Section; Künzle Walter, TG Civil Engineers; Levental Mario, Cantonal Noise Protection Service, GE; Dagani Mauro, Construction Division, TI; Bosshardt Dieter, Coordination, Frey + Gnehm Olten AG; Schmid Dieter, Coordination Delegate, Neuchâtel

Research group

Coordination:	Acoustics:	Pavements:
Dieter Bosshardt	Hans-Jörg Grolimund	Christian Angst
Frey + Gnehm Olten AG	Grolimund & Partner AG	IMP Bautest AG
Leberngasse 1	Thunstrasse 101a	Hauptstrasse 591
4603 Olten	3006 Berne	4625 Oberbuchsiten
Tel. 062 206 24 24	Tel. 031 356 20 00	Tel. 062 389 98 99

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Translation
Lionel Rey, DES sc. nat. de l'environnement, Grolimund & Partner AG, Aarau

Design
Ursula Nöthiger-Koch, 4813 Uerkheim

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> Abstracts

Over a three-year period, the tyre/road noise and the pavement texture were periodically measured on a series of 21 full-scale sites situated in urban areas with a speed limit of 50 km/h. The study involved a wide range of noise-reducing asphalt mixtures, including semi-dense macro rough asphalt AC MR and porous asphalt PA. It has been shown that the acoustic performance decreases asymptotically as a function of traffic volume. For PA the decrease can be delayed provided the pores do not become clogged by dirt. According to the current results, AC MR shows promising acoustic and structural performance. AC MR test stretches may achieve acoustic lifetimes of up to 10 years depending on the traffic volume.

Keywords:
Low-noise road pavements
Acoustic lifetime
Pavement texture
Long-term performance
Urban areas
Low speed

Während dreier Jahre wurden auf 21 Teststrecken innerorts mit maximal zugelassener Geschwindigkeit von 50 km/h das Rollgeräusch und die Textur der Strassenoberfläche periodisch gemessen. Dabei wurden vor allem semidichte (z. B. Rauasphalt AC MR) und offenporige PA-Beläge untersucht. Es wurde aufgezeigt, dass die akustische Leistung asymptotisch in Abhängigkeit der Verkehrsbelastung abnimmt. Beim PA verzögert sich diese Abnahme, solange die Poren nicht verstopft sind. Aufgrund der aktuellen Ergebnisse erweisen sich feinkörnige AC MR als vielversprechend, sowohl in akustischer als auch in bautechnischer Hinsicht. Bei den AC-MR-Teststrecken wird, je nach Verkehrsbelastung, eine akustische Dauerhaftigkeit von bis zu 10 Jahren erwartet.

Stichwörter:
Lärmarme Strassenoberflächen
Akustische Dauerhaftigkeit
Belagstextur
Langzeitverhalten
innerorts
Niedrige Geschwindigkeiten

Un suivi du bruit de contact pneumatique/chaussée et de la texture de surface a été réalisé pendant trois ans sur une série de 21 planches d'essai situées en zone urbaine, où la limitation de vitesse est fixée à 50 km/h. L'étude a porté sur une large gamme de revêtements peu bruyants, notamment des enrobés macrorugueux AC MR à teneur en vides élevée et des enrobés poreux PA. Les résultats montrent que les performances acoustiques diminuent asymptotiquement en fonction du volume de trafic. Dans le cas du PA, la diminution n'est amorcée qu'une fois les pores colmatés. Les performances acoustiques et structurelles des AC MR s'avèrent prometteuses. Ainsi, certaines planches d'essai AC MR pourraient atteindre une durabilité acoustique estimée à 10 ans.

Mots-clés:
Revêtements peu bruyants
Durabilité acoustique
Texture de surface
Performance à long terme
Zone urbaine
Vitesse réduite

Durante tre anni, per 21 tratti pilota in zona urbana a bassa velocità, limitata a 50 km/h, sono state effettuate misurazioni periodiche delle caratteristiche della pavimentazione e dei relativi valori acustici. Sono state esaminate una vasta gamma di pavimentazioni fonoassorbenti, principalmente di tipo macrorugoso AC MR con elevata percentuale di vuoti residui e di tipo poroso PA. I risultati indicano una diminuzione tendente all'asintote dell'efficacia fonica in funzione del volume di traffico. Per il tipo PA tale effetto inizia dal momento in cui i vuoti residui si sono colmati. Le prestazioni acustiche e strutturali delle pavimentazioni tipo AC MR sono promettenti. Alcuni tratti pilota AC MR potrebbero raggiungere un effetto fonoassorbente della durata fino a 10 anni.

Parole chiave:
Pavimentazioni stradali fonoassorbenti
Risanamento fonico durevole
Caratteristiche delle pavimentazioni
Efficacia nel lungo periodo
Zona urbana
Bassa velocità

> Foreword

The Environmental Protection Act defines limiting noise emissions at source as a basic principle. It was recognised at a very early stage that the quality of the road pavement has a considerable effect on the level of noise emissions due to road traffic. Laying a low-noise road pavement may represent a measure which is both effective and economical for reducing road noise. Indeed, it has no negative impact on the landscape or on constructed sites, or on road safety.

These pavements are of particular interest for areas with a high population density, which continue to have the greatest shortcomings in terms of noise abatement. Moreover, these are often the only measures which can be taken on roads in urban areas.

As early as the 1990s, the FEDRO and the Federal Office for the Environment, Forests and Landscape (now the FOEN) therefore awarded an initial joint research mandate, the purpose of which was to compile the technical and acoustic foundations concerning low-noise pavements. Although clear data had in the meantime been defined for the use of these pavements to improve high-speed roads, there was still a lack of well-founded information on their use in urban areas.

In 2003, the two Offices therefore initiated a second project, with a view to developing long-term low-noise pavements for urban areas, which would be economically feasible. This work was to take into account recent research at the international level.

The highly promising results of these four years of research are compiled in the present final report. It includes concrete and relevant recommendations on the choice of specific types of materials and on laying them. Road owners who follow these recommendations make a marked contribution to noise reduction in urban areas.

We would like to express our thanks to all those cantons which provided us with sections or roads for the tests carried out as part of this research project.

Further development of low-noise pavements is taking place throughout Europe. In Switzerland, the two Offices wish to encourage the large-scale use of this type of pavement. They intend to proceed with a research and awareness-raising programme, incorporating all interested parties, in order to extend knowledge of the long-term performance of these road pavements.

Dr. Bruno Oberle
Director
Federal Office for the Environment (FOEN)

Dr. Rudolf Dieterle
Director
Federal Roads Office (FEDRO)

> Summary

Mandate

The purpose of the research mandate initiated jointly by the Federal Roads Office (FEDRO) and the Office for the Environment, Forests and Landscape (now the FOEN) is a study of the various significant parameters for low-noise urban road pavements, on both existing and new road sections. It is expected to provide enhanced knowledge of pavements which are simultaneously durable, economically acceptable and low-noise in urban use. The formulation of initial recommendations is intended to promote their use.

Long-term low-noise

The subject of the joint research project initiated in 2003 by FEDRO and the FOEN is to draw up proposals for long-term low-noise urban road pavements. These are intended to provide road owners with an efficient, economical method of noise abatement.

Procedure

Twelve new low-noise test pavements were evaluated and laid on ordinary urban road sections with a maximum 50 km/h speed limit. In addition, a further 9 existing low-noise pavements with good results from experience were included in the test programme. The surfaces were monitored using measurement technology for 3 years; the results were recorded in a database and the key acoustic and technical values were correlated.

Measurement results

High initial noise reductions of –3 to –6 dBA, compared with average asphalt pavements, were achieved with all the newly-laid test pavements. Over the 3 years observed to date, a reduction in acoustic performance of 1 to 3 dBA was noted. The main causes of this are changes to the surface structure, due primarily to mechanical and thermal loading, and contamination. A marked reduction in acoustic performance as a function of traffic volume was recorded.

Recommendations

- On the basis of the current results, fine-grain AC MR mixtures are proving to be very promising, in both acoustic and structural/technical respects. Laying of thin-layer AC MR4 or AC MR8 pavements with a high voids content is recommended, on a stable binder layer. This creates good conditions for high initial noise reduction and for simple, economical replacement of the thin-layer pavements as soon as their acoustic performance no longer meets the requirements.
- PA surfaces impose considerable challenges when they are laid; they are more expensive than dense/semi-dense pavements, are sensitive to mechanical loading and require special maintenance. PA pavements may be considered in individual cases. However, they are currently not recommended for widespread use in urban environments.

Comparative calculations of the proposed AC MR pavements with conventional pavements indicate that they are practically always cost-efficient in urban and semi-urban areas. The total costs for remaining noise abatement work on existing main roads and other roads can be drastically reduced by using these surfaces. In addition, they generate a potential economic benefit running into billions of Swiss francs.

Cost-effectiveness

The goals formulated at the beginning of the research mandate have been achieved. The acoustic performance of the experimental pavements in the next few years will require confirmation. Continuation of the acoustic measurements should make it possible to gather the necessary information.

Achievement of the project goals

1 > Introduction

1.1 The problem

Legal basis
Road noise manual

The technical possibilities of low-noise pavements are well known on high-speed roads (motorways). In principle, corresponding solutions are also available for urban roads. However, to date they have been employed only to a very limited extent.

Yet it is precisely in urban areas that the use of low-noise pavements is of great importance. Here, structural measures such as noise-abatement walls or embankments are feasible only in exceptional cases, due to limited space or the need to guarantee access. In many cases, topographical reasons militate against such measures, and operational measures such as restrictions on speed or traffic are generally impossible to implement on urban roads with heavy traffic because of more important criteria.

Long-term low-noise
Goals

Long-term acoustic performance represents the main problem with low-noise urban road pavements. Measurements indicate that it is perfectly possible to achieve an initial acoustic improvement of 3 dBA or more compared with the reference bituminous pavement. This corresponds to at least a halving of the subjectively perceived traffic volume. However, these coated materials lose their good acoustic properties after a few years. This is mainly due to transformation of the surface structure as a result of mechanical and thermal loads and contamination.

1.2 Purpose and research goals

Research goals

The main goal of the joint research project initiated in 2003 by FEDRO and the FOEN was to examine the different variables of low-noise urban road pavements on test stretches and derive reliable findings for long-term low-noise urban road pavements. This is an essential prerequisite for road owners to consider widespread future use of these pavements as a noise abatement measure.

Organisation

The work was performed by a research team consisting of the three partners: Frey & Gnehm AG (Coordination), Grolimund & Partner AG (Acoustics) and IMP Bautest AG (Pavements). Project management was provided by a Project Commission which was composed of representatives of the two above-mentioned Federal Offices and pavement and/or acoustics specialists from several cantons.

1.3 Reporting

Reports

The test results were summarised in reports on a continuous basis. The following documents are available for downloading at *www.umwelt-schweiz.ch/div:*

> Status report 2003: summary of an extensive literature search, drawn up as a basis for the evaluation of the test pavements [1]
> Annual reports 2004, 2005 and 2006: summary of the annual test results [2]
> Final report 2007: Main report with full documentation of the tests carried out and their results [3]

2 > Working basis and procedure

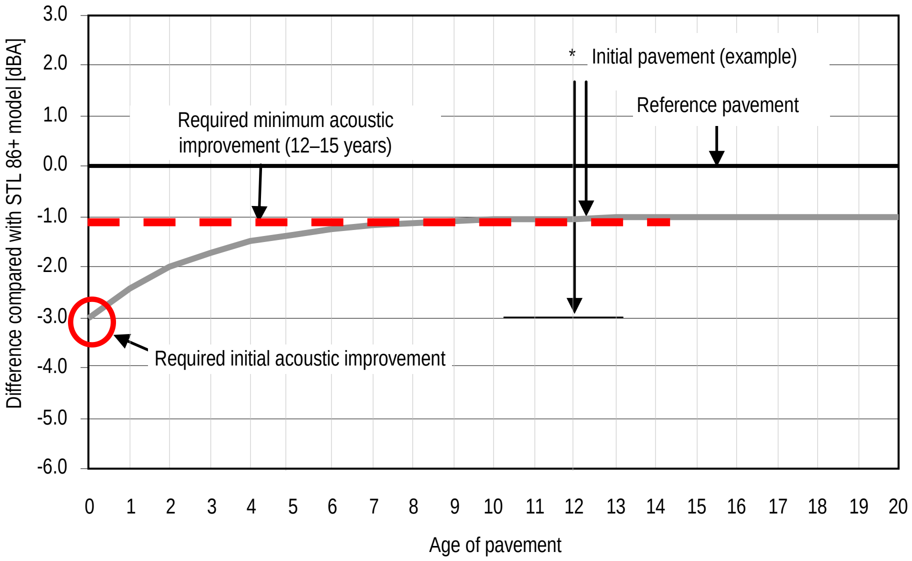
2.1 Definition of long-term low-noise urban pavements

Definition of long-term low-noise

For the research project, urban pavements are defined as low-noise if they achieve an initial noise reduction of at least –3 dBA, for mixed traffic, compared with the reference pavement of the Swiss standard noise calculation model STL 86+, and if they retain a noise reduction of at least –1 dBA over their working lifetime.

Fig. 1 > Definition of long-term low-noise urban pavements

A pavement is defined as long-term low-noise if the initial acoustic improvement is equal to –3 dBA and if the reduction is maintained at –1 dBA for at least the 12–15 years of its useful life.



Source: Summary Report 2003, FOEFL/FEDRO 2004

2.2 Test sections

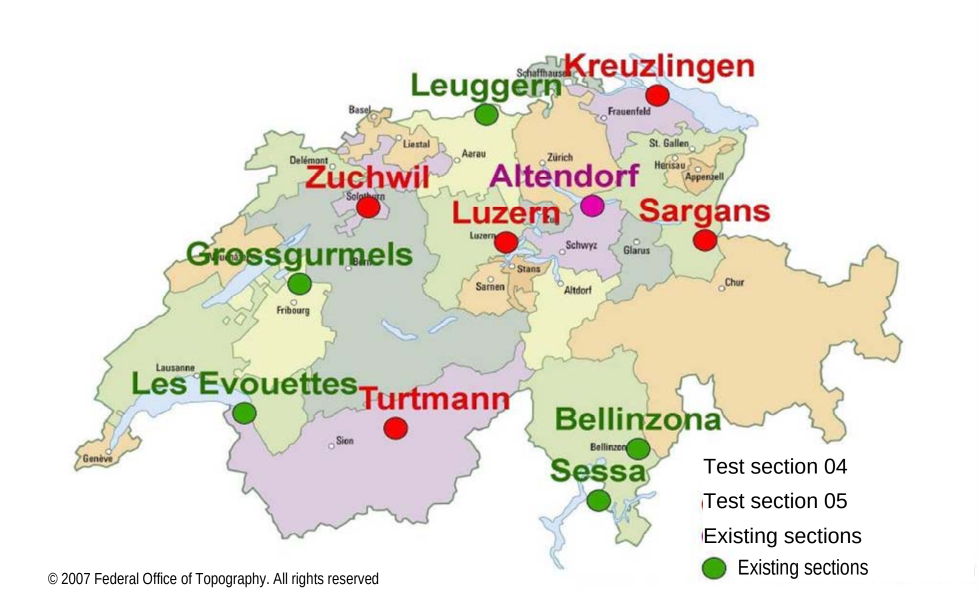
Selection of test sections

All cantons were invited, by way of a questionnaire, to notify suitable sections for the laying of test pavements. A noise abatement programme had to exist for the test sections in accordance with the EPA/NPO. The geographical location of the selected test sections is shown below (fig. 2).

Distribution of sections in Switzerland

Fig. 2 > Geographical distribution of sections

Distribution of sections with low-noise pavements, new and existing



2.3 Test pavements

Status report

The currently available knowledge on low-noise urban road pavements was first compiled and analysed, using a search of the literature and a questionnaire addressed to the cantons. The results are summarised in a status report [1]. On this basis, 12 different pavement types were defined and laid on the selected test sections. The selected pavement types vary within the applicable standards or within the framework of many years of experience.

New test pavements

For the new test pavements, different types of pavement were selected, with different particle sizes (0/4 mm and 0/8 mm) and aggregates; some with added rubber particles. In addition, one pavement with an epoxy resin coating and a dispersed chrome ore slag 1/3 mm was laid (table 1).

Existing test pavements

In addition to the new test pavements, 9 other existing low-noise test pavements were included in the test programme on the basis of satisfactory experience with them and at the suggestion of the cantons.

Tab. 1 > New test pavements

Test sections	New test pavements	Layer thickness [mm]	Origin of aggregate
Kreuzlingen TG	PA 4 / PA 8 Twinlayer	12+33	Walliswil
Sargans SG	PA 8 / PA 16 Twinlayer	25+55	Hagerbach
Turtmann VS	SPA 4	15	Famsa
	AC MR 4 EOS rubber particles	15	Stahl Gerlafingen
	AC MR 4 EOS	15	Stahl Gerlafingen
	AC MR 4	13	Famsa
Sargans SG	AC MR 4	12	Gasperini
	AC MR 8 EOS rubber particles	25	Stahl Gerlafingen
Zuchwil SO	AC MR 8 EOS	28	Stahl Gerlafingen
Luzern LU	Whisper-Grip®	3…4	Chrome ore slag
Altendorf SZ	SPA 8 layer thickness 15 mm	18	Gasperini
	SPA 8 layer thickness 20 mm	24	Gasperini

Tab. 2 > Existing sections and pavements

Sections	Pavements	Layer thickness	Origin of aggregate
Leuggern AG	PA 8	31	
	SPA 8	32	
	MA 8 with dispersed 2/4	48	
	MA 8 with dispersed 3/6	48	
Sargans SG	AC 11		
Sessa TI	AC 11 Leca		Gasperini
Bellinzona TI	AC 11 Leca	34	Gasperini
Les Evouettes VS	Colsoft 8®		
Grossgurmels FR	Wecophone 6®	32	Famsa

2.4 Measurement and investigation programme

Measurements performed

Measurements of technical and acoustic performance of the pavement were performed on all test surfaces each year. The collected data were managed in a database. The initial measurements taken in 2004 and the periodic repeat measurements from 2005 to 2007 are summarised below (table 3).

The mean profile depth (MPD), texture spectra and form factor were derived from the laser texture measurements.

The acoustic pavement performance measurements were performed using the statistical pass-by method SPB, ISO 11819-1 and FEDRO's "Technical Notice for acoustic pavement performance measurements on roads" [4].

Programme

Tab. 3 > Measurement programme 2004–2007

Year	Measurements/analyses	Period
Initial measurements 2004	Technical examinations of pavements • Core analyses • Transversal and longitudinal evenness • Anti-skid performance (PTV method) • Flow time (Moore's method) • Texture depth (sand stain method) • Laser texture measurement • Laser roughness measurements • Permeability of draining pavements	October 2004 (Altendorf 2005)
	Acoustic • Measurements of acoustic properties of experimental pavements (SPB measurements)	
Periodic measurements 2005 to 2007	Technical examinations of pavements • Laser texture measurement • Laser roughness measurements	Autumn 2005, 2006 and 2007
	Acoustic • Measurements of acoustic properties of experimental pavements (SPB measurements)	

The following additional tests of individual parameters complete the measurement programme:

> effect on acoustic performance of high-pressure pavement cleaning with a special cleaning vehicle
> verification of assumptions for temperature correction of the measurements of acoustic performance of pavements
> Texture and noise changes in the first 6 months of operation with regard to the periodic scheduling of acoustic acceptance measurements.

3 > Results

3.1 Technical pavement-related aspects

Materials used

The use of special construction materials (rubber particles, electric furnace slag and special aggregate particle sizes) did not constitute a problem, assuming appropriate planning. The preparation of very fine-grained surfaces with gap grading such as ACMR 0/4 or even PA 0/4 is difficult but feasible. Stringent requirements must be imposed on the regularity of the grain size distribution of the 2/4 aggregate.

Laying

The surface structure of the pavements may be considerably affected by the type of roller, its weight and vibration. An investigation of these factors was not the subject of the present research project, but is recommended.

Twinlayer pavements

Laying twinlayer porous pavements is very demanding and sensitive to weather conditions. In view of the thin layers, there is a risk that the lower PA layer will be excessively compacted.

3.2 Acoustic pavement performance

Acoustic pavement performance with mixed traffic

The acoustic performance of the test pavements is shown below for mixed traffic, assuming an 8 % percent proportion of HGVs and is compared with the definition of low-noise pavements.

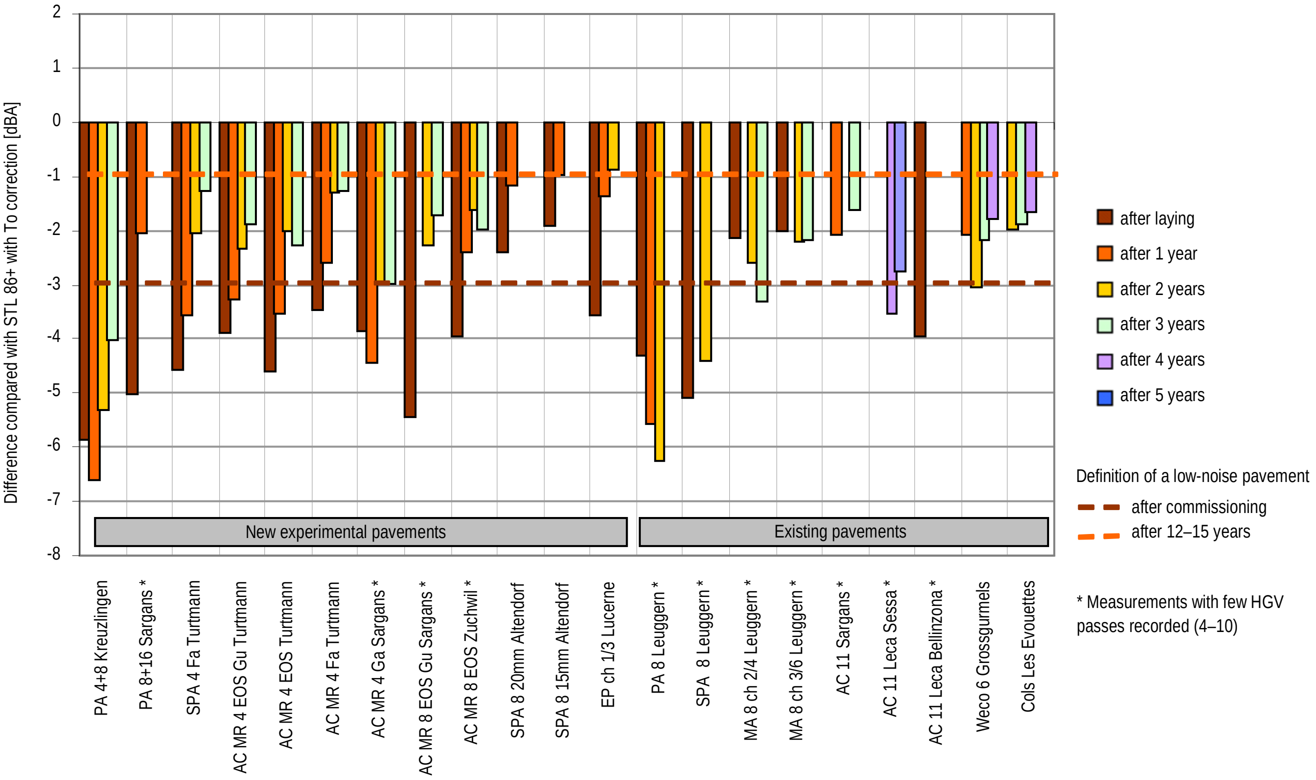
After 2 years, the new test surfaces in Altendorf and Lucerne no longer met the requirements for low-noise pavements and were subsequently omitted from the 2007 measurement campaign.

Initial acoustic improvement

In the case of the new test pavements, an initial noise reduction of –3dBA was achieved or significantly exceeded. The two SPA 8 pavements in Altendorf, which have a high roughness, are an exception.

Fig. 3 > Acoustic performance of pavements under mixed traffic conditions

Results of the 2004-2007 measurement campaigns. The values represent the difference compared with the STL-86+ model, which is based on an average reference pavement which is neutral in acoustic terms. The differences were calculated for mixed traffic with 8 % HGV traffic. The results of measurements with less than 4 HGV passes are not shown.



Acoustic lifetime

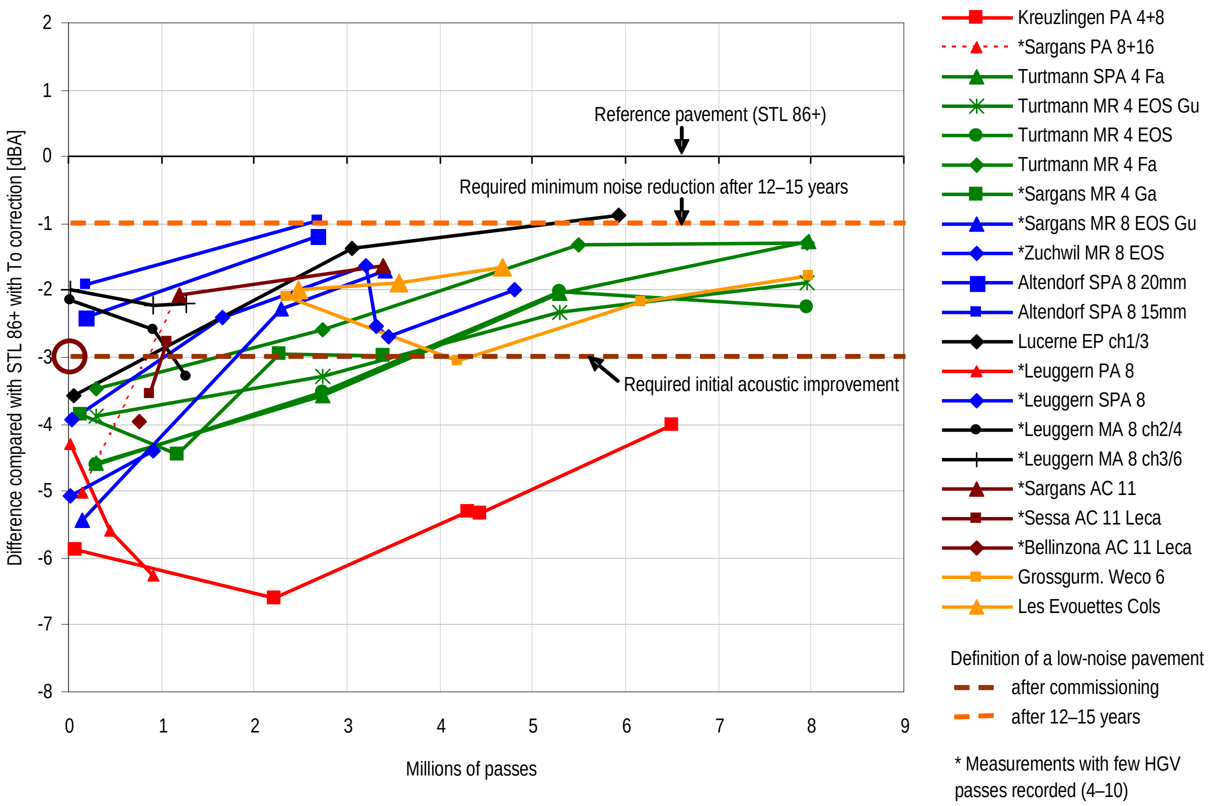
Acoustic performance decreased in a more or less marked fashion for all the new experimental pavements and most of the existing pavements. In the first 3 years, the decrease in performance was between 1 and 3 dBA, though this became less pronounced in the third year. Of the newly laid, semi-dense pavements, the AC MR 4 pavement in Sargans exhibited the best acoustic performance after 3 years.

The initially very good acoustic performance of the twinlayer in Kreuzlingen decreased significantly in the last two years. At the same time it was found that the pores were largely clogged; this could not be remedied, even using intensive pressure/vacuum cleaning with a special vehicle.

The acoustic performance of pavements subjected to low traffic volumes decreased less rapidly than those subject to higher traffic volumes. Traffic volumes are therefore an important factor in relation to acoustic lifetime of pavements.

Fig. 4 > Acoustic perfomance of pavements as a function of the cumulative traffic load with mixed (8 % HGV) traffic

The number of vehicle passes since commissioning was calculated on the basis of average daily traffic.
Red: porous pavements. Green: grain size 4 pavements. Blue: grain size 8 pavements. Brown: grain size 11 pavements.
Black: gravels. Orange: special pavements.



3.3 ## Relationship between pavement properties and noise

Texture depth

A relationship between texture depth (in this case the MPD value) and acoustic properties was established for the AC MR and SPA (fig. 18) pavements. A reduction in the mean texture depth directly causes an increase in noise emissions.

The reduction in texture depth may be due to either contamination or an irreversible, load-related change in the surface texture. It is to be assumed that the latter is caused by traffic loads at high temperatures.

Particle size

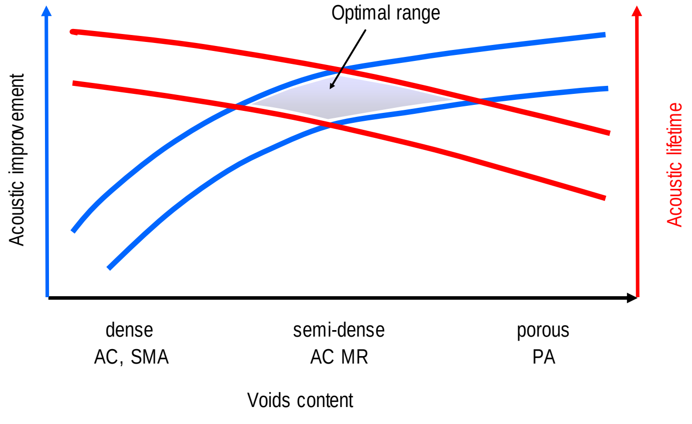
The test pavements with a maximum particle size of 4 mm exhibit better acoustic properties than pavements with a larger maximum particle size.

Voids content

Positive experiences were achieved on test sections with materials with an 8 to 16 % voids content. These types of pavement are known as "semi-dense". When the material is chosen, a compromise must be found between optimal acoustic properties (a high voids content) and long service life (low voids content). These opposing tendencies are shown diagrammatically in figure 5. The target voids content must be in the "optimal range".

Fig. 5 > Voids content, noise reduction and working lifetime of a pavement

Diagrammatic representation of the possible effect of the voids content on noise reduction (blue curve) and lifetime (red curve) of a bituminous surface. The intersection of the two curves indicates the optimal voids content range. The noise reduction curve is based on the project results (fig. 16); the lifetime curve is based on empirical Dutch values [18].



4 > Conclusions

4.1 Porous pavements in urban areas

Requirements and high risks

As expected, the PA pavements studied are superior to dense pavements in acoustic terms even in urban areas. However, they do impose stringent requirements. Laying PA pavements is very demanding and they are more expensive than dense or semi-dense pavements. In addition, they are highly sensitive to shear stresses (snow chains, intersections, exits and entrances, roundabouts), and this makes their acoustic lifetime more uncertain (loss of grains). Moreover, they require special maintenance (winter service, cleaning).

PA pavements may be laid in special situations, for example on by-passes with regular, continuous traffic, or on sections with especially stringent acoustic protection requirements. The generalised used of PA pavements in urban areas is not currently recommended. The technical lifetime of this type of construction remains to be optimised.

4.2 Dense/semi-dense pavements in urban areas

Recommended pavements

From the tests carried out to date, the following recommendations can be made for the selection of the type mixtures:

A proven solution, without risks and with good acoustic performance:

> *Standardised material:*
> *AC MR 4 or AC MR 8 according to standard SN 640 431-1b-NA*
> *(valid from 01.02.2008) with a voids content of 6 to 10 % by volume*

A promising solution, potentially with excellent acoustic performance:

> *Non-standardised material:*
> *AC MR 4 or AC MR 8 with a higher voids content of 10 to 13 % by volume.*

Binding layer

Thin-layer pavements require a stable, smooth substrate. This can be guaranteed by using an appropriate pre-laid binding layer. This also meets the requirements for trouble-free periodic replacement of the thin-layer pavement.

Laying

Consistent use of thermosilos for trucks is recommended. Compaction must take place immediately behind the production unit, using smooth, non-vibrating rollers. Since the voids content may exceed 10 % by volume, procedure D according to SN 670406 is recommended for determining the bulk density.

Comparison of mixtures

The table below provides a direct comparison of the two mixtures AC MR 4 and AC MR 8.

Tab. 4 > Bituminous mixtures AC MR 4 and AC MR 8

Evaluation of properties

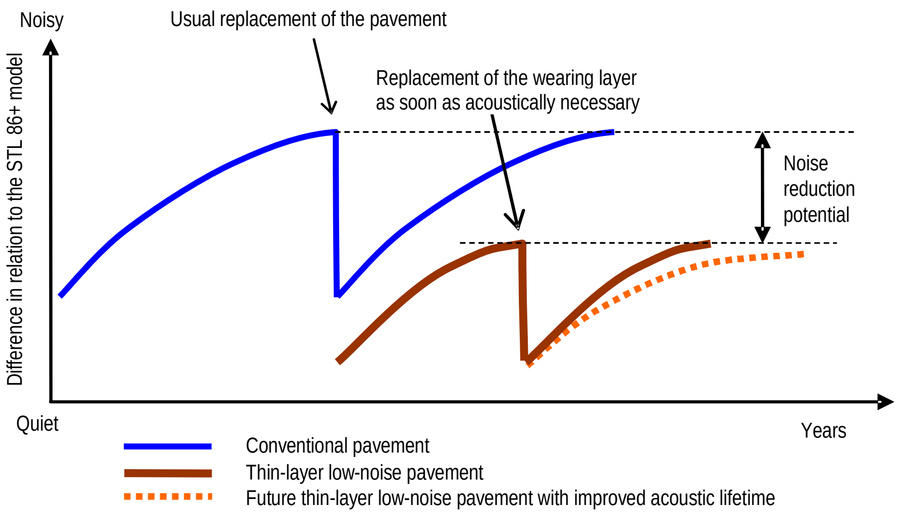
	AC MR 4	AC MR 8
Acoustic performance	Very good	Good
Preparation	Stringent requirements concerning regularity of the 2/4 particle size	Standard mixture
Mixture preparation test	Essential	Recommended Essential for AC MR with a high voids content
Laying test	Essential	Recommended Essential for AC MR with a high voids content
Requirements relating to the base layer	Stringent requirements concerning the evenness of the base layer: to achieve this goal, it is advisable to lay a binder layer (e.g. ACB 16 S; 55 mm).	Less stringent
Layer thickness	15 to 20 mm	20 to 30 mm
Acoustic lifetime	The 3-year observation period was insufficient to answer this question with certainty.	
Mechanical lifetime	Good	Good
Anti-skid performance, road safety	At low speeds, fine-grained pavements are more efficient than coarse-grained ones.	

Long-term performance

The recommended pavements achieve good to very good initial acoustic performance. The 3-year observation period, however, does not allow any conclusive statements to be made regarding their long-term acoustic performance. The pavement design with a binder layer and a thin-layer surface, however, allows simple, economical replacement of the thin-layer surfaces as soon as their acoustic performance no longer meets the requirements. The time for possible necessary replacement of the wearing layer is determined by acoustic monitoring, which is obligatory with the use of low-noise pavements as a remediation measure according to the FOEN/FEDRO guidelines.

Fig. 6 > Maintenance strategy for thin-layer low-noise pavements

The periodic replacement of thin-layer low-noise pavements takes place according to the results of acoustic monitoring in accordance with the FOEN/FEDRO road noise manual (2006). In this way, a considerable reduction of noise in the long term is achieved. The acoustic lifetime of thin-layer low-noise pavements will be further improved by future research.



4.3

Cost-effectiveness

Low-noise pavements reduce the costs of noise protection

Low-noise pavements increase road costs but reduce the need for other remedial measures. Consequently, the cost-effectiveness of a low-noise pavement must be examined in relation to the total costs of remediation.

A life-cycle cost analysis of the proposed low-noise AC MR 4 pavement (including a 60 mm binding layer) with a conventional AC MR 8 pavement and complementary sound protection measures (walls, soundproof windows) shows that the potential savings in noise remediation costs in urban areas are very high, at up to 35 %. Low-noise pavements are almost always cost-effective even in semi-urban areas.

Economic benefit

Low-noise pavements, however, not only reduce the costs of structural remediation measures but also generate economic benefits. Estimates indicate that on sections of main and other roads which have yet to be remediated the maximum possible economic benefit of low-noise pavements is over one billion Swiss francs. The economic advantages therefore clearly outweigh the total costs of all structural noise protection measures on these sections of roads requiring remediation.

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Abbreviations

AC MR
Asphalt concrete, macro-rough

AC
Asphalt concrete

dBA
Decible with A weighting

EOS
Electric furnace slag

EPA
Environmental Protection Act

Gu
Rubber particle composite pavement

NPO
Noise Protection Ordinance

MA
Mastic asphalt

MPD
Mean profile depth

PA
Porous asphalt

SPA
Aggregate asphalt

STL86+
Noise calculation model applicable in Switzerland

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