LOW-NOISE PAVEMENTS AS AN EFFECTIVE NOISE ABATEMENT MEASURE IN URBAN AREAS – A "NEW" TECHNOLOGY BECOMES A PROVEN STANDARD

Erik Bühlmann
Grolimund +Partner AG – Environmental engineering, Bern, Switzerland
email: erik.buehlmann@grolimund-partner.ch

In Switzerland, low-noise pavements have established themselves in many places as an effective noise abatement measure at the source: Since 2010, nearly 1000 low-noise pavements were constructed, many of them in urban areas. Thanks to the research efforts of recent years and many practical experiences, the asphalt mixtures have been improved with regard to their noise-reducing effect and durability. This article highlights the most important steps in development and optimization of low-noise pavements, provides data on the achieved long-term noise reductions and answers questions about their successful practical implementation. With the mixtures available today, permanent noise reductions of up to 4 dB can be achieved. In the first years after installation, the effect is significantly greater. On the basis of today’s findings, it can be assumed that high traffic loads (especially with heavy traffic) and increased ingress of dirt only slightly increase the risk of above-average loss of efficiency. Due to the significant reduction in noise emissions and the resulting lower masking of annoying impulse noise, elements such as structural markings, manhole covers, concrete carriageway elements or even joints to conventional pavements can lead to annoying noise level changes. These, however, can be largely prevented by the best practice solutions presented in this study. Thanks to the various research projects and the practical experience of recent years, many questions about the use of low-noise pavements have been addressed. In summary, nothing stands in the way of a large-scale application of low-noise pavements as an effective and long-term noise abatement measure at the source.

Keywords: low-noise pavements, road traffic noise

1. Introduction

With a population density of 205 people/km², Switzerland can be considered a densely populated country. Considering the fact that around 25% of its area are covered by mountains and are unproductive and inhabitable, population density increases to around 275 people/km² in the remaining areas. This leaves every seventh person in Switzerland exposed to excessive road traffic noise which can make people ill and impair their well-being. The Federal Council therefore decided in 2017 to combat excessive road traffic noise more strongly and effectively than before by taking measures at the source [1]. Possible measures are primarily speed reductions, traffic diversion and low-noise pavements. Due to the recent development of acoustically optimized engines and the improved noise insulation of the engine compartment, tire/road noise is dominant at speeds of approximately 15-20 km/h and above under free flowing traffic conditions [2]. Low-noise pavements’ effectiveness starts right there. Due to
their noise reducing texture and voids accessible from the surface, low-noise pavements reduce vibration and airflow noise substantially. In addition, they absorb sound waves when they hit the road surface [3]. Another means of reducing tire/road noise emissions is by adding rubber aggregates to the pavement mixture and thereby lowering vibrations excited by the rolling tire. [4] Thanks to the trends in the automotive industry, low-noise pavements are becoming an increasingly effective way to protect people from excessive road traffic noise levels at all speeds. This is good news for cities and countries in which a large portion of the population live near roads. The federal government supports cantons, cities and municipalities with subsidy contributions to cushion the additional costs of low-noise pavements. In addition, several practice-oriented research projects were commissioned to optimize low-noise pavements in terms of noise reduction and durability.

The objective of this study is, firstly, to provide an overview of the knowledge acquired over the last decade with regard to the production and construction of low-noise pavements in urban areas. Secondly, the study provides data on the achieved long-term noise reductions and answers questions about their successful practical implementation. The study concludes by listing advantages and disadvantages of the individual technologies and provides recommendations for action to road authorities.

2. Materials and methods

2.1 The technological development of low-noise pavements in Switzerland

The first low-noise pavements were constructed in Switzerland in the late 1980s and early 1990s. At that time, these consisted primarily of porous asphalts (water-permeable drainage surfaces with a void content of > 18%), which are still used on high speed roads today. However, porous asphalts have a short service life and only work if they are not clogged with dirt. For successful application, porous asphalts require high speeds (>80 km/h) in order to enable the self-cleaning effect by the traffic. To be able to reduce noise emissions on municipal and urban roads by means of low-noise pavements, new solutions had to be developed. The first attempts in this direction were made in the mid-1990s. The focus of the first tests of low-noise pavements in urban areas was on rather dense and texture optimized solutions. Noise reductions were considerably lower than the ones of porous asphalts. In 2003, the federal government initiated a research project with the aim of developing low-noise road surfaces specifically for the lower speed range. The study showed that semi-dense asphalts (SDA) with small aggregate sizes and medium void content are the most effective in the low speed range. More recently, research in Switzerland has therefore focused on semi-dense asphalts as a compromise between noise reduction and durability.

In 2010, the federal government launched a research package in which semi-dense asphalts in urban areas were extensively tested on 15 test tracks with substantial traffic volumes. In addition, a Swiss standard was developed [5], which should allow any construction company to produce and construct noise-reducing SDA. The findings on the acoustic effect and the structural requirements of these test pavements were recorded in the final report of the accompanying long-term monitoring [6]. The asphalt mixtures have also been tested by various cantons with further implementation on busy roads. The availability of additional test results under full traffic load allowed for new conclusions to be drawn about the most important parameters for the successful implementation of SDA. In a new study commissioned by the federal government and the Canton of Aargau, the most important material, mixture and construction parameters were identified by statistical analysis of a sample of approx. 150 SDA [7]. The results of this study allowed for a further increase in noise reduction and durability of SDA. These results are currently being incorporated into the existing standard.
2.2 Data on low-noise road surfaces in Switzerland

In Switzerland, a large number of semi-dense asphalts have been installed in urban areas since 2010. As there are currently no complete statistics available on the low-noise pavements installed in Switzerland, a comprehensive database of measurements carried out by Grolimund + Partner AG (G+P) using the Close Proximity method (CPX) [8,9] is evaluated. The CPX method is often used to test the conformity with the demanded values and to undertake a monitoring of the acoustic performance of low-noise pavements. The advantages of the CPX method are that it is both cost-effective and capable of evaluating the acoustic pavement characteristics along entire road sections. With the CPX measurement method (see Figure 1), the sound level is recorded in two separate sound-insulated chambers of a measurement trailer in the immediate vicinity of sets of test tires with two microphones to the front and the rear of the contact patch.

![Figure 1 – CPX measurement system of Grolimund + Partner AG](image)

The acoustic performance of a road surface is evaluated by comparing the measured tire-road noise on a particular surface with the ones of dense asphalt concrete DAC with a maximum aggregate size of 11 mm of 2 to 5 years of age.

3. Results & Discussion

3.1 Low-noise pavements in Switzerland and their acoustical performance

To estimate the acoustic long-term performance of low-noise pavements in Switzerland, G+P’s database, containing a total of 2000 measurements on nearly 1000 different low-noise pavements carried out throughout Switzerland in the last decade, is evaluated. This compilation contains measurement data of the most important clients from all parts of the country. The present evaluation thus provides a reliable estimate of the number of and the acoustic performance of low-noise pavements constructed in Switzerland. The geographical distribution of low-noise pavements in Switzerland is displayed in Figure 2. The figure distinguishes between low-noise pavements SDA with a maximum aggregate size of 4 mm, 6 mm and 8 mm.
As Figure 2 shows, low-noise pavements are constructed in almost all parts of Switzerland, particularly in the cantons of Aargau, Fribourg, Geneva, Solothurn and Valais. The noise reductions obtained by those low-noise pavements are evaluated as a function of their age and maximum aggregate size in Figure 3.

As Figure 3 shows, for 4 mm low-noise pavements a mean long-term noise reductions of 4 dB is obtained in comparison to dense asphalt concrete DAC 11 pavements. This corresponds to a noise reduction of more than halving the volume of traffic. When new, the mean noise reduction measured on
those surfaces is considerably higher (7 dB). With 8 mm low-noise asphalts, an average long-term reduction of 1.5 dB is obtained, while an average noise reduction of 4.5 dB is measured in its new state. Figure 3 also reveals a rather large spread of the acoustic performance for both road surface categories. This can be explained by differences in the asphalt mixtures. A previous study [7] revealed that with semi-dense asphalts, the filler and sand content are the most decisive factors regarding acoustic performance (long-term and after construction). The study presented interdependent maxima for these two factors with the aim to ensure that voids in the pavement are connected to the surface and, hence, are acoustically effective (i.e. that the voids are not blocked by the filler and sand fractions). An analysis of the tyre-road noise spectra from CPX measurements for a subset of these pavements is provided in Figure 4. The analysis investigates the energy contributions of different parts of the tire/road noise spectrum to overall tire/road noise: third-octave-bands 315 to 630 Hz as a proxy for vibration noise, third-octave-bands 800 to 1250 Hz as a proxy for the pavements sound absorption properties (in this frequency range, sound absorption is commonly most effective), and third-octave-bands 1600 to 5000 Hz as a proxy for air-flow noise.

Figure 4 – Tyre/road noise levels $L_{CPX,F}$ in function of pavement age and contribution from the low, mid and high frequencies (colour codes): 315-630 Hz as a proxy for vibration noise, 800-1250 Hz as a proxy for sound absorption properties, and 1600 – 5000 Hz as a proxy for airflow noise.

Figure 4 shows that the spread in acoustic performance throughout its service life is mainly due to differences in the sound absorption properties of the pavement. Sound absorption is directly linked to the degree of connection between the voids in the constructed layer. In order to prevent such differences in the acoustic performance of low-noise road surfaces in Switzerland, the Swiss standard for SDA is currently being revised by narrowing down the allowed grading curve of aggregates in the mixture. This measure is designed to ensure the accessibility of voids and a better (and more homogeneous) long-term performance for SDA in the future.

Another source of variation in the acoustic performance of low-noise road surfaces stems from differences in mechanical strains (e.g. due to the traffic volumes and deviating quantities of heavy vehicles), climatic strains and other external factors. This is further explored in the following sections.
### 3.2 Area of application

The practical experience gained from nearly 1000 low-noise pavements installations in Switzerland, together with the research work listed in section 2.1, made it possible to derive more detailed knowledge about the most suitable area of application for the different types of low-noise pavements. The most important properties of the tested SDA mixtures are shown in Table 1 as a decision-making aid.

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>4 mm pavements</th>
<th>8 mm pavements</th>
<th>conventional asphalts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>semi-dense asphalts, or own products similar design (with 4 mm aggregate size)</td>
<td>semi-dense asphalts, or own products similar design (with 8 mm aggregate size)</td>
<td>dense asphalt concrete DAC 11</td>
</tr>
</tbody>
</table>

**Chosen when…**
- large noise reductions are required or when the noise limits have been substantially exceeded.
- average noise reductions are required or the noise limit values are exceeded to a medium extent

<table>
<thead>
<tr>
<th>Recommended void content*</th>
<th>approx. 14%</th>
<th>approx. 12%</th>
<th>&lt;6%</th>
</tr>
</thead>
</table>

**Noise reduction**:
- after construction
  - 4 mm pavements: -6 to -9 dB
  - 8 mm pavements: -5 to -3 dB
  - conventional asphalts: -2 dB
- after 5 years
  - 4 mm pavements: -4 dB
  - 8 mm pavements: -2 dB
  - conventional asphalts: 0 dB
- at the end of the acoustic service life
  - 4 mm pavements: -3 dB
  - 8 mm pavements: -1 dB
  - conventional asphalts: + 1 dB

<table>
<thead>
<tr>
<th>Expected service life</th>
<th>10 to 15 years</th>
<th>15 to 20 years</th>
<th>20 to 25 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per ton in relation to DAC 11</td>
<td>133%</td>
<td>128%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area of application</th>
<th>- All road types in urban and overland areas</th>
<th>- All road types incl. national roads</th>
<th>- All road types incl. national roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application not recommended or recommended with caution*</td>
<td>- Frequent frost cycles (above 100 cycles/ year)</td>
<td>- Increased shear forces (e.g. many turning trucks, snow chains on heavy vehicles, tanks, accelerating trolleybuses/buses etc.)</td>
<td>- Frequent frost cycles (above 100 cycles/ year)</td>
</tr>
</tbody>
</table>

* current state of research
** noise reduction in comparison to DAC 11 (2-5 years after constr.), current state of research.

As Table 1 shows the application area and main features of 4 mm and 8 mm low-noise pavements SDA tested in Switzerland. The long-term noise reductions obtained by 4 mm low-noise pavements correspond energetically to more than a halving of the traffic volume. The noise reduction during the first five years after construction is often significantly higher. With the increasing establishment of technologies on the market, the costs for producing and constructing low-noise pavements are today only slightly higher than for conventional pavements. Additional costs arise primarily due to the shorter service life. Early replacement of the surface course also reduces the service life of the binder course underneath, which has to be renewed every second time the surface course is replaced. When planning low-noise pavements, this should be taken into account with a detailed cost-benefit analysis. As Table 1 shows, low-noise pavements can be used in most situations. However, there are still situations in which low-noise pavements seem not to be capable of resisting the heavy mechanical strains. In such situations conventional pavements should be used.
3.3 Risk factors for above-average acoustic aging

As can be seen from Table 1, all road surfaces become a little louder over time. The statistical analyses of a study [10] conducted in 2015 revealed three main influencing factors. Firstly, a high number of frost cycles increases the risk of a loss of efficacy the most. Secondly, with increasing traffic load, quiet road surfaces also lose their effect somewhat faster. Here, however, the share of heavy traffic is more relevant than the total traffic load. Thirdly, a rather small influence is shown by high dirt input, e.g. due to agriculture or construction activity. Interestingly, this influence is greater for 8 mm pavements than for 4 mm pavements. This supports the hypothesis that water and dirt are less able to penetrate semi-dense asphalts with a maximum aggregate size of 4 mm due to their finer pore structure. Initial findings from ongoing studies on cleaning measures show that cleaning can effectively remove dirt from the pavement, especially when it is located near the surface (acoustic effect up to 2.5 dB). Once the dirt has penetrated deep into the cavities of the semi-dense asphalt, it can only be partially removed (effect 0.5 to 1 dB). When cleaning, the suction power seems to be of central importance. The water pressure must not be set too high to prevent damage to the texture of the pavement.

3.4 Critical factors for successful implementation

One factor for the successful implementation of low-noise pavements is the location of the joints to the adjacent pavement, the design of manhole covers and manholes, cement concrete elements (e.g. at bus stops and roundabouts) and road markings. These elements can cause disturbing impulse noises or annoying frequency shifts. Although these phenomena also occur with conventional road surfaces, they are much more noticeable with low-noise pavements because they are masked to a lesser degree by vehicle noise. According to [11], following best practice solutions should be envisaged to avoid annoyance by such elements:

- Joints to adjacent pavement: The differences in noise emission can be up to 10 dB between a newly constructed low-noise pavement and the adjacent pavement. Although the residents in the transition area also benefit from a noise reduction, abrupt level changes occur during the transition, which can be perceived as very annoying. To avoid perceptible level increases and audible frequency shifts an approximate distance of 70 m the distance between the transition and the nearest neighbor should be respected. Where this is not feasible, a pavement of medium acoustic property should be constructed as transition area.

- Manholes and cement concrete elements: Where possible, manhole covers and cement concrete elements should not be located in the wheel tracks. Since their position in existing road infrastructures can usually not be changed, such elements should be levelled in the exact same horizontal plane as the pavement surface. Moreover, they should be implemented with a noise-optimized texture.

- Road markings: Structured markings (markings mixed with quartz sand), especially on new low-noise pavements, can lead to complaints from residents, as they cause audible level increases and frequency shifts. On highly performant low-noise pavements, color markings should therefore be preferred to structure markings if safety requirements permit. It, however, needs to be emphasized that pure color markings have drawbacks in terms of visibility and wet adhesion.

4. Conclusions

In Switzerland, low-noise pavements have established themselves as effective noise protection measures at the source. Semi-dense asphalts are widely used, especially in urban areas. Thanks to their widespread use, they only entail marginally higher costs for production and construction. If the entire life cycle of a low-noise pavement is considered, additional costs are incurred. This is especially true for fine-textured 4 mm pavements, as these have a shorter service life than conventional pavements. This should be taken into account in the cost-benefit analysis during the planning phase. Thanks to the
research efforts of recent years, it has been possible to improve the mixture designs in terms of their noise-reducing effect and durability. With the solutions available today, permanent noise reductions of up to 4 dB can be achieved. In the first few years after installation, the effect is even greater. On the basis of our current knowledge, it can be assumed that the risk of above-average loss of effectiveness over time due to high traffic loads (especially with a high proportion of heavy vehicles) and increased dirt input, increases only slightly. However, low-noise pavements do not seem to be able to withstand particularly high shear forces - such as those that occur at bus stops, at sections with many turning trucks or with snow chains on heavy vehicles. In addition, a reduced service life was often observed with frequent frost cycles. This problem can probably be solved with improved binder characteristics adapted to such climates. With low-noise pavements, joints to conventional pavements, shaft covers and cement concrete elements etc. can lead to annoying noise level changes. These, however, can largely be prevented by the best practice solutions offered in this study. The correct implementation of these measures must always be ensured. Thanks to the various research projects and the practical experience of recent years, many questions regarding the practical use of low-noise pavements have been clarified. If correctly executed, nothing stands in the way of a large-scale application of low-noise pavements as an effective and long-term measure at source in the future.

ACKNOWLEDGEMENTS

The author is grateful to Felix Schlatter for performing data analysis and for preparing and designing the illustrations of this paper.

REFERENCES

5 VSS SNR 640 436. Semidichtes Mischgut und Deckschichten (in German), VSS, Bern, Switzerland (2017).