The importance for noise reduction of the bottom layer in double-layer porous asphalt
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Abstract: Double-layer porous asphalt concrete (DPAC) pavements are generally considered to be the acoustically most effective low noise road surfaces ready for implementation. While DPAC used on highways in warm climates may have an average life of around eight years, in Scandinavia with severe winter climate DPAC usually survive only about three years; partly due to wear of studded tyres.

An ongoing project in Sweden, applying DPAC and single-layer porous asphalt (PAC), the latter consisting of the top layer of the DPAC, on motorway E4 in Jönköping-Huskarva, has revealed interesting performance. Initial noise reduction was 7-8 dB(A) compared to a set of reference surfaces (conventional SMA 16). Amazingly, after one year of operation this noise reduction is unchanged. The clogging had not yet affected the acoustical properties significantly.

Most interesting is that the noise reduction difference between the single-layer and double-layer PAC is approximately 5 dB(A). Since the single-layer PAC is identical to the 30 mm thick top layer in the DPAC (although 5-8 mm thicker), it follows that 2/3 of the noise reduction is due to the bottom layer of the DPAC; i.e. what lies approx. 35-40 mm below the top surface.

The paper studies the effect of the bottom layer on the overall acoustical efficiency of the DPAC and concludes that the 80 mm thickness tunes the sound absorption well to tyre/road noise.

Keywords: Road surface, double-layer asphalt, sound absorption

1. Introduction

It is widely recognized that double-layer porous asphalt is the road surfacing type which has the greatest potential for tyre/road noise reduction. Double-layer porous asphalt (DPAC) pavements are characterized by the combination of two different, porous asphalt layers, where the top layer typically is 20-30 mm thick and the bottom layer typically 40-60 mm thick. Since it is difficult to lay asphalt layers thicker than 50-60 mm in one operation, while preserving homogeneity and evenness, the two layers are laid in two separate operations or, preferably, in one operation "wet-on-wet" where two asphalt pavers are combined in order that the top layer is paved over the bottom layer before the latter has cooled off.

To achieve optimum acoustical properties, generally, the design involves four major features:

- a relatively smooth texture in the top layer that is achieved by the use of a small maximum aggregate size (4, 6 or 8 mm are common); this texture is also affected by the rolling
- high air voids content in both the top and bottom layers; this is usually 22-28 % in the most effective cases; the choice within this range is essentially a compromise with durability
- total thickness should be 60-80 mm; although versions thicker than 80 mm have not been tried
- the air voids in the bottom layer should be made-up by relatively wide pores in order to reduce clogging; this calls for a relatively large maximum aggregate size (16 mm is common).

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In an ongoing project in Sweden, with the purpose to reduce noise exposure along a motorway, several variations in the design of noise-reducing porous surfaces are tried; the two major ones being double-layer porous asphalt and a single-layer surface consisting of the top layer of the double surface. This project allows some interesting studies, of which the comparison of the single-layer and the double-layer surfaces is the subject of this paper.

2. Brief description of the project

The location of the low noise road surfaces (LNRS) is on motorway E4 through the twin cities Huskvarna and Jönköping in southern Sweden. The motorway here runs between lake Vättern and a residential area; the houses of which enjoy a beautiful view over the lake; see Figure 1. Due to this, constructing noise barriers is not popular among the residents; nevertheless, partly transparent noise barriers have been erected by the Swedish Transport Administration (STA) along some of the motorway.

Actually, the LNRS is required by a court decision, which aims at bringing down the noise exposure below 65 dB $L_{Aeq(24h)}$ for the closest residential homes. This is the regular noise exposure limit in Sweden for existing roads. The goal was to achieve a 5 dB noise reduction by the LNRS, but to get below 65 dB along the entire motorway section, it was also necessary to reduce the posted speed to 90 km/h (from 110) for the light vehicles. The heavy traffic has an unchanged limit of 80 km/h (in practice often 90 km/h as controlled by the mandatory speed limiters). Additionally, along some parts of the motorway, noise barriers are used to get below the 65 dB limit.

The motorway has two lanes in each direction, AADT is approx. 22 000 per direction and the heavy vehicles constitute 17 % of the total traffic. Most of the heavy vehicles are long-distance trucks with semi-trailers or trailers traveling between middle Europe, southern Sweden (or the west coast) and the Stockholm area; some of this traffic continuing by ferry to Finland.

As contractor for the paving works, the Swedish company Svevia was chosen. They chose to use two LNRS which are subject of this study (plus a few variants which are not reported here):
• a double-layer porous asphalt with 11 mm max aggregate in the 30 mm thick top layer, and 16 mm max aggregate in the 50 mm thick bottom layer;
• a single-layer porous asphalt which is exactly the same composition as the top layer in the double-layer pavement, except that it is approximately 5-8 mm thicker than the top layer.

The single-layer pavement was laid in a location south of but adjacent to the major test section which has the double-layer pavement. Other data of the pavements are listed here:
• air voids 25 %
• highly modified binder from Nynäshamn
• the top layer was laid in June 2010 the day after the bottom layer was laid (which is unique). Ambient temperatures were 10-15 °C.

The maximum aggregate size in the top layer was 11 mm. This is higher than usual in European LNRS, but is considered as needed in Sweden, Norway and Finland since in wintertime the majority of tyres here are equipped with steel studs which constitute a serious source of wear to the surface. To avoid the steel studs crushing the aggregate at speeds of 90 km/h and higher it is considered necessary to use at least 11 mm of maximum aggregate.

Figure 2 shows a typical look of the surface. The left half shows the top surface of the porous asphalt (both the single- and double layers) and the right half shows the dense reference surface used against which noise reductions are calculated; see further Section 4.

![Figure 2 – Typical appearance of the surface of (both) the porous pavements subject of this study (on the left) and the reference pavement (on the right). The coin in the picture is 25 mm diameter.](image)

3. Measurement methods

Macrotecture, megatexture and unevenness measurements were made with the Laser RST (Road Surface Tester) from VTI.

Noise measurements were made using the CPX method [ISO/CD 11819-2, 2011], conducted by the TUG using their Tiresonic Mk.4 trailer. Two tyres in new condition were used as references: an SRTT tyre (designated SRTT here) according to the international standard ASTM 2493, and a tyre AV4 from Avon Tyres in the UK (designated AA V4 here). These two tyres are currently subject of standardization in ISO/TS 11819-3, to be used in conjunction with the CPX method, where the SRTT is intended to have properties similar to new passenger car tyres and the AV4 V4 have properties similar to new truck tyres. In this way, the CPX method is considered to give pavement classification and ranking reasonably representative of both light and heavy vehicles.

Both noise and geometrical measurements were made in the wheel tracks of the pavements, in both the slow and the fast lanes.
Limited noise measurements were also made with the SPB method (ISO 11819-1), but not by VTI and only at the double-layer pavement. There was no speed measurement in connection with the latter.

4. Reference pavement

As reference pavement, stone mastic asphalt (SMA) with 16 mm maximum aggregate was chosen. As these may differ somewhat from site to site, the average values for three road sections with SMA 16 pavements, 1-5 years old were chosen. Two of these were located on motorway E4 while one was located on highway 34 west of Linköping city. Posted speeds were 90-110 km/h for these roads. Figure 2, right part, shows a typical close-up of the surface of one of the SMA pavements.

5. Some notes about the first two years of operation

The court decision that required the use of the DPAC pavement has been implemented by the motorway authority (the Swedish Transport Administration) as a requirement that when the noise reduction from the latest repaving operation has decreased below an annual average of 5 dB, the pavement must be either cleaned to restore the average to above 5 dB, or repaved with a new DPAC; in this way keeping the long-term average noise reduction above 5 dB. This means that annual measurements must be made on the low-noise pavements and on the reference pavements. As written above, these are made by the CPX method using the mentioned two reference tyres.

After one year of operation, in July 2011, cleaning was made by a truck emitting water jets onto the surface and sucking-up the dirt water. This was not really needed but is seen as an "exercise" for a possible future need when noise reduction has dropped below an annual average of 5 dB.

Some concerns were raised about the paving being made on two separate days rather than wet-on-wet. This means a cost saving as it does not require a special machine, but it is feared to result in lower adhesion between the two layers since they are not "connected" when both layers are still fresh and warm. However, now after almost two years of operation, no indications of problems due to this have been noted. Ravelling has been observed to a minor extent after almost two years of operation, but has not yet reached any alarming levels. Sealing by Fog Seal was made in the autumn of 2011 in order to protect the pavement from oxidation.

Some clogging was visible at some locations after the first year of operation, such as at an entrance to the motorway, but did not seem to give serious effects on noise reduction on the major road sections.

As is reported below, the experience of the first year of operation is excellent. Arguably, it is the most successful application of DPAC in Sweden so far.

6. Results of noise measurements

The noise properties of the porous pavements have been checked so far two times the first summer and two times after one year of operation. The very first measurements, however, were made on the very fresh surface to check that it gave the intended noise reduction, and are not worth reporting here.

Table 1 shows the results of tyre/road noise measurements with the CPX method, for tyres SRTT and AAV4, at three occasions:

- July 2010 at an age of one month
- June 2010 at an age of 12 months (before cleaning took place)
- July 2011 at an age of 13 months (after cleaning had been made).

The values in the table are noise reductions in A-weighted dB relative to the average of the reference SMA16 pavements (first two rows) and as difference between double layer and single layer (third row).

Figures 3-4 show the frequency spectra measured on the single-layer and double-layer at an age of one month and on the ref. SMA pavements 1-5 years old. It appears that the single layer pavement has its major noise reduction at 1250-2000 Hz while the double-layer has its major effect at 630-1000 Hz.

Measurement speed was 90 km/h. Measurements were made also at 70 km/h and a few tests also at 50 km/h, but as the results correlate very closely with those at 90 km/h they are not reported here.
Table 1 – Results of tyre/road noise measurements with the CPX method at 90 km/h, for tyres SRTT and AAV4, expressed as noise reductions in A-weighted dB, at three occasions. See text for more information.

<table>
<thead>
<tr>
<th>Type of pavement</th>
<th>July 2010</th>
<th>June 2011 (bef. cleaning)</th>
<th>July 2011 (aft. cleaning)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SRTT</td>
<td>AAV4</td>
<td>SRTT</td>
</tr>
<tr>
<td>Single-layer porous asphalt</td>
<td>2.3</td>
<td>1.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Double-layer porous asphalt</td>
<td>7.6</td>
<td>7.3</td>
<td>7.8</td>
</tr>
<tr>
<td>Double layer – single layer</td>
<td>5.3</td>
<td>6.2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Figure 3 – Third-octave band frequency spectra for tyre SRTT, measured at 90 km/h.

Figure 4 (below) – Third-octave band frequency spectra for tyre AAV4, measured at 90 km/h.

7. Texture and unevenness data

Texture and unevenness measurements made when the surfaces were one and eleven months old gave the results presented in Table 2. Mean Profile Depth (MPD) is measured according to ISO 13473-1 and megatexture according to ISO 13473-5. Corresponding MPD value for the reference pavements was 0.93 mm.

It appears that for both macro- and megatexture of the pavements there is no significant difference between them; the values are within 2% of each other in new condition. For IRI (unevenness – “International Roughness Index”) there is a slightly higher IRI for the single-layer pavement, but the values are low (typical of high-quality pavements on motorways) and the indicated difference would hardly be noticeable in practice. IRI is not known to affect exterior noise levels.

The measurements in July 2010 and May 2011 showed similar values; except that all values, mostly megatexture, had increased marginally on both pavements over the 10 month period.

Table 2 – Texture and unevenness measurement results on the porous pavements.

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Time</th>
<th>Macrotexture - MPD [mm]</th>
<th>Megatexture RMS [mm]</th>
<th>IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-layer asphalt</td>
<td>July 2010</td>
<td>1.76</td>
<td>0.70</td>
<td>0.82</td>
</tr>
<tr>
<td>Double-layer asphalt</td>
<td>July 2010</td>
<td>1.79</td>
<td>0.71</td>
<td>0.61</td>
</tr>
<tr>
<td>Single-layer asphalt</td>
<td>May 2011</td>
<td>1.86</td>
<td>0.84</td>
<td>0.93</td>
</tr>
<tr>
<td>Double-layer asphalt</td>
<td>May 2011</td>
<td>1.81</td>
<td>0.79</td>
<td>0.65</td>
</tr>
</tbody>
</table>
8. Discussion

The only physical difference between the single- and double-layer porous pavements should be that in the double-layer there is an extra bottom layer. The top 30 mm in the double-layer is designed "exactly" like the 35-38 mm thick single-layer pavement. The texture measurements confirmed that there is no texture difference between the single- and double-layer porous asphalt pavements. Air voids measurements on bore cores indicated that air voids was 25% in both pavements [Pettersson, 2011].

The frequency spectra results seem to suggest that the reason for the noise reduction in both cases is sound absorption. For the single-layer (approx 35-38 mm thick) the most effectively reduced frequency bands are twice as high as that of the 80 mm thick double-layer; i.e. the sound absorbing frequency peak is proportional to layer thickness. This has been observed before; see e.g. [Sandberg & Ejsmont, 2002].

Could the results be due to some unknown cancellation effect for the particular microphone positions used in the CPX method, which is a near-field method since microphones are only approx. 0.25 m from the tyre/road contact areas; i.e. are the results due to some artifact in the CPX method? Or could the results be due to geometrical source-receiver effects, such as that the "effective" layer thicknesses happen to be optimal for the CPX microphone positions, but would not be so for the more grazing incidence for microphones in the SPB method? The authors were unable to do SPB measurements, which would have revealed such effects, but a sub-contractor to the STA made some far-field measurements. One site was measured according to the SPB method (ISO 11819-1), but with only 20 cars and 20 trucks and on a smoother dense asphalt ("Remix") than the SMA16 [Wennblom & Jerson, 2011]. It appeared that the spectral differences between the double-layer pavement and the dense Remix have a shape which is almost identical to that of our CPX measurements. Also, LAeq measurements at facades further from the road showed similar differences in overall A-weighted levels as we measured with the CPX method. Thus, it seems that the CPX measurements give similar results as far-field measurements.

Unfortunately, it was not possible to make sound absorption measurements (yet), since bore cores suitable for sound absorption measurements by the tube method have not been made available to the authors. Such measurements would have been highly desirable, and are planned in 2012.

9. Conclusions

It is amazing how important for noise reduction the pavement at the depth between 30 and 80 mm under the surface is. The results of this study suggest that the top layer reduces noise by only 1–3 dB, whereas the bottom layer reduces noise by 5-6 dB and that the main reason is sound absorption in the pavement layers. A thickness of 80 mm tunes the maximum sound absorption to coincide with that of maximum A-weighted tyre/road noise energy, while 35 mm thickness tunes the absorption to too high frequencies. It must be noted that the high noise reduction will not prevail when clogging starts to fill the air voids.

10. Acknowledgements

It is gratefully acknowledged that this work is sponsored by the Swedish Transport Administration (STA); both within a project for noise measurements on the E4 test sections and within a general project for noise properties of Swedish pavements. Very good cooperation with Svevia is also acknowledged.

11. References and links

Petersson, Gustav (2011): Personal communication with Mr Gustav Pettersson, Svevia, Jönköping.