Abatement of traffic noise...

... the arguments for asphalt

EAPA

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1. Introduction

Economic development in Europe throughout the last decades has been accompanied by a growth in traffic of the same magnitude. One of the negative effects of this is that the source of noise emission now affecting most people in their everyday lives is traffic noise. Therefore, abatement of traffic noise in general has a high priority for many people.

The EU Commission estimates that 80 million people (20 %) in the EU suffer from unacceptable noise levels. An additional 170 million citizens are living in so-called "grey areas" where the noise levels are such as to cause serious annoyance during the daytime [1.].

The Commission's Green Paper "Fair and Efficient Pricing in Transport" estimates that the external cost of noise to society is 0.2 % of GDP or around 12 billion ECU annually [2.]. Further to its 1996 Green Paper (COM(96)540), the European Commission developed a new framework for noise policy, based on shared responsibility between the EU, national and local level, and including measures to improve the accuracy and standardisation of data to help improve the coherency of different actions. This document led to a comprehensive set of measures, including:

1. The creation of a Noise Expert Network, whose mission is to assist the Commission in the development of its noise policy.
2. The Directive on Environmental Noise aimed at requiring competent authorities in Member States to produce strategic noise maps on the basis of harmonised indicators, to inform the public about noise exposure and its effects, and to draw up action plans to address noise issues.
3. The follow-up and development of existing EU legislation relating to sources of noise, such as motor vehicles, aircraft, railway rolling stock and the provision of financial support to different noise related studies and research projects.

Further to the Commission proposal for a Directive relating to the assessment and management of Environmental noise (COM(2000)468), the European Parliament and Council have adopted Directive 2002/49/EC of 25 June 2002 whose main aim is to provide a common basis for tackling the noise problem across the EU. The underlying principles of this text are similar to those for other overarching environment policy directives:

- Monitoring the environmental problem; by requiring competent authorities in Member States to draw up "strategic noise maps" for major roads, railways, airports and agglomerations, using harmonised noise indicators L_{den} (day-evening-night equivalent level) and L_{night} (night equivalent level). These maps will be used to assess the number of people annoyed and sleep-disturbed respectively throughout Europe
- Informing and consulting the public about noise exposure, its effects, and the measures considered to address noise, in line with the principles of the Aarhus Convention
- Addressing local noise issues by requiring competent authorities to draw up action plans to reduce noise where necessary and maintain environmental noise quality where it is good. The directive does not set any limit value, nor does it prescribe the measures to be used in the action plans, which remain at the discretion of the competent authorities.
- Developing a long-term EU strategy, which includes objectives to reduce the number of people affected by noise in the longer term and provides a framework for developing existing Community policy on noise reduction from source. In this respect, the Commission has made a declaration concerning the provisions laid down in article 1.2 with regard to the preparation of legislation relating to sources of noise.

Important achievements in abatement of noise can be reported. For instance, the noise from individual cars has been reduced by 85 % since 1970 (= 8 dB(A)) and the noise from lorries by 90 % (= 11dB(A)) [2.]. However this achievement has been negated through the growth in the number of vehicles on the roads and the longer distances travelled.

Traffic noise generated by a vehicle originates from the vehicle power train (engine and transmission), the tyre/pavement interaction and the air circulation around the vehicle. The noise generated by the vehicle power train depends primarily on the engine characteristics and dominates at low traffic speeds. The noise emission from the tyre/pavement interaction, often referred to as rolling noise, relies on tyre and pavement surface characteristics and dominates at higher traffic speeds. At very high speeds of over 120 km/h the air circulation around the vehicle is the major noise source.

Concurrently with the fact that the motor industry has been able to lower the noise emission from lorries [3.], the surface characteristics of the pavement have become more and more critical to the total noise emission from driving vehicles. Therefore, the asphalt industry, especially in the last 15-20 years, has put a lot of effort into developing different kinds of low noise road surfacings.

Today pavement selection provides a good tool to reduce noise production and propagation as well as to absorb noise that is produced. While conventional low noise road surfacings especially reduce traffic noise on roads carrying vehicles at higher speeds, newly developed low noise surfacings also offer considerable noise reductions on urban roads with slower moving traffic. The road surface has to fulfil a number of functions to provide a safe and comfortable drive, ranging from evenness to low maintenance. Noise abatement is just one of these. Depending on design priorities a higher amount of noise reduction can be strived for.

By elimination of the noise at the source the need for noise barriers is reduced. For example, in one study, the use of Double layer Porous Asphalt in combination with noise barriers was found to be cheaper than the use of higher noise barriers alone [4].

This report describes the mechanisms leading to the emission of rolling noise, which are closely linked to the road surface, and it gives an overview of the different types of road pavements designed to decrease rolling noise. Some recommendations/guidelines are given in the end of the report. The optimum solution will depend on the economic and environmental constraints in each individual case.

2. Noise emission from road traffic

This chapter outlines the basic terms and definitions connected to noise measurements and explains the noise emitting mechanisms during tyre/road interaction.

2.1. Noise measurements

Noise is a quick variation of atmospheric pressure in time. It is characterised by frequency and intensity and measured by acoustic pressure. The latter is the difference between atmospheric and sudden pressures as they can be perceived by the ear. The noise level is a logarithmic function of the acoustic pressure and noise emission levels are normally expressed in decibel (A), abbreviated dB(A). The A in brackets denotes A-weighting and means that especially deep or high-pitched sounds in the noise are lowered, allowing a better simulation of the human ear.

The noise emission from traffic is also described in frequency spectra normally ranging from 32 to 8,000 Hz, showing the noise level at different frequencies. The total noise level is obtained by adding the sound energy at all the different frequencies.
Since noise measurements are based on the logarithmic scale, a halving of the acoustical sound impression is equivalent to a 3 dB(A) decrease. A 3 dB(A) noise reduction is also equivalent to a 50 % reduction in traffic flow or a doubling of the distance between a linear noise source and the listener.

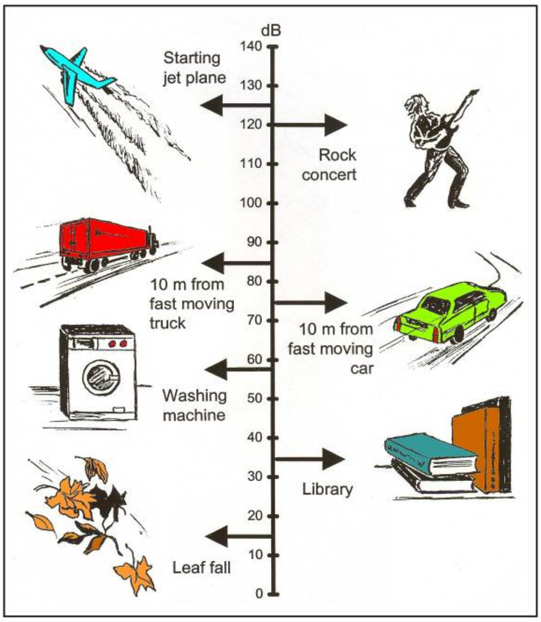

Figure 2.1. Typical noise levels from different traffic sources.

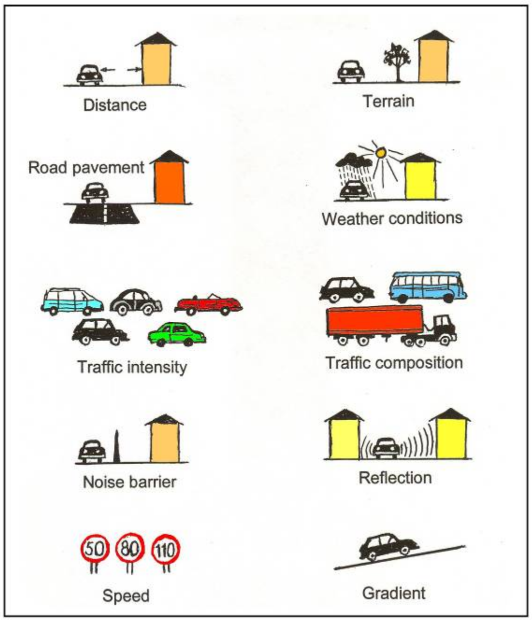

Figure 2.2. Parameters affecting road noise.

The typical noise levels from different sources, including traffic, are shown in figure 2.1.

Furthermore, the parameters affecting the level of traffic noise and thereby actual noise measurements are summarised in figure 2.2. The traffic noise level depends on distance, terrain, type of road pavement, weather conditions (dry or wet, temperature etc.), traffic intensity, traffic composition, noise barrier, reflection, traffic speed and gradient of road. For example, a temperature increase of 10 °C is accompanied by a decrease in noise level of around 1 dB(A). Consequently noise measurement schemes require exact information about the test conditions.

2.2. Noise measurement methods

There exists a whole range of different traffic noise measurement methods, and when talking about a defined noise level, it is necessary to state the measurement method or standard it refers to.
Some preliminary researches try to link together results obtained through different measurement methods, but it seems that the pavement surface has a strong influence and therefore no direct relationship can be established.

2.2.1 Time-averaged measurements

The notion of discomfort linked to environmental noise conditions is quite complex, as noise generated by the flow of traffic is mainly variable. It is therefore necessary to characterize it in a rather simple way to define the associated level of discomfort.
For this purpose, the notion of equivalent energy level is used, namely $L_{Aeq,\ or}$ L_{DEN} average in 24 hours, and L_{Night} for the most sensitive period, according to the new European regulations. It corresponds to a continuous signal that would show the same energy as the fluctuating signal on a given time basis. It then represents the average level of energy received during the reference period.

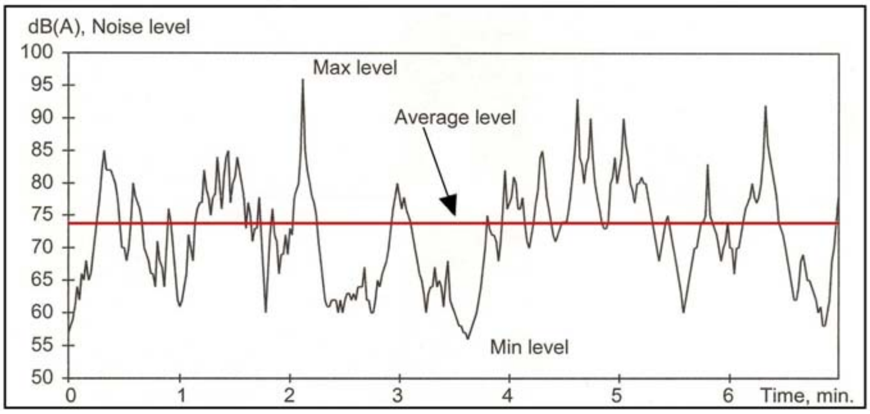

Figure 2.3. Noise level as a function of time and time-averaged measurements

This method consists in evaluating at a fixed given location the average sound level in front of houses. It therefore reflects the noise level as it is perceived by neighbouring inhabitants.
This measurement is the basis on which noise nuisance reduction plans should be defined, especially when a road infrastructure is modified.

2.2.2 “Statistical Pass-by” method (EN ISO 11819-1)

The EN ISO 11819-1 standard [18.] allows the contribution of the road surface within its environment to the whole traffic noise to be evaluated. For this purpose, the maximum acoustic level is measured as vehicles pass by in front of a microphone located 7.5 meters away from the lane centreline according to very strict specifications.

The reference level for a specific surface course $L_{A\ Ref}$ is calculated at a given speed (generally 50 or 90 km/h, depending on the test location), and at a temperature of 20°C.

However, due to very tough operating specifications for the microphone environment (no obstacles such as safety barriers in front or reflecting walls behind), this standard can only be used as a comparative tool in urban areas. Moreover, as it is quite time consuming, it is not possible to have a global view of an infrastructure, but only data applicable to one location.

Figure 2.4: Statistical Pass-By measurements

2.2.3 Close proximity method (CPX)

This method, based on microphones directly located on a vehicle or a specific trailer at around 30 cm from the tyre, allows measuring the performances and the homogeneity of a wearing course, independently of the surrounding conditions. In particular, comparisons are quite easy to obtain at a location before and after road treatment.
Due to the proximity with the main noise source, this method totally eliminates surrounding noise, and can easily be used in urban conditions.

An international ISO group has been working on a standard for this method for several years but faces several difficulties such as the choice of reference tyre.

Figure 2.5: Trailer or car-based CPX equipments

2.3. Traffic noise emission

In general, the traffic noise generated by a vehicle both affects the internal (inside the vehicle) and the external environment. Since the latter by far constitutes the major problem, all references to noise in the following concern the impact of traffic noise on the surroundings.

The total noise emission from driving vehicles has four principle sources, as can be seen on figure 2.4:

- The vehicle power train (engine, shafts, radiator, transmission, etc.)
- The exhaust pipe
- The tyre/pavement interaction
- The air circulation around the vehicle.

The relation between the noise levels coming from these main sources will vary depending on vehicle type and mode of operation. In general, the noise emission originating from the tyre/road contact dominates over the vehicle power train noise at speeds exceeding 40 to 50 km/h for passenger cars. For lorries, this figure will normally be higher. Only at speeds over 150 km/h does the noise emission from the air circulation become the major noise source.

Under all circumstances, it is obvious that it is advantageous to focus on the tyre/road interaction especially when the objective is to reduce the level of noise from roads carrying vehicles at higher speeds.

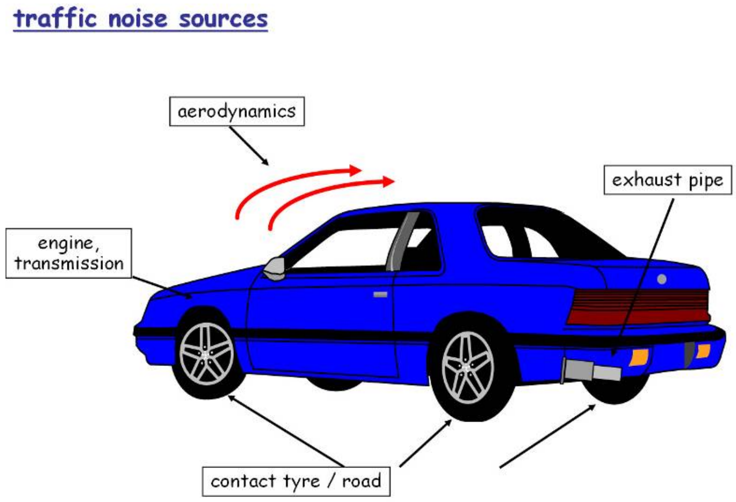

Figure 2.6. Traffic noise sources.

2.4. Rolling noise - tyre/road interaction

The contact between tyre and road generates noise which depends on a whole range of different characteristics. Limiting the rolling noise therefore requires precise knowledge of the noise sources and of how much they affect the overall noise emission.

Rolling noise depends principally on the characteristics of the tyres of the vehicle and the pavement surface and, more indirectly, is also influenced by the vehicle (load, traffic composition, number of tyres, vibration, body) and the rolling conditions (torque, speed, ambient temperature). An optimal result can not be reached for all conditions at one time, but will be restricted to a certain speed range and traffic type.

The mechanisms governing the generation of rolling noise can be classified into 4 phenomena briefly described in the following notes and illustrated in figure 2.7.

Generation mechanism

- Mechanical vibrations, through impact between tyre tread pattern and surface asperities and also deformation of the tyre around the contact area. This impact noise is therefore strongly related to features of tyre tread patterns and road surface macrotexture
- Air vibrations, through air pumping and organ resonance in the cavities between the road surface and the tyre grooves
- "Slip-stick" effect: Due to the shifting adhesion (stick) and gliding (slip) of the tread pattern, the tyre is under influence of horizontal forces in the contact area between tyre and road surface which generate vibrations
- "Stick-snap" or suction pad effect, when the tread pattern abruptly leaves the pavement surface at the rear of the tyre/road contact area, which leads to radial vibrations

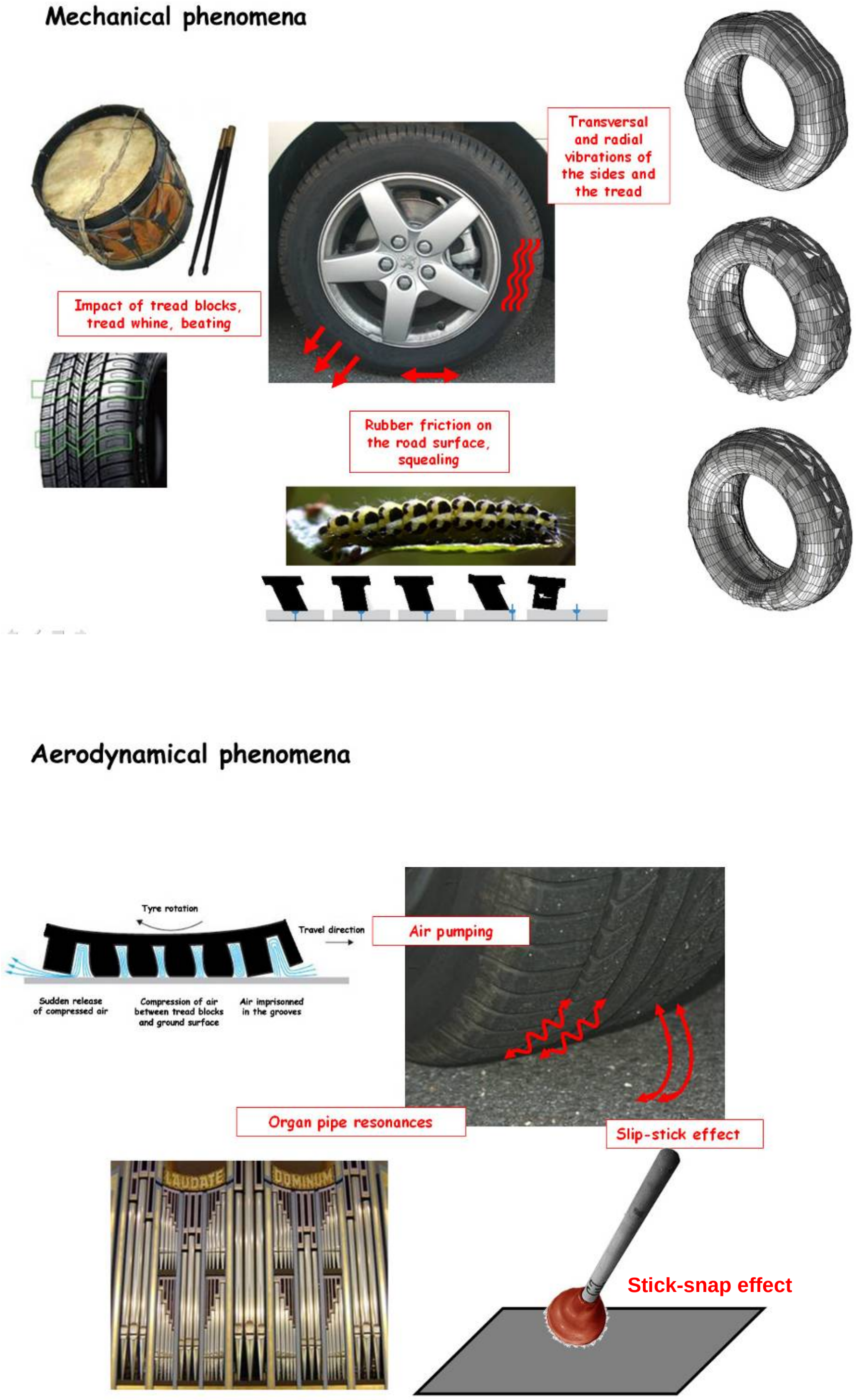

Figure 2.7. Tyre road noise generation mechanisms

In addition to the generation mechanisms, the generated noise is amplified, due to an effect commonly known as the “horn effect”, linked to the geometry of the volume between the flat surface and the rounded wheel. This amplification depends on the porosity of the surface, and is the same along the whole frequency spectrum (see fig. 2.8).

Figure 2.8. Amplification by “horn-effect”

And finally, the propagation conditions affect the noise level perceived by the neighbouring resident,

- On a short distance, where absorption by the road material porosity can be efficient
- On a long distance, but in this case the geometrical configuration of the ground, its nature and the weather conditions affect sound propagation, and even if the original sound spectrum has an influence on the final results, this domain is beyond the scope of this paper.

Summing up it can be stated that:

- An increased macrotexture generally means a higher noise emission from the tyres (lower frequency range) and less air pumping noise (higher frequency range),
- Porosity yields less air pumping noise and reduces noise propagation through absorption,
- Elastic (asphalt) pavements may lead to less tyre vibrations and consequently less noise (especially at low frequencies). This topic has been mentioned for several years, but no detailed research was carried out so far.

The above facts underline the importance of focusing especially on the road surface (mainly macrotexture and porosity) when the objective is to reduce the tyre-road noise, keeping in mind that this goal cannot be separated form other constraints such as grip level, rolling resistance and long term mechanical behaviour.

The next chapter describes in more detail the different types of low noise road pavements which the European asphalt industry can offer its clients.

3. Low noise road pavements

The main function of roads is to ensure constant traffic flow from one place to another at maximum driver safety and comfort. For many years, the most commonly used type of asphalt surface course on major roads in continental Europe has been asphalt concrete, while in the UK the principal surface course has been chipped hot rolled asphalt. Both have proved satisfactory over many decades.

During the last 15-20 years, the asphalt industry has been faced with growing demands for more specialized products with specific features, including noise reducing properties. This fact has led to the development of a whole range of new asphalt types and the improvement and optimization of existing ones.

The noise reducing properties of a pavement depend principally on the surface macrotexture and aggregate grading and size, i.e. porosity. Therefore, the design of low noise road pavements consists primarily of optimizing these factors without compromising other functional pavement characteristics.

Generally the following characteristics need to be optimal to have a good road surface:

- Skid resistance
- Evenness
- Noise
- Visibility
- Durability / availability
- Aesthetics.

As stated above, there could be a conflict in the selection of the surface material when optimizing the characteristics individually. In other words, the final surface is always a balance in satisfying as many of these characteristics as possible.

The conventional low noise road pavements especially reduce traffic noise on high speed roads but recently developed low noise surfacings also offer considerable noise reductions on urban roads with slower moving traffic.

This chapter presents a short general overview of the noise properties of common existing asphalt surfacings followed by a more detailed description of the design and mode of operation of different types of low noise road pavements.

3.1. Noise measurements on different road surfacings

Generally noise measurement results on road pavements are presented either by a comparison of absolute noise levels or by a registered noise reduction (increase) in relation to a reference pavement. The most commonly used reference pavement is a traditional dense or semi-dense asphalt concrete which has a widespread use in most European countries. Dense or semi-dense asphalt concrete is a continuously graded mixture where the aggregate structure is filled with a mortar of very fine aggregate/filler and binder. A more thorough description of the different kinds of noise reducing pavements is given in the following sections.

Figure 3.1 presents noise measurements carried out on different types of surface layers [19.] subdivided by maximum aggregate size according to the Statistical Pass-By Method (formerly NF S 31-119-1, now EN ISO 11819-1). For each type of surface layer the figure contains information about the mean value of the noise measurements, the single registered noise measurements and the noise range.

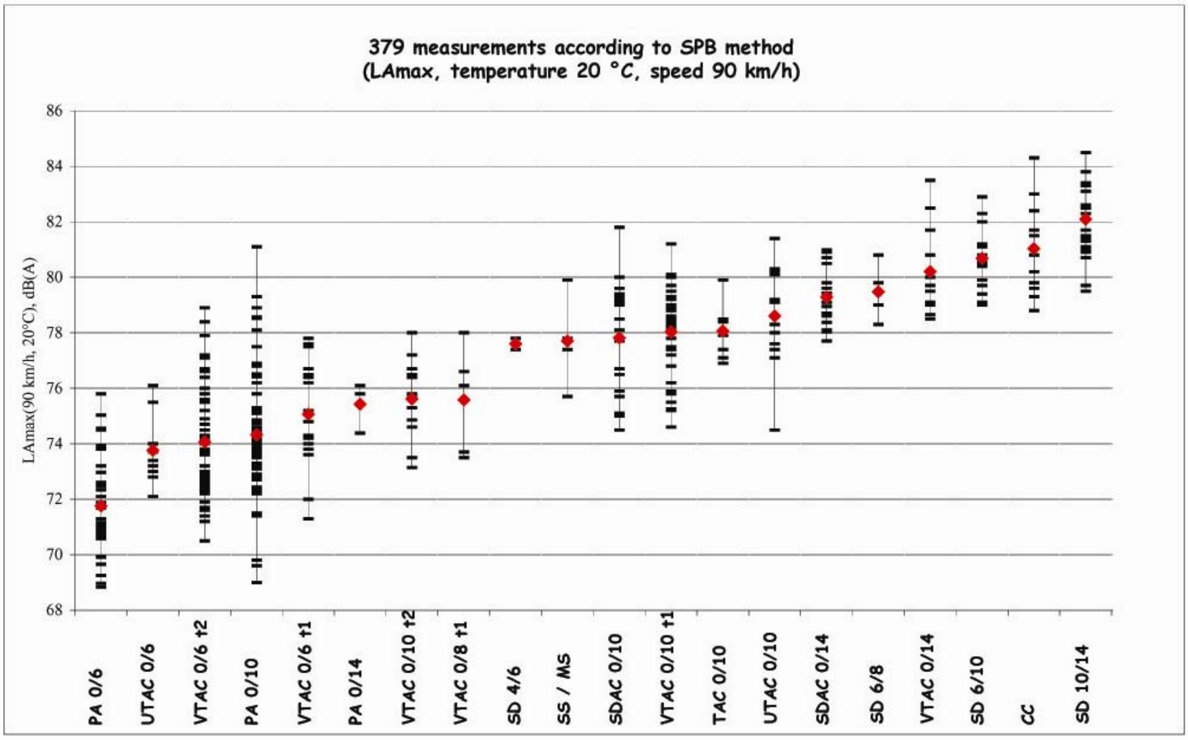

Figure 3.1. Noise levels for different types of overlays [19].

The abbreviations used in Figure 3.1 are as follows: PA = Porous Asphalt, TAC = Thin Asphalt Concrete VTAC = Very Thin Asphalt Concrete, UTAC = Ultra Thin Asphalt Concrete, SCAC = Semi Coarse Asphalt Concrete, SS = Slurry Seal, MS = Micro Surfacing, SD = Surface Dressing and CC = Cement Concrete.

The noise measurements give a good impression of the relative noise reducing properties of the most common types of surface on European roads. Comparing mean values the figure implies a difference of more than 10 dB(A) between the lowest noise levels measured on fine grained porous asphalt and the highest noise levels registered on asphalt concrete with a large maximum aggregate size, on cement concrete, and on different types of Slurry Seals or Surface Dressings. The figure furthermore indicates that a larger maximum aggregate size generally is associated with higher noise levels.

The great difference between maximum and minimum noise levels for the same overlay can be explained by difference in age (clogging in case of porous asphalts), texture degradation through ravelling, edge conditions etc.

It should be added that more recent noise measurements on further developed VTAC 0/6 pavements show even lower noise levels than presented in figure 3.1.

In addition to the data in figure 3.1 it can be mentioned, that chipped hot rolled asphalt, on average, is considered to be approximately 2 dB(A) noisier than conventional asphalt concrete used as reference surface in the following sections of this Chapter. This means that the noise reducing properties cited in the following sections becomes even more advantageous in countries with a widespread use of chipped hot rolled asphalt where it is more appropriate to use this pavement type as a reference surface.

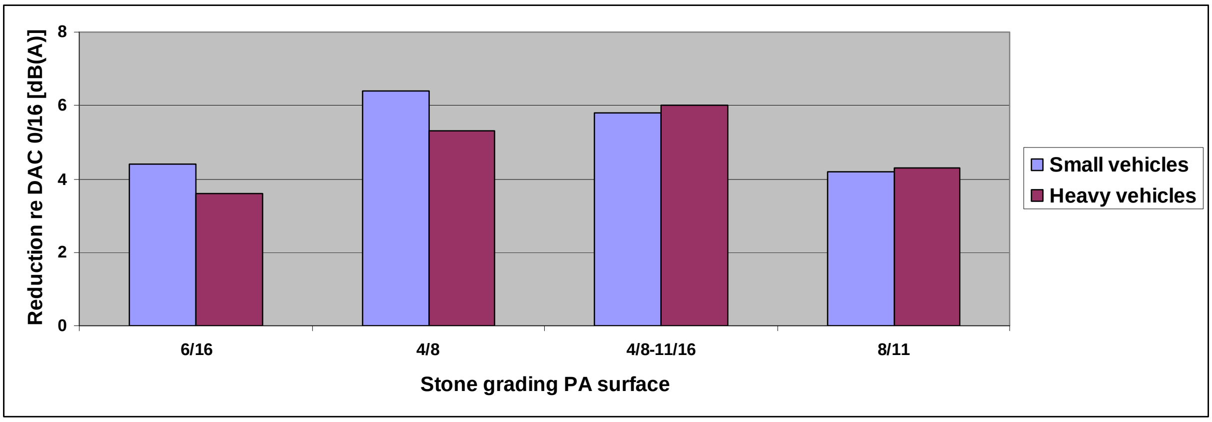

Figure 3.2. Noise reductions of 4 types of porous asphalt concrete relative to dense asphalt concrete (DAC) 0/16 mm.

Figure 3.2 presents the results from noise measurements on a motorway stretch with 4 different types of porous asphalt pavements in relation to an adjacent pavement of traditional dense asphalt concrete. The measurements are carried out according to the Statistical Pass-By method (EN ISO 11819-1 [18.]). The measurements clearly demonstrate the advantageous noise reducing properties of porous asphalt compared to dense asphalt concrete.

Furthermore it is evident that the very positive noise reducing effect is not only limited to passenger cars (small vehicles) but also applies for heavy trucks.

Concerning urban areas it can be underlined that experience with alternative surfacings as concrete, bricks and cobblestone also points to higher traffic noise levels on these pavements compared to asphalt concrete.

Investigations also indicate that it is possible to obtain noise reductions particularly on roads in built-up areas simply by replacing an uneven surface with an even one.

From the above facts, it is evident that pavements of porous asphalt without doubt provide the best noise reducing properties. The following section will focus in more detail on porous asphalt and mention some new types of low noise road surfacings, which basically are developed through an additional improvement of the beneficial acoustical properties of porous asphalt. The chapter is concluded by a section on Stone Mastic Asphalt (SMA) which under certain conditions also possesses advantageous noise reducing properties.

3.2. Porous Asphalt

The first applications of porous asphalt date back to the 1960s. The use of porous asphalt was limited in the beginning, but from the mid-1980s, renewed interest in some of its advantageous properties in relation to conventional asphalt concrete, including noise reducing properties, has led to a widespread use of porous asphalt as a road surface on heavy trafficked roads in many European countries today. Nowadays many European countries have experience with porous asphalt [5, 6]. In total more than 195 km2 of main road surface is covered with porous asphalt.

Large applications of more than 25 km2 can be found in France, Italy, Spain and the Netherlands. In the beginning Porous Asphalt was used because it improved driving conditions during rain by reducing splash and spray, a better skid resistance in wet conditions and the storage of water. Subsequently, the noise reducing properties were discovered and that became a main argument for using porous throughout Europe. Additional beneficial features of porous asphalt encompass resistance to fatigue and rutting. Experiences from the use of porous asphalt in different European countries show however that the noise reducing properties are considered to be of most universal benefit.

Porous asphalt pavements principally diminish the emission of traffic noise in two ways:
- Reduction of rolling noise: The special surface macrotexture and pavement porosity allowing air to be pressed into the wearing course reduces the generation of rolling noise.
- Noise absorption: The noise generated by the vehicle is absorbed by the road structure.

At normal layer thicknesses of porous asphalt, the attenuating effect originates mainly from reduced noise generation due to favourable aerodynamic conditions in the tyre/road contact area and only to a lesser extent from noise absorption.

During the last 15-20 years, recordings on sections on the primary road network in different European countries have proved the positive acoustic properties of porous asphalt in comparison to conventional dense asphalt concrete. For example, studies in the Netherlands have shown porous asphalt in normal layer thicknesses give, on average, a noise reduction of about 4 dB(A) [7, 8, 9].

Another important feature concerning the noise reducing properties of porous asphalt is the fact that it alters the frequency spectra of the tyre noise compared to dense asphalt concrete. Noise emitted at higher frequencies (over approximately 1,000 Hz) decreases and low frequency noise increases. Since noise at higher frequencies is more annoying to humans than noise at lower frequencies (not too low), the noise reduction on porous asphalt pavements is perceived to be more than the actual recordings, because a more "pleasant" noise is emitted [10].

The fundamental characteristic of porous asphalt in relation to conventional dense asphalt concrete is the very high void content of 20 % or more. The high volume of interconnecting voids allows water and air to penetrate through the porous pavement. The high voids content is reached through a very high fraction of aggregate of more than 2 mm and consequently, the volumes of sand, filler and bitumen are small. The grading curve is frequently gap graded between 2 and 10 mm. A typical mix composition for porous asphalt is indicated in table 3.1.

Reference can also be made to the CEN product standard for porous asphalt (EN 13108-7). Additionally, figure 3.3 illustrates the difference in surface texture of porous asphalt and conventional dense asphalt concrete.

Material parameter	Characteristic value
Void content	> 20 %
Thickness	30 – 50 mm
Max. aggregate size	6 – 20 mm
Aggregate > 2 mm	80 – 85 %
Binder (pure/mod.)	4 – 7 %

Table 3.1. Typical mix composition of porous asphalt

Figure 3.3. Surface texture of porous asphalt (left) compared to dense asphalt concrete (right).

The special mix composition of porous asphalt requires that special attention is paid to surface microtexture and binder exposure compared to conventional dense asphalt mixes.

The open surface structure of porous asphalt constitutes a macrotexture with good properties of skid resistance. This puts emphasis on the surface microtexture (texture of stone), which is ensured by stringent demands to the polished stone value of the aggregate.

It is also necessary to pay special attention to binder properties such as ageing and drainage in porous mixes. Possible ways to enhance binder performance is the addition of fibres or rubber powder enabling a higher binder content, which leads to thicker binder films and the use of modified binders with improved rheological properties.

As the noise reducing properties are closely related to the porosity of the overlay, clogging by dirt will decrease the advantageous acoustic properties of porous asphalt. To preserve the noise reducing properties through time, it is therefore important to maintain a high content of efficient voids. Experience shows that heavy and fast traffic tends to produce a self-cleaning effect due to the tyres pumping action, which preserves the noise reducing properties to some extent. Consequently, problems with clogging especially occur on urban roads with slow moving traffic and on emergency lanes where the self-cleaning effect is low. For this reason the use of Porous Asphalt is not recommended in urban areas with traffic speeds of 50 km/h or less. In these areas Double layer Porous Asphalt could be used or noise reducing Very Thin Layer Asphalt Concrete.

To maintain the void content at a high level on the emergency lanes of highways, it is necessary to employ declogging machines at regular intervals (twice/year). These machines inject water at high pressure into the pavement and then suck it out again.. Despite this cleaning, a loss of porosity of 5 to 10 % accompanied by a slight decrease in acoustic properties is generally to be expected through the lifetime of a porous asphalt pavement of 10 - 12 years [11.], depending on traffic intensity. At the end of the service life, the worn porous asphalt pavement can either be milled off and replaced by a new pavement or it can be made watertight by e.g. Slurry Seal followed by the application of a new pavement on top of the existing one.

Porous asphalt requires special winter maintenance measures. At temperatures around the freezing point, the surface temperature of porous asphalt respectively falls faster below and rises slower above the freezing point compared with dense asphalt mixes. The frost and ice creation is not notably increased in porous asphalt, but it emerges earlier and lasts for longer periods. Furthermore, experience points at a 1 to 2°C lower temperature in porous asphalt than in dense mixes [10.]. Winter maintenance on porous asphalt pavements generally requires an increased use of salt (de-icing chemicals) and competent winter management systems.

3.3. Double layered porous asphalt

As stated earlier, one of the main problems with conventional porous asphalt is the fact that it tends to clog, which lowers the positive acoustic properties of the pavement through time. Several pavement types which have been developed and designed especially to prevent clogging and to reduce the traffic noise even further are the double layered porous asphalt constructions, which are often marketed under a trade mark.

Figure 3.4. Double layered porous asphalt.

The double porous layer concept is shown in figure 3.4. It consists of a base and top layer of porous asphalt with coarse and fine aggregate, respectively. The fine surface structure reduces especially tyre vibration and hence noise production.

The upper layer acts like a sieve and prevents most of the dirt (especially coarse dirt) from penetrating into the construction. The difference in air flow resistance between the two layers additionally adds to the self-cleaning effect originating from the traffic. Finer dirt retained in the upper layer can be removed by vacuum cleaning equipment.

To secure the durability of the special structure of the double layer pavements, it is necessary to use a modified binder. Depending on traffic, the service life of the double layer pavement is estimated at 7 to 10 years. Furthermore, the double layer composition presents the possibility of replacing only the top layer.

The individual mix composition and noise reducing properties for the different types of double layered porous asphalt's may vary significantly as can be concluded from the following two examples.

In the Netherlands double layered porous asphalt may consist of a bottom layer of porous asphalt with a coarse single-grained aggregate (11/16 mm) which acts as a drainage layer and a thin upper layer of fine porous asphalt (4/8 mm), where the sand fraction is left out especially designed to possess advantageous acoustic properties due to the fine surface texture. The thickness of the bottom and upper layer is normally 45 mm and 25 mm, respectively.

The durability of the special structure is secured by using a modified binder which allows a high percentage of bitumen in the mix.

Noise measurements carried out *(According to the Statistical Pass-By method (EN ISO 11819-1* [18.]) on a specific double layered construction show considerable noise reduction figures for both cars and lorries at both high and low traffic speeds in comparison to dense asphalt pavements. The noise reduction at high speeds is 5-6 dB(A) (refer figure 3.2) and at low speeds (urban areas) about 5 dB(A) [12]. Ten years of experience has demonstrated that it is possible to preserve the noise reducing properties on motorways and urban roads with slower traffic paved with double layered porous asphalt. Compared to conventional porous asphalt pavements, the double layer concept therefore offers a considerable maintainable noise reduction not only on motorways, but also on urban roads with slow traffic [13, 14, 15].

3.4. Very Thin Asphalt Concrete (VTAC)

Very Thin Asphalt Concrete (VTAC) especially designed to possess advantageous noise properties has also been developed in the last ten years. Experience shows that in some cases the obtained noise reduction on these very thin asphalt pavements is of a magnitude close to or comparable to those registered on some conventional porous asphalt sections.

Compared to porous asphalt, VTAC also offers easier winter maintenance, lower initial investments and easier repair. In comparison to normal dense or semi-dense asphalt concrete, the specially designed thin low noise pavements present a minimum noise reduction in the range of 3 to 5 dB(A) and sometimes more, depending on the maximum aggregate size used.

VTAC is traditionally a gap graded 20 to 30 mm thick bituminous concrete with small sized high quality aggregate (0/6 or 0/10 mm and sometimes 0/4). The mixture customarily has a moderate sand content, and a polymer modified binder. Depending on the variety of road companies proprietary techniques, other additives such as fibres or rubber powders can be added, together with special aggregates (porous materials such as expanded clay, pouzzolane or blast furnace slag)

The void content of this pavement is typically between 15 and 25 % after 25 gyrations on the gyratory compactor.

The open surface texture of VTAC provides good noise reducing properties but also very high skid resistance due to a high level of macrotexture, with sand patch test results between 0.7 and 1.2 mm.

VTAC 0/10 is mostly used on roads with heavy traffic and high velocities, whereas VTAC 0/6 is particularly intended for urban and peripheral roads.

The main experiences with this material are in French urban areas. The noise reduction for these pavements especially designed for urban conditions can be as important as for porous asphalt.

These products, some of which have been in use for several years, exhibit good mechanical behaviour together with quite stable low noise levels, which allow them to appear among the quietest surfaces in the database mentioned in paragraph 3.1. They are not too sensitive to clogging and the texture does not change much under traffic. Polishing of the larger aggregate at the surface due to the traffic may even tend to a reduction of the energy emission in the lower part of the spectrum, because the surface becomes a bit smoother. Therefore, if a change of sound levels of the VTAC’s can be observed with time, they rather tend to converge to one level within the same pavement family.

Finally, it should be mentioned that recent products based on a continuous grading curve with reduced maximal size (0/4 or 0/6 mm), controlled void size distribution and highly modified binders achieve a very good compromise between high friction grip and low noise levels, with a noise reduction of up to 8 dB(A) compared to traditional pavements.

3.5. Ultra Thin Layer Asphalt Concrete (UTLAC)

UTLAC is a hot mix asphalt road surface course laid at a nominal thickness between 10 and 20 mm. Before the surface course is laid, a thick layer of polymer modified bitumen emulsion is spread on the existing road surface. On top of this unbroken bitumen emulsion a very open graded hot mix is laid. The unbroken bitumen emulsion fills the air voids of the pavement layer leaving only the upper part of the structure open. This method of bonding is an essential part of the process. The grading curve of this hot mix is generally gap graded and the upper sieve size of the mix is not less than 5 mm and not larger than 11 mm".
If there is not too much binder used in the UTLAC (to leave the open structure in the upper part) the noise reduction is about 2-3 dB(A) compared with Asphalt Concrete 0/11.

3.6. Stone Mastic Asphalt (SMA)

The use of SMA for the surfacing of heavily trafficked roads in Europe has become more and more widespread during the last decade. The reasons for the increased application of SMA are manifold. SMA pavements have high durability, they offer excellent resistance to permanent deformation, and they provide comfortable riding characteristics, including relatively low levels of traffic noise compared to dense asphalt concrete. Noise measurements carried out in different European countries have shown significant noise reductions on SMA pavements. SMA pavements with a maximum aggregate size of 11 mm (0/11 mm) or less (0/6 mm) have given up to 2 - 3 dB(A) [11, 16] less noise compared with dense asphalt concrete.

SMA is a gap-graded mixture with an aggregate skeleton of relatively coarse aggregates filled with a mastic of bitumen, filler and fine aggregate, resulting in a higher voids level in the aggregate structure compared to traditional dense asphalt. Normal layer thickness varies between 15 (SMA 0/6 mm) and 45 mm (SMA 0/16 mm).

Volumetrically SMA is very similar to porous asphalt as both asphalt types consist of an aggregate structure of relatively coarse aggregate. The level of voids filled with mastic is however different. The remaining void content in SMA after filling the aggregate structure with mastic is 3-6 %. The same number for porous asphalt is much higher (20 % or more) as described in section 3.2. Nevertheless, the relatively open surface texture of SMA offers advantageous noise reducing properties. *(Generally SMA is not used in France. Instead very thin asphalt concrete is used. Noise reductions are obtained by using small graded mixes).*

Due to the many advantageous properties of SMA pavements, attention is drawn to the EAPA report "Heavy Duty Surfaces: The Arguments for SMA" [16] which describes the properties of SMA pavements in more detail.

4. Conclusions

Over the last 15 years the asphalt industry has developed a whole range of new types of environmentally friendly road pavements, which can be applied to abate traffic noise. The great variety of asphalt products makes it possible for the client to choose a pavement that suits any specific situation.

The optimal selection of the specific asphalt product depends on parameters like the speed of the traffic, its amount and composition. Furthermore aspects like road geometry and climatic conditions need to be taken into consideration.

Although the Statistical Pass By method is the first European standard available to measure traffic noise level, the fact that reference pavements still vary between the different countries makes it difficult to compare on a European basis the gains that can be achieved by using low noise asphalt pavements.

However, it can be stated that a very significant noise reduction can be achieved by adopting well-selected asphalt pavements. This is the case both on urban and on inter urban roads.

The possible choice of a noise reducing pavement especially involves the consideration of the following factors (in random order):

- Desired amount of maintainable noise reduction
- Winter maintenance
- Cleaning methods
- Durability
- Price of pavement
- Drainability
- Recycling and addition of reclaimed asphalt
- Resistance to deformation
- Reduction of noise barriers > better use of available space.

The optimum solution is obtained by balancing the environmental benefit of the noise reduction against the total costs and will vary from place to place.

Except for traffic management and speed limitations, low noise pavements offer the most convenient compromise between financial cost, noise reduction performance and landscape preservation, to assist infrastructure planners and managers in dealing with the nuisance of noise pollution in the 21st century.

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