

# LOW NOISE ROAD SURFACES

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## 1. HISTORICAL REMARKS

Road traffic noise has become one of the major environmental problems of this century. It is, however, a much older problem; already the old Romans were complaining over road traffic noise as their carriages were rattling over uneven pavements causing serious annoyance (Embleton, 1977). This is perhaps the earliest indication we have that tire/road interaction really causes annoying noise. The Romans would certainly have had benefits from low noise road surfaces. However, people had more important things to worry about, and no significant measures were undertaken to reduce this noise.

Two thousand years later, in 1869, the problem seemed to be more or less the same, as noted by Sir Norman Moore, a British physician, who gave a graphic description of the noise in a London street: "Most of the streets were paved with granite sets and on them the wagons with iron-tired wheels made a din that prevented conversation while they passed by. The roar of London by day was almost terrible - a never varying deep rumble that made a background to all other sounds" (Crocker, 1984).

An early application of "low noise" surfaces was to replace cobble stones or other paving stones with wood blocks. This made the surface less uneven and softer, both of which resulted in lower tire/road noise. However, naturally, the advantage was won at the expense of durability and cost. Crocker writes further: "In the late nineteenth century the cobblestones in the streets of London were replaced with creosoted wood blocks of asphalt. This development occurred later in the big cities of North America so that cab and wagon noise was reduced". However, the noise abatement objective was often only secondary. See



*Fig. 1 Laying of wood blocks in a street in Oslo around 1914.*

Only by the end of the 19th century, the invention in 1888 by the Irish veterinarian J.B Dunlop of a practical air-inflated rubber tire radically changed the tire/road noise emission. The increased transportation work also required smoother and more even roads. In practice, this led to that tire/road noise soon was negligible as a traffic noise component in relation to engine noise.

The increased public concern over the tremendous increase in traffic after the second world war, as well as the vehicle drivers requiring lower cab noise, soon forced the manufacturers to produce quieter power-trains of their vehicles. In the period 1955-1965, tire/road noise again was observed to be of importance, a tendency which was amplified by the ever-increasing speed of highway traffic.

Research on this matter was first initiated in the latter part of the sixties, although a handful of reports were presented also in the preceeding ten-year period. The work was then often concentrated on tread pattern optimizations - mainly randomization of the block impact period - by the tire industry itself as well as a few investigations by acoustic consultants on behalf of environmental authorities.

The road surface development has been of great importance for tire/road noise emission. During later decades this has mainly concerned the three following development trends:

1. With the purpose of reducing hydroplaning hazards, grooving of cement concrete surface has become common.
2. With partly the same purpose, partly for economical reasons, a change-over from smooth asphaltic surface to rough surface dressings (chip seals) has occurred on a large portion of the road network.
3. In order to utilize a lot of advantages, not the least low noise, the interest in porous drainage asphalt surfaces has increased.

The first trend has essentially increased tire/road noise emission; often resulting in frequent objections from people living close to these roads (and the drivers as well). Also the second trend has increased the noise somewhat - especially indoors - while the third trend appears to have a considerable potential for reduced traffic noise.

The advantage in terms of noise reduction of drainage pavements was pointed out in British and American investigations already 15-20 years ago. However, there was never any break-through for these pavements as noise reduction measures. During the last 5 years there have been extensive investigations on this particular problem in many countries. In the years 1981-83 drainage pavements were first used as noise reduction measures in Sweden. At present, a common Nordic project deals with this subject. The recent "International Tire/Road Noise Conference 1990" was dominated by papers on road surface design for reducing noise, which illustrates the current interest in this subject. See further (INTROC 90, 1990).

## **2. VEHICLE NOISE EMISSION**

### **2.1 NOISE SOURCES**

Noise emission from a road vehicle is composed of several components. The various sources are indicated in Fig. 2. The two major components are tire/road noise and power-train noise. It is necessary to discriminate between these since they are fundamentally different and are influenced differently by reduction methods and driving conditions.

Typically, one may say that the relation of tire/road noise versus speed follows a logarithmic law: approx. 12 dB(A) increase in peak level per doubling of speed. Power-train noise, on the other hand, is only slightly influenced by speed. Therefore, there is a "cross-over speed" over which tire/road noise is dominating the overall noise and under which it is negligible. This speed presently lies in the range 30-50 km/h for cars and 40-70 km/h for trucks.

Since traffic work in cities is made up of traffic at speeds both above and below these "cross-over speeds", it is obvious that both power-train and tire/road noise must be reduced in order to obtain a better environment.

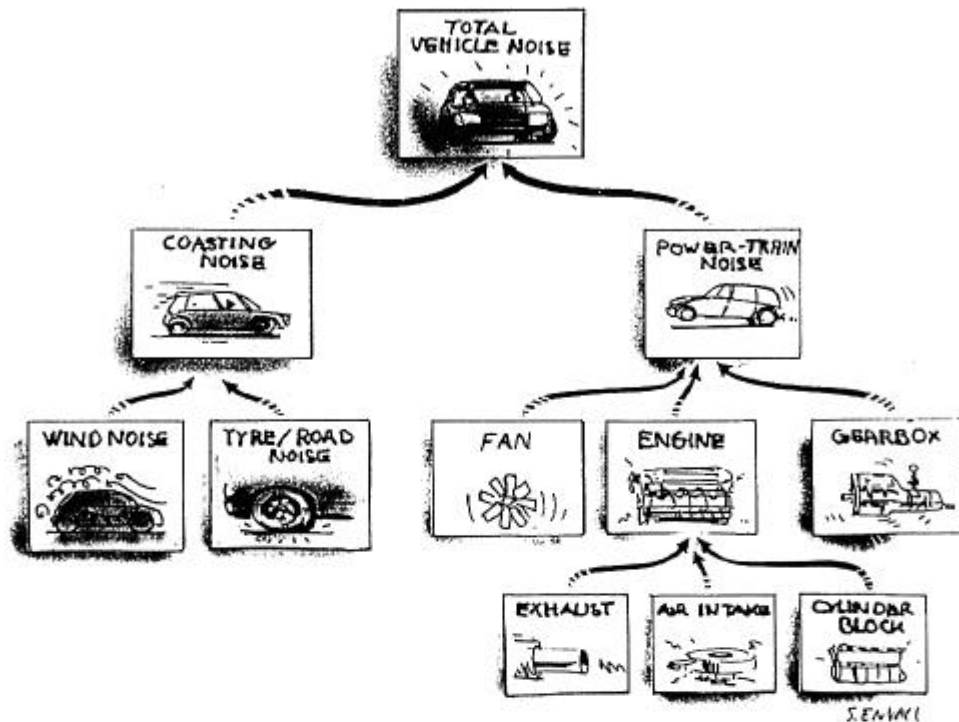


Fig. 2 The most important noise sources of a road vehicle.

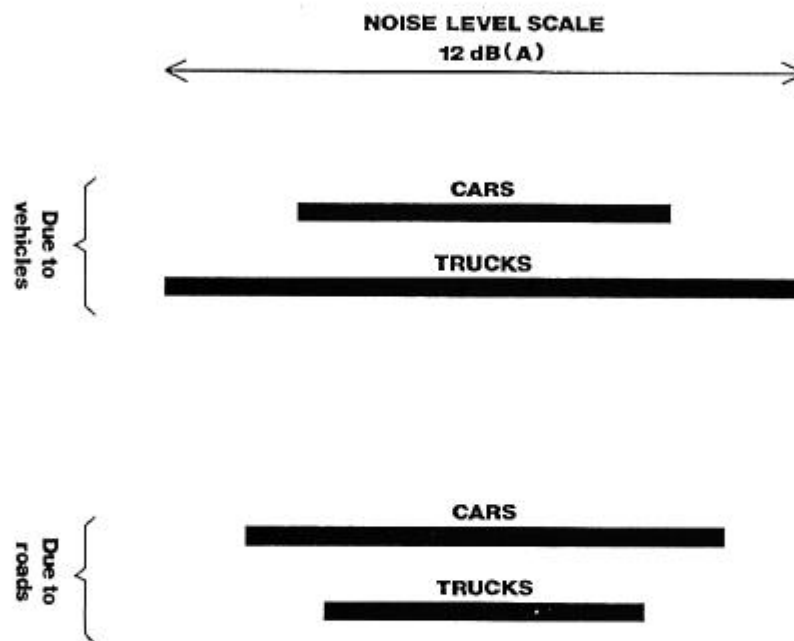
Currently, and with the new generation vehicles, it is being realized that tire/road noise plays a bigger role in urban traffic noise than expected before. Measurements of full-throttle acceleration noise for new vehicles, according to present noise emission regulations, have shown that tire/road noise may determine much of the overall noise even at acceleration on medium gears of the vehicles (Betzl, 1990 and Åhsberg, 1990).

## 2.2 THE SHARED RESPONSIBILITY OF VEHICLE, TIRE AND ROAD MANUFACTURERS

Investigations at the Swedish Road and Traffic Research Institute (VTI) have shown that the spread of traffic noise levels on different road surfaces with similar traffic is as large as the spread of vehicle noise levels from separate vehicles on one surface. This applies to free-flowing traffic at a posted speed of more than 50 km/h. It is consequently as easy or as difficult to influence the overall traffic noise by choice of road surface as by selection of vehicles.

Fig. 3 illustrates the above. The bars show the spread in vehicle noise from the "most silent" to the "noisiest" case (the 95-percentile is referred to) for the case that the vehicles

are different but the road surface is the same (the two bars to the left), as well as the case that the vehicle composition is constant but the road surface varies (the two bars to the right). Consequently, the left two bars show how much the noise from different vehicles vary (mainly due to tires) and the right two bars how much the noise varies when driving on different road surfaces. Thus the result is that the road surface influences the overall noise about as much as the individual vehicle.



*Fig. 3 Spread in traffic noise on different road surfaces and from individual vehicles, according to measurements at VII 1982-88 in free-flowing traffic at about 70 km/h. Only dry, bituminous road surfaces are included. The bars indicate approx. the 5 to 95 percentiles, i.e. there are generally 5 % more extreme values at either end.*

The figure refers to free-flowing traffic at about 70 km/h, but is valid also for higher speeds. At lower speeds, or by accelerating traffic, the right two bars will decrease, i.e. the effect of the road surface will be reduced. The left two bars may then increase instead and power-train noise becomes the major factor. However, wet or extreme surfaces have

not been included in the figure. If wet surfaces, cement concrete or paving-stone surfaces had been included, the effect of the road surface would have increased further.

A consequence of the above is that the road building and maintenance authorities as well as vehicle and tire manufacturers and drivers should assume the joint responsibility for reduction of traffic noise.

### 2.3 TIRE/ROAD NOISE GENERATION MECHANISMS

In order to understand the influence of road surfaces on traffic noise it is necessary to have a basic understanding of how tire/road noise is generated. Here is a brief summary of the mechanisms considered to be significant:

- |                               |   |
|-------------------------------|---|
| 1. Radial vibration mechanism | 1A. Impact of tire tread blocks or other pattern elements on road surfaces  |
|                               | 1B. Impact of road surface texture on the tire tread.                       |
| 2. Air resonant mechanism     | 2A. Pipe resonance  |
|                               | 2B. Helmholtz resonance   |
|                               | 2C. Pocket air-pumping (this may also be a special case of 2B)              |
| 3. Adhesion mechanism         | 3A. Stick/slip motions causing tangential tire vibrations (see also 2A, 2B) |
|                               | 3B. Rubber-to-road stick/release (adhesive effect)                          |

In addition to this, there are some phenomena influencing the amplitude:

- I. The horn effect
- II. Sound absorption in the road surface
- III. The mechanical impedance effect

Comments:

Tread radial vibrations are caused by small deflections in the tire tread due to the impact and release forces, and radiate as sound after low-pass filtering in the tire.

The pipe resonance is due to standing waves in the "air tube" in the grooves of the tire tread. Concerning the Helmholtz resonance, the volume of air in a cavity will act as a

spring resonating with the mass of air in the "throat" between the cavity and the external air. In a tire-axle-fixed coordinate system, a cavity in the tread travels out of the road contact area and up the tire circumference. The resonance frequency and probably also the amplification then change with the revolution.

Air pumping occurs when a cavity is closed and opened and the air is compressed/expanded with such a speed as to cause great air turbulence and thus noise. The Helmholtz resonance may amplify the noise.

Between the curved tire tread fore and aft of the tire/road interface and the road surface, there is a space forming an acoustical horn which increases the radiation efficiency backwards and forwards. This may be largely ineffective if one side of the "throat", e.g. the road surface, is made porous.

The stiffness of the road surface, or the matching of mechanical impedance tire-to-road, influences the tread block or road texture impact so that it may be amplified (stiff road) or attenuated (soft road), i.e. influences mechanism No. 1.

Mechanism No. 1 is limited to rather low frequencies (below 1 kHz generally) while mechanisms No. 2 and 3 seldom occur below 1kHz. Mechanisms No. 2B, 2C and 3 should be most important at the trailing edge, accentuated also by the horn effect.

Thus, the generating mechanisms encompass many interesting acoustical phenomena of a fundamental nature, but altogether form a very complicated pattern.

#### **2.4 ROAD SURFACE INFLUENCE ON NOISE**

In a cooperative Belgian/Swedish program a study was made to find which parameters of the road surface influence noise generation. Parameters such as macrotecture, friction, water drainage, sound absorption and mechanical stiffness of the roads were considered. The outcome was that there was no influence by friction or water drainage on noise that could not equally well or better be attributed to the macrotecture. Sound absorption influenced the noise, but only for drainage surfaces. Mechanical stiffness could perhaps influence the noise, but to a minor extent only.

It was preferred to replace the commonly measured sand-patch texture depth by a measurement of the profile curve of the road surface. This profile curve was analyzed either by filtering it using an analogue technique or by calculating its spectral content with a digital technique to obtain a third-octave band texture spectrum. The reason is that it was found that simpler values such as the sand-patch texture depth are not sufficient to describe the road texture in this case.

Over the range of road surfaces tested, the noise levels at each acoustic frequency were correlated against the road texture levels at each texture wavelength. The best correlation between noise and road texture was obtained for certain frequencies of the noise and certain spatial frequencies or wavelengths of the macrotecture. Fig. 4a illustrates the correlation of the noise at low frequencies with the texture at long wavelengths for one of the tires and Fig. 4.b illustrates the same relation between high frequencies of the noise and short wavelengths of the texture. The relation appears to be reverse in these two cases!



These facts imply that there is no simple and general relation between the overall noise level and texture. Rather, the overall noise level is composed of the sum of these two effects which may favour any of them depending on the exact circumstances.

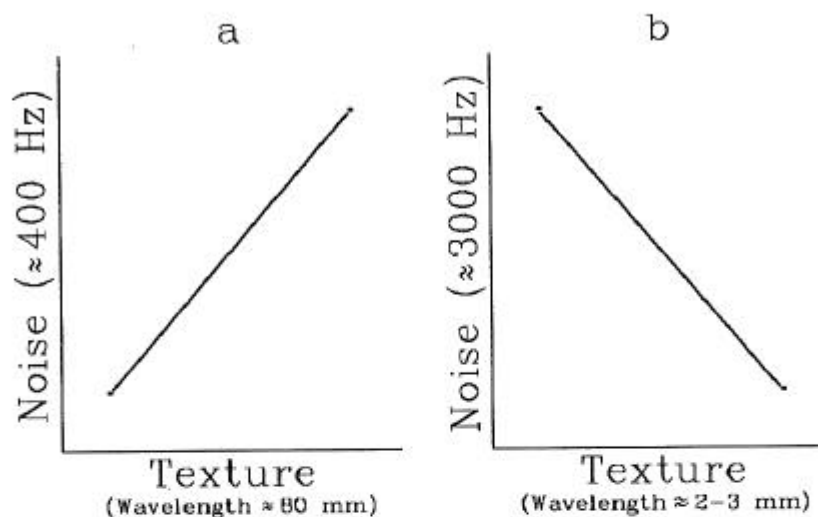


Fig.4. Illustration of how noise and texture are related for the two most pronounced cases:  
*a.* Noise at a low frequency (approx. 400 Hz) versus texture at a long wave length (approx. 80 mm).  
*b.* Noise at a high frequency (approx. 3 000 Hz) versus texture at a short wavelength (approx. 2-3 mm).

The correlation between the noise and texture for all noise frequencies and all texture wavelengths is illustrated in (Sandberg, 1987-I). It was concluded that there are (at least) two major generation mechanisms which are uncorrelated with each other; one in the low-frequency range (below 1 000 Hz) with a positive correlation with road macrotexture and another in the high-frequency range (above 1 000 Hz) with a negative correlation with macrotexture.

The low frequency mechanism is No. 1 and the high frequency mechanism No. 2 and/or No. 3 described in section 2.3.

### 3. CORRECTIONS FOR ROAD SURFACES IN NOISE PREDICTION MODELS

It has been recognized for a long time that road surfaces influence road traffic noise. Consequently, when noise prediction schemes are used, it is desirable to include a road surface correction to the basic noise emission values in order that the noise predictions be as accurate as possible.



This principle is employed in, for example, the prediction methods used in the U.K. (DoT, 1988) and in Germany (RLS-90, 1990). The U.K. method utilizes a correction according to this:

"For roads which are impervious to surface water and where the traffic speed ( $V$ ) used in Chart 4 is  $>75$  km/h the following correction to the basic noise level is required; for concrete surfaces

$$\text{Correction} = 10 \text{ Lg} (90 \text{ TD} + 30) - 20 \text{ dB(A)};$$

for bituminous surfaces

$$\text{Correction} = 10 \text{ Lg} (20 \text{ TD} + 60) - 20 \text{ dB(A)};$$

where TD is the texture depth measured by the sand-patch test.

For road surfaces and traffic conditions which do not conform to these requirements separate correction to the basic noise level is required.

**Tabelle 4: Korrektur  $D_{\text{StO}}$  für unterschiedliche Straßenoberflächen**

	Straßenoberfläche	$D_{\text{StO}}^*$ in dB(A) bei zulässiger Höchstgeschwindigkeit von		
		30 km/h	40 km/h	$\geq 50$ km/h
	1	2	3	4
1	nicht geriffelte Gußasphalte, Asphaltbetone oder Splittmastixasphalte	0	0	0
2	Betone oder geriffelte Gußasphalte	1,0	1,5	2,0
3	Pflaster mit ebener Oberfläche (Bild 1)	2,0	2,5	3,0
4	sonstiges Pflaster (Bild 1)	3,0	4,5	6,0

\*) Für lärmindernde Straßenoberflächen, bei denen aufgrund neuer bautechnischer Entwicklungen eine dauerhafte Lärminderung nachgewiesen ist, können auch andere Korrekturwerte  $D_{\text{StO}}$  berücksichtigt werden, z. B. für offenporige Asphalte bei zulässigen Geschwindigkeiten  $> 60$  km/h  $- 3$  dB(A).

*Fig.5. The German correction for road surface influence on traffic noise (RLS-90, 1990).*

### ***Impervious road surfaces***

For impervious bituminous and concrete road surfaces, 1 dB(A) should be subtracted from the basic noise level when the traffic speed (V) used in Chart 4 is <75 km/h.

### ***Pervious road surfaces***

Roads surfaced with pervious macadams have different acoustic properties from the surfaces described above. For roads surfaced with these materials 3.5 dB(A) should be subtracted from the basic noise level for all traffic speeds\*.

The German model has another construction of the correction; see Fig. 5.

Translation of the text to the left:

1. Non-grooved mastic asphalt, asphalt concrete or split mastic asphalt
2. Cement concrete or grooved mastic asphalt
3. Block surface, even
4. Other block surface.

The footnote is translated:

For low noise road surfaces, for which on the basis of new developments in construction a long-lasting reduction is obtained, also other corrections DStrO can be observed, e.g. for open-porous asphalt at posted speeds >60 km/h - 3 dB(A).

These are just examples, however from two of the major prediction methods, showing that there is no consensus regarding how road surfaces are classified with respect to noise emission.

This therefore identifies an important subject for research and investigation. See further the Chapter about measurement methods.

## **4. MEANS OF NOISE CONTROL BY AUTHORITIES**

Environmental and traffic authorities may control noise in urban areas by using four main principles:

1. By controlling traffic.
2. By specifying a certain design of roads/streets, buildings, barriers, etc, as well as the location of such structures (design strategy).
3. By specifying objective or limiting values in terms of noise level(s) which must not be exceeded at a certain time or location (performance strategy).
4. By encouraging the use of "low-noise devices" by providing certain advantages to the constructor, supplier or user (encouragement strategy).

It has appeared that, for free-flowing traffic, the type of road surfacing influences the traffic noise as much as the individual vehicles do (within each vehicle class) as was described in Chapter 2.2. It implies that it is equally efficient to encourage the use of quiet

road surfaces as the use of quiet vehicles or quiet tires. In those urban areas where the traffic is not free-flowing the effect of surfacings is less but it is rarely completely unimportant. The following, therefore, focuses the noise control on road surface selection.

The first approach to noise control as stated above has no relevance to road surface design or use.

The second approach can be used, for example, to limit or exclude the use of "noisy" road surfaces in disturbed areas. It is not uncommon that block pavements are replaced by other pavements in towns and cities, for example. In some cases, authorities may also exclude the use of transversely grooved cement concrete or rough-textured chip seals in such areas.

It may also be required that a porous surface be used. This has been decided in the Netherlands where all the state road network is to be surfaced with porous asphalt when re-surfacing is necessary.

The third approach is indirectly related to road surface selection, since it may be easier to comply with certain noise limits when using a low noise surface. The use of a low noise surface may also relax the requirements for other noise control measures, e.g. the complexity and cost of a noise screen could perhaps be reduced if it is combined with a low noise road surface.

The fourth approach is applied in certain cases today regarding vehicles. Special "low noise vehicles" may get a certain tax relief, or they may be allowed (alone) to travel in certain areas at certain times. The latter is employed in Austria where there is a ban for night-time heavy traffic on some transit roads, with the exception for trucks which emit max. 80 dB(A) during type approval. Some countries define "low-pollution" vehicles which may be required in certain areas or be given other advantages.

Even though this principle is not yet utilized, one could consider to give an economical advantage to the road responsible organization which makes use of some low noise road surface.

One problem is common to the approaches above (except traffic control) and that is how the noise classification of road surfaces shall be made. This problem is addressed later in this paper and it shall be mentioned here that the practical implementation of road surface selection is more or less based on the assumption that there is an accepted way of measuring the influence on noise of road surfaces.

## **5. MEASUREMENT STANDARDS AND REGULATIONS**

### **5.1 INTRODUCTION**

Standardized methods to measure noise from different types of vehicles exist today (specified for instance within the ISO, the ECE and the EC). This is justified since different vehicles can be designed for different noise levels and these methods enable the desired control of vehicle noise. Similarly, it has been proposed to impose regulations on noise emission from tires and proper measurement methods are already suggested (ECE, 1990).

Corresponding international methods to measure traffic noise do not exist, nor are there methods to separately measure the influence of the road surface on traffic noise.

Therefore, it has been realized that a new measuring method for classification of road surfaces ought to be developed. This method should allow comparable and reproducible measurements of the effect of different road surfaces on traffic noise. It would then supplement existing methods which allow the measurement and comparison of noise emission from different vehicles and also supplement the suggested method(s) for classifying tires.

A working group with the task of developing such a method was established at the beginning of 1991 within the International Organization for Standardization (ISO). The group is named ISO/TC 43/SC 1/WG 33 and is convened by this author.

With the intensified European co-operation and commercial exchange it is important that classification of road surfaces from the point of view of noise is uniform so that a surface which is proven to be good in one country also can be accepted in another country (of course, considering also climatic influences). Results of measurements should be comparable from time to time, from place to place and from country to country.

## 5.2 MAIN TYPES OF MEASURING METHODS

The following main types of methods suitable for measuring tire/road noise have been used:

1. The coast-by method
2. The trailer method
3. The laboratory drum method
4. The on-board microphone method (variant of the trailer method)
5. The drive-by method (variant of the coast-by method)
6. The propagation or sound absorption methods
7. The statistical method

In the coast-by method, a test vehicle presumably equipped with some test tires is rolling (coasting-by) with the engine switched-off past a road-side located microphone. The microphone is 7.5 m from the center of the test or road track on which the vehicle coast. The peak noise level is recorded when the vehicle coasts by, usually with the FAST time constant.

The method is often used to classify the road surface influence on noise, but it has some disadvantages:

- It is impractical and sometimes even impossible to use on motorways
- It requires special test vehicles and, furthermore, a low traffic intensity in order not to be disturbed by noise emitted by the traffic
- It requires some sets of reference tires which can always be used on all road surfaces

**The trailer method** requires fewer reference tires and is not very sensitive to noise from traffic. The test tire is mounted on a trailer which is towed by a vehicle. Close to the test tire, generally within 0.1-0.5 m, one or more microphones are located. The noise level is measured as an average over a certain time interval, generally 4-60 s. Most trailers

have an enclosure around the microphone and test tire in order to provide screening from wind and traffic noise.

The method has the advantages of being fast, simple, precise, requires relaxed demands on the topography and areas close to the road, and is nearly independent of surrounding traffic. It has, nevertheless, some disadvantages:

- It measures only tire/road noise. Traffic noise must be estimated from this
- It underestimates the noise reduction of porous road surfaces since it measures close to a test tire and so does not consider the noise absorption of these surfaces over longer distances
- It requires reference tires
- It requires a special trailer

The main questions are what reference tires are to be chosen (this is likely to be a controversial issue), how typical and longlived these are, and how the disadvantage of not considering the sound propagation effect of porous road surfaces is to be compensated.

The disadvantages have, however, not prevented some researchers to use this method also to measure on porous road surfaces.

**The laboratory drum method** can be excluded for road surface classification since it is impossible to test actual road surfaces on a drum surface. This is a sheer laboratory method and there is yet no generally available equipment that admits samples from road surfaces to be mounted into or onto a drum without presenting unacceptable problems.

**The on-board microphone method** is somewhat similar to the trailer method. The main difference is that one of the tires of the test vehicle is used as the test tire and the microphone/tire are never screened.

The method's only advantage compared to the trailer method is that no trailer is needed, but it has a whole range of additional disadvantages, which makes further consideration superfluous; for example it is sensitive to disturbances from surrounding traffic and very sensitive to air turbulence noise in the microphone.

**The drive-by method**, which is measuring tire/road noise (or vehicle noise) from an accelerating vehicle, is difficult and impractical. Often, uniform testing is made according to the ISO 362 or ISO 7188 procedures. It is irrelevant here, since in those cases where the properties of the road surfaces are important, the traffic probably flows freely without much acceleration, which makes this method unrepresentative in this context.

**The sound propagation or sound absorption method** is used to study only a part of the problem: the sound propagation from source to receiver, i.e. the immission. Either samples of the road surface are mounted at the end of a tube (Kundt's tube) and the sound absorption coefficient measured, or a loudspeaker emits a "reference" noise which is picked up by a microphone at some distance (generally the same source-receiver configuration as in the coast-by method). By doing the latter on different surfaces, their relative influence on propagation can be studied. The method is useful in this context to study porous asphalt coatings but it cannot alone provide the desired information about the noise properties of road surfaces in general since their influence on the emission is not being considered with this method.

**The statistical method** has been used in different forms during more than a decade and is the method with the closest resemblance to a real traffic situation. The procedure

is that one or several microphones are mounted by the roadside (usually 7.5 or 10 m, and not more than 15 m from the road) and the sound levels and/or noise spectra from the passing traffic are measured during a time period long enough to let a large number of vehicles pass by so that an average for "typical" and "normal" traffic is obtained.

Normally, also the speeds of the vehicles are measured and the number of vehicles of various types are registered. If the mean speed and/or the vehicle composition deviates from a "normal value", corrections are made so that the obtained values be comparable.

Either the equivalent sound level from all the traffic is measured (often the whole distributive or cumulative sound level distribution is measured at the same time), or else the peak levels from separate passing vehicles, or both, are measured. Frequency spectra may also be measured.

The advantages are:

- This method measures actual traffic noise and can distinguish between light and heavy vehicles
- This method is relatively fast and requires only two persons to conduct the measurements
- This method does not require reference tires or special test vehicles
- This method already exists in various forms in a number of countries

The disadvantage is:

- The obtained noise levels apply to the vehicle mix that passes precisely while the measurement is being made. By measuring a sufficient number of vehicles, an accurate average can be obtained. However, over time periods of several years, the noise emission can change due to new types of vehicles and tires.

### **5.3 REGULATIONS**

There is not yet any regulation known to the author regarding the use of road surfaces with respect to noise reduction. Such regulation must be based either on "design strategy" or "performance strategy". The former gives no incentive for improvements, so the latter should be preferred. However, it is impossible to apply the "performance strategy" until the measurement problem is solved.

## **6. ASSESSMENT OF THE POROUS SURFACES**

### **6.1 TERMINOLOGY**

Road surfaces which have a porosity allowing water to flow vertically through them have been given many names, for example:

- o Drainage asphalt
- o Drainage surfaces
- o Porous surfaces (or asphalt)



- o Pervious surfaces (or asphalt)
- o Pervious macadam
- o Open-graded asphalt
- o Open-graded friction mix
- o Porous friction mix
- o Open-textured asphalt
- o etc (the author could mention at least twice as many)

This author thinks that the most relevant terms would be "porous surfaces" or "pervious surfaces". Asphalt or cement concrete could replace "surfaces" if that distinction is necessary. Porous surfaces evidently possess a significant porosity, i.e. air voids. However, at least in principle, this does not make them pervious. Pervious means that water and air can flow through the surface, i.e. that the pores are open, and should be the characteristic that determines the acoustical properties. However, usually the pervious and porous characteristics are well correlated.

In this paper, the term porous has been used consistently, even though it is recognized that pervious may be a more relevant term. This is because the term porous seems to be more commonly used than pervious, although people very often mean pervious when they speak about porous.

## 6.2 CONSTRUCTION

In a **conventional** asphalt concrete wearing course, the mix that is laid on the road is composed of:

- o Stones or "chippings" of max. sizes 2-16 mm (bigger ones may occur but are rarely used due to the rough texture caused by them). Typically the weight fraction of the stones lies in the range 40-55 % (by total weight of the mix).
- o Sand of grain sizes 0.06-2 mm. The weight fraction of sand is usually in the range of 35-45 %.
- o Filler, a very fine sand with grain sizes <0.06 mm. This weight fraction may be around 5-10 %.
- o Binder, i.e. bitumen ("asphalt") or corresponding. Typical binder fractions are around 4-8 % by weight.

Thus, an "asphalt" road surface is mainly made up of stones and sand and the real "asphalt" is often not more than 6 % of the total weight.

The "concrete" that is created by this mix is bound together by the binder to which it is nowadays common to add polymers, rubber powder, fibers, etc. The intention with this mix is to combine strength with high compaction. Typically, the air voids in the mix will be around 3-5 % by volume, and these voids are mostly not interconnected.

The mix of stones, sand and filler is proportioned according to "grading curves" like the ones in Fig. 6 which describe the fraction of stones or sand passing a certain sieve size.

When the binder is cement instead of bitumen, one speaks of a "cement concrete" surface, commonly called just "concrete". The latter is not a recommended term here since "concrete" technically refers just to a certain mix which could be bound by any



binder, including asphalt. Cement concrete surfaces have slightly different proportions of the ingredients above as compared to the asphalt concrete surfaces.

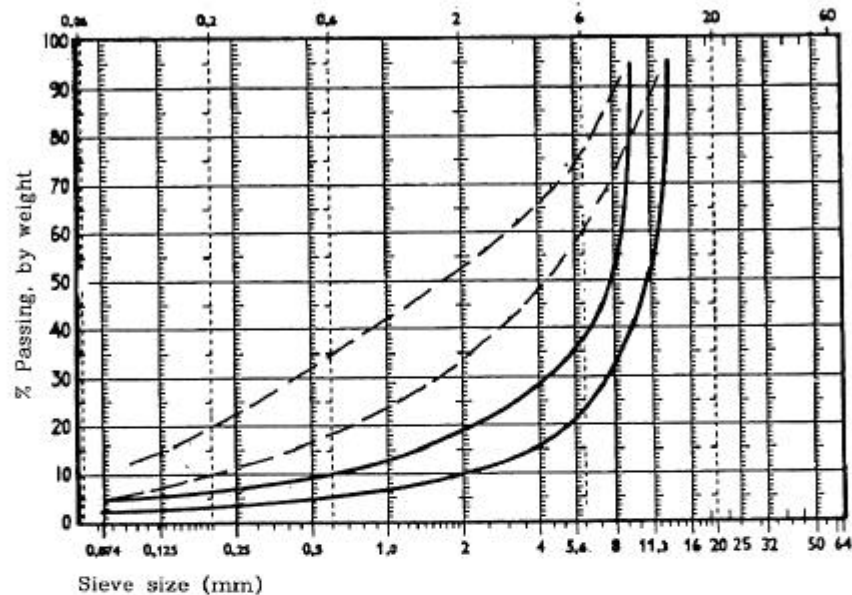


Fig 6. The grading curves for conventional asphalt concrete with max. stone size 12 mm (broken lines show the upper and lower tolerances) and for a porous asphalt concrete, "Drainage Asphalt" (solid lines show the upper and lower tolerances). This figure refers to the Swedish standard (BYA, 1984). Other countries may have slightly different standards.

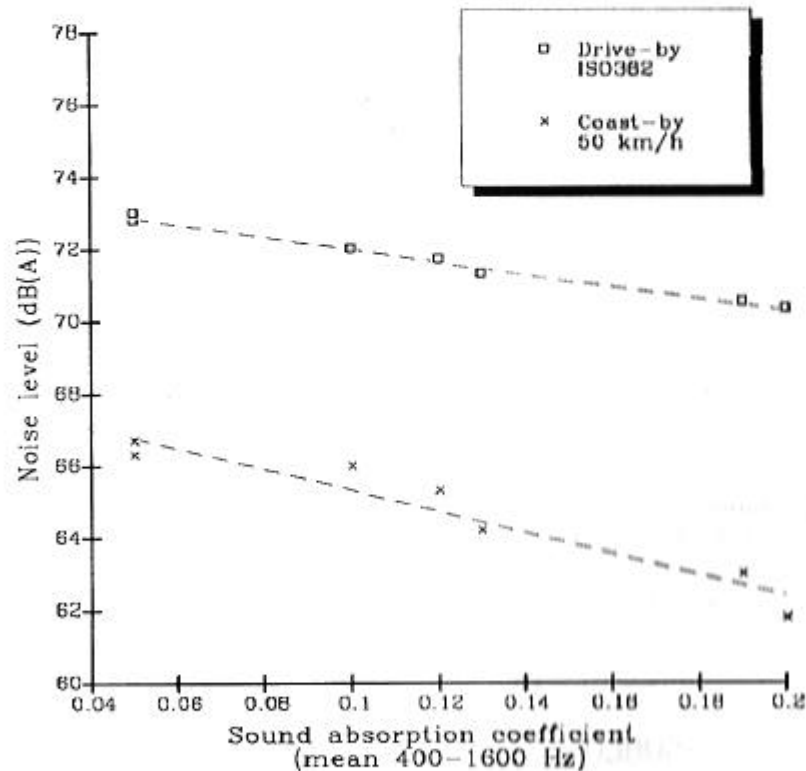
To get a porous mix, the proportions of stones, sand and filler are changed radically, in the direction that the "middle sized" fractions are reduced (in the case of Fig. 6 sizes approx. 1-4 mm). This will result in the air voids increasing radically, i.e. a porosity between the dominating bigger stones is created. Typically one aims at a porosity in the range of 15-20 % by volume, although even higher porosities are desired from the drainage point of view. However, it is always a balance between strength and drainage. The porous surface according to Fig. 6 will have an initial air voids content of 15-25%. In the following, the term "semi-porous" is used for surfaces which have an air voids content around 10-15 %.

### 6.3 ACOUSTICAL REDUCTION PROPERTIES

The porous surface obtains three major properties of importance to vehicle noise reduction:

1. Its porosity will eliminate the compression and expansion of air entrapped in the tire/road interface when tires are rolling over the surface. "Air pumping and air resonant tire noise" will then be reduced (mechanism No. 2 in Chapter 2.3).
2. Its porosity will also reduce the amplifying effect of the acoustical horn existing in the space between the curved tire tread and the plane road surface (the phenomenon No. 1 in Chapter 2.3).
3. Finally, the porosity will give the surface an acoustical absorption, which will influence the reflection and propagation of the noise. This will influence not only tire/road noise but also other types of vehicle noise (phenomenon No. II in Chapter 2.3).

Several investigations have penetrated the theoretical effects of porous surface design parameters on noise reduction. Characteristics like porosity, thickness, flow resistance, shape factor and tortuosity have been considered. The reader is referred to papers by Hamet, Attenborough, Berengier, Storeheier and von Meier in (INTROC 90, 1990) if further information is required. However, in this paper only a brief summary of the parameters which can most easily be influenced by the road constructor are reviewed.



*Fig. 7 The relation between noise level (tire/road noise and noise from acceleration vehicles, respectively) and sound absorption coefficient. Data averaged for 5 vehicle/tire combinations, measured at 7.5 m from the centre of lane.*

#### 6.4 THE IMPORTANCE OF AIR VOIDS

As mentioned earlier, it has been desired to obtain an air voids content of 15-20 %, preferably even higher. An air voids content of 15-20 % is supposed to correspond to sound absorption around 0.20-0.30. However, recently, it has been shown that a sound absorption coefficient in the range 0.10-0.20 also affects the noise; see Fig. 7 which is based on data collected in a round robin test conducted by the working group ISO/TC 43/SC 1/WG 27 which is producing a proposal for a low noise test track surface with negligible sound absorption.

For higher air voids contents, the next two figures could supply interesting data. In order to achieve a noise reduction of about 3-5 dB(A), 20-25 % voids are obviously required.

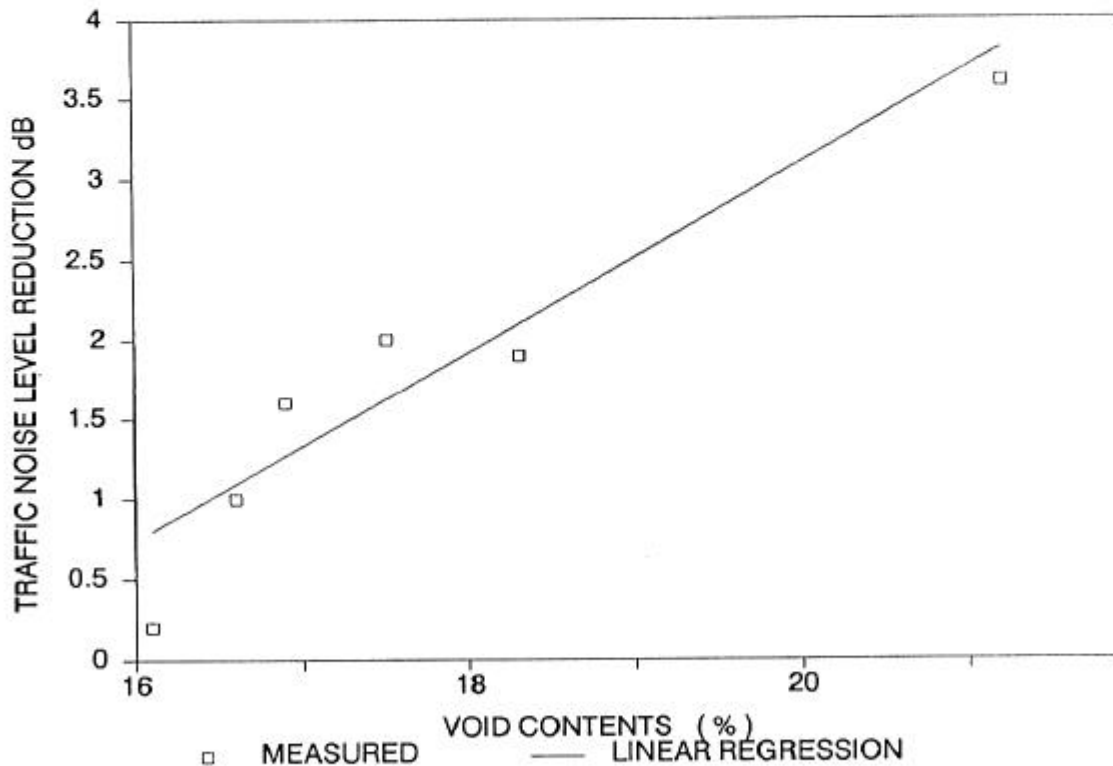


Fig. 8 Traffic noise reduction as a function of air voids content. Measured at the road-side for roads/streets in the Oslo area with posted speeds 50 km/h and mixed traffic (Storebeier & Arnevik, 1990).

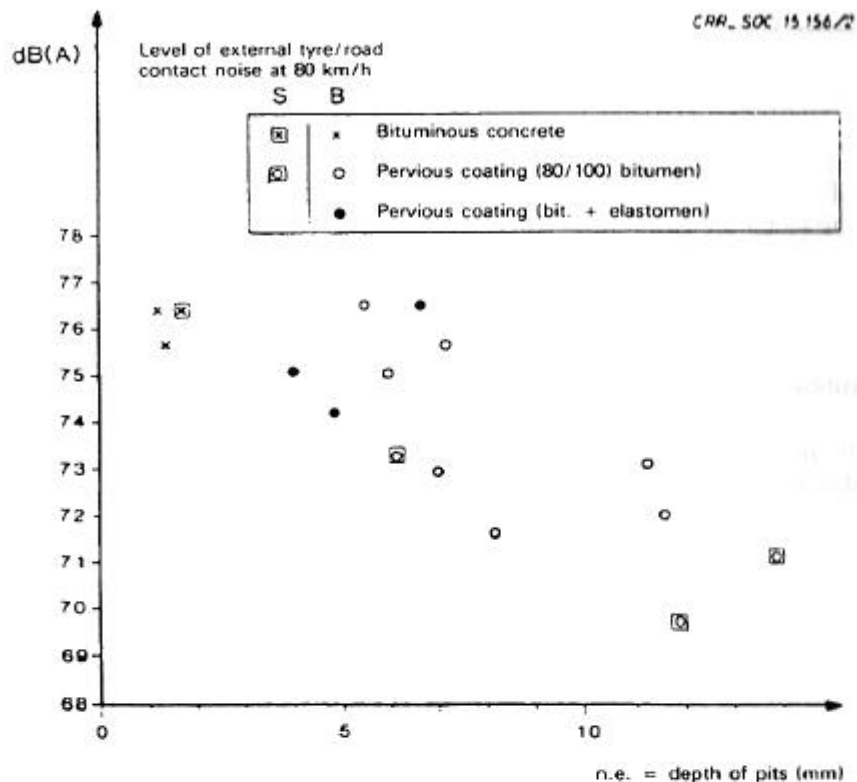


Fig. 9 The relation between tyre/road noise at 80 km/h (at 7.5 m) and the product of air voids content (in fraction of 1.00) and layer thickness in mm ("n.e."). From (PIARC, 1987).

## 6.5 THICKNESS OF THE LAYER

Already in Fig. 9 it is indicated that the thickness of a porous surface has a positive influence on noise reduction. Generally, the effect of thickness is to displace the frequency at which sound absorption is maximum to lower values. At the same time the absorption versus frequency dependence is smoothed out from a very "peaky" curve at small thickness (30 mm) to a much smoother curve at big thickness (600 mm). See e.g. (Hamet, Berengier and Jacques, 1990). In most cases this will increase noise reduction since the fit between the sound absorption frequency spectra and that of the emitted noise coincide better then.

Several of the papers in (INTROC 90, 1990) show thickness influence on noise reduction. For example, (Storeheier, 1990) shows that the effect in an urban area of using a double layer of porous surface instead of a single one (80 instead of 50 mm) is one additional dB(A) of traffic noise reduction.

Some researchers have also experimented with super-thick porous structures, up to 700 mm. Preliminary results indicate a total noise reduction of approx. 8 dB(A), instead of 4 dB(A) for thin layers, in relation to conventional, dense asphalt concrete (Pipien & Bar, 1991). Very recently (Stenschke, 1990) reported that a 500 mm thick structure reduced vehicle noise at coast-by and pass-by by 6-11 dB(A) depending on binder type and driving condition and 5-7 dB(A) for a stationary car. The latter indicates the big potential for improvement due to the third effect as stated in Chapter 6.3, i.e. sound propagation.

## **6.6 INFLUENCE OF THE BINDER**

Binders like pure bitumen, cement, "plastic", bitumen added with fibers and bitumen added with rubber powder have been tried.

In those cases where a direct comparison have been possible between the binder effects, no influence has been demonstrated. For example, this author has tried surfaces with and without 8 % of the binder being rubber powder and found no significant difference. Measurements on a commercial surface in Sweden including fibers have not indicated any increased noise reduction in relation to one with pure bitumen binder.

Results presented in (Stenschke, 1990) showed that for a 500 mm thick structure a cement binder gave approx. the same noise reduction as when using a bitumen binder. However, a "plastic" binder gave approx. one additional dB(A) of reduction. It is not clear how the plastic binder could improve the surface.

According to (von Meier, 1988) cement shows promising properties as a binder since the internal porosity structure may be favourably altered. However, later field tests with porous cement concrete have not yet been fully successful since such surfaces have become uneven and thus uncomfortable to drive on. More research is needed and there is even a special international working group on porous cement concrete.

However, when investigating the effect of the binder, it is important to consider also long-term effects. The binder could have some influence on how fast a surface gets clogged with dirt and thus have an effect on traffic noise which is different from other binders.

## **6.7 NOISE REDUCTION OF NEW AND OLD POROUS SURFACES**

### **6.7.1 Reference Surface**

Some recorded noise reductions have already been mentioned. The word "reduction" directly implies a comparison, i.e. a noise reduction value of a road surface is always referred to a reference road surface. A problem with all "noise reductions" reported by various authors is that the reference surface often is different. Mostly, however, the authors refer to a conventional asphalt concrete of the dense type. Not even this is perfect, because a new surface of this type is quieter than an older surface. Also the chipping sizes may be rather different.

This author suggests that the reference surface for estimating "noise reduction" be a Dense asphalt concrete essentially complying with the broken grading curves in Fig. 6. It means that the max. chipping size should be 10-13 mm. It should be at least one year old.

This has the essential advantages that this type of surface

- a) often represents the most common type in urban areas
- b) in most cases is the closest "relative" to the most commonly used porous surfaces

### 6.7.2 Results

There are numerous studies on noise reduction of porous asphalt. The following table summarizes a 4-year experiment in Sweden with porous asphalt with maximum 12 mm chipping size (20-30 % initial voids content) with three different thicknesses, corresponding to 50, 80 and 100 kg/m<sup>2</sup>. The total life-time before re-surfacing was approx. 5 years. Results both for equivalent 2 hour average levels as well as peak pass-by levels (average peak levels for all vehicles) are presented. Measurements were made 10 m from the road centre. Speeds were constant in the range 60-100 km/h.

AGE OF SURFACE	NOISE REDUCTION	
	In Leq	In Lmax
0 years	5-7 dB(A)	6-7 dB(A)
2 years	4-5 dB(A)	2-3 dB(A)
4 years	1-2 dB(A)	0-1 dB(A)

*Table 1. Noise reduction relative to an old conventional dense asphalt.*

It can be noticed from the table that:

- The reduction in noise decreases with age
- The average reduction is around 3 dB(A)
- A bigger reduction is obtained for the equivalent levels than the peak pass-by levels. It can be explained by an extra reduction due to sound propagation over a "semi-absorbent" road surface at long distances.

Furthermore, it should be pointed out that:

- If the common reference would have been a dense asphalt surface of equal age as the porous surfaces, then the noise reduction value for the new surfaces would have been reduced by 2 dB(A), since this is approximately the difference between a new and old dense asphalt concrete.
  - The reduction for trucks is approx. the same as for cars.
  - Increased thickness was advantageous when the surfaces were new, but of little importance later.
  - It has been noticed in other studies that the voids content should be as high as is possible with respect to durability. At least 20 % is required initially.
- Fig. 10 shows how frequency spectra are influenced typically.

The decrease of noise reduction with age may be a typical winter climate effect. Such impaired efficiency has not been noticed in for example England (Nelson and Abbot 1990). There are reasons to believe that the efficiency of drainage asphalt can be better maintained in countries in southern Europe.

The previous data concerned free-flowing traffic on roads. How is the situation at interrupted-flow on streets where tire/road noise is much less important? According to for example (Sandberg, 1984), drainage asphalt reduces also power-train noise. The reduction is around 3 dB(A) for new surfaces in relation to a totally reflecting surface; a value which has been confirmed by several later studies.

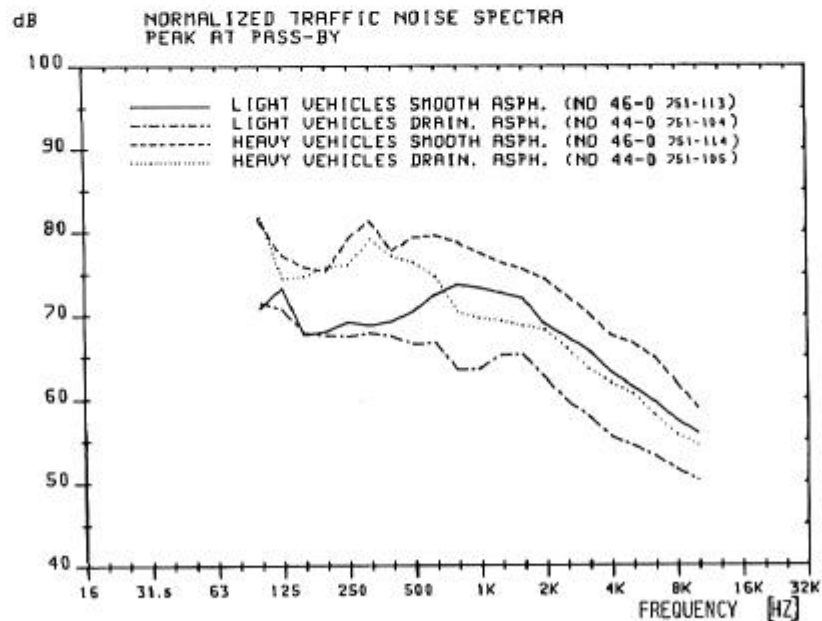


Fig. 10 Frequency spectra (peak pass-by) for traffic noise of light and heavy vehicles travelling at 80-90 and 70-80 km/h, respectively, on an old, smooth, dense asphalt and a new porous asphalt surface.



This leads to the prediction that in urban traffic a reduction of at least 3 dB(A) could be obtained on new porous surfaces. Studies regarding the application of porous asphalt in urban areas is underway, e.g. extensive programs are going on in Norway and Germany; see further below.

Results from some other countries follow.

### Norway

(Storeheier & Arnevik, 1990) reports a noise reduction of traffic noise in urban areas with 50 km/h posted speed with mainly free flowing traffic of:

- o 1.5 dB(A) for 50 mm surfaces with 17-19 % voids
- o 3.5 dB(A) for 50 mm surfaces with 21-22% voids
- o 4.5 dB(A) for 2-layer surfaces (42+38 mm)

The values above concern new surfaces. After one year the noise levels had increased by 1.5 dB(A) in the first case and 2.6 dB(A) in the second case. Therefore, the remaining noise reduction is only 1 dB(A) in the second case (0 dB(A) in the first case). Then it should be observed that the reference surface was all the time the same new surface and it is possible that it has become around 1 dB(A) noisier as is usual with such surfaces, so that a fair comparison probably would indicate 2 and 1 dB(A) reduction, respectively. (The latter is just a speculation by this author.)

### Germany

The following table which comes from (Steven, 1990) summarizes some German results.

	number of test sites	surface	percentage of max. shipping size	difference of pass-by levels between DA and AB 0/11 in dB (A)		
				min.	average	max.
residential roads	3	DA 0/11	40-70	+0,5	-1,3	-2,1
	5	DA 0/8	67-92	-1,0	-2,5	-4,3
	2	DA 0/5 0/3	100	-3,0		-3,6
Country roads	6	DA 0/14 Belgium	41	+0,7	-1,6	-4,1
	5	DA 0/12 0/11	64-70	-0,7	-1,6	-4,1
	7	DA 0/12	50-60	-0,8	-2,9	-5,5
	5	DA 0/8	70-95	-3,0	-4,3	-6,0
	5	DA 0/8	50-60	-2,9	-5,0	-6,0

Table 2. Reduction of car pass-by noise-levels (7.5 m) on different German surfaces (DA=Drainage asphalt; AB 0/11=dense asphalt, 0-11 mm stones). The speed probably was 30-60 km/h in the residential areas and 60-120 km/h on the country roads

## Spain

In a paper by (Banuelos, Irache and Zabala, 1990) it is reported that porous surfaces gave approx. 2.5 dB(A) lower noise than dense asphalt concrete surfaces.

## France

Fig. 11 summarizes some French results (Pipien & Bar, 1990) reported at the recent tire/road noise conference.

In addition, tests with drainage asphalt in actual city streets have been conducted in Paris. The result was a reduction of 1-5 dB(A) depending on the proportion of heavy vehicles and the test site (Delanne and Le Bret, 1988).

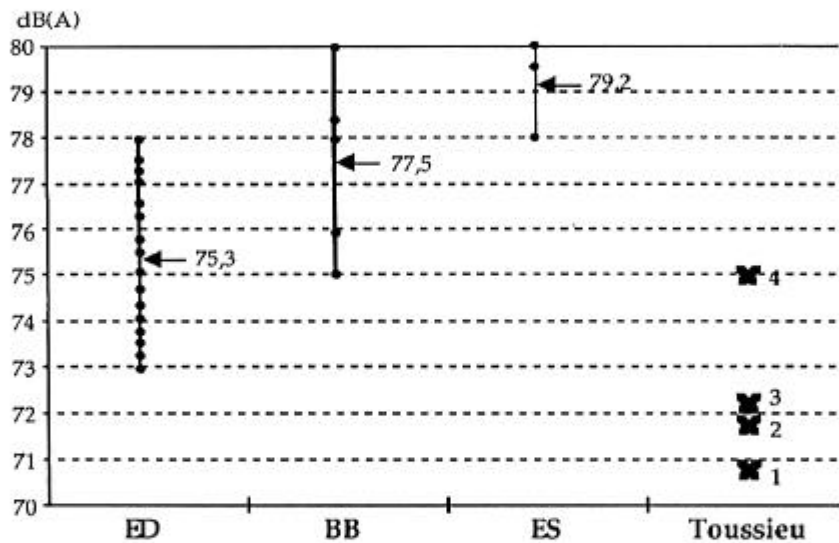


Fig. 11 Reduction of car pass-by noise levels at 90 km/h, according to (Pipien & Bar, 1990)

ES= Chip Seals

BB= Dense asphalt concrete

ED= Porous asphalt concrete (single, normal layer)

Toussieu= Super-thick structures (400-520 mm)

## 6.8 Poroclastic Surfaces

A road surface composed of rubber granulate made of used tires and bound by polyurethane has been tested in Sweden and Norway (Zetterling and Nilsson, 1990) and (Storreheier and Arnevik, 1990). It reduces vehicle and traffic noise by 5-10 dB(A) in relation to a conventional, dense asphalt surface. However, problems with wet friction, inflamma-

bility and adhesion to the base have resulted in trials being interrupted after 2-4 months. It is also expensive but it could, nevertheless, be motivated in many cases as an alternative to noise screens, provided the mentioned problems can be solved. There are many problems with screens which can be avoided if a poroelastic surface could be used instead. Research and development regarding this surface will continue in Sweden in 1991.

Since a poroelastic surface has not yet been tried over a long period of time, it is not possible to say that it is a durable surface. However, it has the potential of being long-lasting in at least two respects:

1. It is resistant to wear from studded tires, since the rubber is resilient to the stud impacts.
2. Due to its resilient properties, it is likely that clogging may be a smaller problem than on conventional porous surfaces. The dirt which accumulates will probably never get stuck in the porosities, since the rubber layer is all the time moving when a tire rolls over it.

Therefore, if other porous surfaces fail to have a long-lasting noise reduction effect in urban areas with low-speed traffic, the poroelastic surface may well be the only effective alternative, provided its major problems can be solved.

### **6.9 Porous Surface on Sidewalks and Parking Areas**

In large urban areas, a big proportion of the total ground area is covered by non-pervious materials such as dense asphalt and concrete. This is, of course, a big problem for water run-off and capacity during rain storms but it is also a big problem for the general water balance in the urban area. A solution to this problem is to use porous instead of dense pavements whenever possible.

Generally, there are less durability and wear problems on sidewalks and parking areas than on streets and it is then easier to apply porous asphalt on such surfaces. This is used to a considerable extent in Tokyo (Bendtsen, 1988). Although these Japanese surfaces are not intended for noise reduction, and not tested for noise (?), they should have a measurable effect on noise. An acoustically absorbent surface should reduce noise due to the sound propagation over semi-soft ground instead of hard ground or due to absorbing effects in the multireflecting volume contained within streets surrounded by buildings.

### **6.10 Porous Surfaces in Tunnels**

The portals of tunnels are often significant sources of traffic noise. Also, due to multi-reflections inside tunnels, noise inside tunnels can reach very high levels which are annoying the vehicle users, unless sound absorbing materials are mounted. A better solution may be to use a porous road surface in the tunnel. This would reduce noise emission as well as the build-up of a reverberant field in the tunnel. This principle has been used in Belgium, but noise effects are not yet reported as far as this author is aware of.

### **6.11 Cleaning of Porous Surfaces which have become Clogged**

Trials to clean porous surfaces which have become clogged with accumulated dirt have been made the latest years. It is reported in (Bendtsen, 1988) that in Japan high-pressure water jets have been employed to clean porous surfaces. The effects on noise were not reported and probably not measured. Similar studies have been conducted in Sweden without significant success. It is reported in (Steven, 1990) that cleaning with high pressure water jets have improved noise reduction by 1.6-2.0 dB(A), given as a before-after comparison. However, the method was not economical. Trials have been made also in Austria and the Netherlands but no results have yet been available to this author. According to verbal contact the results have not been fully successful, however.

Last year, cleaning of the Oslo test roads mentioned earlier have been successful in the respect that an improved air voids content has been recorded. The difference is certainly visible. The cost for doing this is reported (verbally) to be comparable to that of de-icing during a winter. It can thus be economical if employed at a larger scale. Extremely high water pressures were used. However, it is yet unclear whether the cleaning really improved the noise situation or not.

It must not be forgotten that traffic may have a self-cleaning effect on porous surfaces. It is reported from several researchers that the general observation is that:

- a) at high speeds, porous surfaces preserve their porosity better
- b) this is especially pronounced in the wheel tracks
- c) at low speeds, the self-cleaning effect seems to be small

The clogging effect may make the use of porous surfaces more or less unsuitable in urban areas where the speeds are less than (say) 70 km/h.

In summary, it is still an open question whether clogged surfaces can be restored or not, or if one has to accept the sometimes quick deterioration with time.

### **6.12 Safety**

One of the main purposes with a porous surface is to provide drainage of water away from the surface. It is obvious that this is in line with safety requirements. It is concluded in (Sandberg, 1987-II) that there is no general conflict between low noise and safety.

There is one problem, however. Water freezing on the surface may make the surface extremely slippery at some times. Normally, this is handled by de-icing with salt. On a porous surface, however, more salt is required since some of it is pouring down into the porosities and has no effect on the surface. Also, the different thermal effects in a porous layer as opposed to a dense layer may require an earlier action with salt. Finally, after a rainfall or after becoming wet for other reasons, it may take longer until the surface is dry. If freezing occurs then, this type of surface may have a disadvantage.

Road maintenance authorities can handle this problem, as is pointed out in (Ohlsson, 1990), once they are aware of it and have gained experience. However, some experiments with porous surfaces have been interrupted due to poor knowledge of this.

It should also be noted that on a porous surface the sound absorption effect is reduced during wet conditions. Consequently, some of the noise reduction does not occur fully during rainy conditions and for some time afterwards.

### **6.13 Economy**

There are different views on whether a porous surface is more expensive than a dense one or not in production. An advantage is that it may require less bitumen than a conventional one. However, more care must be observed during construction, for example with the base being even, with ambient and mixing temperatures, etc.

There may be increased maintenance costs due to the different de-icing policy required. A somewhat shorter life-time (in certain cases, for example when maximum noise reduction is desired) may also increase the total costs. If cleaning of accumulated dirt is required the costs will increase also.

The Swedish Road Administration, as a very rough rule, currently considers porous surfaces as being in total approximately 50 % more expensive than dense surfaces. According to Austrian experience (Breyer, 1990) reports increased costs of between 30 and 100 %.

One should observe that in urban areas, water drainage systems may be a very expensive part of building and maintenance costs. The use of porous surfaces will reduce the requirements on such systems, since there is a natural accumulation capacity in porous surfaces. If such effects can be utilized, this could possibly waive the increased costs as mentioned above and turn it into an overall cost advantage.

Experiences from extensive use of porous asphalt in the city of Gothenburg are reported in (Ohlsson, 1990). It is stated that "The alternative to porous asphalt in Gothenburg is to use split mastix, a gap graded hot mix. Comparing porous asphalt with this alternative the price per square meter is just about the same. However the great difficulty is to place a value on noise reduction, accidents caused by skidding or poor visibility, etc, versus decreased resistance to abrasion".

### **6.14 Public Response**

In many cases where porous surfaces have been laid in order to reduce traffic noise, the road authorities have been surprised about the positive public response, which has been better than expected from pure objective measurements. As far as this author is aware of, this has been investigated more systematically only by (Mezgallis, 1990) where it was stated that "The surveys and political responses indicate overwhelming public support for open-graded asphalt surfacing".

It should be followed-up better by investigators how the subjective reactions really are. It could be noted for example, that noise barriers usually suffer from a "penalty" of around 5 dB(A) just to compensate for the negative reactions to their appearance, prevention of sight, etc (Krell, 1984). Porous surfaces would not suffer from such an effect which could make them more competitive to barriers than indicated by pure noise reduction values.

## 7. ASSESSMENT OF VARIOUS OTHER SURFACES

### 7.1 Asphalt Concrete (dense)

Even within a group of surfaces like dense asphalt concrete there may be a large variation in traffic noise levels. This depends on the different macrotexture that a surface can obtain by selection of the grading curve and by wear. Practical experience in Sweden indicate that it generally differs around 3 dB(A) between such surfaces on actual roads in Sweden if overall traffic noise is considered. The surfaces with large chippings (up to 16 mm) are the noisier ones and surfaces with small chippings (8 mm) less noisy. However, more important than the chipping size is how dense the surface may become and how well the areas between the large asperities are filled with smaller particles. As open texture as possible is preferred.

See further in Chapter 7.6 regarding a special low noise surface of this type.

Another effect, which has already been mentioned is that a new asphalt concrete surface is less noisy than one which has been exposed to traffic for one year and more. The difference is usually around 1-2 dB(A), see page 3:18 in (Sandberg, 1987-I). It is not clear what the reason is for this.

### 7.2 Cement Concrete (dense)

It is concluded in (Huschek and Springborn, 1989) that cement concrete surfaces are no noisier than asphalt concrete surfaces having the same texture. This is based on a very large number of measurements. However, the statement is based on measurements with just one special tire (the PIARC ribbed reference tire) and by the trailer method.

This author does not share this view. Measurements reported in (Sandberg, Ejsmont & Gustavsson, 1990) show that, no matter what tire types (of 5) or speeds (50-90 km/h) that were used, the noise penalty was approx. 2 dB(A) in relation to a smooth asphalt concrete. However, as was measured very recently, longitudinal grooving of the surfaces have resulted in approx. the same noise reduction as the penalty of 2 dB(A), but this treatment has rather short durability.

Transversal grooving of cement concrete surfaces may result in extremely annoying noise. On some roads, the authorities have had to install special road signs as a warning to the drivers that the noise they hear is due to tire/road noise and is "normal". Public reaction to such noise is sometimes so extensive that the authorities have had to change their re-surfacing policy to avoid grooved cement concrete. In any case, periodic grooving must be avoided since the tonal noise resulting from this will be very annoying. The spacing of the grooves should be randomized.

Another factor to consider is when there are joints in cement concrete surfaces. The joints may not necessarily increase the average sound level very much, but the periodic and very pronounced impact sound may annoy people much more than any objective measure describes.

According to (Breyer, 1990) new techniques are tested in Austria with some success. For example, longitudinal texture may be created by using a jute cloth finishing. Also, a



washed surface (washing away the new fine material in the surface during the construction) which exposes an aggregate of 4-8 mm chippings will give a pronounced but favourable texture. This has been tested recently also by the author of this paper by predicting tire/road noise from texture measurements on laboratory samples. The washing can give some improvement, but there is doubt whether the affect can be long-lasting.

### 7.3 Chip Seals

Regarding chip seals (or surface dressings as they are also called) the noise effects are largely depending on the chipping size:

- a) Chipping sizes of max. 12-20 mm:

Such surfaces generally increase tire/road noise by 1-3 dB(A) compared to smooth, dense asphalt concrete. The increase is only for cars. For trucks, noise may even decrease! Therefore, for total traffic noise the situation is not clear-cut.

- b) Chipping sizes less than 8 mm:

Such surfaces may be very quiet. In (Sandberg, 1987-1) it is concluded that such a texture would be very appropriate for noise reduction, and it is also shown that one of the quietest surfaces measured there was a resinous slurry with small chippings, a surface which in principle is similar to a chip seal.

In (Breyer, 1990) it is reported that such a surface bound whit epoxy and having 3-4 mm chippings was very successful for noise reduction. However, at least for Swedish conditions with stud wear such surfaces would not be long-lived. Possibly, they could be useful on low speed roads.

In summary, chip seals with very small chippings may be almost as quiet as porous surfaces! However, note that they will be effective for reduction of tire/road noise only. In interrupted-flow urban traffic they will not be effective since they do not provide any absorption.

- c) Double layer chip seals:

Double layer chip seals with (say) 12-16 mm chippings in the bottom layer and 4-8 mm on top are less noisy than single layer surfaces with the same max.chipping size. Truck tire/road noise may be reduced by such surfaces while there may be a penalty for cars, at least at low speeds.

When surfaces of this type are worn, they appear more and more like smooth and dense asphalt concrete. Noise emission also approaches that of a corresponding asphalt concrete surface.

### 7.4 Block Surfaces

In old towns and cities, paving stones is still a common type of surfacing. In (Meshik, 1990) there is a review of the effect on noise of such surfaces. The noise increase is 1.5-8 dB(A) according to this.

In this case there is obviously a conflict between environmental and cultural ambitions. Paving stones are mainly used today because cultural values must be preserved.



In some types of streets, paving blocks of modern types have been introduced. Although the traffic usually is not intense on such streets, there have sometimes been some concern over the increased noise they cause. This has been investigated by (Samuels and Sharp, 1985).

### 7.5 The Pavetex Surface

It was reported at the recent tire/road noise conference by (Iwai et al, 1990) that a new surface called "Pavetex" could reduce tire/road noise as much as a porous surface: The Pavetex surface is a very peculiar surface, since it is similar to a very complex semi-soft carpet, see Fig. 12.

One could doubt that such a surface be durable. However, according to the Japanese authors it has resisted 16 months of traffic without problem...

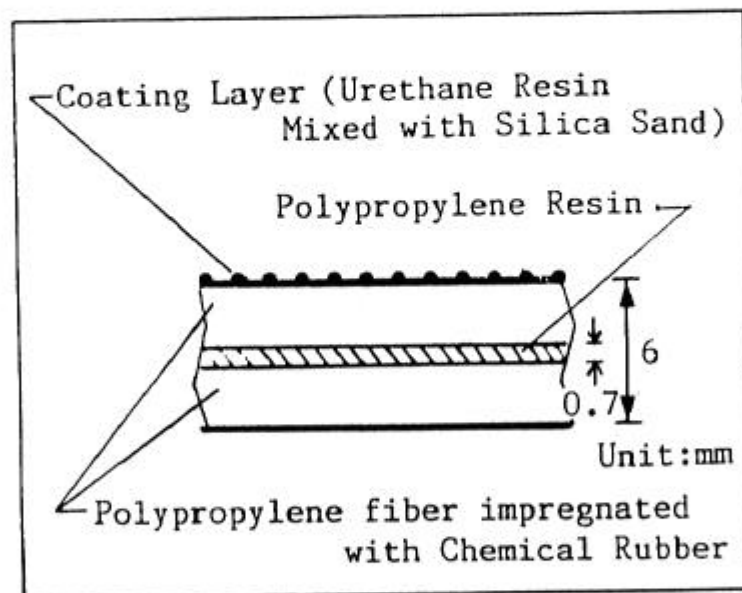


Fig. 12. The structure of the Pavetex surface. From (Iwai et al, 1990)

### 7.6 The ISO Test Track Surface

The working group ISO/TC 43/SC 1/WG 27 has had the task to develop a test track surface for use during vehicle noise homologation tests according to ISO 362 and 7188. This surface shall be as quiet as possible, without being sound absorptive.

There is now a tentative recommendation ( Reference: please contact this author) for such a surface which is basically a dense asphalt concrete surface with maximum 8

mm chippings and with a special grading curve. It has been shown that this surface reduces tire/road noise by around 1-3 dB(A) in comparison to "normal" asphalt concrete surfaces. It could be suitable in urban areas when speeds are not too high. It is not yet known how it performs under very intensive traffic.

### **7.7 Rubberized Asphalt.**

It is claimed that "Asphalt-Rubber" is an effective means of reducing traffic noise (ARPG, 1990). Scrap tires could be used as the raw material in such surfaces. References are given to lots of investigators and the noise reductions are claimed to be very high. However, when checking all the references, it is clear that they all refer to comparisons of porous surfaces in relation to dense surfaces but where the porous surfaces have included some rubber. All the noise reductions can, in fact, be due to the porosity and not the rubber, according to this author's view. There is nothing which shows that it is the rubber in the surfaces which is causing the noise reduction. Therefore, the suggestions of using rubber for noise reduction have no support.

This author has investigated the effect of adding rubber granulates in a dense asphalt concrete, so called "RUBIT", see (Sandberg, Ejsmont and Gustavsson, 1990). The proportion of rubber by weight has been 3-6 %. The result was that it was not possible to trace any noise reduction to the effect of rubber.

Similarly, the effect of adding rubber to the binder has not had any significant effect, see Chapter 6.6.

However, when using rubber as the main ingredient of the surface the effect on noise can be dramatic. See Chapter 6.8.

### **7.8 Wet Roads and Streets**

Water on roads and streets increases the noise by 1-10 dB(A). By designing street and road drainage properties in a proper way traffic noise can be reduced. The best effect is obtained with porous surfacings.

## **8. THE IMPORTANCE OF PROPER MAINTENANCE OF SURFACES**

If drainage wells and man-holes are located in the street there is a risk that vehicles will hit these sources of unevenness which may cause bump noise and rattling noise of loose goods. Maintenance may increase or decrease such noise depending on whether the surface level differences are reduced or not when a new surface is laid.

Maintenance also affects rutting in the surface, and thus water depths in wet weather and consequently traffic noise.

The longitudinal unevenness is influenced by road and street maintenance which affects bump and rattling noise according to the above, but also the so-called megatexture (texture wavelengths 50-500 mm) which influences tire/road noise at low frequencies.

Finally, newly laid asphalt pavements appears to be more quiet during its first year than the following years. This noise difference is generally:

- For dense asphalt concrete: 1-2 dB(A) lower noise first year rel. to later years.
- For porous asphalt concrete: 1-2 dB(A) lower noise first year rel. to second year.

Also, a way of reducing noise of smooth cement concrete surfaces is to groove them longitudinally with close and narrow grooves. Reductions of 2-3 dB(A) have been recorded by VTI recently. However, resurfacing must be made at intervals of 1-2 years since the grooves are quickly worn.

In summary, a poor maintenance of a road and street network in urban areas influences traffic noise in many, additive ways. Frequent resurfacing may reduce the time average noise level in the order of one dB. However, the subjective effects may be bigger than expected from the objective measures, since people notice a sudden noise change but may not notice a gradual noise increase afterwards.

## 9. DEFINITION OF A "LOW NOISE ROAD SURFACE"

In analogy with vehicles, it would be desirable to be able to define a "Low Noise Road Surface". Once this definition is decided it would be possible for road and environmental authorities to encourage the use of such surfaces with certain favours or simply to require it in some cases.

Such a definition should preferably be based on functional properties, not on design. A design definition would not encourage development and not make possible optimizations which take also other characteristics into consideration.

What should a definition look like? It is still premature to give a final recommendation, but this author would suggest (tentatively) that it is based on these two principles:

1. The sound absorption coefficient. Data indicate that a sound absorption coefficient averaged over the range 400-1600 Hz is the most relevant value and that noise is influenced when the coefficient exceeds approx. 0.10. However, to have a long-lasting and significant noise reduction the coefficient needs to be considerably higher.
2. The macrotexture. A rough macrotexture will create tire/road noise of the typedescribed as mechanism No. 1B in Chapter 2.3 and may thus counteract the noise reduction by absorption.

Possibly, a macrotexture requirement could be provisionally supplemented or replaced by a design limit, e.g. that the max. chipping size be 12 mm or less. This design limitation would not be that severe that it prevents development and alternatives.

Another problem is how to handle the impairment of the porosity and sound absorption from initial high values to lower values when the surface has become worn?

As has been argued before, even though a surface can not preserve its high initial noise reduction, the public will still notice a considerable improvement and may not react so much to the slow, gradual increase of noise. So, possibly, the problem of ageing must be left aside at the moment.

## 10. INFORMATION SEARCH (BIBLIOGRAPHY)

At present, more than 800 papers or other documents with relevance to tire/road noise are available (INFORMEX, 1991). A large proportion of this number deals with road surface influence on the noise. With such an extensive literature available, it is natural that each new research project should be started where others finished, i.e. one should begin with conducting a literature survey.

The most comprehensive single source available at present is the proceedings of a recent conference (INTROC 90, 1990). At least half of the papers deal with the subject of road surfaces. Some of the information provided there is briefly mentioned in this paper.

Tire/road noise investigations have been reported at least since 1925. The number of publications in this field grows so fast that it is not possible to handle all of them without a modern data base system. General bibliography data bases which are world-wide available are not detailed enough in their keywords to help with a search for particular problems related to tire/road noise and they are also very incomplete. In order to handle this, a computerized bibliography has been presented recently where all known tire/road noise papers are classified based on 70 keywords specialized on the subject (INFORMEX 1991).

This bibliography is also possible to edit and supplement by the users themselves. See the figure below for a typical printout.

Search	Supplement	Edit
		Select: _____
		Next
		Printer + Next
		Quit
<b>Record Number:</b> 544		
<b>Author (s):</b> Pottinger, M.G., Marshall K.D., Lawther, J.M., Thrasher, D.B.		
<b>Title:</b> A Review on Tire/Pavement Interaction Induced Noise and Vibration		
<b>Source:</b> The Tire Pavement Interface, ASTM STP 929, Edited by M.G. Pottinger and T.J. Yager		
<b>Year:</b> 1986. <b>Size:</b> 105 pages, <b>Language:</b> English, English summary included		
<b>Type of document:</b> DISCUSSION, S-O-A, BOOK <b>Comments:</b> Excellent review		
<b>Keywords</b> (primary keywords written in upper case): GENERAL REVIEW, VIBRATIONS, TIRE NONUNIFORMITIES, Bibliography external t/r noise, internal t/r noise, public reaction, gener, mechanisms, vehicle vibrations, tire influence, road surf, influence, road characterization, operating parameters.		

Fig. 13. Typical printout of a bibliography record in the TRN database (INFORMEX, 1991).

## 11. CONCLUSIONS

The paper has provided a review of how vehicle noise emission in urban areas is influenced by road/street surface design and how this factor may be controlled.

It is concluded that:

- Porous asphalt is a type of surfacing which may be effective for noise reduction in some urban areas. Up to 5 dB(A) could be obtained on high-speed roads. In some countries these surfacings become less efficient with time, in other countries they continue to work well. On low-speed roads it is more common that reductions of 2-3 dB(A) are obtained initially, but by using multi-layer surfaces or extremely high void contents, 5 dB(A) can be obtained even at low speeds.
- Most commonly, however, the noise reduction efficiency is reduced very quickly with time, due to clogging. Already after the first winter season the reduction may be halved relative to the initial one. After some more years there is no reduction left.
- The clogging effect is most pronounced in urban areas with low speed traffic. High speed traffic will give a "self-cleaning" effect.
- Cleaning of porous surfaces with high-pressure water have so far not been very successful. However, in Norway and Germany some tests have proven worthwhile.
- A special type of porous surface is the poroelastic road surface made of rubber granulate from scrap tires. It can reduce traffic noise by 5-10 dB(A), i.e. have the same effect as a noise barrier. However, there are severe problems which have to be solved until this surface type can be used at a larger scale and with acceptable durability.
- The use of rubber as just a small fraction of the mix has not been shown to be successful for noise reduction. The same effect could probably be obtained without rubber.
- Porous surfaces may be useful for urban noise reduction also when laid on sidewalks and parking areas due to the absorption it provides, especially in reverberant spaces.
- Porous surfaces are also recommended on roads in tunnels.
- Poor maintenance of roads and streets may to a large extent increase traffic noise. On the other hand, frequent re-surfacing may reduce traffic noise.
- Conventional asphalt concrete road surfaces are usually less noisy when they are new. By special design of the grading curve, low noise variants can be obtained also by such a type, such as the "ISO Test Track" Surface.
- Chip seals may both increase and decrease noise emission, depending on the size of chippings. Very small chippings may result in a very quiet surface, in some cases almost as effective as a porous one.
- In Japan, a new surface called "Pavetex" has been tested with apparently good results. It needs more testing.

As a concluding remark, it is necessary to point out that the noise reduction effect of the appropriate road surfaces which are available today shall not be exaggerated. Most

tests conducted and presented so far have been done on new surfaces. Experience have shown that the reduction generally deteriorates with time. Consequently, investigations presented so far have given results which are not really representative of a long-term evaluation.

However, even though initial noise reductions of (say) 5 dB(A) may be reduced to 0 dB(A) at the end of the lifetime of the surface, the average noise reduction is enough big to motivate the use of low noise surfaces in many cases since alternatives may not exist or at least be more expensive.

Low noise road surfaces are often useful as a noise reduction tool not only on country roads but also in urban areas. However, it must never be the only tool, since they do usually offer just a partial solution to the noise problem. Actions to reduce the noise emission by tire and vehicle design are also necessary to reduce the overall emission of traffic noise.

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## SUMMARY

This paper provides a review of how vehicle noise emission and propagation in urban areas is influenced by road/street surface design. The review is based partly on the author's own experiments, partly on information collected at a recent tire/road noise conference.

The first part of the paper contains a review of the historical development of the subject as well as of the noise sources of a vehicle and the generation mechanisms of tire/road noise.

In order to control traffic noise, i.e. reducing it to acceptable levels, it is necessary to employ effective combinations of most of the available measures. Tightened emission limits for vehicles will be necessary but they must be accompanied by subsequent control of tire/road noise. This includes control of tires as well as of road surfaces.

It is possible to obtain noise reductions by road surface selection; if not in each case, at least in several cases. Among the road surfaces, the drainage or porous asphalt stands out as the most promising noise reduction measure, although considerable problems with its long-term performance have been recorded; mainly in countries with a hard winter climate.

By using a porous surface it is usually possible to obtain an initial noise reduction of approx. 5 dB(A) on high-speed roads. Such a reduction could be obtained also on low-speed roads/streets but then more advanced types of porous surfaces are required, like multi-layer surfaces or the air voids content must be particularly high. Most investigations consistently show that the air voids content is crucial. It should be 20-25 % initially. Surfaces get clogged with time and the noise reduction is reduced down to 0 or 1 dB(A) in just a few years.

A porous surface of particular interest for noise reduction in urban areas is the "poroelastic surface", i.e. a surface made entirely of rubber and a binder which can be either polyurethane or bitumen. It could give 5-10 dB(A) of noise reduction, but so far several non-acoustical problems remain to be solved.