EUROPEAN CONCRETE PAVING ASSOCIATION

DURABLE LOW-NOISE CONCRETE PAVEMENTS

CONTENTS

EXECUTIVE SUMMARY

Noise is an important societal issue today because of the nuisance it causes and its negative effect on human health. The European Environmental Noise Directive[1] imposes the Member States to make an assessment and mapping of the noise problem and to develop action plans.

Traffic noise forms a major part of the problem and can be abated by the construction of noise barriers and/or low-noise surfaces, the latter being the most efficient solution. The total traffic noise consists of three components: the engine noise, the aerodynamic noise and the rolling noise. At higher speeds – about 30 km/h for passenger cars and 75 km/h for commercial vehicles – the rolling noise, caused by the tyre-pavement interaction, becomes the dominant contributor to the overall traffic noise. Therefore it is the challenge for road authorities to build quieter pavements that will sustain their noise-reduction benefits over time while not compromising on safety, ride quality and durability.

Quiet pavements are characterized by a smooth surface with no bumps or irregularities. They can be either a porous or a dense structure with small aggregates on the surface.

In terms of surface finishing and texture, concrete surfaces have undergone a significant evolution in the past 50 years. Noisy surfaces are no longer used on motorways or trunk roads and those still in service are there thanks to the extraordinary longevity of concrete pavements. Transversely brushed finishing is still a good compromise for low speed roads (≤ 70 km/h) but the standard surface finishing in Europe is the fine-grained exposed-aggregate concrete, either in a single layer or a double layer concept. Double-layered concrete motorways have been built in several countries, mainly Austria, Germany, Czech Republic, Poland, Belgium and the Netherlands.

Other finishing techniques for concrete pavements are longitudinal tining, micro-milling, diamond grinding and the "Next Generation Concrete Surface", which is an optimised combination of grooving and grinding with very promising results for the future.

In a selection process for the type of pavement or surface, it is important to make a holistic evaluation of the possible options, taking into account not only the noise criterion but also the essential life-cycle performances in terms of safety and durability.

In terms of obtained noise levels, modern concrete pavements are competitive with the stone mastic asphalt surfaces and even outperform them over time.

[1] The Environmental Noise Directive (2002/49/EC)

Provincial road N285
in the Netherlands
Photo: Cement&BetonCentrum

1. INTRODUCTION

Controlling traffic noise has become an increasingly important priority in recent decades. The European Union addressed the general issue of environmental noise in a 2002 European directive known as the "Environmental Noise Directive (END)". The member states were asked to draw up noise maps and to take steps to prevent and mitigate the harmful effects of the noise, with particular focus on busy roads and railways, in densely populated areas, and in proximity to sensitive sites such as hospitals and schools.

Steps have already been taken in various countries including the installation of noise barriers along highways.

However, when it comes to traffic noise, it is more efficient to address the problem at its source by using a quieter pavement. That is why the development of alternative types of pavement and surface finishing currently remains highly relevant. The goal is the reduction of the tyre-pavement noise generated by the interaction between tyres and the road surface, which is the primary cause of traffic noise. At the same time, it is also important that other essential characteristics of the road structure and the surface are preserved, for example, the smoothness and skid resistance of the road surface, but also its durability. Finally, it is important for a quiet pavement to remain intact for as long as possible. **Durably quieter, in other words, is the goal.**

In this brochure we show concrete pavements are not as noisy they are often perceived; provide examples of techniques to ensure low-noise concrete pavements and look at case studies and real data showing concrete's performance.

Examples of noise barriers along highways

2. ABOUT SOUND AND NOISE

We can hear sound all around us: a favourite song on the radio, a crying baby, children playing, a lawnmower or waves on the beach. Noise is sound that we experience as objectionable. This is subjective and will therefore differ from individual to individual.

2.1 WHAT IS SOUND?

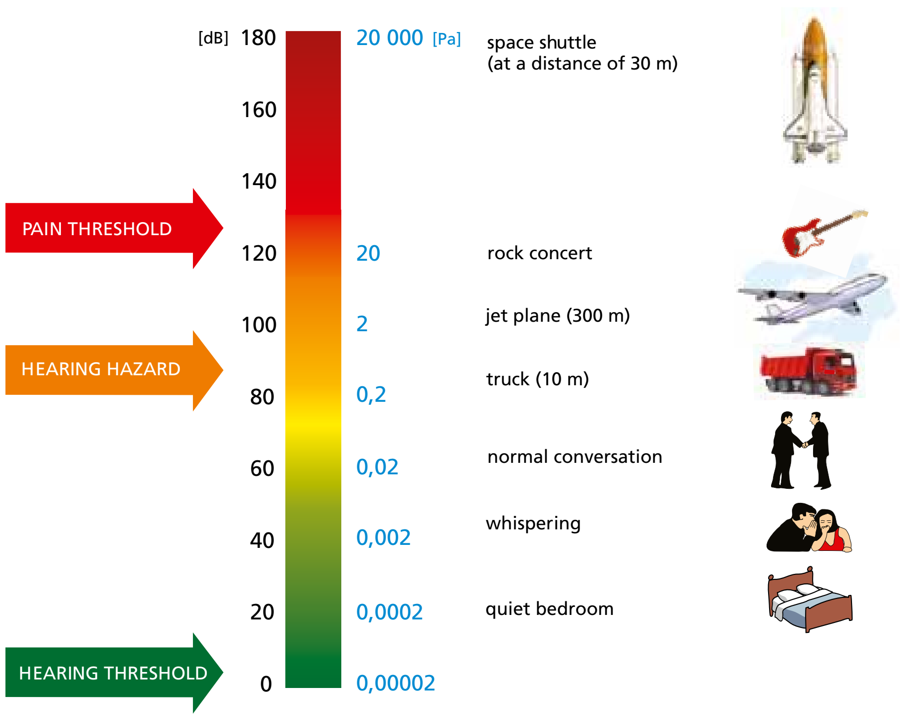
Technically speaking, sound consists of small, rapid, cyclical changes in air pressure. Our hearing system picks up these changes in pressure and converts them into the sound that we hear. However, this is a non-linear process which works according to a logarithmic scale. A pressure difference between 0.1 Pa (Pascal – a unit of pressure) and 1 Pa – meaning therefore a difference of 0.9 Pa - is perceived as approximately the same as a pressure difference between 1Pa and 10 Pa – a difference of 9 Pa. This is why sound level is expressed in decibels according to the following formula:

Sound level (dB) = 20 log (pressure/ 0.00002)

The figure below also shows this conversion, along with pictures that help to identify what kinds of sounds produce the various levels.

Moreover, we hear sound in different frequencies, in a range from 20 to 20,000 Hz (Hertz). Since we are not able to perceive all pitches in the same way, noise levels values are generally filtered for certain frequencies. For traffic noise, the A-filter is used, which focuses mostly on the frequencies between 1000 and 4000 Hz, which are the frequencies for which humans have greatest sensitivity. These are then referred to as "A-weighted decibels" or dB(A).

Rules of thumb regarding sound level are sometimes helpful. To begin, most would consider a 1 to 3 dB change as "just noticeable", and it takes a 5 dB change to be considered definite. This is especially true if there is any gap in time between listening to the sounds being compared. Most also consider 10 dB change a "doubling" (or "halving") of sound. There is one very important thing to note about these rules of thumb: they are only true for the same sound. If the type of sound changes, these changes in perception may no longer be valid.



Comparison of sound pressure, sound levels, and common examples. (Ref. 3)

2.2 TRAFFIC NOISE

The sound that is generated by traffic is usually referred to as "traffic noise". This encompasses sound from various types of sources, which are usually divided into the following categories:

- propulsion: motor, exhaust and other components of the vehicle's drive mechanism;
- interaction tyre-road surface: known as tyre-pavement noise;
- aerodynamic sound: caused by the wind turbulence around the vehicle.

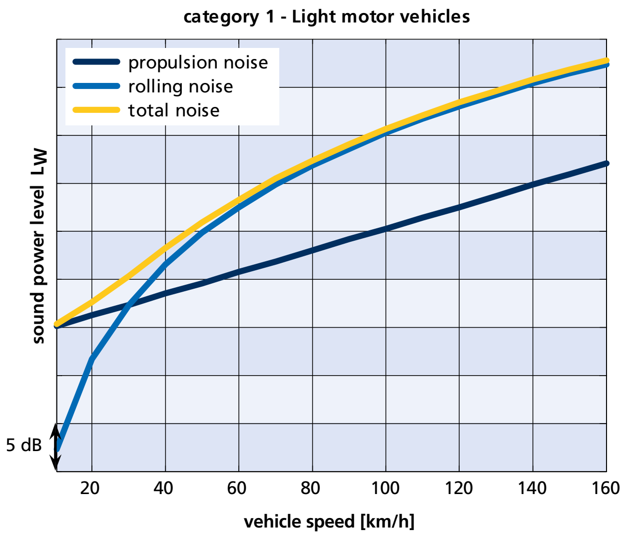
The type of vehicle and its speed play an important role. For passenger cars, the tyre-pavement noise will outweigh the propulsion sound once a speed has been reached of around 30 km/h. For trucks, this level is only reached from approximately 75 km/h due to the greater contribution of propulsion noise. Aerodynamic sound only becomes significant at very high speeds (above 120 km/h). For electric cars, the propulsion sound is almost totally eliminated and the tyre noise will be dominant, also at low speeds.

The graphs below (Ref. 6) presents the total A-weighted level of both the rolling noise and propulsion noise components, as well as the total sound power, as a function of vehicle speed. The curves show the linear relation for propulsion noise and the logarithmic relation for rolling noise.

In addition, these relationships have been established for constant speed on a non-sloped surface.

In practice this means that in urban areas with mixed traffic and a lot of accelerating/decelerating manoeuvres, the influence of the pavement surface and thus the rolling noise becomes less relevant. Other measures in the field of traffic management such as speed limits and traffic flow control become of higher relevance in those cases.

The rolling noise, generated by the tyre-pavement interaction, becomes dominant at speeds of respectively 30 km/h for passenger cars and 75 km/h for heavy vehicles. In urban environment, where the driving speed is low and where city buses operate, the propulsion noise is the most important. Pavements for buslanes should therefore in the first place be designed based on durability.



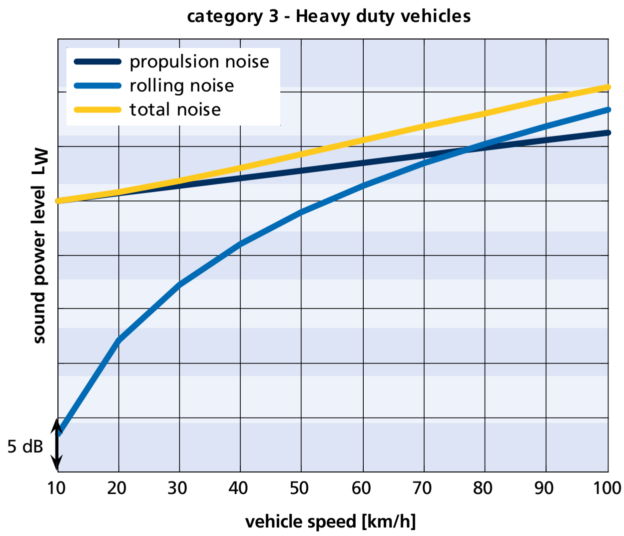


Photo: M. Haider – Ref. 8

2.3 INTERACTION TYRE-PAVEMENT

Of course, both the type of tyre and the pavement play a role in their mutual interaction. It should be borne in mind that both elements are not only designed with a low tyre-pavement noise in mind, but first and foremost, for good traffic safety and a favourable price/lifespan ratio. Various mechanisms are involved in the creation of the tyre-pavement noise generated by the interaction of the tyres of a vehicle with the pavement (hammer effect, air pumping, "stick-slip" and "stick-snap"). Moreover, the sound is further increased by the "horn effect", vibrations and resonance.

2.4 HOW IS TRAFFIC NOISE MEASURED?

In Europe, the *Statistical Pass By Method* or the *Close Proximity Method* are generally used.

With the *Statistical Pass By Method* (SPB, ISO 11819-1), the traffic noise is measured from the side of the road for a large quantity of passing vehicles, whereby a distinction can be made between passenger cars and trucks.

With the *Close Proximity Method* (CPX, ISO/CD 11819-2) it is chiefly the tyre-pavement noise that is measured by attaching a microphone close to the test tyre. These tyres are usually mounted on an acoustically insulated trailer. The type of test tyre that is used will obviously play an important role in determining the results.

In the United States, the On Board Sound Intensity (OBSI) method is often used (Ref. 5), which is somewhat comparable to the CPX. Instead of sound pressure, however, sound intensity is measured by using two microphones which are better able to isolate the tyre-pavement noise for separate measurement.

Since CPX and OBSI measurements take place very close to the tyre, they will result in high values of noise levels. Obviously, those are not the noise levels to which humans are being exposed in real life. This should be kept in mind when reading the case studies, further on in this publication.

Left: Rolling noise measurement with the CPX method
Photo: AWV, Flanders, Belgium

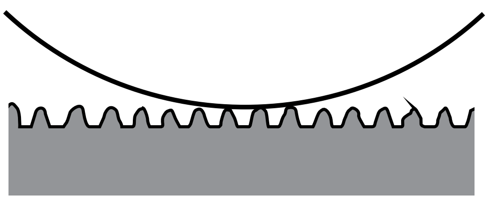
Right: Rolling noise measurement with the OBSI method
Photo: R. Rasmussen

3. BASIC RULES FOR A QUIET PAVEMENT

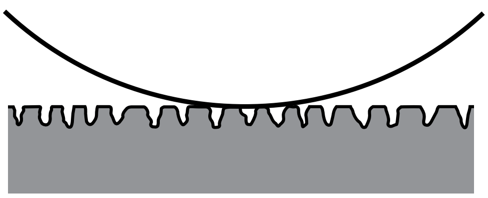
The following factors have an influence on the tyre-pavement noise:

- good smoothness of the road with the absence of bumps or irregularities in the surface (which is also called "megatexture")
- a homogenous but non-systematic distribution of small aggregates, up to 10 mm on the surface (which is considered as "macrotexture"). The air is able to escape between the gaps in the aggregate. Important note: a perfectly flat surface is not low-noise.
- it is better to have a negative texture than a positive one (see figure below).
- porosity: a maximum content of empty space (up to 20% or more), which enables sound to be absorbed, insofar as the pores remain open at the surface.
- limited stiffness of the surface layer.

In optimising a quiet pavement surface, if possible, various factors should be taken into account at once. Moreover, no concessions should be made in the durability of the pavement. In addition, a solution with long-term noise performance should be preferred to surfaces deteriorating after few years.



positive texture



negative texture

Texture of very open concrete (Herne, N255, 1996)

Similar to wearing surfaces of porous asphalt, it is possible to build surfaces of porous (or very open) concrete. By leaving out the sand component in the composition, accessible gaps are created between the coarse aggregates. In order to achieve better adhesion between the stones, polymers may be added. Very open concrete is comparable to very open asphalt: there is great potential for noise reduction and water-spray is eliminated. However, there are also downsides: there is a risk of clogging and the surface is prone to ravelling (aggregates coming loose from the surface).

THE QUIETEST CONCRETE PAVEMENT IS THE POROUS SURFACE OF "MODIESLAB"!

"Modieslab" is a modular pavement system, developed in the Netherlands as a part of the Dutch "Roads to the Future" programme. It consists of precast concrete slabs with a base layer in conventional concrete and a surface in double-layered porous concrete. A trial section was built in the Netherlands as part of a motorway. This structure results in extremely low noise levels: 6 dB(A) less than the Dutch reference surface (densely graded asphalt). In addition, the durability of the noise characteristics is very good: only 0.6 dB(A) decrease in noise reduction after 5 years, which is much better than other comparable surfaces. (Ref. 11).

In 2007, Dr. Robert O. Rasmussen from the Transtec Group (Texas, U.S.) was the leader of a research team that did measurements all over Europe and the United States. His conclusion was clear: "As can be seen, the OBSI level for the porous concrete surface on the Modieslab is very low – just over 96 dBA. This makes it the lowest level of all of the concrete pavement surfaces measured so far by the CP Tech Center team".

Modieslab is also a custom made product; other textures and applications are possible. It has already been used for rapid construction of a bus lane, a road in a commercial area and a tramway.

Photos: Modieslab

4. LOW-NOISE EXPOSED-AGGREGATE CONCRETE


Coarse cured concrete 0/40 or 0/32, left, based on porphyry aggregates, and right, based on crushed gravel.

The technique of aggregate exposure is today the most frequently used surface finishing method on concrete motorways in Europe. It offers a comfortable surface combining a good skid resistance with a low rolling noise.

In the late 1970s, in Belgium, surface finishing by chemically exposed aggregate concrete was introduced. The aim was above all to achieve skid resistance, but tyre-pavement interaction noise was not yet a criterion. The concrete composition consisted of large aggregates (32 to 40 mm) which were exposed on the surface. These were highly noisy pavements and are no longer applied today.

Two slipform pavers laying a double-layered jointed plain concrete pavement on the A1, near Vienna.

In Austria, the fine exposed aggregate concrete was optimised as the surface layer of a double-layer jointed concrete pavement. The bottom layer (15 to 20 cm thick) may contain larger stones up to 31.5 mm, while for the top layer, (5 cm thick) only durable polish-resistant stones with a maximum aggregate size of 6 to 11 mm are used. Since the top layer mixture consists exclusively of small aggregates, these will emerge densely distributed on the surface after compaction of the concrete and washing out of the surface.

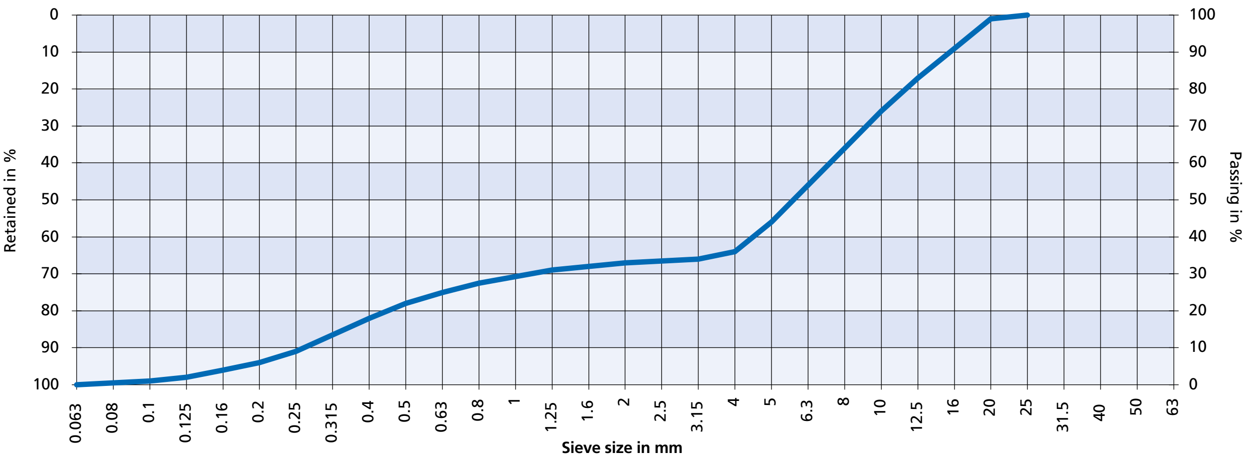
The first applications on Austrian highways date back to 1990. Since then, a significant part of the highway network has been constructed in this way.

In Germany, for many years, the concrete road surfaces were finished with a dragged burlap cloth. This produces a very shallow texture that is effective in terms of tyre-pavement noise but can lead to problems concerning skid resistance. That is why, for the past few years, the technique of double-layer exposed-aggregate concrete has been applied.

In Belgium, a first step in improving the exposed aggregate concrete was the reduction of the maximum aggregate size from 31.5 to 20 mm. Moreover, the proportion of fine aggregate, measuring from 4 to 6.3 mm (or 8 mm), was increased to a minimum of 20% (or 25%) of the mixture of sand and gravel. In this way, the larger stones sink and the smaller ones rise during the vibration of the concrete. After exposing the aggregates by brushing, the smaller aggregates will lie on the surface and form the proper macro texture for a quiet concrete pavement. The same technique can also be applied for a maximum aggregate size of 14 mm.

Texture of an exposed aggregate concrete 0/14
(Brussels, Lorrainedreef, 2003)

Grading curve of a concrete mix with a Dmax of 20 mm and a higher dose of small aggregates (4 to 8mm) for a low-noise single layered exposed-aggregate concrete pavement.



By further optimising the composition (high content of fine aggregate) and a better application technique (modern slipform pavers), it has been possible to further reduce the tyre-pavement noise of a single-layer solution to approximately 99 dB(A), which brings it into a comparable category as a stone mastic asphalt with aggregate of 10 mm (SMA-C).

The double-layer process, similar to the Austrian technique but applied for continuously reinforced concrete pavement (CRCP), has also been used in Belgium. Noise measurements show that the noise level drops another 0.5-1 dB(A).

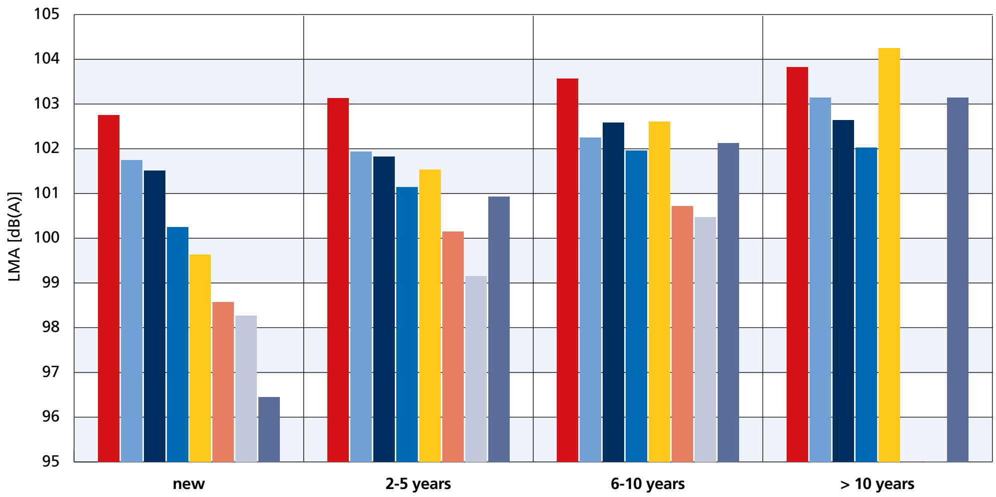

E17 De Pinte – Kruishoutem: single-layer exposed-aggregate concrete 0/20.
Noise levels measured with CPX at 80 km/h: 98.5 dB(A) for a truck tyre and 99.1 dB(A) for a passenger car tyre


E313 Herentals-Grobbendonk: double-layer exposed-aggregate concrete with top layer 0/6.3.
Noise levels measured with CPX act 80 km/h: 98.5 dB(A) for a truck tyre and 98.5 dB(A) for a passenger car tyre

5.1 AUSTRIA – MEASUREMENTS ON HIGH-SPEED ROADS

Measurements were executed on several pavement types and at different ages (Ref. 4). The test-method was according to the Austrian standard RVS 11.03.64, which is a kind of CPX method using a PI-ARC ribbed tyre.

The following surfaces were considered:



- Dense asphalt concrete – max. aggregate size 11 mm
- Stone mastic asphalt - max. aggregate size 11 mm
- Stone mastic asphalt with rubber addition - max. aggregate size 8 mm
- Exposed aggregate concrete - max. aggregate of top layer size 11 mm
- Surface dressing on a concrete pavement
- Surface dressing on a concrete pavement
- Thin bituminous layer - max. aggregate size 8 mm
- Porous asphalt - max. aggregate size 11 mm

Some of the observations that can be made from the diagram:

- **all surfaces show an increase of rolling noise over time;**
- **the superior performance of the open graded asphalt disappears over time, probably due to clogging and/or ravelling;**
- **the fine-grained exposed-aggregate concrete shows a noise increase over time of 2 dB but is still the best performing surface of this comparison.**

5.2 BELGIUM, HERNE – TRIAL SECTIONS OF QUIET PAVEMENTS

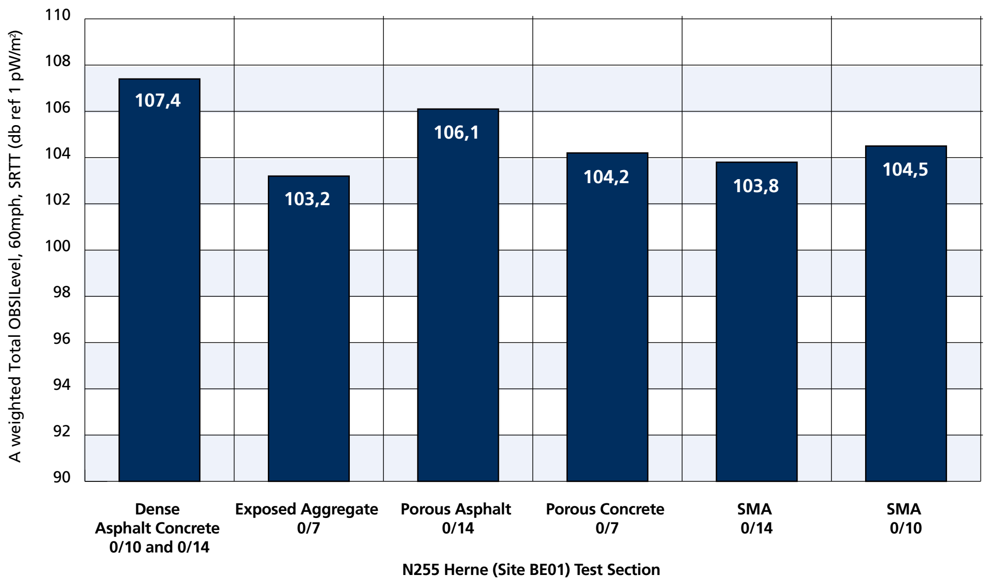
In 1996, in Herne, a number of trial sections were paved with low-noise surfaces (Ref. 1). On an 18 cm thick bottom layer in continuously reinforced concrete, various top layers were applied in fine exposed aggregate concrete, porous concrete, dense asphalt concrete, stone mastic asphalt and highly open asphalt. These test sections were subjected to numerous measurements and assessments, immediately after paving and three years later (1999). In the case of both the highly open asphalt and the highly open concrete, which scored best initially, a noise increase of 2.5 dB(A) was recorded after the three years.

After the three years, the dense asphalt and the fine concrete had the lowest noise levels. In October 2007, a new series of measurements were conducted by an American team using the OBSI method. The results are shown in the figure below. The asphalt concrete had the highest noise production due to degradation. The other surfaces followed the trend seen in 1999.

The general conclusion, today after 18 years of service, is that the top layer in fine exposed aggregate concrete showed the best long-term performance, in terms of both tyre-pavement noise and durability.

Moreover, in 2010 all test sections were covered with a bituminous layer with the exception of the section in fine exposed aggregate concrete, which proves it offers a silent and robust solution.

Results of noise measurements (2007) in Herne:
A-weighted total OBSI level at 60 mph (97 km/h), SRTT tyre



5.3 BELGIUM, ESTAIMPUIS – TRIAL SECTIONS OF DOUBLE-LAYERED CONCRETE PAVEMENTS

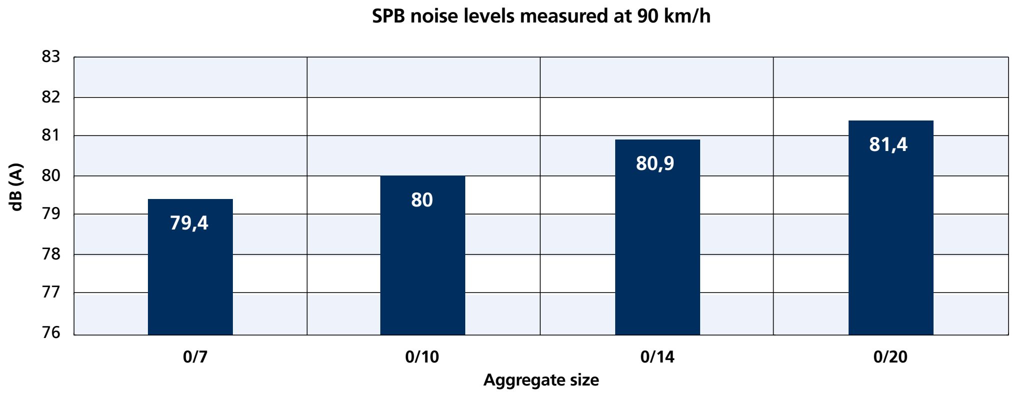
On the regional road N511 in Estaimpuis (BE) between Dottignies and Wattrelos (FR) a pavement section was renewed in 2002 over a distance of 1250 m (Ref. 2). This project provided the opportunity to realize four trial sections in double-layered continuously reinforced concrete. The total thickness was 20 cm but the thickness and maximum aggregate size of the top layer was different for each section – see data in the table right.

At the end of the construction work, measurements were done for skid resistance, evenness and noise. The skid resistance requirements were easily met: the transverse friction coefficient measured by means of the odoliographe was always situated between 60 and 70, far above the required value of 50. Also remarkable were the extremely good results for smoothness. The table below gives the results of the coefficient of evenness, measured with the APL ("Analyseur de profile en long" or "Longitudinal profile analyzer"). Those values are about half of the maximum allowed figures. Double-layered concrete pavements are generally very smooth since the slipform paver needs to compact and smooth only a limited amount of concret-

Nr. Trial section	Bottom layer		Top layer	
	Thickness	Aggregate size Dmax (in mm)	Thickness	Dmax (in mm)
1	15 cm	32	5 cm	7
2	14 cm	32	6 cm	10
3	12 cm	32	8 cm	14
4	12 cm	32	8 cm	20

	Maximum allowed value	Trial section 1 0/7	Trial section 2 0/10	Trial section 3 0/14	Trial section 4 0/20
Average coefficient of evenness (2.5m)	30	15.15	16.2	14.7	17.05
Average coefficient of evenness (10m)	70	33.3	31.4	28.95	41.05

Estaimpuis: construction of the double-layered CRCP



Influence of aggregate size on traffic noise emissions (reference speed 90 km/h)
dB (A) = mean maximum noise level recorded upon the passage of vehicles

Noise measurements were done with the SPB-method at speeds of 70 and 90 km/h. The diagram below gives the results for the different sections at 90 km/h. As expected the traffic noise decreases with decreasing maximum aggregate size of the concrete of the top layer. The gain is about 2 dB between the largest (20 mm) and the smallest (7 mm) grain size.

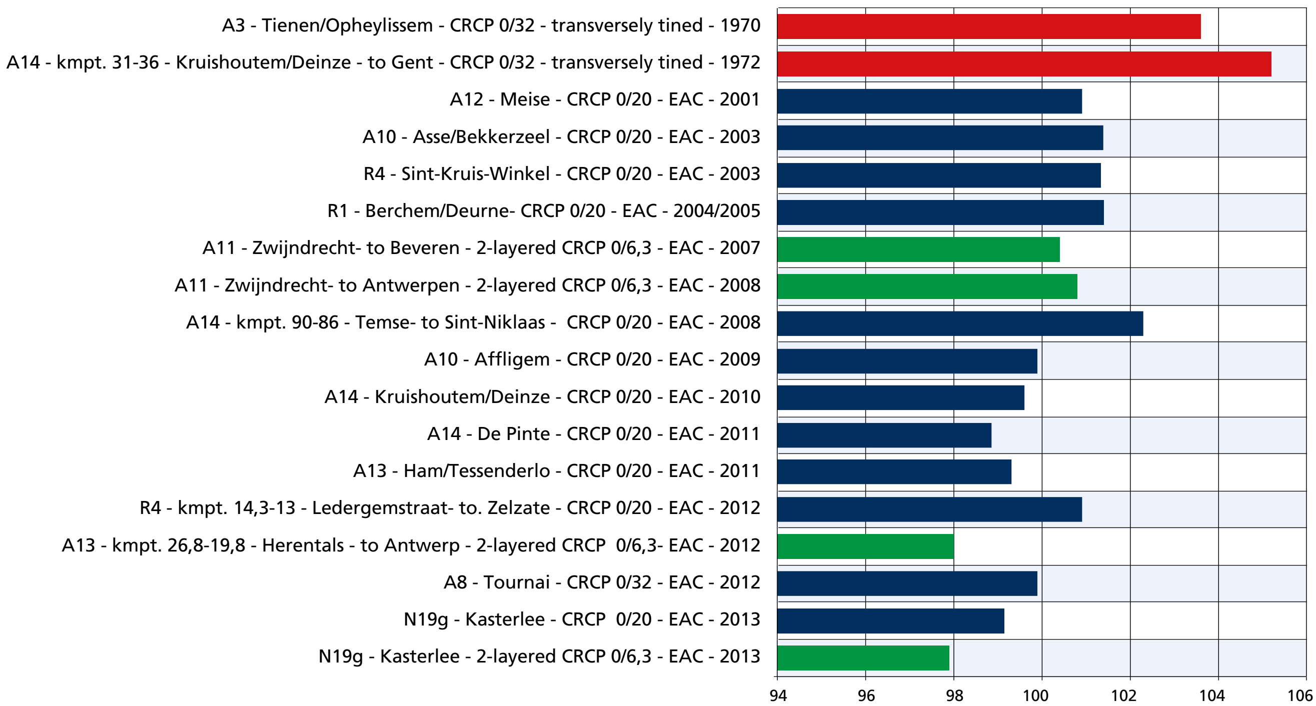
The results of skid resistance and evenness indicate that this road offers a high level of safety and driving comfort. The good results with regard to traffic noise are linked to the choice of the maximum grain size of the top layer, but they are also positively influenced by the smoothness of the CRCP.

5.4 BELGIUM – RESULTS OF RECENT NOISE MEASUREMENTS ON MOTORWAYS

In 2011, the Flemish Agency for Roads and Traffic acquired a CPX-trailer aiming for a systematic execution of noise measurements on motorways and regional roads. In Wallonia measurements were also done on newly built road sections. The diagram below gives an overview of the results of a series of measurements on concrete roads (CPX with SRTT-tyre for light vehicles at 80 km/h in dB(A); measurements done in 2011-2012, in 2013 for N19g).

The red bars represent transversely grooved surfaces, the blue are single layered and the green double-layered exposed-aggregate concrete surfaces.

Measurements on Belgian EAC motorways show that low-noise concrete surfaces are perfectly possible, both in a single and a double layer concept. The noise performance of the surface of a double-layered CRCP is equivalent to that of a stone mastic asphalt wearing course.



Note: CRCP: continuously reinforced concrete pavement – EAC: exposed aggregate concrete

- Transversely tined CRCP 0/32
- Single-layer exposed aggregate CRCP 0/20
- Two-layer exposed aggregate CRCP with toplayer 0/6,3

5.5 THE NETHERLANDS – OPTIMISED EXPOSED AGGREGATE CONCRETE

In the Netherlands, the first trial sections with exposed aggregate concrete surfaces were built in the 1980's. Similarly to Belgium, they started by using large aggregates on the surface, which over time have been replaced with smaller stones up to a size of 8 mm.

In 1992, the provincial road N285, which was an old concrete road, was renovated by means of an overlay in jointed dowelled concrete slabs. The aggregate used was Nordic granite, which is cubic shaped, giving good results in terms of noise reduction. After 23 years of service, the road is still in excellent condition. Another section of the same road, near Zevenbergen, was rebuilt after 40 years of service in 2006-2007. New noise measurements are planned in 2015.

In 2008-2009 the Oost-Veluweweg – an access road to an industrial area - was built in the city of Apeldoorn. A concrete pavement was chosen for reasons of long service life and limited maintenance (Ref. 10).

Measurements (2009) showed a reduction of 1 dB(A) at 80 km/h in comparison with the reference surface, which is a dense asphalt surface. The texture depth, which has a significant influence on the noise level, was 1.27 mm. A more homogenous brushing of the surface and a minimum texture depth of 1.50 mm would have resulted in 0.5 dB(A) extra reduction.

The N285, rebuilt in 1992, is still in good condition after 23 years of service
Photos: Cement&BetonCentrum

6. OTHER LOW-NOISE SURFACE FINISHING TECHNIQUES

6.1 LONGITUDINAL TINING

In the U.S.A., other finishing techniques are used as well. In many states, fine longitudinal grooves are applied to the fresh concrete with a comb. This also produces good results in terms of noise and skid resistance, as long as the process is carefully applied.

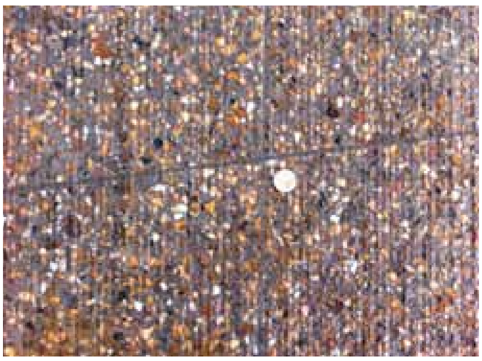
Longitudinal tining of fresh concrete in Illinois, U.S.

6.2 MICRO-MILLING

Micro-milling (or fine milling) is a surface restoration technique using conventional cold mills of which the cutting teeth are more closely spaced on the milling drum.

Detail of the milling drum and fine milling machine in operation
Photos: Wirtgen

Although it is mostly used on secondary roads, micro-milling can be an alternative on motorways as well. This was the case in Leon (Spain). Acoustic characteristics have not been measured but based on earlier trial sections in Belgium, the rolling noise level is about 1dB higher compared to a diamond ground surface.



Detail of the micro-milled surface and view of the motorway in Leon, Spain
Photos: IECA

6.3 DIAMOND GRINDING

The technique of longitudinal tining of the hardened concrete, known as "diamond grinding" is also often used. This technique has already been used frequently in several countries for the restoration of existing concrete surfaces. This can result in tyre-pavement noise levels that are even lower than for exposed aggregate concrete.

Diamond grinding as restoration technique on old concrete slabs

In 2009 a trial section in CRCP was built in Germany, the "Geseke access road" pilot project, in order to investigate the different surface characteristics of the diamond ground texture (Ref. 12). The surface was finished with a longitudinally aligned ground texture whereby two different groove spacing distances (blade spacing 2 mm and 3 mm / blade width 3,2 mm / grinding depth 3 mm) were implemented. Measurements with the CPX-trailer revealed excellent results: as low as 94,9 dB(A) for the 2 mm texture. Repeated measurements in 2013 showed virtually unchanged noise levels (95,2 dB(A)), confirming the high durability of the ground texture.

Detail view of the diamond ground surface and texture of the "Geseke access road" in Germany
Photos: S. Riffel – Ref.11

6.4 NEXT GENERATION CONCRETE SURFACE (NGCS)

In the U.S., the International Grooving and Grinding Association (IGGA) has developed a flatter and smoother surface that still possesses good microtexture and excellent macrotexture, socalled "Next Generation Concrete Surface" (NGCS). During the NGCS process, a thin layer of concrete surface is removed through the grinding process, achieving a smoother texture, and longitudinal grooves are installed. A smoother surface with a less positive or upward texture results in a lower overall noise level, while the grooves increase resistance to hydroplaning by moving water out of the tyre contact patch area.

NGCS provides a smoother, more uniform ride creating a safer road over the long-term. The recent research indicates that although placed as a noise solution, the NGCS also improves ride quality.

In Europe, there are also plans for trial sections of NGCS, the quietest non-porous concrete surface, in order to be able to assess the performance on an existing concrete pavement.

Next Generation Concrete Surface (NGCS)
Photos: International Grooving and Grinding Association

7. CONCLUSIONS

- **In the past there was hardly any attention paid to noise and traffic noise in particular. Today it has become an important criterion in the design and construction of transport infrastructure.**

- **Modern road surfaces in jointed or continuously reinforced concrete with a fine-grained exposed-aggregate surface are competitive in terms of rolling noise with the dense asphalt surfaces. The durability of the noise level is an extra advantage of concrete pavements.**

- **In urban areas with mixed traffic (passenger cars, buses, vans etc.) driving at variable speed, the contribution of the rolling noise becomes secondary. Traffic management measures may be a better solution to reduce the environmental noise.**

- **Finally one should keep in mind that noise is not the only design criterion for road pavements. Its relevance should be defined depending on context and environmental conditions. Road safety and the closely linked characteristic of skid resistance remain a priority. In order to make the right choice of pavement, a global evaluation is needed taking into account the durability, the life cycle cost and the surface characteristics.**

Low-noise double layered concrete pavement combined with noise barriers on the new road link in N19g Geel-Kasterlee (Belgium), realized as a PPP-project.

Motorway in double-layered exposed aggregate concrete, Germany.

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