

New Guidelines for Exposed Aggregate Surfaces in The Netherlands

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Abstract

Today's opinion on environmental aspects, such as CO₂ reduction, does more often lead to the choice of concrete pavements as far as the noise reduction will be solved. On the one hand the ever higher axle loads do ask for rigid pavements, but on the other hand noise also is an environmental aspect especially in built-up areas. Traffic noise, which is in fact the sum of tyre/road and engine noise, is one of the major disturbances for inhabitants. This has resulted into strict legislation with respect to maximum allowable noise levels at the facades of houses. Reducing traffic noise at the source by minimizing tyre/road noise can be achieved by advanced pavement engineering.

In the past, many exposed aggregate concrete surfaces have been realised. This started with concrete with a higher amount of fine aggregates in the surface to special designs with a uniform fine aggregate size. But all these pavements in The Netherlands showed up till about 2008 poor till just acceptable noise emissions. In these cases a poorly textured surface caused these disappointing results. The paper deals with the process of the noise reduction of a concrete pavement and will result in the main topics of the Dutch guidelines.

An important but often underexposed part of the process "The quality Control" of the exposed aggregate surface during the brushing process is also included.

Introduction

The good results that were obtained during the last years with optimized acoustical exposed aggregate concrete surfaces were the reason that Cement & Beton Centrum (Cement & Concrete Centre) decided to develop a guideline for the design and construction such surfaces. Especially the latest project performed in the city of Apeldoorn was decisive.

The city of Apeldoorn requested a long-life low-noise pavement combined with limited maintenance. In the future, residents and the business community are not to be disturbed by noise or reconstructions, neither additional costs are to occur. The underlying contract required a noise reduction of the pavement of 2 dB(A), however, the city of Apeldoorn has built an additional noise barrier in case the noise reduction of the pavement would not meet the required value.

Unique in this project is the short process from initial choice of the mixture to the actual construction. Due to new fundamental insights and models in tyre/road noise generation mechanisms the usual phase of making test tracks could be skipped.

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The ideas and expectations of the road authority

This has led to a significant reduction in time and especially costs. Under the general principle of Green Public Procurement, local authorities in the Netherlands have to find products that cause minimal environmental impact. For the track under study this meant applying a pavement with little maintenance, low costs, and a long lifetime. In order to make an unbiased choice the so-called Life Cycle Analysis has been applied. This also includes a chain analysis or cradle-to-cradle principle. In these analyses the total environmental impact is calculated beginning at the digging of raw materials and ending at recycling of a product after its lifetime. The starting points of the research and the accompanying calculations influence the outcome significantly and, therefore, the results can be controversial.

It is known that the construction of a concrete road is expensive compared to that of an asphaltic one. However, taking the expected lifetime of these two pavement types (i.e. 15 and 30 years, respectively) in the LCA the lower maintenance costs of concrete roads -due to its higher durability- will over-compensate the higher initial costs. For the underlying track it followed from the LCA that the break-even point was approximately ten years. Considering the above it is remarkable that concrete roads are not applied more frequently. This is due to a number of technical, administrative, and acoustical preconditions.

At administration level the high initial costs play a dominant role. Higher budgets have to be reserved which can be a difficult political issue especially during economically hard times. Complicating this is the limited visibility of the effectiveness of the extra investment on the short (political) term.

Nevertheless, in Apeldoorn extra finances were allocated for a durable and reliable solution for the track under study. A constant and reliable accessibility of the city was an important starting point. Because of the intensifying traffic the number of lanes had to be doubled. With respect to the crossings a pavement in asphalt would be logical. However, on the long term, a concrete road would cause less disturbance (such as traffic jams and therefore fewer costs for the community) because of little maintenance. Therefore, a concrete road would fit better in the durability policy and vision of the city of Apeldoorn. With respect to the acoustical precondition, the new road had to meet general legal noise limits. Normally, concrete pavements emit more noise than asphaltic ones. Therefore, a mixture had to be designed that limits the traffic noise significantly.

Asphalt alternatives

To obtain high noise reductions various bituminous alternatives are available. One of these is Porous Asphalt (PA). The noise reduction is significant; however, this is lost after a little number of years. Also, this type of pavement is very sensitive to damage like freezing induced ravelling. All this lead to very high maintenance costs. Applying PA is not a durable investment (the lifetime of the noise reduction of PA is shorter than the lifetime of the constructive aspects); therefore, it was unacceptable for the concerned road (Jurriaans, 2007).

Concrete mix design of the top layer

From previous projects in the Netherlands (Teuns *et al.*, 2004; Van Keulen & Van Leest, 2004; Van Leest & Van Keulen, 2004) it has been shown that optimised exposed aggregate (OEA) performs acoustically equal or even better than standard dense asphaltic concrete (AC surf). Also, in Belgium (Caestecker & Van Messum,

1997) good results have been achieved on the well-known test tracks in Herne. Three major characteristics are important to obtain noise reduction:

1. the application of a fine gap-graded aggregate. This will lead to minimum distances between the tops of the stones in the surface which influences the texture positively with respect to noise.
2. The maximum stone size should not exceed 7 mm. Larger stones will reduce any noise reduction significantly.
3. Maximum exposure depth. This depth is, however, limited due to durability demands. The optimal exposure depth should be $1/3^{\text{rd}}$ of the smallest size of the coarsest fraction.

Based on previous experiences three different mixtures of OEA have been designed for laboratory tests. In figure 1 an example of a test slab can be seen.



Figure 1 – Example of a test slab for texture measurements

Since OEA has no significant porosity the optimisation process only concerned the surface texture, Texture measurements have been performed using a stationary laser profile meter according ISO 13473-1/2/3. Results were then analysed in a rolling-noise model called SIROTOL (Van Keulen *et al.*, 2009) in order to predict the relative noise levels. SIROTOL is designed to predict the acoustical effects of small changes in mixtures very accurately. When the effects of small changes are considered the accuracy is about 0.1 dB(A). The idea behind the model is that calculating the noise levels from any mixture is very complex and, therefore, less accurate. The model, however, calculated the induced acoustic influences of small changes based on the Perturbation Theory which is well-known in Quantum Physics. The accuracy is significantly better than other noise prediction model. However, complete new mixtures cannot be modelled since the accompanying changes are too large which will lead to singularities in the model.

From these tests and calculations, Nordic Granite with a predicted noise reduction of about 2 dB(A) relative to AC surf has been chosen by the contractor. It is known from measurements and models that the type of aggregate has a small but significant effect on the noise reduction. Because of the proven accuracy of the SIROTOL model it was believed by the contractor as well as by the road authorities and their respective consultants that a test track was unnecessary. So, no further test slabs or test tracks have been made which have led to a significant cost reduction.



Figure 2 – Applying the bottom layer (left panel) and the top layer (right panel)

Implementation

The chosen mixture has been applied in the top layer of a two-layered system (Jurriaans, 2008). As stated before, for the aggregate of the top layer Nordic granite has been chosen which was exposed to a depth of 1.5 mm. Some characteristics are given below:

- bottom layer: concrete 4/32 (C35/45, mk XF4, cg C1 with CEM I 42,5 N), 18 cm thick, 7.15 m wide
- top layer: concrete 4/8 (C35/45, mk XF4, cg C1 with CEM I 42,5 N), 7 cm thick, 7.25 m wide, super smoother, smoothing plate
- Verbotop retarder and a foil to prevent evaporation or rain induced washing of the retarder
- After 20 hours the surface has been brushed and rinsed with water.

The total construction took place in two periods being from the end of 2008 until the half of 2009. In total 20,000 m² has been put in two lanes of 1,300 m length each. The two layers have been constructed wet-in-wet by two slip-form pavers running sequentially interspaced as close as possible. The bottom layer was a little bit narrower than the top layer. That gives the execution some freedom for corrections (the width of the pavement) and that is the reason why the top layer will cover also the edges of the pavement. After the job was finished the client was satisfied with the results and the contractor got a sequel part.



Figure 3 – Applying plastic sheet

Measuring-instruments and noise measurements

After construction, noise measurements have been performed according the SPB method (ISO 11819-1) and CPX method (ISO/CD 11819-2). In figure 4 the respective measurement set-ups can be seen.

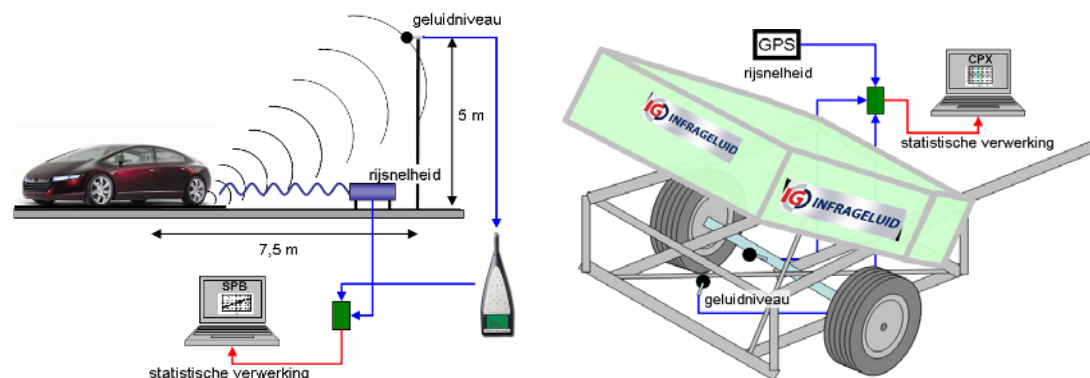


Figure 4 – Noise measurements according the SPB method (left panel) and the CPX method (right panel)

The SPB method is a static method with a fixed microphone along the road side. The results can be compared directly to a reference which is based on DAC. This reference is numerically defined in the Dutch noise act. The CPX method is a continuous method with microphones close to the standardised measurement tyres. For this method there is yet no reference. The CPX data are calibrated by the SPB data at well-defined position on the track which is measured by SPB as well as CPX. These two methods combined are called the Conformity of Production (COP) and provide an accurate measurement of all lanes on the whole track. From these measurements it followed that the average noise reduction of the total track was 1.5 dB(A) relative to the reference AC 16 surf. This result corroborated the model calculations and, more importantly, the demands in the underlying contract and noise emission calculations. Compared to values of more standard concrete surface the measured noise reduction is significantly better.

Additionally, the data from the CPX measurement have been correlated with the *in situ* measurements of the exposed depth by means of the sand patch method (see figure 5). No laser based stationary method was used because of the length of the total track and the costs per measurement. To measure the complete track would be simply too expensive. A secondary reason for not using a laser based stationary method was the unfriendly environment for this sensitive equipment (moist, dust etc) during the construction. At this moment, the correlation between dynamic laser based measurements is under investigation (Van Keulen *et al.*, 2012). This will lead to the possibility to use a dynamic laser based method which will be fast, cheap and reproducible.



Figure 5 – Monitoring the exposure depth

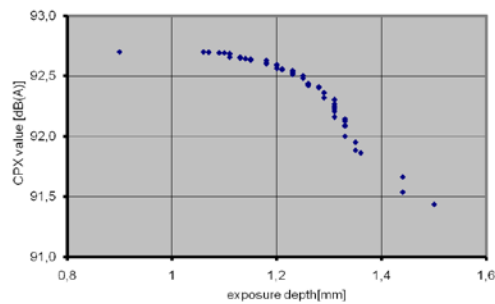


Figure 6 – Relation between predicted noise (CPX) levels according SIROTOL and exposure depth (based on sorted data)

From these analyses it followed that limiting the exposure depth to a minimum of 1.27 mm the predicted noise levels could improve another 0.5 dB(A) according SIROTOL (see figure 6).

New - Guidelines

The Cement&BetonCentrum presented at the Dutch Concrete Pavement conference the new guidelines of optimized exposed aggregates. The guideline shows that one of the most important distinguishing marks for getting a low noise exposed aggregate concrete surface is a *gap-graded* concrete mix with a small maximum aggregate size. This provides a close compaction of the course aggregates. If the “peaks” of the aggregates are separated too far, the impact of the peaks against the tyre will increase and that will lead to more rolling noise.

The influence of the brushing depth has a big influence on the noise emission. For acoustical reasons the brushing depth should be maximal. However in according to durability and sustainability the brushing depth should be minimal (loosening of aggregates from the surface). The most optimum solution of the texture depth is 1/3rd of the smallest aggregate size of the most coarse aggregates.

The main points of attention are:

1. *Noise design aspects:*
 - By 11 mm or larger coarse aggregates no noise reduction can be achieved. On the contrary the noise emission will be higher than the reference surface (AC surf).
 - By 8 mm coarse aggregates the expected noise reduction will be 1 to 2 dB(A).
 - By 5 mm coarse aggregates the expected noise reduction will be more than 2 dB(A).
2. *Concrete composition:*
 - Concrete mix design is of vital importance for the noise reduction
 - Crushed cubic aggregates has to be used for an optimal result
 - Maximum aggregate size:
 - Plain concrete: < 1/4th of the thickness of the layer
 - CRCP: 1/3rd of the thickness of the layer
 - The maximum grain of the grading of the course aggregates does influence the noise reduction
 - One concrete plant only to be used for the top-layer

3. *Construction:*

- Preferable construction in a two layer-system
- Unevenness's do lead to a higher noise level
- The use of a supersmoother and a "haul-plate" do have a positive effect on the noise reduction
- Brushing-/texture depth = 1/3 of the smallest grades of the course aggregates
- The concrete surface has to be cured both after spraying the surface retarder and after brushing

4. *Quality control:*

- The measurements of the texture depth in accordance with RAW-test 76 (sand patch method), however glass grains instead of sand should be used (so no clotting can occur)
- Noise measurements by means of the CPX- and SPB-method

Conclusions

It has been shown that under the right conditions a low-noise concrete pavement can be constructed with little risk of failure. The main conditions, besides the general conditions that are important to get a high-quality concrete road, are:

- Design mixture based on various experiences
- Use the appropriate acoustical models.
- Texture measurements on test slabs are crucial
- Monitoring the exposure depth frequently during construction and feedback results immediately.

Choosing this special concrete pavement will lead to significant cost reduction with respect to maintenance. At the same time, this pavement possesses the necessary noise reduction which will be very durable.

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