Developing a durable and ultra low noise poroelastic pavement

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ABSTRACT

Affordable and effective traffic noise mitigation measures are highly wanted, e.g. for the “action plans” which are due for the European Noise Directive in the EU MS. Low noise pavements are an interesting option as they are a “source measure” and relatively cheap compared to other measures. The problem with the conventional low noise pavements is that the obtained noise reduction (typical 2 to 7 dBA) is lower than what can be achieved with noise barriers (typical 7 up to 12 dBA). A poroelastic road surface (PERS), consisting of a significant amount of rubber and bound with an elastic polymer, such as polyurethane, has proven to be capable of reducing the tyre/road noise with 8 to 12 dBA. A limited durability was one of the major obstacles for its use. Since 2009 a consortium of twelve EU partners is working on the development of a useable type of PERS in the EU funded PERSUADE project. All relevant aspects are being considered and for all remaining problems one tried to find a solution. Mixes which at least perform well in the laboratory have been found and these are currently tested on road test tracks. This paper summarizes the current project status.

Keywords: tyre/road noise, low noise pavement, poroelastic road surface I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION

Tyre/road noise is for cars already at low speeds (typically as low as 30 – 40 km/h) the dominant noise source. Abating traffic noise is hence mainly reducing tyre/road noise. One can (and should) work on the tyre properties to reduce noise (1) but also on the pavement. To reduce the tyre/road noise, one can only “turn on three buttons”: the pavement texture (minimum of megatexture and maximum of macrotexture), the absorption by the pavement (high accessible void content and a proper shape and length of the “channels” formed by the voids) and the elasticity of the pavement. Low noise pavements based on an optimized texture or a high void content do exist and are even widespread in some countries, such as the Netherlands. However, the third possibility to reduce noise, making the pavement elastic, is hardly exploited so far in the commercially available pavements. Some extra noise reduction is gained in some countries by adding rubber to bituminous pavements, but these pavements are still quite “hard” and the gain is limited, typically 1 up to 2 dB(A). One can suppress tyre/road noise much more by making the pavement much more elastic, and this idea is exploited with PERS.

2. PERS: OPPORTUNITIES AND CHALLENGES

2.1 What is PERS?

PERS is a porous (at least 20 % of voids) and elastic pavement containing rubber granulates (at least 20 % by weight, virgin material or recycled) and an elastic polymer as binder, such as polyurethane. It may contain other ingredients, such as natural or artificial stone aggregate, certain chemicals or certain types of fibers. Each of these ingredients may have a specific function: enhancing skid resistance, durability, homogeneity of the wet mix etc.

2.2 Why do we (still) want it?

PERS is in fact not a new idea: it has been invented at the end of the 1970ties by the Swedish consultant Nils-Åke Nilsson and some tests have been done in Sweden, Norway and from mid 1990ties also in Japan, demonstrating its huge and unequalled noise reduction potential: 8 up to 12 dB(A). The low noise pavements with the highest noise reduction which are in use today, two-layer porous asphalt, yield “only” 5 – 7 dB(A). Some further testing has been done in a national project in Sweden and in the national project “Noise Innovation Program” and in the subsequent project “Ultra Silent Pavement” in the Netherlands. A comprehensive overview of the history of PERS can be found in (2).

This huge noise reduction potential makes PERS very attractive. PERS reduces – at least for cars – as much noise as typical noise barriers, opening interesting perspectives for noise abatement, as noise screens do have a lot of disadvantages: they are expensive, their effectiveness depends on the local weather conditions, they are vulnerable to vandalism, intrusive and last but not least: there are a lot of situations where they cannot be used, e.g. in most city streets.

2.3 Requirements and challenges

There are a few reasons why PERS is still a concept and not yet a widespread tool for noise abatement, in spite of the fact that the concept was invented 35 years ago. The history of PERS is up to now a list of failures. The main reasons of the failures where insufficient raveling resistance, insufficient bonding to the sub layer and insufficient skid resistance. In some cases the failures were due to reasons which were “external” to the PERS, such as disintegration or rutting of the sub layer(s) or accidental destruction of the PERS by a snow plough. The lifetime of the PERS varied from a few weeks up to a few years with the latest, relatively successful Japanese experiments. There were also questions about the fire safety and the safety of the workers, the economic feasibility and the sustainability of the product.

3. THE PERSUADE PROJECT

By 2008 some European road research institutes took the initiative to draft a proposal for an FP7 call of the EC. A consortium of twelve partners from eight countries was formed, comprising six road research institutes, two contractors, two universities and two specialist partners with some special know-how. The proposal was approved and in September 2009 the six year project PERSUADE started. PERSUADE is an acronym for PoroElastic Road Surface for Avoiding Damage to the Environment. The aim of the PERSUADE project is to develop PERS from a yet experimental concept to a usable noise abatement measure.

The problems to be solved and questions to be answered about PERS at the beginning of the project were numerous: how to produce a mix which would yield a durable, highly noise reducing pavement with a sufficient skid resistance? How to avoid the PERS to ravel or to loosen from the sub layer? What in the case of a fuel spill? Or in the case of an accidental vehicle fire on a PERS section? How to build PERS without increasing rolling resistance? Which precautions should be taken to protect road workers and people living around from hazardous fumes? What to do with PERS at the end of its lifetime? What about economic aspects?

In order to find an answer to all relevant questions a comprehensive research program was drafted, consisting of the following work packages (WP):

- WP1: Project management
- WP2: Mix design
- WP3: Structural design
- WP4: Test tracks
- WP5: Monitoring of the test tracks
- WP6: Environmental issues
- WP7: Cost-Benefit Assessment
- WP8: Dissemination

After three quarters of the project time have elapsed, the main achievements of the project so far are outlined in this paper. The project started with the drafting of a comprehensive state of the art (2010) on the subject, which can be downloaded free of charge from the project website (**www.persuadeproject.eu**). This paper deals with the mix development, the small and full scale test tracks. More about the interesting findings related to the economic aspects, the sustainability, the environmental impact and the safety during the curing and in the case of an accidental car fire, can be found in (3) and (4).

4. MIX DEVELOPMENT

The PERSUADE project basically aims to develop one or more PERS mixes which would comply with a whole set of requirements, more in particular with respect to:

- Noise reducing capacity
  - Sound absorption
  - Permeability (air)
  - Air voids content
  - Thickness of the layer
- Vibration and noise excitation
  - Mechanical impedance
  - Texture
  - Reducing tyre vibrations
- Safety, wear and durability
  - Friction (wet skid resistance)
  - Polishing resistance
  - Ravelling resistance
  - Resistance to abrasion by studded tyres
  - Resistance to fuel spills
  - Resistance to deicing salt and frost/thaw cycles
  - Resistance to UV light exposure
  - Strength (resistance to cracking and tearing)
  - Permeability (water), draining capacity, water retention
  - Adhesion to base course
  - Other environmental factors (fume toxicity, particulates in the air,…)
  - Fire safety
  - Rolling resistance

The difficulty lies particularly in obtaining good properties for all these characteristics in one mix design. Some requirements appear to be contradictory, such as skid resistance and ravelling resistance and a compromise had to be found. There exist a variety of laboratory tests for asphalt concrete, but some of these were not directly applicable to the elastic PERS and had to be modified or an alternative had to be developed, e.g. to measure the strength of the bonding with the sub layer. The ravelling resistance is a critical parameter and a lot of test tracks built in Japan – the longest living ever built as aforesaid – failed on this criterion. Therefore this parameter got special attention from the PERSUADE project team. The ravelling sensitivity was measured with a device available at the University of Aachen, Germany: the **A**achener **R**avelling **Te**ster (ARTe, Figure 1).

Figure 1 – The Aachener Ravelling Tester (ARTe, left hand side) and a PERS test slab after being exposed to the test

A wheel is turning on the sample and the loosened material is sucked-up with an aspirator. The average loss of thickness after a treatment with the ARTe is a good measure for the sensitivity of the pavement to ravelling. More than forty samples have been tested so far on the ARTe in the frame of PERSUADE.

Figure 2 shows an overview of the results obtained on the respective samples. As a reference, also the values measured on a ultra-thin asphalt layer (UTLAC 5,5%) with a good ravelling resistance and the result on an UTLAC with a poor ravelling resistance (UTLAC 4,9%) are shown. The first mixes, numbers 2 and 4 gave an excellent ravelling resistance, but appeared to be very slippery. They were made using a recipe with a large amount of rubber, a small fraction of stones and polyurethane binder. This type of mixture was quickly abandoned and versions with a much larger stone content were produced (numbers 5 – 17), initially showing a very poor ravelling resistance. A sample produced later showed a very good ravelling resistance (25b), although the same mix showed also a less good value (25c). Skid resistance appeared to be good. Although the results of the repeated tests were not completely consistent, this mix was used for the first small scale test track in Arnakke, Denmark (see 5.1). Some more variants were than tested, with little success until an alternative mix was designed with very small aggregate (rather sand) with "special properties". Samples 43 and 44 are the same as 25b and 25c, but with aggregates from a Polish quarry, also yielding excellent ravelling resistance combined with a good skid resistance.

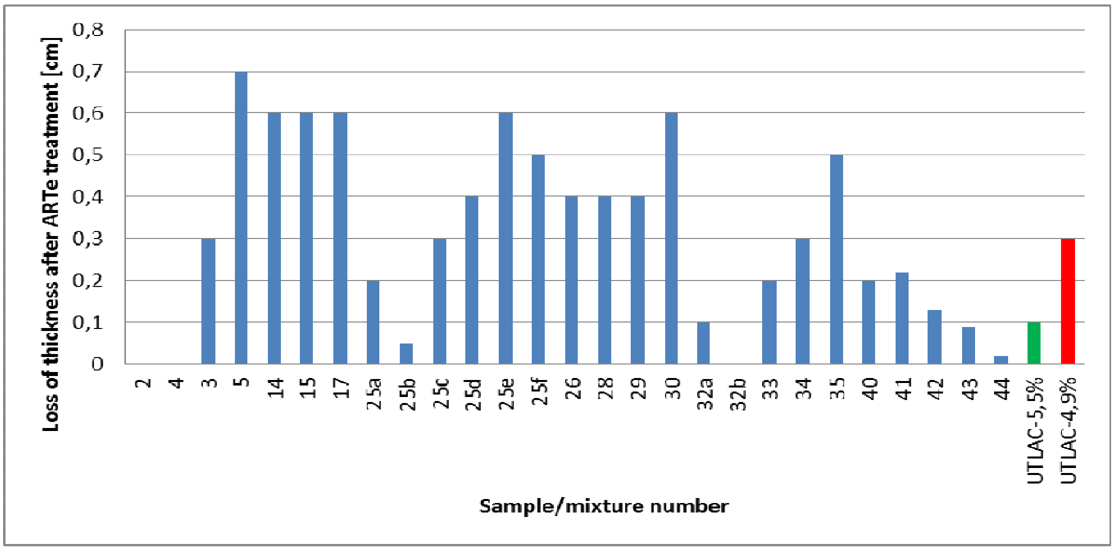


Figure 2 – Results of the ARTe on the PERSUADE samples

PERSUADE research further revealed among others that it is possible to glue the PERS to the sub layer with PUR in such a way that the bonding potentially should resist the emergency braking of a 40 tonnes lorry on the pavement. PERS appears to be insensitive to UV radiation. Repetitive exposure to deicing salts and frost-thaw cycles weakens the material somewhat, but the loss of strength remains within reasonable limits. The skid resistance of PERS remains acceptable after laboratory polishing of the sample and is of the same order as that of asphalt layers. The stone type appears to be an important factor for the polishing resistance.

5. TEST TRACKS

It was originally planned that, once at least one well performing PERS was developed in the laboratory, it would be tested one time on a small scale and then seven full scale test tracks would be built on trafficked roads in five partner countries. The building would be staggered in three rounds, with a pioneer test track in Denmark, six months later a test track in Belgium, Sweden, Slovenia and Poland and one year later two more test tracks, one in Belgium and one in Sweden. Nevertheless, one found out that building more small scale test tracks was not a luxury, as it is a big step from the laboratory scale slabs to a full scale test track with an area of the order of a few hundred m². Most involved road administrations judged it wise to let the contractor "practice" with the novel product by building a few m² of it on a location with little or no traffic.

5.1 Small scale, "pilot" test tracks

Table 1 summarizes the six small scale test sections which have been built in four PERSUADE countries. "Still existing" means "still existing in July 2014", i.e. the moment that this paper was drafted.

Table 1 – Summary of the small scale test tracks built in the frame of PERSUADE

Pre-test track	Country	Date of constr.	Dimens. (L x W x H) in m	Type of construction	Mix	Remarks
Arnakke I (rest area)	DK	8/2011	10 x 1 x 0,03	In situ (man.)	Arnakke (n° 25)	Severe foaming, removed
Arnakke II (rest area)	DK	11/2011	10 x 1 x 0,03	In situ (man.)	Arnakke (n° 25)	Slight foaming, mushroom shaped humps, pothole, still existing
Linköping (moderate traffic street)	SE	7/2013	6 x 1 x 0,025	In situ (man.)	Local variant of n° 25	Ravelling, loosening from sub layer, removed
Nova Gorica (low traffic street)	SI	8/2013	4 x 3 x 0,03	On cement blocks	HET mix (n° 41)	Slight raveling initially which stabilized, still existing
Sterrebeek I (closed road)	BE	9/2013	15 x 3 x 0,045	In situ (mach.)	Arnakke (n° 25)	Uneven due to too fast curing (clots), slippery when wet, removed
Sterrebeek II (closed road)	BE	10/2013	15 x 3 x 0,045	In situ (mach.)	Arnakke (n° 25)	Mushroom shaped humps, local foaming, skid resistance ok, still existing

Specific problems have been encountered when building the pilot test tracks, mainly due to the fact that the mix quantities are larger than in the laboratory, which is more demanding to obtain a homogeneous mixture. And the environmental parameters, such as temperature and humidity, are more difficult to control. The temperature and moisture heavily influence the polymerization speed and residues of moisture in the air or accidentally spilled water (e.g. from a car air-conditioning) can cause moderate to severe foaming of the polyurethane. Valuable experience has been gained, even with the pilot test tracks that failed early after their construction. Note that the second Danish test track, already dating from autumn 2011 still exists, albeit not in very good shape and on a rest area access road. The test track in Slovenia, the only pilot test track with prefabricated slabs is doing quite well, which is logical as the PERS has been produced in the factory under better controlled circumstances, apparently leading to a better quality. Figure 3, Figure 4 and Figure 5 show the pilot test tracks in respectively Sweden, Slovenia and Belgium.

Figure 3 – The Swedish pilot test track in Linköping; on-site construction (pictures: U. Sandberg, VTI)

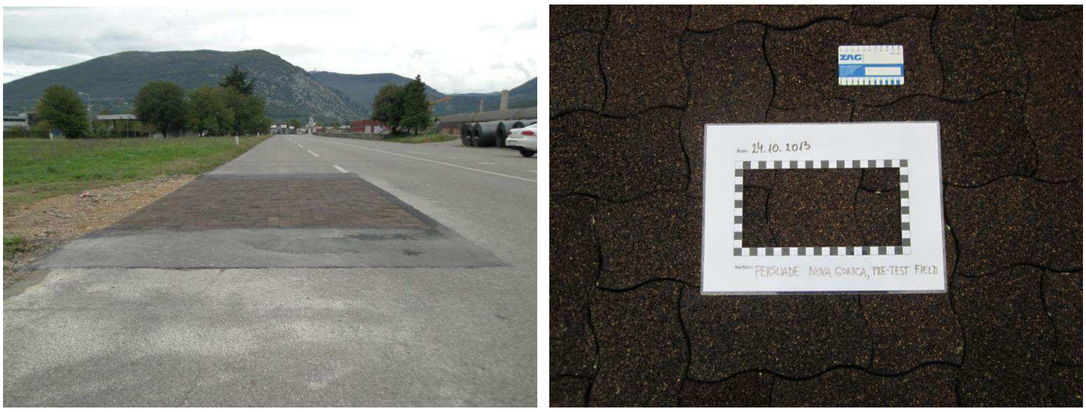


Figure 4 – The Slovenian pilot test track in Nova Gorica; prefab PERS on concrete setts (pictures: D. Kokot, ZAG)

Figure 5 – The Belgian pilot test track in Sterrebeek; on site construction: Sterrebeek I (two top pictures) and Sterrebeek II, which had to be constructed under a tent due to the cold and wet season (lower picture) (size of black/white squares is 10 mm) (pictures: A. Bergiers, BRRC)

5.2 Full scale test tracks

After the relative success of the second pilot test track in Arnakke, the Danish PERSUADE partners felt confident enough to build their full scale test track on a trafficked road (secondary road) near the village of Kalvehave, about 100 km South of Copenhagen. The construction took place in August 2013 with very sunny and warm weather. The construction of this first "large scale" test track (80 m x 3 m x 0,03 m) went quite well, using a gussasphalt paver and a small compaction roller, except that the binder appeared too liquid and there was some inhomogeneity of the mix before it was applied. This effect caused premature raveling after a few months and on 25 June 2014 it was replaced by a second test track with a slightly modified mix and binder. The viscosity of the binder was lower and the mix seemed very homogeneous when applied. So far no problems have been observed (Figure 6).

Figure 6 – The second full scale test track in Kalvehave, Denmark, built in June 2014 (pictures by H. Bendtsen, DRD). Each square in the frame is 10x10 mm.

In November 2013 the Swedish PERSUADE partner VTI constructed a “large scale” (but only in one wheel track, 25 m x 1 m x 0,03 m) test track with prefabricated slabs (Figure 7), made by another PERSUADE partner. Due to the harsh weather conditions, a tent was used here as well, but the circumstances for gluing the slabs (with epoxy) to the cold underlayer appeared anyway not ideal and there was some loosening of the sub-layer already during winter. The disintegration process was accelerated by huge dumper trucks passing the site from and to a large construction site nearby. The PERS was also almost constantly soaked with water, as the drainage to the roadside by porous asphalt strips appeared inefficient, which was an extra adverse effect for the durability.

Figure 6

Figure 7 – The first “full scale” test track in Linköping, Sweden, built in November 2013 (pictures by U. Sandberg)

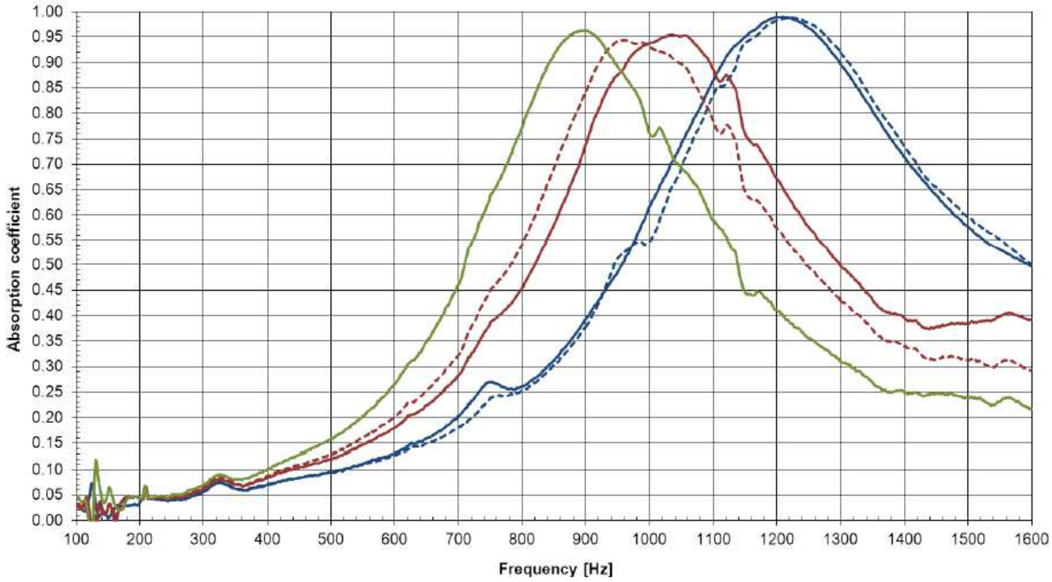
6. MONITORING

6.1 Small scale test tracks

The small scale test tracks were primarily meant to practice with the application of PERS on the road, to have an idea about the durability and to monitor some safety features (skid resistance, winter behaviour). Nevertheless, as much as possible other testing was carried out on them, as far as their limited size allows: absorption, drainability, mechanical impedance, texture, microscopic aspect and on the Belgian small scale test tracks even “Controlled Pass By” measurements were done.

Skid resistance ranged from just sufficient to very good, except on the Belgian Sterrebeek tracks, where it was slightly insufficient, due to the existence of a polyurethane film on the aggregates. An effective solution to deal with this problem is sanding while the PERS is still uncured and this has been successfully tried in the laboratory.

Examples of absorption curves measured on samples from Arnakke II and Sterrebeek II are shown in Figure 8. (5), (6)



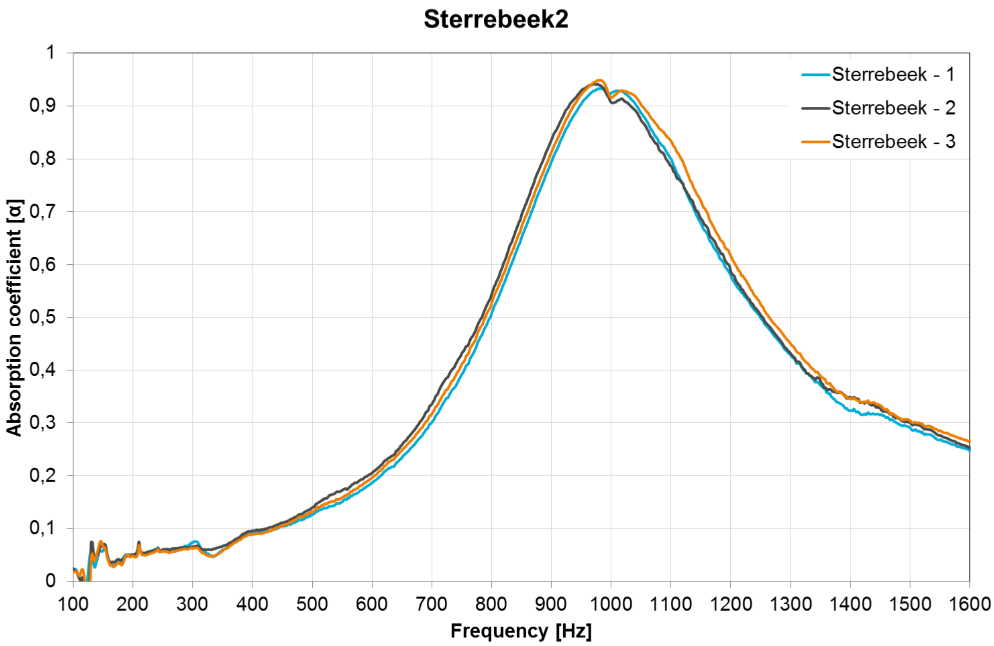


Figure 8 – Similar absorption curves measured on samples from Arnakke II (top) and Sterrebeek II (bottom)

Pictures of the controlled pass by measurements are shown in Figure 9. The noise reductions measured on both Sterrebeek test tracks for two types of vehicles each are given in Figure 10.

Figure 9 – Controlled Pass By measurements on the Sterrebeek II test track and on an ordinary dense asphalt concrete pavement (reference) (pictures by A. Bergiers, BRRC)

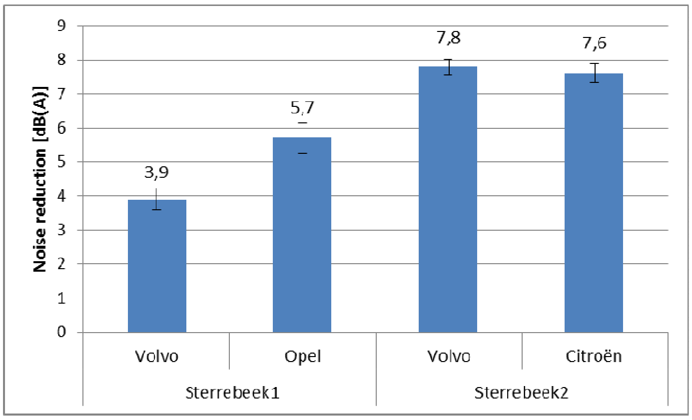


Figure 10 – Noise reductions obtained with the Controlled Pass By measurements on the Sterrebeek test tracks compared to on an ordinary dense asphalt concrete pavement

The noise reduction on Sterrebeek I was rather disappointing, but on Sterrebeek II one measured for both cars almost 8 dB(A) reduction at 50 km/h, which is promising, but it must be kept in mind that this is not a standardized measurement method and hence has only an indicative value. SPB was not possible in Sterrebeek (track not under traffic) and for CPX measurements the test section was too short.

6.2 Full scale test tracks

6.2.1 The Danish Kalvehave test tracks

Only monitoring data from Kalvehave I are available at the moment this paper is drafted. The skid resistance was measured with the SRT pendulum, the VTI portable friction tester and the Danish ROAR. For all skid resistance measurements a more than sufficient value was obtained, e.g. the average SRT value was 78 whereas 45 is generally the limit and the ROAR yielded 0,54 and 0,60 in the respective wheelpaths whereas 0,40 is the threshold value.

SPB measurements were carried out to assess the acoustic properties. The noise reduction compared to the Nord 2000 reference is 6,2 dB(A) at 50 km/h and 7,7 dB(A) at 80 km/h. CPX measurements with the SRTT tyre showed a reduction of 6,5 dB(A) and 7,2 dB(A) at 50 km/h and 80 km/h, which is a bit less good than one hoped for. The Kalvehave II test track might perform somewhat better as it seems to have a better texture.

The rolling resistance measured on Kalvehave I is between 3,9 % and 8,9 % higher on the PERS than on asphalt, corresponding to 0,8 % up to 1,8 % more fuel consumption. This is not a disaster, as the increase is limited and the goal is to use PERS on black spots, i.e. road sections causing noise problems and not on the whole road network. The total impact on the fuel consumption will hence be negligible.

6.2.2 The Swedish Linköping full scale test track

The initial skid resistance, measured with the Swedish “Saab Friction Tester”, appeared to be rather poor and “on the edge” of the acceptable: one measured 0,49 – 0,50 whereas 0,50 is the threshold. After some light “grinding” of the PERS surface (grinding off excess binder), a more than acceptable 0,61 – 0,63 was measured. SPB measurements were not possible, but one carried out CPX measurements. The results for 80 km/h and the SRTT tyre are shown in Figure 11. With the “prefab” test track in Sweden, a very nice 10 dB(A) could be achieved, compared to the “quiet” Danish reference surface. Much more data for this test section is reported in another Inter-Noise paper (7).

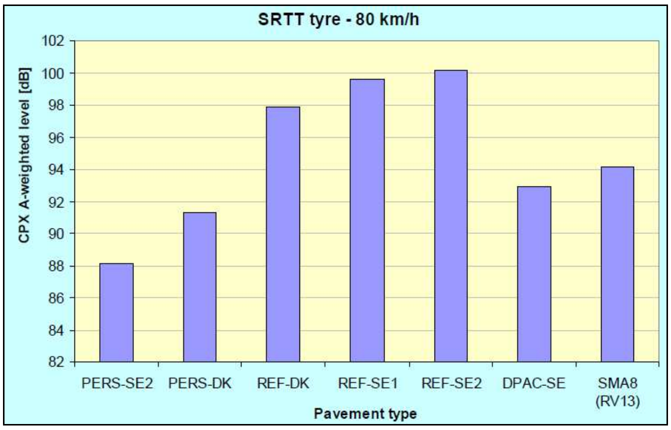


Figure 11 – Noise levels measured with the CPX method on the Linköping full scale test track (PERS-SE2) and the Kalvehave I (PERS-DK), as well as on the reference test tracks in Denmark and Sweden (REF-XX). For further comparison, also the CPX levels on a Swedish double layer porous asphalt (DPAC-SE) and on an SMA8 pavement is shown (the latter two in new condition).

7. CONCLUSIONS

A mix, well performing in the laboratory, is not simply “transferable” to a well performing pavement on the road. The upscaling and outdoor construction and curing involve specific problems, such as larger quantities (making it more difficult to obtain a homogeneous mixture) and less controllable environmental parameters (such as temperature and humidity). It was a good approach to do more testing with small scale test tracks, which allowed to practice with this novel pavement type and to observe and deal with specific problems, such as a too liquid binder, foaming of the binder and insufficient initial skid resistance. The construction of the full scale test tracks had to be postponed, but is ongoing now. The newly laid Danish test track looks good and makes the author hopeful that success can be achieved with the PERSUADE project.

As for the performance, it looks like the in situ PERS performs well in terms of noise reduction and rolling resistance (about 8 dB(A) noise reduction and max. 9 % increase of rolling resistance), whereas the prefab type appears to perform excellent (10 dBA noise reduction and a decrease of the rolling resistance).

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REFERENCES

1. European Tyre Directive 2005/69/EC
2. Sandberg, U.; Goubert, L. "Poroelastic Road Surface (PERS): A review of 30 years of R&D work", proceedings of INTERNOISE 2011, Osaka (2011)
3. Świeczko-Żurek, B.; Ejsmont, J.; Motrycz, G.; Stryjek P. "Risks related to car fire on innovative Poroelastic Road Surfaces - PERS", Fire and Materials, (2014), Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/fam.2231
4. Pigasse, G.; Jensen, M.P.; Bendtsen, H. "Cost-benefit analysis of a poroelastic road surface", Euronoise 2012, Prague (2012)
5. Bendtsen, H.; Olesen, E.; Pigasse, G.; Andersen, B.; Raaberg, J.; Kalman, B.; Cesbron, J. "Measurements at the Arnakke test site with small PERS sections", PERSUADE Technical Report (2013), downloadable from www.persuadeproject.eu
6. Bergiers, A.; Cocu, X. “Measurements on the small scale Sterrebeek test sections” PERSUADE Technical Report (2014), downloadable from www.persuadeproject.eu
7. Jerzy Ejsmont, Beata Świeczko-Żurek, Ulf Sandberg, Piotr Mioduszewski, "Tyre/road noise on poroelastic road surfaces", Proc. of Inter-Noise 2014, Melbourne, Australia.