THE PORO-ELASTIC ROAD SURFACE (PERS): A POWERFUL TOOL FOR TRAFFIC NOISE REDUCTION

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ABSTRACT

Limited noise tests on poroelastic road surfaces (PERS), mainly in Sweden and Japan, have shown a high noise-reducing potential; 10 dB(A) and more compared to dense asphalt is feasible. This makes it a potential alternative to noise barriers; especially where such are impractical or not desirable.

The specific feature of PERS is that it consists mainly of rubber granules from recycled tyres bound with a synthetic resin, such as polyurethane. However, in the present state of the art, its durability remains inadequate. Especially, problems with ravelling, debonding, skid resistance and drainage need to be solved.

In September 2009, the large-scale EU-funded PERSUADE project was started. The goal of this project is the development of PERS into a usable product, and it will be carried out by a consortium of twelve partners from eight European countries. The project programme comprises an extensive investigation in the laboratory to develop a durable PERS mixture, the construction of seven test sections in five partner countries, a monitoring effort for the test sections (noise, rolling resistance, skid resistance, durability, winter behaviour, etc), and a study of all conceivable environmental and economic aspects.

This contribution deals with the usefulness of a PERS wearing course, project goals, work plan and reports some of the work carried out so far.

RESUME

Des essais restreints réalisés sur des PERS, principalement en Suède et au Japon, ont démontré leur important potentiel de réduction du bruit: il est possible d'arriver à une réduction de 10 dB(A) et plus par rapport à un enrobé fermé. Cela représente une éventuelle alternative aux écrans antibruit lorsque ceux-ci ne sont pas envisageables.

La spécificité des PERS est qu'ils sont principalement constitués de granulés de caoutchouc issus du recyclage de pneus d'automobiles et liés avec une résine synthétique, telle que le polyuréthane. Néanmoins, à l'état actuel de la technique, leur durabilité reste inappropriée. Plus spécifiquement, des problèmes d'arrachement, d'adhérence et de drainage doivent encore être résolus.

En septembre 2009 a débuté PERSUADE, un projet européen à grande échelle. L'objectif de celui-ci est de développer les PERS. Il est dirigé par un consortium de douze partenaires provenant de huit pays différents. Le programme du projet comprend une étude approfondie en laboratoire afin de développer un mélange PERS durable, la réalisation de sept sections expérimentales (bruit, résistance au roulement, adhérence, durabilité, comportement hivernal, etc), ainsi qu'une étude de tous les aspects environnementaux et économiques envisageables.

La présente contribution traite des objectifs du projet et du programme, ainsi que du travail déjà réalisé.

1 INTRODUCTION

This paper deals with poroelastic road surfaces (PERS), which can be described as a wearing course for roads with a high content of interconnected voids which at the same time is elastic due to the use of rubber as a main aggregate [1]. Design air void content is at least 20 % and design rubber content at least 20 % by weight. The binder is an elastic polymer, most often polyurethane. Mixtures with rubber granules, bitumen and stones, having much lower rubber content than 20 %, are generally referred to as asphalt rubber or rubberized asphalt and are out of the scope of this paper and the PERSUADE project.

Experiments with various types of poroelastic road surfaces (PERS), mainly in Sweden and Japan, have shown that substantial noise reductions can be achieved – 10 up to 12 dB(A) in comparison with dense asphalt concrete (DAC) - which cannot be matched by any conventional type of road surface. Not even the so far best performing types such as double layer porous asphalt 2/4 and 2/6, reach more than 8 dB(A) noise reduction, at the very best.

However, previous tests with PERS all failed prematurely in one way or the other, mainly owing to problems with durability, adhesion and/or skid resistance. The unique noise reduction potential of the concept, nevertheless, justifies further research to convert PERS from a promising but still highly experimental concept into a usable noise-abating measure. The typical noise reduction obtained with PERS is comparable to that of common noise barriers and the cost is likely to be very competitive if durability is enhanced. The EU-funded FP7 project PERSUADE (PoroElastic Road Surfaces to Avoid Damage to the Environment) aims at achieving this goal. The work programme of the PERSUADE project will be outlined in the final part of this contribution.

2 WHY CAN PERS REDUCE TYRE/ROAD NOISE BETTER THAN CONVENTIONAL SURFACINGS?

The mechanisms contributing to tyre/road noise have been investigated since the 1970's. It is now known that tyre/road noise is generated and emitted due to a number of interacting mechanisms [1]. The relative contributions of these mechanisms depend on driving style, road surface and tyre conditions. The mechanisms can be classified into three main categories: vibrational (structure-borne), aerodynamical (air-borne) and amplification/reduction mechanisms. The main mechanism in the first category is radial vibrations, generated mainly by texture and tyre tread impact. Due to the elasticity of the surface, the deflections in the tyre will be lower, which gives lower noise generation. A second important mechanism, which belongs to the second category mentioned above, is air pumping. When a tyre is running on a smooth surface, air is compressed at the leading edge of the tyre/road contact zone and air is sucked-in at the trailing edge. This can be avoided by providing the road surface with macrotexture or by making it porous, which will allow air to escape horizontally or vertically, respectively, before it is compressed/sucked. The horn effect is an amplification effect, caused by the multiple reflections of sound generated in the tyre/road contact zone (e.g. by tyre vibrations) between the tyre tread and a reflective road surface. This effect can be suppressed by providing the road surface with accessible voids and making it sound-absorbing.

The reason why PERS can be such an extraordinary quiet road surface is that it combines effective "countermeasures" against these three principal noise-generating mechanisms:

- PERS has a very smooth surface and is elastic, which allows efficient suppression of radial vibrations by less excitation by the texture impact on the tyre tread, but also due to that some of the deflections in the tyre/road contact occur in the PERS and thus the tyre deflects less. This is favourable also for rolling resistance.
- PERS has a high void content, typically 25-40 %, whereas for conventional, hard porous surfaces, void content is generally limited to 25-30 % for durability/stability reasons. A higher void content accounts for a more efficient suppression of air pumping (efficient evacuation of air through accessible voids).
- The higher void content also more effectively suppresses the horn effect (sound absorption), while also roadside noise is reduced by avoiding reflection from the road surface.

3 HISTORY OF PERS AND MAJOR RESULTS SO FAR

3.1 Brief history

The concept of PERS was invented in Sweden at the end of the 1970's by Mr. Nils-Åke Nilsson [2]. Some limited laboratory and small scale field experiments were carried out in Sweden during the 1980's, demonstrating the exceptional tyre/road noise reduction potential of this new type of road surface (up to 12 dBA) but durability appeared insufficient. In 1994 the Japanese Public Works Research Institute (PWRI) initiated research in the field, building on the first Swedish results. PWRI made extensive work, including several field tests, in the coming years up until the present time. Prefabricated panels, PERS-covered interlocking paving blocks, and site-constructed materials have been tried over the past 15 years. These trials have focused on adhesion systems (PERS to the base-course), structural durability and long-term skid resistance. Some of these tests have been rather successful, some have failed, but so far there is no solution that promises to solve all the mentioned problems.

Apart from the PWRI work, substantial efforts have been made by Japanese manufacturers of PERS materials. Some have given up these efforts, but some are still trying. The best example (known to the authors) is full-scale field tests going on in at least two Japanese cities, in cooperation between Yokohama Rubber and Nippon Hodo companies.

In 2004, the Swedish National Road and Transport Research Institute (VTI), after considerable laboratory work, carried out a full-scale test on a street in western Stockholm, comprising a site-constructed type and two types with precast panels (1x1 m^2). Unfortunately, the experiment had to be aborted and the PERS layers removed only five months after the construction, owing to problem with a disintegrating base-course. During that short time period, however, the PERS performed well.

In the Netherlands, within the so-called noise innovation programme (IPG), conducted 2002-2008, as a "fourth generation" quiet road surface, PERS was included to a limited extent. Six short test sections were built on a test track. They essentially confirmed earlier experience. In an extension of the IPG programme, now called the SSW project, in November 2009 a new 260 m test section of a new PERS composition was built on a service road along the A50 motorway, but this pavement failed within a few months and was closed for traffic.

Much more about these experiences can be read in [3] and [4].

3.2 Major results

3.2.1 Noise reduction

The extreme noise reduction which appears to be feasible with PERS is the main motivation for investigating this type of road surface and the ongoing attempts to find solutions for the major problems associated with it.

In Table 1, the major results of the acoustic assessment of the most important trials with PERS are summarized.

It appears that in full-scale tests noise reduction of 7-12 dB(A) has been measured for passenger cars or for car tyres. Since at 50 km/h car noise emission is essentially the same as tyre/road noise emission, these conditions are basically similar. A typical value for the state of the art “classical” low noise pavement, double-layer porous asphalt, is 5-8 dB(A). The latter may in the best cases deteriorate by approx 0.4 dB/year due to clogging and ravelling, in some conditions by up to 2 dB/year, while it is hoped that the PERS will be much less subject to clogging, since it is so flexible that dirt should not get stuck in it.

Table 1 – Noise reductions for cars or car tyres at 50 km/h, obtained in some historic “full scale” trials with PERS

Country	Year	Manufacturer	Type of measurement	Noise reduction [dB(A)]	Remarks
Norway	1989	ViaNova A/S	CPB	7-9	On-site mix
Sweden	2004	VTI/Spentab	CPX	12	On-site mix
Sweden	2004	Rosehill	CPX	8	Prefab panels
Sweden	2004	Tokai	CPX	11	Prefab panels
Japan	2005	Tokai	SPB	7	Prefab panels
Japan	2005	Sumitomo	SPB	10	Prefab panels
Japan	2005	Yokohama Rubber Co.	SPB	10	On-site mix
Japan	2006-2009	Yokohama Rubber Co. & Nippon Road Co.	SPB	10	On-site mix

3.2.2 Skid resistance

Problems have been reported in Japan about insufficient skid resistance of PERS, but this problem can be solved by a proper mix design (adding of mineral aggregate), as has been found in Japan and in Sweden (Figure 1). The red curve in Figure 1 is for a mix which includes effective friction-enhancing material.

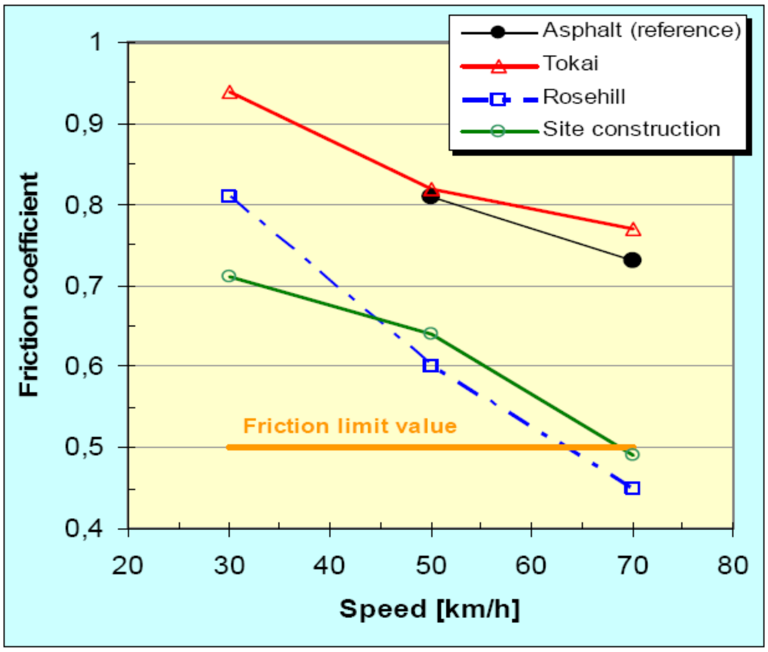

Figure 1 – Results of the measurements with the SAAB Friction Tester on the three Swedish PERS sections constructed by VTI in 2004 in a Stockholm city street

3.2.3 Rolling resistance

Solving the traffic noise problem must not result in another environmental problem, such as an increase CO_2 emission by an increased rolling resistance of the pavement. Therefore, the issue of rolling resistance is one of the other major aspects. One of the three Swedish PERS types (Rosehill) was tested on the drum of the Technical University of Gdansk (TUG) and it turned out that the rolling resistance was not higher than the rolling resistance for conventional dense asphalt concrete. Measurements of the rolling resistance with the coast-down method on the most recent Japanese PERS sections yielded similar results.

3.2.4 Durability

Durability remains the main challenge to be dealt with at this moment. All full scale experiments failed prematurely, except one of the most recent Japanese sections, which lasted three years before it was removed, when it was in fairly good condition (the last one in Table 1). The main problems with durability are insufficient ravelling resistance and adhesion to the base-course.

4 USE OF PERS

4.1 The need for measures with an high noise-reducing potential

The WHO recently identified high noise levels as a threat to health and causing many premature deaths [5], which should call for increased efforts to reduce the highest noise levels. PERS may be the solution, and sometimes a unique solution, on some of these "black spots" (locations with the highest noise exposure).

The European Environmental Noise Directive (END) imposes the production of action plans in order to reduce noise pollution at the black spots. There is in Europe hence a growing need for effective and cost-efficient noise-reducing measures. As stated above, noise barriers are not effective everywhere, especially not in built-up areas with multi-floor buildings, and they are also associated with problems such as limiting the view for residents, graffiti, etc. PERS will provide an alternative which is useful in some cases, provided PERSUADE will be successful.

4.2 Advantages and disadvantages of PERS

PERS is a low noise road surface (LNRS) and LNRS have several “intrinsic” advantages when compared with other noise abatement measures. LNRS are not intrusive like noise barriers and they are not sensitive to vandalism (tagging or breaking of noise barriers made of glass or plexiglass). While noise barriers provide noise reduction at most in the "acoustic shadow" behind the barriers, LNRS provide noise reduction in all directions. Wind and/or temperature effects can cancel the noise reducing effect of barriers, even behind barriers, which is not the case for LNRS. Porous LNRS have some additional advantages: they tend to reduce splash and spray during rainy weather and lights of vehicles driving in the opposite direction are not reflected on the road surface.

LNRS are generally much more expensive than ordinary pavements. Nevertheless, in a Danish study some years ago three noise abatement measures (LNRS, barriers and façade insulation) were compared in three different cases (city street, ring road and highway) and the LNRS turned out to be by far the least expensive in all cases, both in terms of investment per km and in cost per dwelling and per dB. PERS will be an expensive product and its lifetime will maybe be shorter than those of conventional pavements. The cost effectiveness of PERS is hence an important issue, that will be dealt with thoroughly in PERSUADE (see 5.3).

A disadvantage of (conventional) LNRS compared to barriers is that the noise reduction which can be reached is lower (initially 5-8 dB(A)) than what can be reached with noise barriers (typical noise reduction 7-12 dB(A)). Therefore, in situations where a certain high noise reduction has to be achieved one almost automatically ends up with noise barriers. Revolutionary about PERS is that it can yield as high noise reduction as a "normal" noise barrier, at least for passenger cars. And last but not least, once the durability problems with PERS are solved, one can apply it in principle on any road. Noise barriers, on the contrary, cannot be effective everywhere.

An important disadvantage of PERS will be that its lifetime will most likely be lower than that of conventional road surfaces, even when the actual durability problems will be solved. More frequent replacement of the road surfacing will cause more traffic hindrance. Nevertheless, resistance to wear by studded tyres has been shown to be much better than that of conventional asphalt pavements, at least for one type of PERS, so in such cases lifetimes might be longer rather than shorter, but the road to achieve this while meeting also the other objectives is very long.

4.3 A typical situation for which PERS would be very useful

The idea is to use PERS as an alternative to other noise abatement measures on black spots on noise maps produced within the framework of the END. Using it as a standard pavement would not be feasible from a budget point of view and there would not be enough waste tyres available to produce the raw material. A typical situation in which PERS would be most useful would be high-speed roads with mainly cars driving through densely populated built-up areas. Figure 2 depicts a road section in Gent (Belgium) which is the exit of the E40 highway, allowing cars to drive quickly into the city centre. Multi-floor apartment buildings stand on both sides of the road, being exposed to high noise levels. Noise barriers are far from ideal, as the road is on a viaduct and they would have to be very tall to interrupt the line of sight to the apartments on the highest floors, which is nearly impossible from a technical and budget point of view.

Figure 2 – Typical high-speed road in Gent (Belgium) causing severe noise nuisance at the surrounding dwellings and for which PERS would be an excellent solution.

5 THE PERSUADE PROJECT

5.1 Goal and strategy of the PERSUADE project

The project aims at developing a durable, cost-effective PERS using recycled tyres. The general goal is to remove doubts about the technical and economical feasibility of the PERS solution for abating road traffic noise by demonstrating its potential in successful full-scale applications. The project has been scheduled for a duration of six years and an overall budget of € 4,7 million. Twelve partners in eight countries are involved. The strategy comprises five steps.

5.1.1 Laboratory and small-scale testing

To maximize chances of technical success, the following preliminary work is carried out:

- laboratory tests with a view to optimizing the mix design for mechanical properties (complex elastic modulus, flexural fatigue and hysteresis), acoustic properties (sound absorption), adhesion (to different sub-base materials), workability, porosity/drainage, resistance to tear and wear, resistance to rutting and oil and fuel resistance;
- small-scale field tests of resistance to emergency braking by heavy vehicles and for performance in connection with fires.

5.1.2 Production of PERS material

Once an optimum mix design has been chosen, the material will be produced by specialized partner factories in different forms for different laying/construction methods: delivery of batches of bulk material, application of PERS on paving blocks for urban streets, prefabrication of sheets or mats and laying in long stretches followed by rolling on a drum for subsequent transport and unrolling on site (so-called Rollpave technique).

5.1.3 Time-staged construction of seven test sections in five countries

The conditioned material will be delivered to the five partner countries that will build test sections on real roads (Belgium, Denmark, Sweden, Poland and Slovenia) in order to study the behaviour of different variants of PERS under different traffic and climate conditions. The tested solutions will partly differ from country to country. The full-scale sections will be built in two phases, with the second following twelve months after the first one. The aim of this time-staged approach is to be able to learn from the experience gained in the first stage when preparing the second one.

5.1.4 Monitoring of the test sections

The test sections will then be monitored by initial and periodic measurements of rolling noise (SPB and/or CPX measurements), acoustic absorption, skid resistance, rolling resistance (on the basis of which fuel consumption and greenhouse gas emissions will be estimated), drainage (to test for possible clogging) and winter behaviour (de-icing by salt and snow removal).

5.1.5 Evaluation of PERS technology

Finally, an overall evaluation of PERS technology will be made and disseminated based on the technical results from the full-scale experiments and on cost/benefit and Life Cycle Assessment (LCA) using the information gathered from the activities throughout the project, including consideration of waste management balance and global greenhouse gas emissions balance.

5.2 The PERSUADE consortium

The Consortium is formed by six national research institutes:

- Belgian Road Research Centre (BRRC, coordinator of the project, Belgium)
- Swedish National Road and Transport Research Institute (VTI, Sweden)
- Danish Road Institute – Danish Road Directorate (DRI, Denmark)
- Slovenian National Building and Civil Engineering Institute (ZAG, Slovenia)
- Polish Road and Bridge Research Institute (IBDiM, Poland)
- and Laboratoire Central des Ponts et Chaussées (LCPC, France),

two universities:

- Technical University Gdansk (TUG, Poland) and
- Catholic University of Leuven (KU Leuven, Belgium)

and four industrial partners:

- NCC (contractor, Denmark)
- Duravermeer (contractor, Netherlands)
- Heidelberg Elastomertechnik GmbH (HET, SME specialized in manufacturing products with rubber granules and polymers, Germany)
- and European Tyre Recyclers Association (ETRA, representing tyre recycling companies in Europe, based in France).

The five national research institutes will build and follow-up experimental sections with the support of their respective national or local road administrations.

5.3 Progress so far

The project started 1 September 2009 and work has already been done on:

- dissemination: a website has been constructed (see below) and a comprehensive state-of-the-art report [3] has been produced. The state-of-the-art report has a "public" status and can be downloaded free of charge from the project website.
- mixture design: feasible test methods have been selected, moulds for samples have been manufactured and the first samples have been prepared. Figure 11 shows one of the first PERS samples produced in the PERSUADE project, intended for adhesion testing in the laboratory of BRRC.
- a cost-benefit analysis (CBA) has been initiated. PERS will be compared in a few typical case studies with other candidate noise-abating measures and the costs and benefits will be assessed.

For more information, please visit the PERSUADE website (www.persuadeproject.eu)

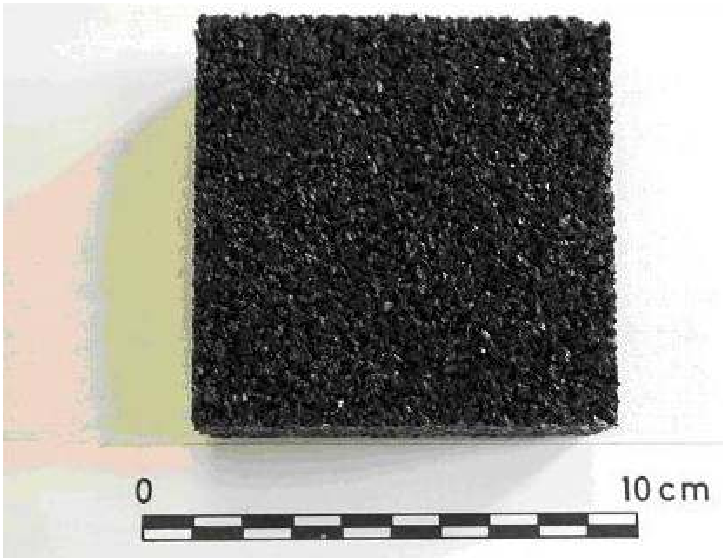

Figure 3 – PERS test sample prepared for adhesion testing in the PERSUADE project

6 FINAL REMARKS

In view of the long series of historical attempts and subsequent failures, it cannot be denied that there is a risk that this research project will not be successful. Nevertheless, the "reward" in case of success would be substantial, as an effective alternative to noise barriers would become available for abating traffic noise. Noise barriers have several disadvantages, such as intrusiveness, vulnerability to vandalism, high cost, etc, but in many circumstances they are even ineffective due to geometrical reasons. The chances of success have been optimized in the PERSUADE project by a stepwise approach, an extensive laboratory program, time-staged construction of the test sections, but the know-how available in the consortium and its "balanced" membership is perhaps the best resource available for a successful project.

A series of papers on various aspects of PERS will be published at the upcoming Inter-Noise 2011 conference in Osaka, Japan, in September 2011 (at the time of writing these papers are still in the draft stage). The reader who wants more information than provided in this paper is recommended to search for these papers, or to contact the authors for references. The PERSUADE website will reference these papers after September 2011.

7 ACKNOWLEDGMENTS

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