Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

THE PERSUADE PROJECT: DEVELOPING THE PORO-ELASTIC ROAD SURFACE INTO A POWERFUL TOOL FOR TRAFFIC NOISE ABATEMENT

L Goubert Belgian Road Research Centre, Brussels, Belgium
U Sandberg Swedish National Road and Transport Research Institute, Linköping, Sweden

1 INTRODUCTION

This paper deals with PERS, which can be defined[1] as a wearing course for roads with a high content of interconnected voids which is at the same time elastic due to the use of rubber as a main aggregate. 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 are generally referred to as rubberized asphalt and are out of the scope of this paper and the PERSUADE project. In this paper, one will discuss first the principal rolling noise generation and amplification mechanisms. The role of the road surface properties will be explained, showing that the obvious way forward for substantial additional rolling noise reduction is to make the road surface elastic. Then a historical overview will be presented for PERS. Experiments with various types of poro-elastic road surfaces (PERS) mainly in Sweden and Japan, show that huge noise reductions can be achieved – 10 up to 12 dB(A) in comparison with dense asphalt concrete (DAC) - which cannot be approximated by far with the conventional silent road surfaces – not even with the so far best performing types like double layer porous asphalt 2/4 and 2/6, reaching an 8 dB(A) noise reduction at the very best. However, historical tests with PERS all failed in one way or another prematurely, mainly owing to problems with durability, adhesion and/or skid resistance. The enormous 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 noise screens and the cost is likely to be very competitive if durability is enhanced. The EU-funded FP7 project PERSUADE (Poro-Elastic Road Surfaces to Avoid Damage to the Environment) aims at achieving this goal. The set up of the PERSUADE project will be outlined in the final part of this contribution.

2 WHY CAN PERS REDUCE ROLLING NOISE IN AN EXCEPTIONAL WAY?

The mechanisms contributing to rolling noise have been investigated since the 1970ties. It has turned out that rolling noise result from a large number of interacting mechanisms [1]. The relative contributions of these mechanisms depend on driving, road surface and tyre conditions. The mechanisms can be catalogued in three main categories: vibrational (structure-born), aerodynamical (air-borne) and "amplification/reduction mechanisms". The main mechanism in the first category consists in *radial vibrations* (Figure 1), generated mainly by texture and tyre tread impact. To minimize this effect on conventional, "hard" road surfaces, irregularities with horizontal dimensions between 1 cm and say 20 cm (mainly megatexture range) must be avoided as much as possible. For that reason, small-size aggregates are used for silent road surfaces. Nevertheless, tyre tread impacts cannot be avoided and there will always be some residual megatexture, which means that tyre vibrations cannot be completely suppressed.

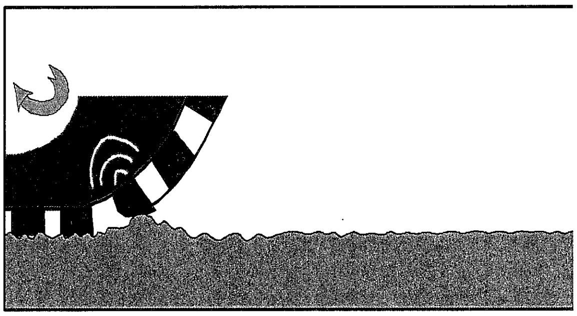

Figure 1 – Radial tyre vibrations by road surface irregularity impact.

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 at the rear edge (Figure 2). 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.

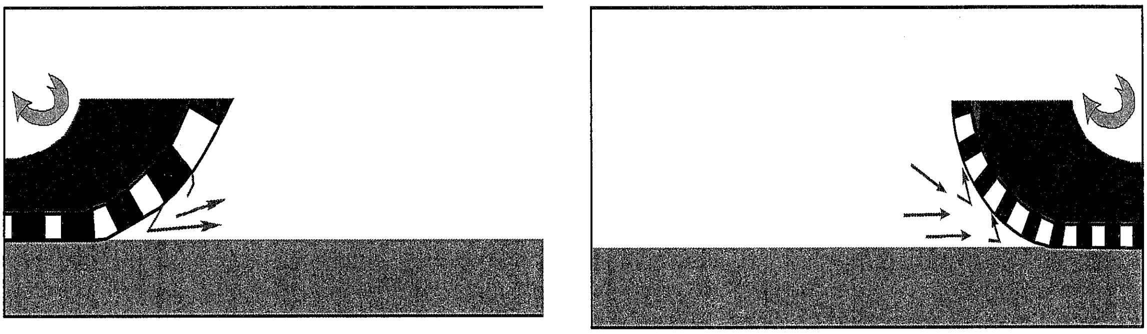

Figure 2 – Air pumping effect: compression and suction of air

The horn effect is an amplification effect, caused by the multiple reflections of noise generated in the tyre/road contact zone (e.g. by tyre vibrations) between the tyre tread and a reflective road surface (Figure 3). This effect can be suppressed by providing the road surface with accessible voids and making it noise-absorbing.

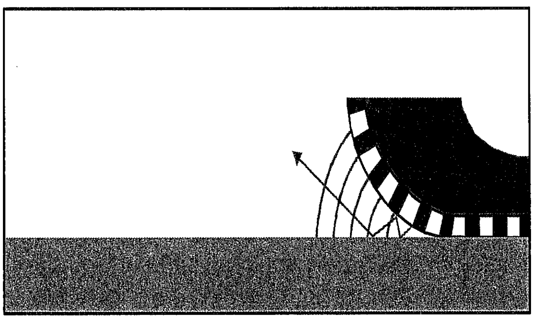

Figure 3 – Horn effect.

The reason why PERS can be such an extraordinary silent road surface is that it combines 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 the "prolonged" contact between tyre and road surface. As a result, noise emitted by the tyre vibrations is much lower than on conventional hard road surfaces. This is most probably the main reason for the exceptional acoustic properties of PERS.

Figure 4 shows the influence of an increase of the elasticity of the road surface: a rolling noise spectrum was measured on a hard, concrete surface covered with sand paper and on an elastic surface covered with the same sand paper. The difference in the two rolling noise spectra shows the important influence of the elasticity: a noise reduction between about 500 and 2,000 Hz. The noise reduction peaks at 1,000 Hz and reaches 5 dB.

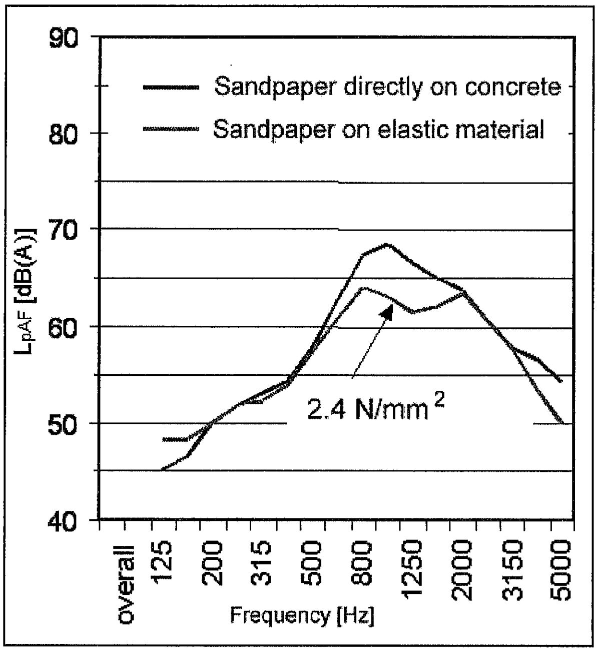

Figure 4 – Effect of elasticity or road surface on rolling noise spectra[2].

- PERS has a high void content, typically 25 up to 40 %, whereas for conventional, hard porous surfaces, void content is generally limited to 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) and the horn effect (noise absorption). Road side noise is reduced by avoiding reflection from the road surface, which accounts for an additional noise reduction in comparison with impervious road surfaces like DAC.

3 HISTORY OF PERS[3]

3.1 Invention and early trials in Scandinavia (1979- 1990)

The concept of PERS was invented in Sweden at the end of the 1970ties by Mr. Nils-Åke Nilsson. Some limited laboratory and small scale field experiments were carried out in Sweden during the 1980ties, demonstrating the huge rolling noise reduction potential of this new type of road surface (7,5 – 12 dBA). Inspired by the Swedish experiments, a 130 m-long test section in PERS was constructed on a street in Oslo in the beginning of 1989, but this experiment failed after the surface was destroyed accidentally by a snowplough in the autumn of that same year. Noise reduction on the Norwegian test track was found to be 7 – 9 dB(A) for passenger cars.

3.2 Japan (1994 – present)

In 1994 the Japanese Public Works Research Institute initiated research in the field, building on the first Swedish results. A series of laboratory tests were carried out and a first test track with 1 m x 1 m prefabricated panels was built on the PWRI circular test track for durability testing in 1996. The Japanese found that adhesion was not very durable with DAC as a substrate. They now use a semi-flexible surface (porous asphalt with the pores filled with cement), thus avoiding any problems with adhesion. In the beginning elongated, fiber-like particles were used, which were bound with 15% of polyurethane. Three more types of PERS were also applied in 1996 on the PWRI test facility, with 30, 35 and 40 % of voids. Cruise by tests with a car, a light and a heavy truck yielded noise reductions of 7 – 11 dB(A), 4 – 5 dB (A) and 3 – 5 dB (A), respectively. As friction was too low on the first generation of Japanese PERS types, four new types (Figure 5) were developed with an acceptable initial skid resistance. Test sections with these new types of PERS were built on the PWRI test facility in 2000, complying well with Japanese friction standard (Figure 6).

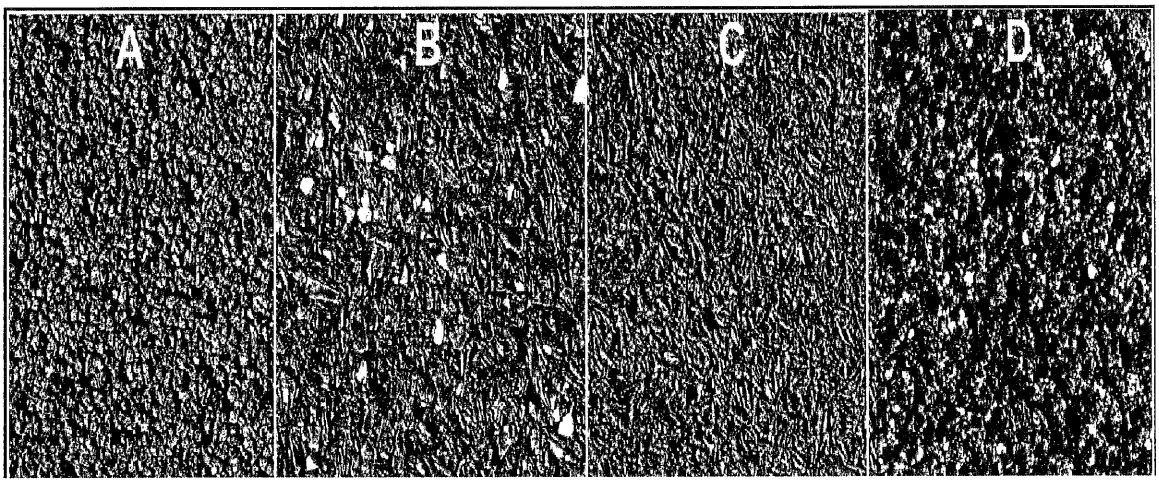

Figure 5 – Four types of Japanese PERS with enhanced skidding resistance.

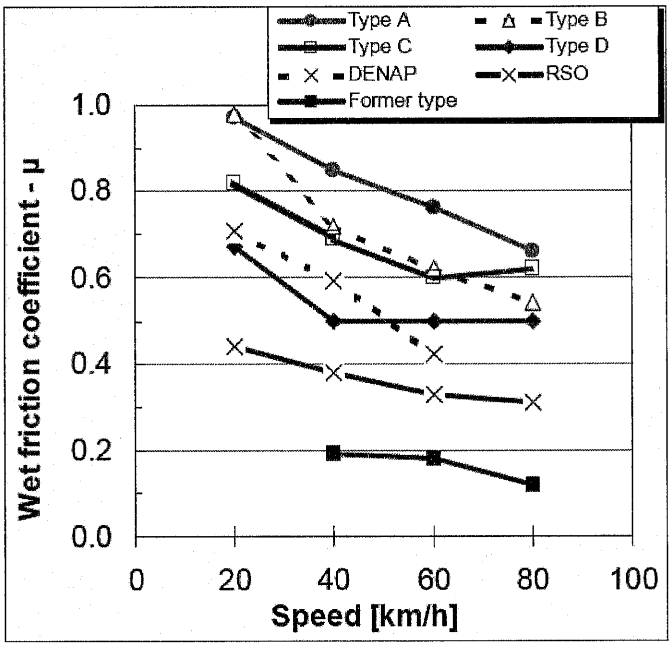

Figure 6 – Skidding resistance on the four types of Japanese PERS with enhanced skidding resistance (RSO = Japanese friction limit and DENAP = kind of DAC).

In the period 2002-2005 full-scale experiments were carried out on Japanese highways. Eight different PERS types were tested on three locations. They all failed in a relative short delay after construction (max. about 1 year) owing to rutting, adhesion and friction problems.

In the period 2005-2008 PWRI investigated on how to improve the durability of the skid resistance of PERS and tested three new PERS types with enhanced skid-resisting properties on the highway immediately outside PWRI in Tsukuba City. A new adhesion system, double adhesive tape, was used, but the three sections failed within 1.5 year as a result of adhesion problems. Skid resistance remained OK during the short test period. The noise reduction was estimated to be around 6 dB(A), but the sections were far too short (5 m each) for proper noise testing.

Three new test sections were built in the beginning of 2009 on the PWRI circular test track and subjected to passages of unmanned, GPS-guided HGVs: a PERS constructed on site by Yokohama Rubber Company to a thickness of 30 mm with approx. 50 % of rubber and 50 % of fine aggregate (2,5 – 3 mm) and a binder (details are company secret); and two sections with precast panels by Sumitomo Rubber Industries, one fixed with epoxy on a semi-flexible base course and one fixed with adhesive tape on new asphalt. In February 2010, after exposure to some 500 000 HGV wheel passages, the sections were reported to be still in good condition.

The site-constructed Yokohama type tested on the PWRI circular test track is also tested on full-scale experiment on two city streets: one in Zama City and one in Hiratsuka (Figure 7). The section in Zama City was constructed in December 2006 and the one in Hiratsuka in the summer of 2008. Both test sections were still in good condition when one of the authors (LG) took the pictures of Figure 7 during a visit to the sites (April 2009). From Japanese data, noise reduction could be estimated to be about 10 dB(A) in comparison with new DAC 0/16. Details about composition were not revealed, but air void content would be about 30%, silica sand with a maximum diameter of 5 mm was used as well as rubber granules about 1 mm in size. The rubber/aggregate proportion is estimated to be about 40/60. While walking over it, the surface felt quite rigid, almost like plain asphalt. The binder is polyurethane and a polyurethane primer and tack coat were used. Skid resistance still complies with Japanese standards.

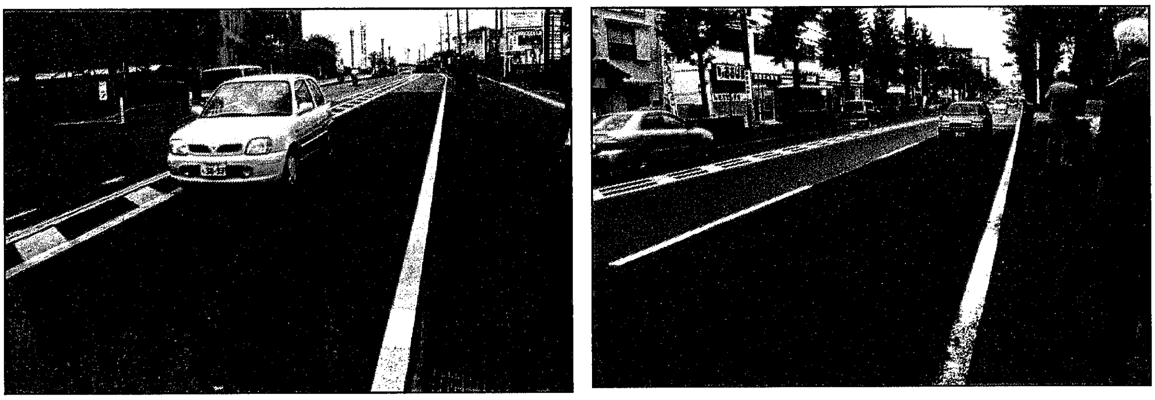

Figure 7 – Yokohama built, on site constructed PERS types in Zama (left hand side) and Hiratsuka (right hand side).

The Zama City test section has, in the mean time, been removed after the test period of three years has expired. Some problems with the binder course were observed when removing the PERS layer. This is investigated further.

3.3 Later Swedish experiences (2000 – 2005)

In the period 2000 till 2005, VTI could carry out its PERS project thanks to national and European funding (SILVIA-project) and some local support (City of Stockholm). Lots of laboratory tests were carried out, including wearing tests in the VTI Road Simulator machine. It was demonstrated that the use of PERS would not necessarily lead to an increase of rolling resistance. In the autumn of 2004 a full-scale test was carried out on a street in western Stockholm, comprising three test sections: a section with a PERS type called Spentab, which was a site-constructed type, and two types with precast tiles (1 m x 1 m): Tokai (Japanese product) and Rosehill (British product). Figure 8 shows the test sections right after their construction. The noise reductions found in comparison with the old adjacent DAC 0/11 were between 9 and 11 dB(A). Unfortunately, the experiment had to be aborted and the PERS layers removed only six weeks after the construction owing to a problem with the disintegrating binder course.

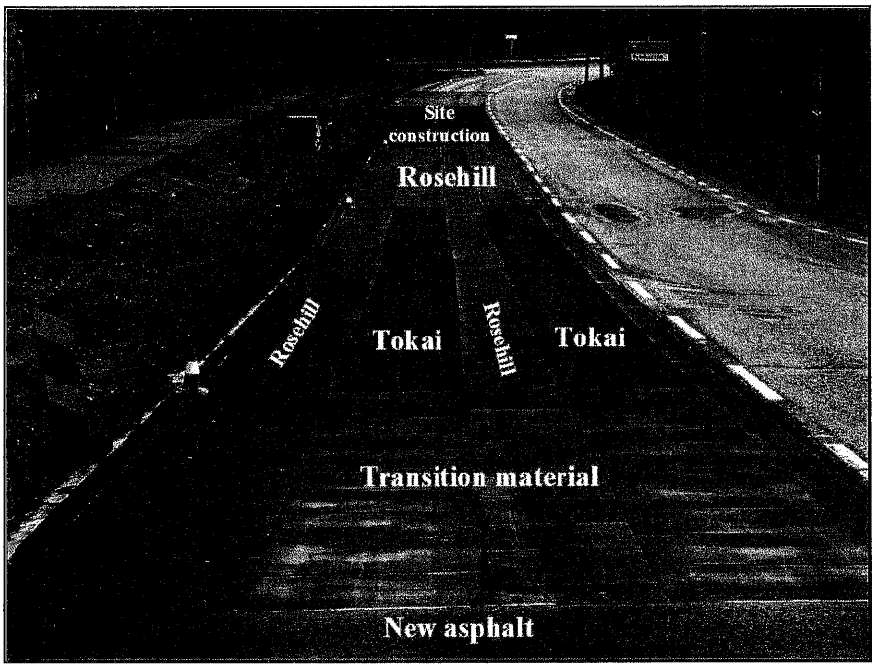

Figure 8 – VTI test track with three types of PERS just after construction in September 2004. (photo: Ulf Sandberg, VTI)

3.4 Dutch experiments (2002 – present)

In the Netherlands awareness of the huge traffic noise problem led to the noise innovation programme (IPG), which started in 2002 and ended in 2008. This national large-scale project aimed at developing effective tools for abating road and railway noise in an affordable way. Silent road surfaces were considered to play an important role. As a "fourth generation" silent road surface, PERS was included only to a limited extent in the IPG programme. Six short test sections were built on the Kloosterzande test track. The test track was not subject to traffic, but the results of CPX measurements were rather disappointing, most probably owing to the joints. Poro-elastic road surfaces were included in the Acoustic Optimization Tool (AOT), a sophisticated software package for rolling noise prediction developed under IPG. The further development of PERS is the subject of a follow-up project on "supersilent" road surfaces (SSW), which started in 2008 and will end in 2011. Within this project, a joint venture of Duravermeer and INTRON built a new 40 m-long PERS section in Kloosterzande for Rijkswaterstaat in August 2009, using the experimental Rollpave-technique (Figure 9). Thickness was 32 mm and it consisted of small rubber granules (0/1 mm) and small aggregates (0/1 mm), bound with polyurethane. The prefabricated roll was glued to the sub layer with epoxy. Noise reduction measured with the CPX method was 7,9 dB(A).

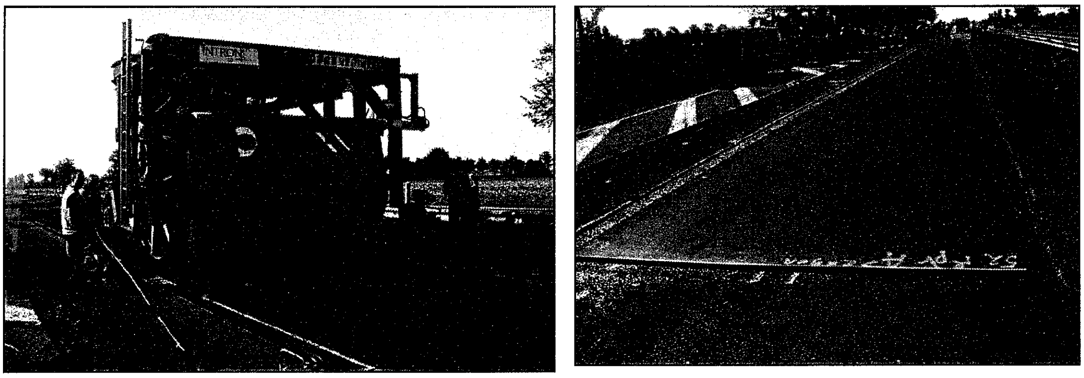

Figure 9 – Construction of 40 m-long DWW PERS test section at Kloosterzande (Netherlands) using the Rollpave technique, by INTRON/Duravermeer.

Subsequently, in November 2009, a new 260 m-long test section was built by the same technique on a service road along the A50 in Apeldoorn (Figure 10). No measurement results have been received so far by the author.

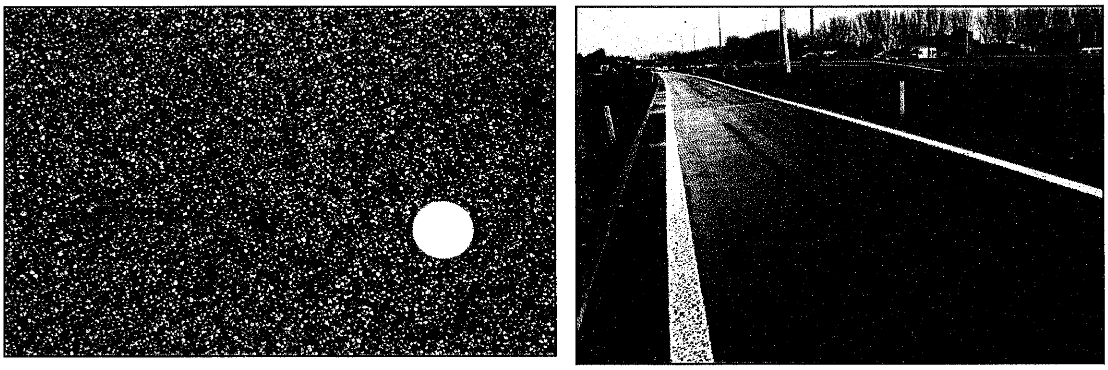

Figure 10 – 260 m-long DWW PERS test section along A50 highway near Apeldoorn (Netherlands). The coin on left hand side picture has diameter of 24 mm.

4 THE PERSUADE PROJECT

4.1 Goals of the PERSUADE project

The project aims at developing a durable, cost-effective PERS using recycled tyres. This would benefit the environment by not only significantly contributing to abating traffic noise and vibrations, but also helping to solve the problem of over three million tons of waste tyres to be dumped or burned every year in the twenty-seven EU Member States, with the consequence on ground and air pollution. It is anticipated that advanced optimization of the poro-elastic rubber compound could also lead also to some decrease in rolling resistance for the vehicles travelling on such a pavement and, as a result, could contribute to reducing CO2 and other emissions.

4.2 Strategy

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.

4.2.1 Laboratory and small-scale testing

To maximize the 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 fire performance.

4.2.2 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 (Rollpave technique).

4.2.3 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. 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.

4.2.4 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 (to be converted into fuel consumption and greenhouse gas emissions), drainage (to test for possible clogging) and winter behaviour (salting, snow removal). As a result of the time-staged construction of the test sections, steps 4.2.3 and 4.2.4 will be partly simultaneous.

4.2.5 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.

4.3 The PERSUADE consortium

The Consortium is formed by six national research institutes: BRRC (coordinator of the project, Belgium), VTI (Sweden), DRI (Denmark), ZAG (Slovenia), IBDiM (Poland) and LCPC (France), two universities: TU Gdansk (Poland) and KU Leuven (Belgium) and four industrial partners: NCC (contractor, Denmark), Duravermeer (contractor, Netherlands), HET (SME specialized in manufacturing products with rubber granules and polymers, Germany) and ETRA (representing tyre recyclers, France).

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

4.4 Progress so far

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

- dissemination: a website has been constructed (http://persuade.fehrl.org) and a comprehensive state-of-the-art report has been drafted. 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.

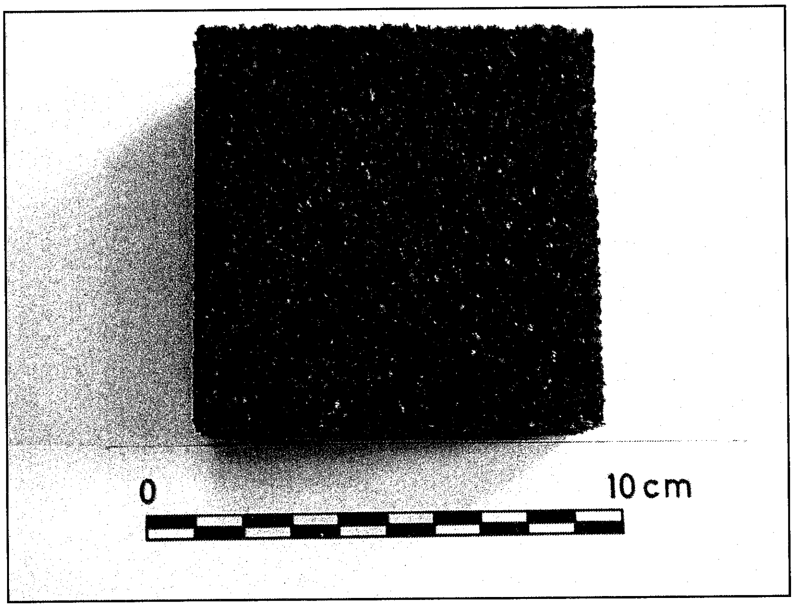

Figure 11 – PERS test sample prepared for adhesion testing in the PERSUADE project.

- cost-benefit analysis (CBA), which 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.

5 FINAL REMARKS

In view of the long series of historical attempts and subsequent failures, it cannot be denied that there is quite some risk that this research project will not be successful. Nevertheless, the "reward" in case of success would be huge, as a powerful alternative for noise screens would become available for abating traffic noise. Noise screens do have a lot of disadvantages: intrusiveness, vulnerability to vandalism, high cost etc. 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, and the know-how available in the consortium and its "balanced" membership.

6 ACKNOWLEDGMENTS

The PERSUADE project consortium gratefully acknowledges the financial support granted by the European Commission through its 7th Framework Program (FP7).

7 REFERENCES

1. U. Sandberg and J. Ejsmont. Tyre/Road Noise Reference Book, Informex, Kisa, Sweden (2002).
2. T. Beckenbauer, Akustische Eigenschaften von Fahrbahnoberflächen, Strasse+ Autobahn, Vol. 54 (10) 553-561 (2001).
3. U. Sandberg, L. Goubert, K. Biligiri, B. Kalman, State-of-the-Art regarding poroelastic road surfaces, Deliverable D8.1 of the PERSUADE project, downloadable from http://persuade.fehrl.org (2010).