Tyre/road noise reduction by a poroelastic road surface

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ABSTRACT

Low noise road surfaces of existing types may in favourable cases and in new conditions provide up to 7 dB of noise reduction. For higher noise reductions, innovative solutions must be sought. Poroelastic road surfaces (PERS) may be such a solution, which currently is studied in the EU project PERSUADE. This paper presents results of trials with a PERS version prefabricated by one of the project partners. Tests were made in a laboratory at TUG, where different tyres were tested on drums covered with PERS, and later field tests were made on a local street in Sweden where VTI had constructed a 25 m long trial section. The field tests were made with a CPX trailer from TUG. Both laboratory and field results showed that tyre/road noise reductions of 9-11 dB were achieved compared to a dense asphalt concrete pavement with maximum aggregate size 11 mm. This is the best result so far in the project. At the same time, this PERS, despite being relatively soft, reduces rolling resistance of passenger car tyres to record-low values, which is important for reducing fuel consumption and CO_2 emissions. It is concluded that this type of prefabricated poroelastic road surface offers a very efficient way of reducing tyre/road noise, provided current durability problems can be solved.

Keywords: Tyre/road noise, Poroelastic road surface, Noise reduction, Quiet pavement
I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION AND OBJECTIVE

When road traffic noise reductions higher than approx. 7 dB are required, noise barriers or tunnels are generally the only measures available. However, in many cases noise barriers are inefficient or not accepted by the residents, and tunnels are too expensive. Low noise road surfaces (LNRS) of existing types may in favorable cases and in new conditions provide up to 7 dB of noise reductions. Above this level, innovative solutions must be sought. Poroelastic road surfaces (PERS) may be such a solution, which currently is studied in the EU project PERSUADE (www.persuadeproject.eu). A more comprehensive description of this project appears in another Inter-Noise 2014 paper [1]. A state-of-the-art report about PERS, including the history of its development and all major experiments performed so far is found in [2].

The objective of this paper is to present results of laboratory and on-road trials in Poland and Sweden with a version of PERS which has been manufactured in sheets in a factory by one of the project partners.

2. THE POROELASTIC MATERIAL (PERS) AND OTHER TEST SURFACES

2.1 General

The material utilized in the Polish and Swedish experiments mentioned in this paper was manufactured by the PERSUADE partner HET Elastomertechnik GmbH, with headquarters in Germany. The most essential components are a hard aggregate of small stones and sand particles, a soft aggregate of rubber granules from recycled tyres and a binder of polyurethane. The exact composition cannot be revealed for reasons of intellectual property, but it can be mentioned that the content of

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rubber is more than 40 % of the total solid volume and the content of air voids is more than 25 % of the overall volume. The hard and soft particles (aggregate) have maximum dimensions of less than 4 mm. This is a rubber content which is 10-20 times higher than that of the pavement family called ‘asphalt rubber’ or ‘rubberized asphalt’. When stepping on such a surface it feels a little softer than an asphalt surface, and it is possible to bend sheets of it around a drum of 1.7 m diameter by hand. Each prefabricated sheet is 0.5 m wide by 1.0 m long and its thickness is 30 mm; however, in the laboratory tests a width of 0.22 m was used.

2.2 Laboratory experiment

In the laboratory experiments designed for testing with passenger car tyres, the PERS material was bent and glued on the 5.4 m long circumference of a steel test drum at TUG having a diameter of 1.7 m (see Fig.1). These measurements were made in early 2013. More information can be found in an earlier conference paper [3].

Figure 1. Mounting of the PERS sheets on the test drum for car tyres.

Other surfaces used as references in the car drum experiments were replicas of the following pavement types:

- DAC12r: Dense Asphalt Concrete, with max. aggregate size of 12 mm; a replica made in epoxy material by means of a mould from an actual Swedish road surface. This has a very smooth-textured surface, with an MPD of 0.4 mm (MPD according to ISO 13473-1).
- SD11r: Surface Dressing, with max. aggregate size of 11 mm; a replica of a surface dressing glued in a rubber base by a French company, and labeled as APS-4. This has a very rough-textured surface, with an MPD of 2.0 mm.

In the laboratory experiments designed for testing with truck tyres, the PERS material was bent and glued on the 6.3 m long circumference of a steel test drum at TUG having a diameter of 2.0 m (see Fig. 2). These measurements were made at the end of 2013.

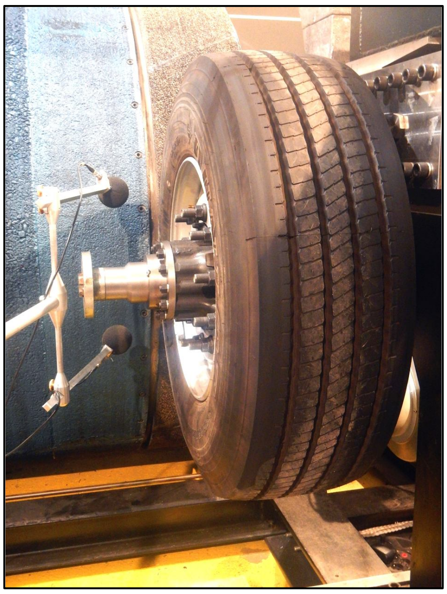

Figure 2. Measuring setup on the drum for truck tyres. The tyre is T-1084 mentioned later in the paper, which is tested on the PERS surface.

Other surfaces used as references in the truck drum experiments were replicas of the following pavement types:

- DAC16r: Dense Asphalt Concrete, with max. aggregate size of 16 mm; a replica made in epoxy material by means of a mould from an actual Polish road surface. This has a very smooth-textured surface.
- ISOr: A replica made in epoxy material by means of a mould of an actual test track surface meeting ISO 10844:1994. This has a medium-textured surface, with an MPD of 0.85 mm.

2.3 Field experiment

In the on-road test, 50 sheets of PERS were mounted over an area 1.0 m wide and 25 m long on a basecourse of dense asphalt concrete, newly laid in a basin made by milling away 70 mm of the existing asphalt pavement. The glue was epoxy. This row of PERS was mounted to correspond to the right wheel track of the traffic in the southern-going lane of Landbogatan in Linkoping, Sweden (see Fig.3). The posted speed on the street was 50 km/h, but average speeds were higher, partly due to posted speed increasing to 70 km/h approximately 100 m after the test site. The traffic volume measured as AADT was 5400.

The test section was laid on the street in the last days of November and was opened to traffic on 3 December 2013. Noise and rolling resistance measurements were made on the first two days, on PERS as well as on two conventional pavements used as references in the field experiments. The references were the following pavement types:

- DAC11: Dense Asphalt Concrete, with max. aggregate size of 11 mm; which is the asphalt surface surrounding the PERS on this street. This had a medium-textured surface (MPD = 0.93 mm).
- SMA16: A stone mastic asphalt surface, with max. aggregate size of 16 mm; on Highway RV34, 2 km south of Linkoping urban area in Sweden. This has a medium-textured surface, with an MPD of 0.9 mm. It is the dominating type of road surface on Swedish highways and motorways.

A second noise test (performed in similar way as the first one) was made 12-13 March 2014 when the PERS was in a poor state and the intention was to remove it. Thus, noise measurements by the CPX method were made both when the PERS was in new condition and when it was at the end of its lifetime.

Figure 3. The 25 m long and 1 m wide test strip of PERS mounted on a local street in Linkoping, Sweden. It covers the right wheel track of the traffic (which runs towards the viewer).

3. TEST TYRES AND MEASUREMENT METHODS AND EQUIPMENT

3.1 Laboratory experiment

Tyre/road noise emission was tested on drum facilities at the Technical University of Gdansk (TUG). Three facilities with drums having an outer diameter of 1.5, 1.7 and 2.0 m were used; the two smaller ones for car tyres and the larger one for truck tyres. The smallest one was used only for testing car tyre/road noise on a DAC12r surface, while the bigger ones were used for both noise and rolling resistance measurements. The bigger ones have as a regular surface a sand-paper-like surface with product name Safety Walk since either a smooth steel or a sand-paper-like surface are allowed for rolling resistance measurements according to the ISO standard used (ISO 28580). The Safety Walk surfaces were replaced temporarily by samples of the PERS material. The Safety Walk surface is irrelevant for noise measurements since it gives totally non-representative results for noise.

The noise measurements were made with two microphones located near the test tyre in a position similar to that used in the CPX method as of ISO/DIS 11819-2 (they can be seen in Figure 2).

In the laboratory measurements 12 passenger car tyres, including reference tyres SRTT and AV4 intended for the CPX method (to be specified in ISO/TS 11819-3), were tested at speeds 30, 50, 80 and 100 km/h. One of the tyres (235/45R17 94W), called SLICK, was without tread pattern. These tyres were loaded to 3200 N and inflated to 200 kPa (cold) [4]. The test tyres are listed in [4].

In the other part of the laboratory experiment, two truck tyres, designated as T-1084 (Dunlop SP242, 385/65R22.5 160K) and T-1085 (Bridgestone R168, 385/65R22.5 160K), were tested on the drum facility with a 2.0 m diameter drum. These tests were performed at 50 and 80 km/h.

3.2 Field experiment

The field testing of noise was made by using the TUG CPX trailer marked "Tiresonic Mk.4"; see Figure 4 where the trailer runs over the PERS test section. Tests were made according to ISO/DIS 11819-2 except that the length of the PERS test section was shorter than the ideal minimum of 100 m. On the PERS, only approx 20 m test length could be used. This was compensated by running many more times than normal (at least 10 runs for each tyre/speed combination) and calculating the average. In this way, a stable average was achieved of the same precision as for regular CPX measurements over lengths of 100-1000 m.

During the noise measurements performed in December 2013 two tyres were used: SRTT and AV4. In March 2014, the same tyres were used but they were supplemented by a steel studded winter tyre: Hakkapelliita 7 (denoted "*H7WS*" here). See Fig. 5. The tyre load during measurements was fixed at 3200 N and the inflation pressure was adjusted to 200 kPa in cold conditions. Measurements were performed at 50 and 80 km/h, according to ISO/DIS 11819-2. The steel studded winter tyre was tested also at a speed of 30 km/h. The intention by adding the studded tyre in the test program was that studded tyres dominate the Swedish car park in wintertime and results for this tyre (which was one of the popular premium types) would give an idea of how much noise reduction can be gained in winter time when noise from the studs dominate traffic noise in Sweden.

More details about measurements and tyres can be found in [4]. In all cases, the test tyres were brought to a stable test temperature by a run-in time period of 15-20 minutes before the testing commenced.

Figure 4. CPX noise tests with the TUG Tiresonic Mk.4 trailer on the 25 m long PERS section in Linkoping in March 2014. The test tyre is mounted in the middle of the chamber.

Figure 5. The three test tyres used during the CPX noise tests. From left to right: SRTT, AV4, H7WS. The latter winter tyre was used only in the late-winter tests. Its steels studs can be weakly seen as bright spots near the shoulders.

4. RESULTS OF NOISE MEASUREMENTS IN THE LABORATORY

4.1 TESTS WITH PASSENGER CAR TYRES

Figure 6 shows the relations between tyre/road noise measured on PERS and tyre/road noise tested on replicas of the road surfaces (DAC12r and SD11r). The relations are shown for four speeds with the noise level of each one of the 12 test tyres indicated with a symbol.

The results indicate that the correlation between noise on PERS and the other surfaces is low or non-existing. The displacement from the 1:1 line indicates that the PERS gives much lower noise levels than the replica road surfaces. However, the difference between noise measured on PERS and on the other surfaces depends on the speed; at higher speeds it is greater than at lower speeds.

This is more clearly shown in Figure 7. At the speed of 80 km/h the average difference is 10 dB in the favour of PERS, compared to the rough surface dressing and 12 dB compared to the dense asphalt concrete. At 50 km/h the noise reduction is 2 dB less.

Third-octave-band frequency spectra are shown in Figures 8-10 for a selection of three of the tested tyres. These indicate that, generally, the reduction of noise is achieved for all frequencies above 125 Hz. In this way the PERS seems to be unique, since other low noise road surfaces tend to reduce noise either at low and medium or at medium and high frequencies.

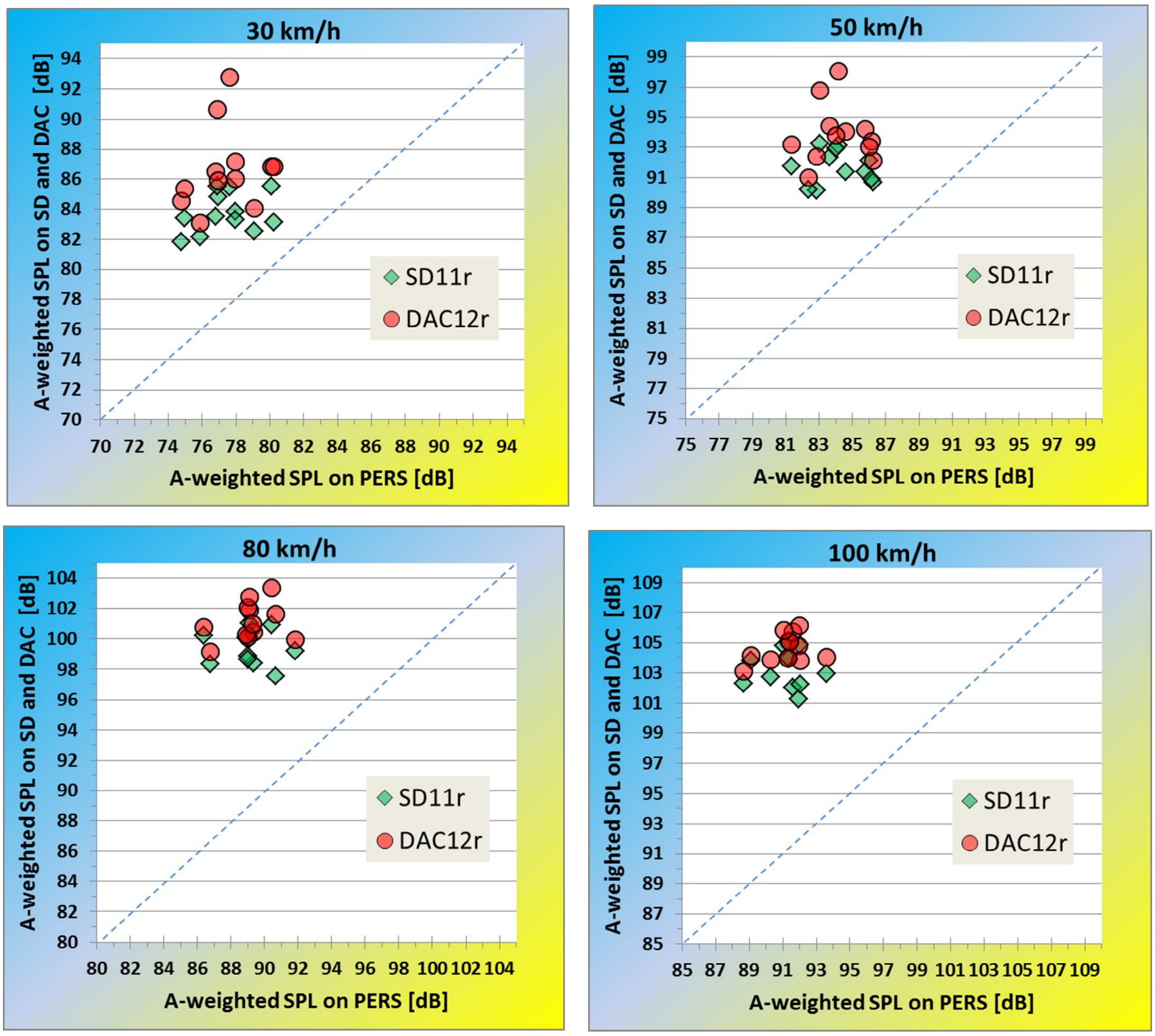

Figure 6. Relation between noise on PERS and the DAC12r, as well as on the SD11r replica road surfaces, for speeds of 30, 50, 80, 100 km/h. Each symbol in the diagrams corresponds to one of the tested 12 tyres.

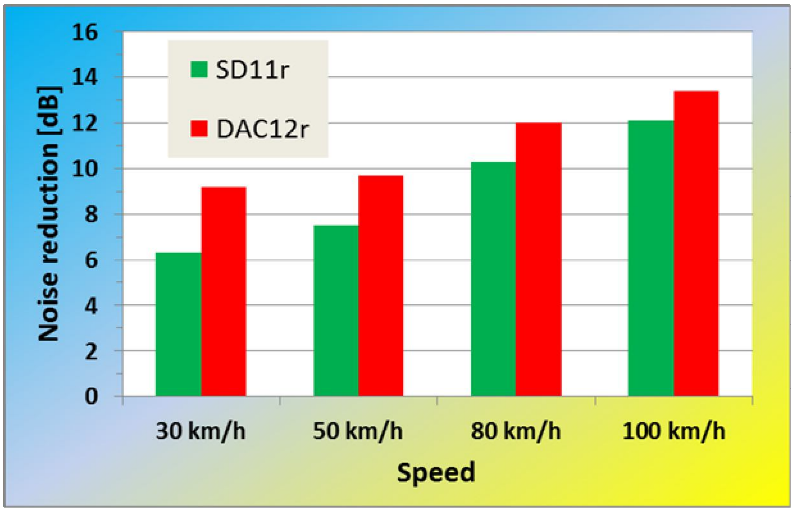

Figure 7. Difference between noise (expressed as A-weighted SPL) measured on PERS and on the two replica road surfaces, for the four test speeds.

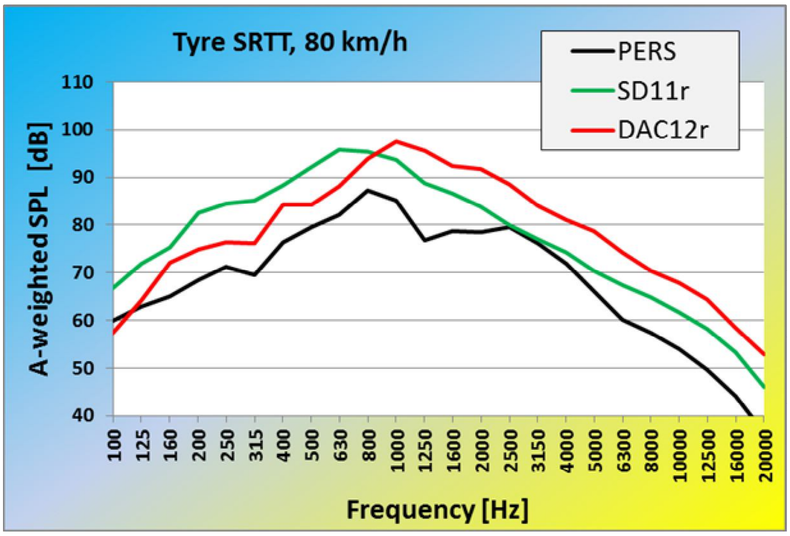

Figure 8. A-weighted frequency spectra for tyre SRTT, running at 80 km/h on the three different surfaces.

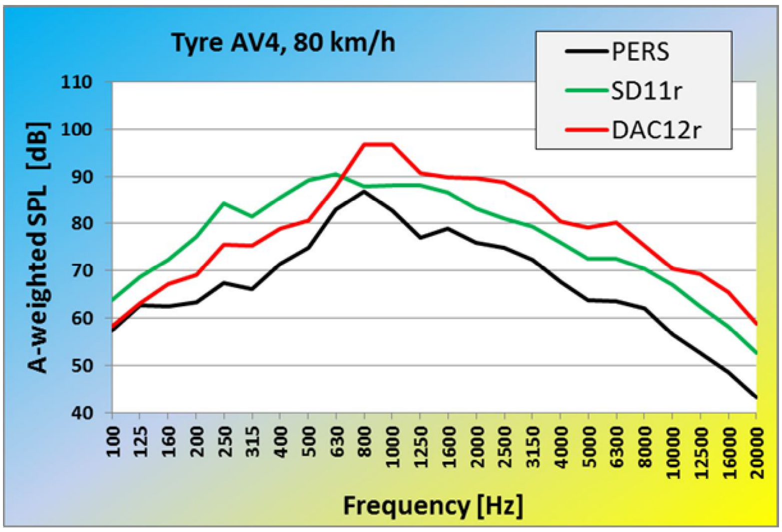

Figure 9. A-weighted frequency spectra for tyre AV4, running at 80 km/h on the three different surfaces.

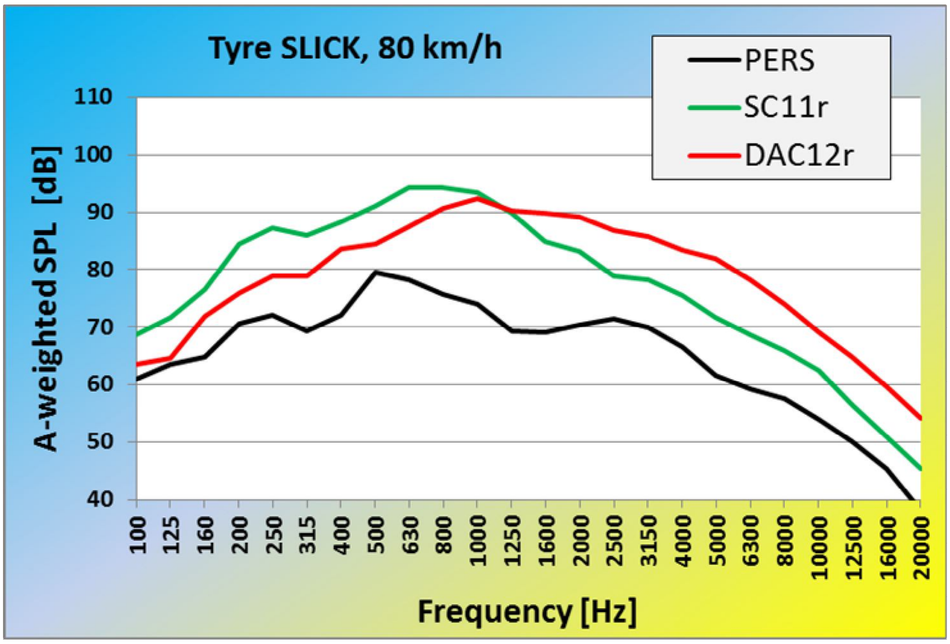

Figure 10. A-weighted frequency spectra for the SLICK tyre, running at 80 km/h on the three different surfaces.

4.2 TESTS WITH TRUCK TYRES

Most tyre/road noise measurements reported in the open literature are conducted with passenger car tyres only. With the current technical progress, PERS is not durable enough for use on roads with intense traffic of heavy vehicles. Nevertheless, it is interesting to investigate if truck tyre noise is reduced on PERS as much as noise from passenger car tyres. This has been made in the TUG laboratories, using a drum with 2.0 m diameter (see above) and two truck tyres.

A-weighted sound pressure levels obtained for different speeds and replica road surfaces are presented graphically in Fig. 11 and summarized in Table 1. The average decrease of noise on PERS in comparison to DAC16r is 8.3 dB, while in comparison to the ISOr it is 11.6 dB. Frequency spectra of tyre T-1085 tested at the speed 80 km/h are shown in Fig. 12. The shape of the spectra for tyre T-1084 (not shown in this paper) is similar to that of tyre T-1085.

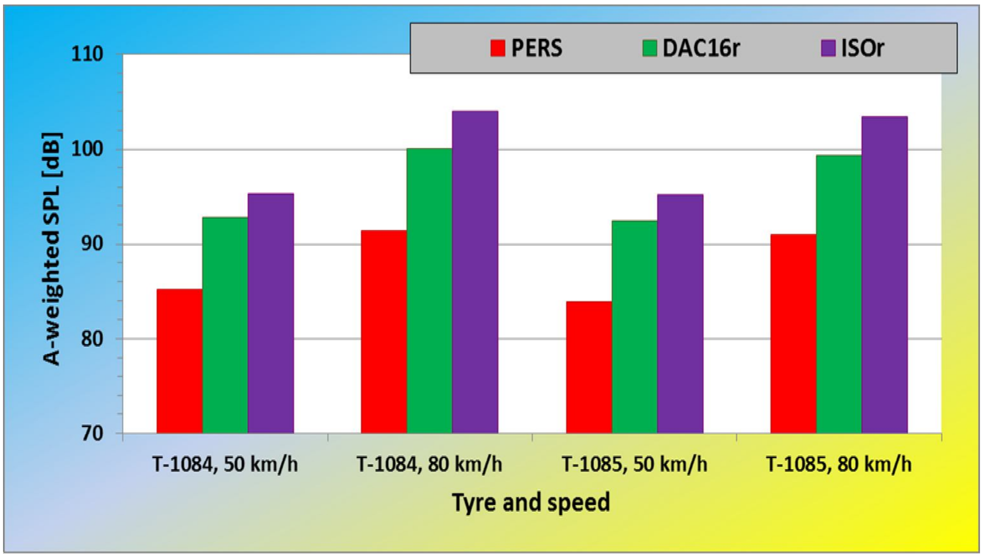

Figure 11. A-weighted sound pressure levels measured on PERS and on the two replica road surfaces, for the two truck tyres and for two test speeds.

Table 1. A-weighted sound pressure levels for the two truck tyres tested on the drum equipped with three different surfaces

Surface -->		PERS	DAC16r	ISOr
Test tyre	Speed [km/h]	SPL [dB]	SPL [dB]	SPL [dB]
T-1084	50	85.2	92.8	95.3
	80	91.4	100.1	104.0
T-1085	50	83.9	92.4	95.2
	80	91.0	99.4	103.4

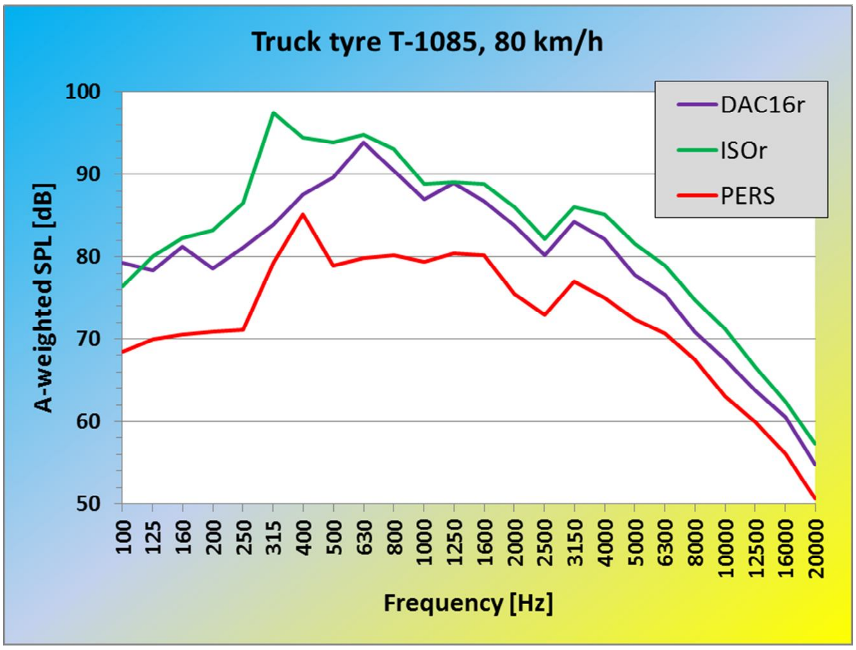

Figure 12. A-weighted frequency spectra for truck tyre T-1085, running at 80 km/h on the three different drum surfaces.

5. RESULTS OF NOISE MEASUREMENTS IN THE FIELD

The measurements on the road sites reported in this paper were carried out on the PERS test section in Linköping, Sweden (designated PERS-SE in this paper) as well as on two reference pavements in the same area (see above). Noise measurements were conducted with the CPX method on 3 December 2013, when the section was just a few days old, and then repeated 13 March 2014; i.e., 3½ months after its construction. It should be pointed out that winter conditions with snow and rain precipitation with daily average air temperatures between – 13 and +10 ºC took place during that period.

During the tests air temperature changed with time of day and depending on test site within a range from 6 to 14 ºC. A temperature correction of -0.09 dB/ºC (from actual air temperature to the reference temperature of 20ºC) was applied to all obtained values. This correction seemed to be the best estimate at the time of writing but had not yet been confirmed for PERS surfaces.

The results of the measurements are summarized in Figures 13-16. It appears in Figure 13 that the overall noise reduction on PERS-SE in comparison to the reference road surfaces is 10-11 dB for the SRTT and approx 1 dB less for the AV4 tyre. The corresponding frequency spectra (Figures 15-16) indicate that noise reduction is obtained over the entire frequency range.

It is interesting to analyze the noise generated by the studded tyre H7WS; see Fig. 14 and Table 2. Its noise reduction on PERS-SE amounts to an amazing 13-16 dB; more the lower the speed is. Studded tyres are the most influential noise source in Swedish winter traffic at speeds of 30-50 km/h, so such a noise reduction would have an excellent effect on the acoustic environment in wintertime.

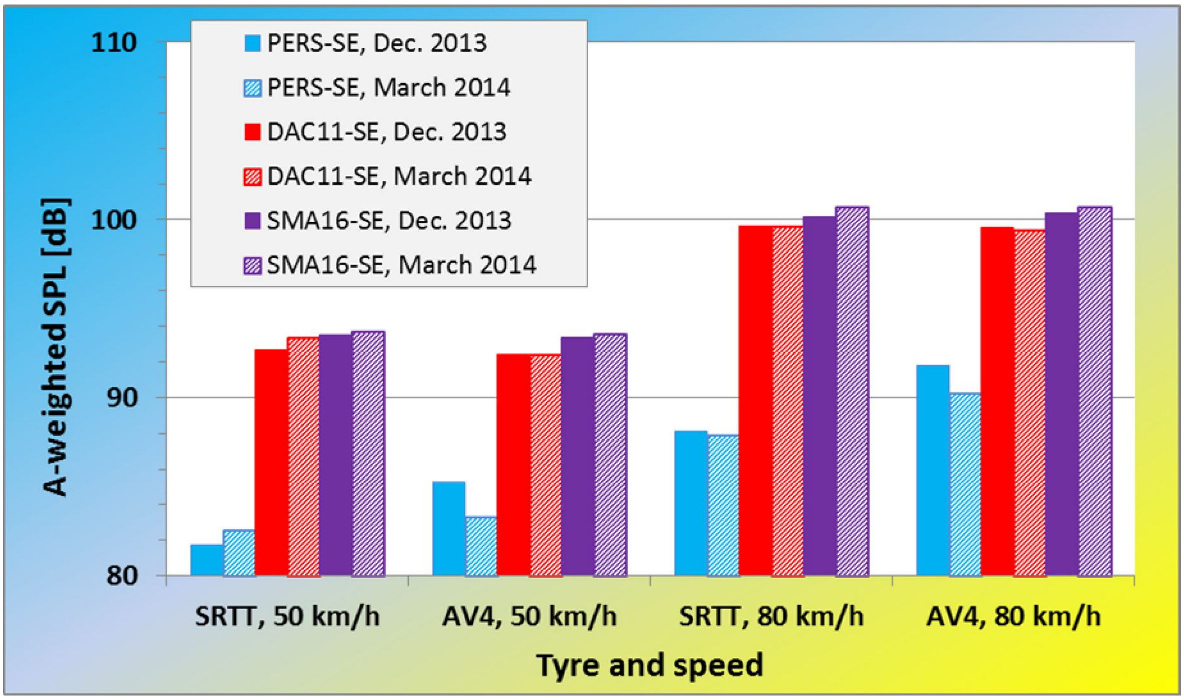

Figure 13. A-weighted SPL measured on PERS-SE and the reference road surfaces for the "ordinary" CPX tyres SRTT and AV4.

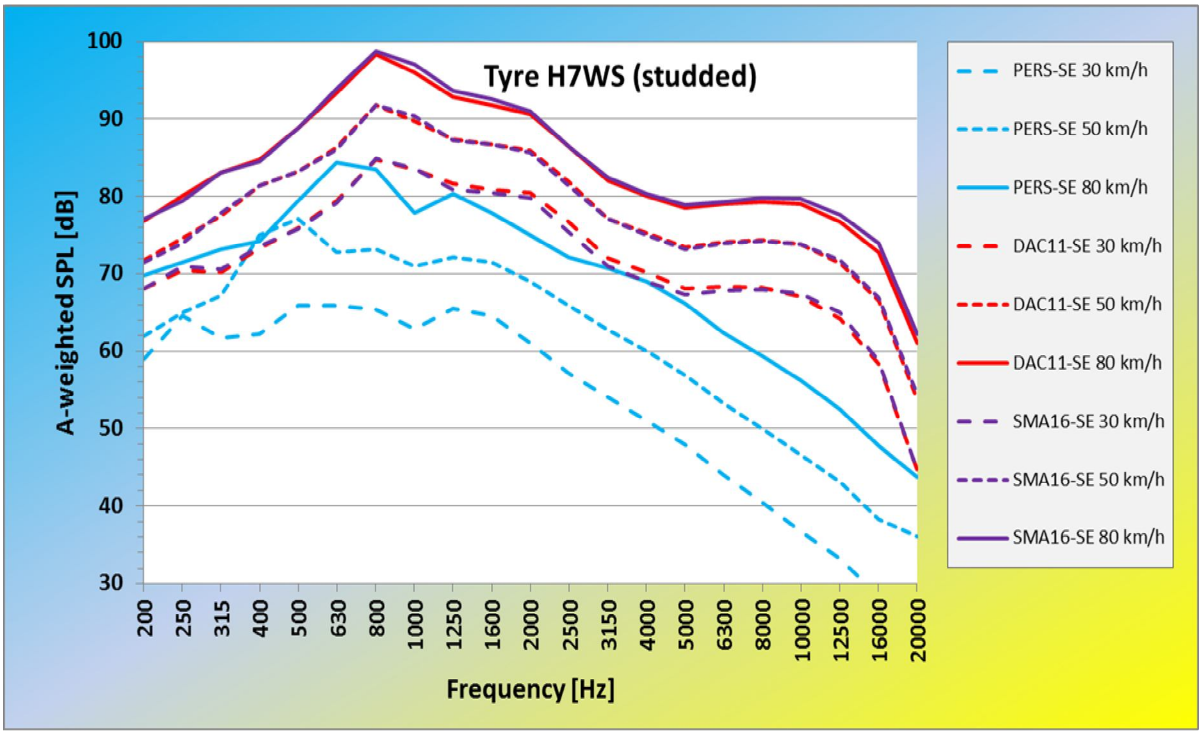

Figure 14. A-weighted SPL measured on PERS-SE and the reference road surfaces for the studded winter tyre H7WS.

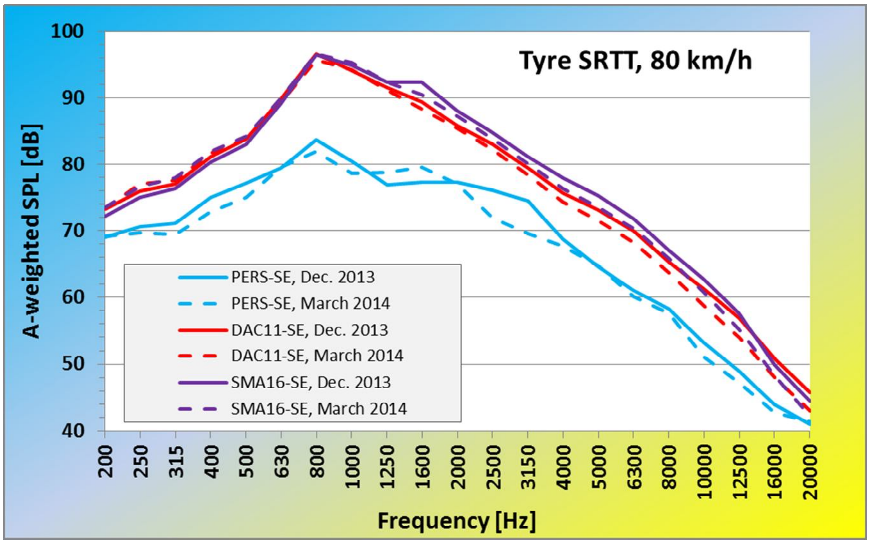

Figure 15. A-weighted frequency spectra measured on PERS-SE and the two reference road surfaces, for tyre SRTT at 80 km/h.

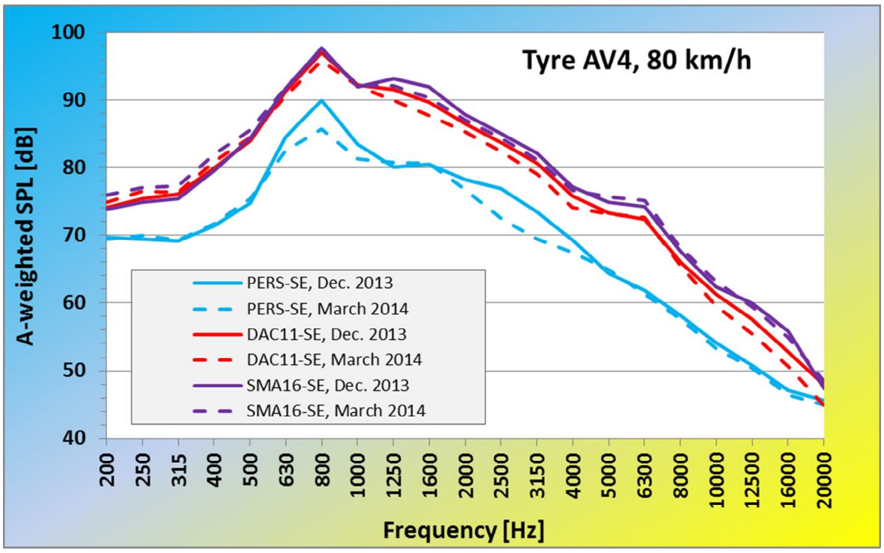

Figure 16. A-weighted frequency spectra measured on PERS-SE and the two reference road surfaces, for tyre AV4 at 80 km/h.

Table 2. A-weighted sound pressure levels for the three test tyres measured on the PERS-SE and the two reference road surfaces.

Surface -->		PERS-SE	DAC11-SE	SMA16-SE
Test tyre	**Speed [km/h]**	**SPL [dB]**	**SPL [dB]**	**SPL [dB]**
SRTT	50	82.6	93.3	93.7
	80	89.5	99.6	100.7
AV4	50	83.3	92.4	93.6
	80	90.3	99.4	100.7
H7WS	30	74.7	90.4	90.1
	50	82.6	96.5	96.7
	80	89.5	102.5	103.2

6. DISCUSSION

6.1 The Polish laboratory data

The results indicate that the correlation between noise from various tyres on PERS and on the other surfaces is low or non-existing, suggesting that the noise generation mechanisms have very different influences. The spectra show that noise reduction is substantial over the entire relevant frequency range, which is unusual and indicate the PERS surface reduces both vibration-excitation and air pumping noise; possibly also offering sound absorption.

The noise reduction for truck tyres seems to be 7-13 dB, which is equally large as for car tyres; something which surprises the authors. In the frequency spectra for the truck tyre shown in Figure 12, there is a peak at 400 Hz for the PERS but at different frequencies for the other surfaces. This should be studied more, in order to see what causes the peaks to vary in frequency.

6.2 The Swedish field data

The noise reductions (10-11 dB for SRTT and 9-10 dB for tyre AV4) on the PERS-SE are impressive. They are almost the same as in the Swedish project conducted in 2004-2005 [5] when, however, PERS with much higher rubber contents were tested. The goal with the PERSUADE project is to achieve a noise reduction of 10 dB, which clearly is within reach with the PERS-SE.

For the studded tyre, noise reduction is even more impressive. On the hard reference road surfaces, for this tyre, there is very pronounced (and audible) noise in the high frequency range 6 300-16 000 Hz which is generated by the metal studs hitting the hard aggregates of the road. For the PERS-SE surface there is no level increase in this frequency range. This observation supports the speculations that the soft rubber aggregate of PERS-SE very efficiently decreases noise related to the impacts of studs on the pavement. The rubber surface is resilient to the studs.

The objective of the Swedish field experiment in 2013-2014 was to see how well the surface could resist studded tyres during the winter and to see how friction was compared to conventional surfaces, as a pre-test for a larger experiment in 2014. It was not to check durability. For example, attempts were not made to provide efficient drainage from the PERS "basin" to the roadside. Therefore, the PERS was more or less water-filled during the entire winter. Furthermore, somewhat unexpected, when the experiment was started, transportation of clay and soil from one place to another started on the street where the test section was located. The very heavy trucks and dumper trucks travelling over the test section during the entire test period not only created extreme loading of the pavement but also dropped dirt very frequently. The PERS thus got clogged very soon and in the worst days looked totally contaminated by clay and soil. Only rain or melting snow would clean the pavement.

Following the extreme dirt depositions it was interesting to see that after the 3½ months long period when the PERS-SE pavement was subjected to harsh winter conditions in Sweden, the favourable acoustical properties of these surfaces were preserved, despite heavy clogging by clay and other soil, and the severe ravelling (see below). It appeared that when the surface had been subject to rain it was cleaned by the passing heavy trucks and when it became dry remaining dust in the pores was pulled up behind truck tyres into the air, something which never happened on the adjacent asphalt pavement. The ravelling, mainly of the hard aggregate, may have created a softer surface (higher rubber/sand&stone ratio) which could have contributed to reduced noise.

6.3 Comparison of laboratory and field data

It is interesting to note that the laboratory and field measurements give very similar results. With a tolerance of about 1 dB, all noise reductions measured in the lab were reproduced in the field at the mutually tested speeds of 50 and 80 km/h. One may also note that the results of the field tests with the SRTT gave similar results as the results of the average of the 12 car tyres used in the laboratory and that the AV4 used as a proxy for truck tyres gave similar results as the real truck tyres in the lab.

6.4 Comparison with Danish PERS experiment

Simultaneously with the PERS-SE there was a Danish version on a highway in Denmark, which was laid in August 2013. Instead of using pre-fabricated sheets, the Danish PERS was mixed immediately before laying and laid on-site by an asphalt paver machine. That version of PERS became inhomogeneous and uneven and measurements of noise with the same CPX equipment revealed a noise reduction which was 1-3 dB lower than for the PERS-SE. There is another paper at this conference presenting results from the Danish PERS experiment [6].

6.5 Rolling resistance and other pavement properties

While noise is the main subject in this paper, it shall be mentioned that a number of other road surface characteristics have also been measured. This includes rolling resistance, skid resistance (in several ways), water permeability, sound absorption, texture and unevenness. Skid resistance was found to be well above the Swedish limit for new constructions and influenced very little by weather conditions and climate; even in conditions with black ice the PERS performed almost like in wet condition.

With regard to rolling resistance, measurements by TUG, both on laboratory drum and on the Swedish test section, showed that rolling resistance was extremely low when passenger car and light truck tyres (SRTT and AV4) were used as test tyres. The PERS-SE then had lower rolling resistance coefficient than any other road surface measured. However, measurements on a TUG drum with heavy truck tyres showed higher rolling resistance than on conventional and common road surfaces. This seems confusing but the authors will offer possible explanations in a forthcoming paper or article focusing on rolling resistance.

6.6 Durability of the PERS

All field experiments made so far with PERS have failed in supplying a durable pavement, and the PERS-SE is no exception. In the construction tested 2013-2014, the pavement endured only 4 months of service until it had to be removed. Ravelling occurred with a loss of primarily the hard aggregate, and at a few places the PERS sheets loosened from the basecourse. However, the PERS-SE was (by intention) not ideally constructed for durability and it was exposed to extreme loads of heavy truck tyres. A new and larger test section to be laid in August 2014 will hopefully be much more durable.

7. CONCLUSIONS

Results of noise measurements presented in this paper indicate that the PERS pavement pre-fabricated by the PERSUADE partner HET, tested in a laboratory in Poland and on a street in Sweden, provides substantial noise reduction in comparison with the conventional asphalt pavements serving as references. One may expect tyre/road noise reductions of about 10 dB and the measurements at the end of the pavement's lifetime suggests that ravelling and clogging do not reduce its acoustical function; something which is unique when it comes to low-noise road surfaces. Therefore, PERS seems to be a very promising pavement option for substantial reduction of traffic noise, but it requires that present durability and longevity problems are solved, which is a significant challenge to the project.

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