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Noise monitoring within LIFE NEREiDE: methods and results

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ABSTRACT

LIFE NEREiDE is an EU funded Project (LIFE15/ENV/IT/000268) aiming to the implementation of new low noise surfaces made of recycled materials as rubber from end of life tyres (ELTs) and recycled asphalts (RAP). The objective is to mitigate noise exposure with green technologies achieving better acoustical, psichoacoustical and safety properties. This paper is focused on reporting results of the comparison of ante and post operam noise measurement campaign carried out within the first implementation site on the different stretches of implementation of new pavements and to show pro and cons of selected indicators and measurement protocols. Results are reported according to different parameters: CPX values, environmental noise values at roadside and SPB values with a new method for urban pass by. In fact, a side objective is to establish methods to evaluate pavements efficiency with methods that can be easily implemented in urban contexts, avoiding long manned measurements. The results highlight benefits of innovative pavements compared to reference coeval ones and pointed out the effects on light vehicles noisiness.

Keywords: Noise, Environment, Annoyance, Measurement techniques
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1. INTRODUCTION

Urban noise is one of the main problem reported by citizens and the World Health Organization has repeatedly pointed out the health risks associated with exposure to noise. European Union policies lead to the implementation of the Directive 2002/49/EC (END), which requires the adoption of action plans by the Member States, based upon noise mapping results.

In Tuscany, the implementation of the END allowed to estimate the exposed population in several agglomerations (Pisa, Firenze, Livorno, Prato) and to estimate the

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road traffic exposure as critical also along regional roads outside the agglomerations. There are several sites in the region where actions are planned (including more than 20′000 people leaving over 55 dB(A) LDEN).

All the foreseen actions include the renewal of the pavement. The realization of low noise asphalt pavements that are soundproofing is one of the most popular solutions to mitigate noise pollution in urban areas.

The LIFE NEREiDE project wants to prove the use of new low noise emission asphalt pavements and low noise surfaces composed by recycled asphalt pavements and crumb rubber from scrap tires. The new pavements materials will improve the actual performances reducing annoyance in urban context, with a particular attention to the disturbance perceived by population.

Low Noise Pavements (LNPs) are an interesting and economical solution where traffic noise reduction is necessary since rolling noise emissions for passenger cars are already predominant at urban speeds (30-50 km/h) [1].

The new pavements will be laid in two selected urban areas in Tuscany and will be tested for effectiveness by measurements of surface characteristics, acoustical and psychoacoustical properties and surveys submitted to the exposed population. The criterion used to evaluate the effectiveness is based on a before-after evaluation (*ante*/*post-operam* comparison) of the surface acoustical properties as well as the comparison with other traditional porous asphalt pavements.

A significant amount of literature can be found reporting on experimental test sections, which were monitored along time; the SILENCE project [2] was carried out in order to be able to describe the time of development of noise emission by studying different pavement types used in Europe. Different studies demonstrated that applying the standard monitoring techniques is not enough to establish reliable results and different surfaces are not easily comparable. Therefore, new measurement protocols and methods are developed from standard ones within the project in order to provide institutions with data of reliable monitoring campaigns.

Therefore, the project also aims to provide new guidelines and templates for new measurements methods including psychoacoustical indicators. In fact, the project aims to develop new asphalts not only able to reduce noise level but also suitable to improve perceived noise: it is demonstrated that at the same level different distributions of frequencies can change annoyance in exposed people.

In this paper the ante vs post operam acoustical results in first implementation site is reported, together with results of innovative measurement method for vehicle noisiness at roadside. Pro & cons of evaluation methods and challenges tackled during the project are shown.

2. METHODS

2.1 First site implementation

The project was implemented in the first phase in a site in Massarosa (LU) municipality along the “S.R.T. 439 Sarzanese-Valdera” major regional road with a lot of small houses facing the street.

Six different mixtures were realized intending to compare standard (0/10 mm aggregate diameter mixtures without rubber) and innovative low noise pavements (0/8 mm aggregate diameter mixtures with crumb rubber). Low noise pavements were laid coeval with standard open and gap graded pavements.

The following mixture were established and placed each one on a 400 m long stretch:

1 open reference
2 open dry
3 gap dry
4 gap reference
5 gap wet
6 open wet

In the following, the stretches will be referred with the progressive list index shown above and in figure 1.

***Figure 1** - Location of the six stretches: two at Pian del Quercione (left) and four at Bozzano Quiesa (right). Every coloured segment represent a different pavement type.*

2.2 Measurements and evaluation methods

Monitoring actions are focused on evaluating new surfaces efficiency and are conceived as ante/post operam analysis at the two sites; therefore, four acoustical measurement sessions were foreseen [3]. In this paper measurement campaigns ante and post operam at first site are detailed. Evaluations were carried out both trough standard and innovative techniques and innovative parameters. Some of them are still under evaluation since they will be evaluated together with second implementation site.

Two different monitoring system has been used, a continuous monitoring station and a self- powered vehicle equipped for CPX measurements [4]. At each implementation stretch, environmental noise levels have been acquired with monitoring stations placed in central points or at strategic places like schools. On the other hand, CPX data were acquired in two separate sessions for the two locations. Data were post processed for every single stretch.

The evaluation of noise at roadside by means of a continuous monitoring station is needed to estimate people exposure according to Italian law requirements in terms of average energy received (Daytime LD and Night-time LN equivalent noise levels). Moreover, the evaluation of the European noise indicators LDEN and Lnight is one of the main methods recognized by LIFE programme to rate the outcomes of the project. All the above levels are intended to be A-weighted levels.

In addition to those parameters, C-weighted levels are measured and elaborated in order to verify effects of pavements on noise quality. The A-weighting follows the frequency sensitivity of the human ear at very high noise levels. Differently, the C-weighting scale is quite flat, and therefore includes much more of the low-frequency range of sounds than the A scale. The evaluation of low frequency components through the difference between A and C weighted levels provides indications to be correlated to people surveys [5]. Finally, DALY [6] will be elaborated from acquired L_{Aeq} and population data, since it might be a project performance indicator in terms of health improvements.

Further indicators elaborated from monitoring stations are the SPB index and L_1 defined by the ISO 11819-1 (1997) [7] and measured according to an ad hoc procedure for urban context [8]. The Statistical Pass By (SPB) method aims at evaluating road surface performances in terms of energy perceived at roadside. Unfortunately, application of this method requires strict environmental surrounding conditions that are almost never realized in urban context. Therefore, an urban statistical pass by method is established. As described in [8] the new procedure analyses data matching traffic counter flows with noise data. The analysis provides regression of SEL values and each frequency bands as function of speed. SPB index (SPBI) is estimated according the ISO standard (low speed roads). Attention should be paid to the estimation of heavy vehicles parameters, differentiating light and heavy trucks if the latter category can be easily visible as outlier in a plot of SEL vs speed. Comparison of urban pass by of different stretches might be difficult due to local urban different conditions. For this reason, before reporting data, a distance correction is needed to analyse them at a reference distance, chosen equal to the one of the official standard SPB (7.5 m from the centreline, 1.2 m above the ground). Therefore, a linear correction is applied to acquired spectrum and the fits are performed on corrected data before reporting them on data sheet.

In addition to noise level at monitoring stations, noise from road surfaces can be analysed as the one generated by the road/tire interaction and pavement absorption. This contribution is well represented through the Close Proximity Method (CPX) defined by the ISO 11819-2 (2017) [4] that will be performed in each measurement session over all the old and new surfaces stretches. This method evaluates different road surfaces with respect to their influence on traffic noise, under conditions when tire/road noise dominates. The interpretation of the results essentially applies to free-flowing traffic passing by at constant speeds from 40 km/h and upwards, where tire/road noise is assumed to dominate. The method uses two microphones in proximity to the tire/road contact, aiming to evaluate only the road- tire noise without the influence of noise coming from the engine and the exhaust system of the car. The energy-based average sound level spectra for the two microphones is called “tire/road noise CPX Level” (L_{CPX}). The road surface is characterized averaging all the 20 m long segments.

An adapted protocol for measurement and data post-processing was developed to improve the suitability of the CPX method within the LEOPOLDO project [9]. Thus, data analysis in the post-processing phase is based on the spatial resolution of three tire circumferences long segments (about 6 m) and the sound pressure level Lp_i associated to the i-th segment is estimated by fitting experimental data by the well-known logarithmic relationship with speed data. The fit is calculated for each segment, for each third octave band level in the frequency range between 315 and 5000 Hz. Finally, the overall A-weighted equivalent sound pressure level, at the reference speed, associated to the i-th segment, $L_{CPX,i}$, is obtained through the A-weighted energy-based sum of the third octave bands estimated levels, as required by the ISO 11819-2 [4].

The $L_{CPX,i}$ levels versus distance are used to characterize the road surface installation through its homogeneity and the averaged noise levels on all segments. Unfortunately, during the project a change in ISO standard forced a change in the self powered vehicle to carry out the measurements. Therefore, a different vehicle and tyres were used to perform ante and post operam campaigns. Differences exist in the indicators produced through the two systems (the first was compliant with draft standard and the second with the official standard of 2017). Results are shown for the two vehicles and a temporary correction factor is used to compare data.

Therefore, the following data rare analysed in ante and post operam sessions at first site:

(1) Environmental noise values including: noise equivalent levels L_{Aeq} according to law at continuous station and European indicators; L_{C-A} values; DALY indicator,

(2) SPBI and L_1 for Urban Pass By.

(3) CPX index.

3. RESULTS

3.1 Noise levels, LC-A and DALY evaluation

Table 1 reports L_{Aeq} for daytime and night-time periods and Italian limits by law. LD is the A-weighted equivalent sound pressure level for daytime period while LN is the one for the night-time period

Table 1 – L_{Aeq} values in dB(A) for Italian reference periods and attendant Italian noise limits.

Stretch	L_D daytime (6.00 - 22.00)			L_N night-time (22.00 - 6.00)		
	Ante	Post	Limit	Ante	Post	Limit
1	66.4	63.4	65	60.1	57.4	55
2	68.1	62.8	65	62.1	54.5	55
3	67.9	63.5	50	62.6	57.3	55
4	66.4	64.2	65	60.9	59.1	55
5	70.6	67.8	50	65.0	61.3	55
6	68.6	64.4	65	62.7	59.3	55

Results show that daytime limits at stretches 1, 2, 4 and 6 are now observed while at stretch 3 the limit is observed for inhabitants but not for the school. At stretch 2 also night-time limit is obeyed. However, all sites have values smaller than ante-operam.

Table 2 reports European noise indicators based on Italian defined periods: L_{Day} (6.00 – 20.00);$L_{Evening}$ (20.00 – 22.00); L_{Night} (22.00 – 6.00) and LDEN, the overall day-evening-night noise indicator.

Table 2 – L_{Aeq} European noise indicators. Values in dB(A).

Stretch	L_{Day}		$L_{Evening}$		L_{Night}		L_{DEN}	
	Ante	Post	Ante	Post	Ante	Post	Ante	Post
1	66.8	63.5	65.5	62.6	60.1	57.4	68.6	65.6
2	68.3	63.1	66.9	59.8	62.1	54.5	70.3	63.8
3	68.1	63.7	67.2	61.6	62.6	57.3	70.5	65.5
4	66.5	64.3	65.7	63.5	60.9	59.1	68.8	66.9
5	70.8	67.9	69.3	66.2	65.0	61.3	72.9	69.7
6	68.8	64.3	67.3	62.3	62.7	59.3	70.8	66.7

L_C (C-weighted sound noise levels) and L_A (A-weighted sound noise levels) values had been averaged over each measurement day for both daytime and night-time reference periods. Than an average week L_{C-A} indicator value has been elaborated (see Table 3).

Table 3 – L_{C-A} in dB noise indicator values averaged for each stretch.

Stretch	L_{C-A} daytime (6.00 - 20.00)		L_{C-A} night-time (22.00 - 6.00)	
	Ante	Post	Ante	Post
1	5.4	9.4	4.7	9.4
2	6.1	10.0	4.9	9.5
3	5.2	7.3	3.5	6.6
4	4.8	6.5	3.1	4.7
5	5.6	6.5	4.5	5.9
6	6.0	9.3	4.4	8.8

Acquired values suggest that open pavements (stretches number 1, 2 and 6) have better noise equivalent levels and the lowering is on high frequencies (from CPX spectra), therefore L_{C-A} values are greater on these stretches. This may lead to a lowering of the perceived benefit.

The DALY calculation was based on the assumptions and the methodological procedures described in the WHO publication [6]. DALY is based on the measured noise levels reported above. Annoyance and Sleep disturbance related DALY are calculated according to dose effects relationships associated to noise levels for each stretch. It should be noticed that DALY values reported in following table 4 are based on Years Lived with Disability (YLD) only.

Table 4 – Estimated DALYs

Stretch	DALY Annoyance		DALY Sleep disturbance	
	Ante	Post	Ante	Post
1	0.1	0.1	0.3	0.2
2	1.1	0.6	1.9	1.1
3	1.2	0.8	2.1	1.5
4	0.6	0.5	1.1	1.0
5	0.5	0.4	0.9	0.7
6	0.6	0.4	1.1	0.9
TOTAL	**4.1**	**2.8**	**7.4**	**5.4**

3.2 Urban SPB values

Data provided values of L_1 representing noisiness of a mean light vehicle passing by at 50 km/h at the reference distance (see Table 5) and SPBI (Statistical Pass-By Index) for urban roads (see Table 6) as defined in ISO 11819-1 but starting from SEL fits and not from L_{Amax} as in the standard. Please note that ante operam campaign did not include all the stretches since the method was still under development and all the stretches should sound similarly.

Table 5 – Pass by Values L_1 in dB(A)

Stretch	Direction: to Lucca		Direction: to Viareggio	
	Ante	Post	Ante	Post
1	73.7	70.2	71.7	68.9
2	--	69.5	--	69.8
3	76.1	67.7	74.6	65.4
4	--	71.2	--	71.0
5	74.7	70.5	74.6	69.8
6	75.7	66.0	76.7	67.2

Table 6 – Pass by Values SPBI in dB(A)

Stretch	Direction: to Lucca		Direction: to Viareggio	
	Ante	Post	Ante	Post
1	74.4	70.9	72.1	70.2
2	--	70.1	--	70.3
3	76.3	68.8	75.2	66.8
4	--	71.6	--	71.8
5	75.6	72.0	75.8	71.4
6	76.2	67.8	77.4	68.4

It should be noticed that station at stretch 1 is located in a hilly point. So direction to Lucca is raising and direction to Viareggio is descending, with a higher average speed in sample, thus leading to high variability in the heavy vehicle sample, which contributed to rise the uncertainty of SPBI. At stretch 2, the road is not straight and there is a crossing near the measurement point: this might have affected pass by results in terms of accelerating and decelerating driving behaviour. This method confirms the results obtained in terms of noise levels indicators concerning the effectiveness of single stretches and provides emission values of vehicles passing by that can be used for modelling noise in the area.

3.3 CPX evaluation

The CPX monitoring post operam campaign was carried out according to the recent technical norm ISO 11819-2 using a new reference tyre and a new vehicle able to carry it. Thus, values are not directly comparable with ante operam ones. First considerations allow to estimate that new elaborated values are about 4 dB higher than previous ones in similar conditions, even if emission spectra are different.

Table 7 reports L_{CPX}[v = 50 km/h] for each stretch and direction.

Table 7 – L_{CPX}[v = 50 km/h] values in dB(A).

Stretch	Direction: to Lucca		Direction: to Viareggio	
	Ante	Post	Ante	Post
1	95.5	91.9	96.0	91.0
2	94.6	88.1	96.5	87.1
3	94.5	89.2	96.0	89.0
4	94.3	90.8	94.1	91.7
5	94.5	91.0	96.0	91.3
6	94.8	87.3	95.4	87.5

Post operam values confirms that reference surfaces have acoustic performance not significantly higher than standard ones. Open surfaces generally presents better values than gap ones, being not only able to generate less noise due to rubber but also able to absorb part of the generated noise.

Note that in all previous tables the underlined stretch numbers indicate the reference pavement types

4. CONCLUSIONS

The post operam analysis allows to establish that reference surfaces have acoustic performance not significantly higher than standard new ones. In terms of tyre/road noise open surfaces generally presents better values than gap ones, being not only able to generate less noise due to rubber but also able to absorb part of the generated noise. In terms of equivalent noise levels daytime limits at stretches 1, 2, 4 and 6 are now observed while at stretch 3 the limit is observed for inhabitants but not for the school. At stretch 2 also night-time limit is obeyed. All sites have values smaller than ante-operam leading to a significant decrease of estimated DALYs meaning an improvement on health well-being. The Urban pass by analysis allows confirming good performance of open pavements and it highlights the unexpected high levels at stretch 5. These high values might be due to the specific shape of the road in the measurement point, which is located near a turn but also to the bad installation of manholes, which are not well fixed to the surface.

The indicator L_{C-A} values are greater on open pavements where the lowering on high frequencies lead to smaller A-weighted noise equivalent levels. This may lead to a lowering of the perceived benefit but it has to be confirmed by the holistic analysis, which is ongoing.

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