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Relationship between Pass By results, CPX ones and roadside long-term measures: some considerations

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ABSTRACT

The Close Proximity method (CPX) is surely the simpler tool able to evaluate the road surfaces acoustical performances in terms of rolling noise. Anyway, it is necessary to know the noise reduction at roadside for evaluating the true benefit on the noise mitigation given by a low-noise road surface. The methods mainly used to study the road surface acoustical performance at the roadside are the Statistical Pass By and the Controlled Pass By ones. The relationship between pass-by and CPX results would allow evaluating both the road surface influence on the propagation and the influence of road surfaces inhomogeneity at roadside. Moreover, the relationship between pass-by results and roadside long-term measures would allow creating accurate power level databases for noise mapping purposes, leading to a better estimate of the noise exposure for all receivers close to measured road surfaces. Several different low-noise road surfaces are measured, each one multiple times, with both CPX and pass-by techniques. Results are used to improve the pass-by analysis and the knowledge on the two measurement methods' connection.

Keywords: Road traffic noise, CPX, SPB

1. INTRODUCTION

Road traffic is the main noise source in urban contexts and in the belts next to extra-urban road. It is well known that for cruising speeds higher than 35-40 km/h the noise due tyre/road interaction dominates over all other vehicle sources, so where road traffic noise mitigation actions are needed, low-noise road surfaces can be efficient solutions.

In order to establish if a disturbed site has been recovered, measurements in proximity of exposed receivers are requested by laws. Anyway, noise mitigation actions are planned taking into account several actions and the use of low noise road surfaces is often combined with urban planning, useful to reduce the traffic density, the heavy-trucks percentage and to obtain driving with lower but constant speed. Moreover, actions on the propagation path could be used, such as acoustic barriers. Thus, a diminished exposure level at the receiver does not imply that the road surface is complying with the planned lower emission level.

Furthermore, in order to evaluate acoustic performances among different surfaces, it is necessary to compare measures obtained on pavements laid in different contexts and with different traffic.

The CPX method(1) is the best way to compare emission levels of different road surfaces, but it is a local field measurement. It cannot take into account the road influence on the propagation, neither the directivity of tyre/road noise emission of a vehicle, linked to the pass-by duration in terms of noise

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level above the background at the roadside. Thus, it is necessary to carry out measurements analysing the whole pass by event at the roadside in order to evaluate the road influence.

The methods mainly used to study pass-by at roadside are the Statistical Pass By(2) and the Controlled Pass By(3). Knowing the relationship between CPX and Pass By methods would be useful both to infer the road surface influence on the propagation and to create accurate power level databases to be used in modelling. Finding this relationship was an important focus of EU project as HARMONOISE(4) and IMAGINE(5), and the aim of this work is to improve the knowledge about the problem thanks to the experience gained in the LEOPOLDO project which allowed to survey several different road surface through both CPX and SPB methods(6).

2. STATE OF THE ART

Finding a relationship between results obtained using different methods is not simple, moreover when the two methods, relying on different assumptions, are based on different principles and different measurement techniques. This is the case of the relationship between CPX and pass-by methods: the first method evaluates the average level of noise radiated by a single tyre rolling on a road surface, with the distance microphone-source constrained. On the contrary, the second ones measure the maximum level due to all vehicle sources at the roadside, with a variable source-microphone distance. Some efforts in literature can be found, but a clear model relating CPX and SPB results at the present time does not exist.

Nowadays, some models(7) can predict the roadside noise obtained varying the road surface characteristics and using some tyre parameters as input, but the correlation between CPX and pass-by results is still subject of research and, for example, combining both methods into a harmonized pavement noise emission characterization method is a priority of the ROSANNE Project(8).

3. Measurement methods

3.1 Close Proximity Method

In this paper, the modified protocol based on the CPX method, described by Licitra et al.(9), is used. Results are shown in terms of tyre/road noise levels, without strictly referring to CPX indexes, but for the sake of simplicity they are hereafter named as L_{CPX} values.

The set-up is based on the measurement system mounted on a self-powered vehicle. The main improvements of the modified protocol are briefly resumed in the following: the analysis is based on the spatial resolution of a “segment” about 5.9 m long (defined as three times the tyre circumference); during the measurement session, acquisitions over the tested surfaces are repeated several times, varying the vehicle speed. Then, a minimum chi-squared based iterative algorithm is used for fitting sound levels and speed data, for each segment and for each third octave band level, in order to compute the L_{CPX} values at the reference speeds using the right speed coefficient; finally, the mean value of segments’ results, named L_{CPX} in the following, is used to characterize the whole road surface installation.

The L_{CPX} uncertainty derives from three different sources of data variability. Firstly, segment results obtained by means of the fitting process are provided with the uncertainty due to data dispersion around the fit. Data dispersion is mainly due to the measurement process, thus a clearly random source of error, and at this level it is a “measurement uncertainty”.

The next source of variability is the spatial homogeneity of the installation, i.e. the data (segment) dispersion around the mean value L_{CPX}, computed along the whole installation. Spatial homogeneity is a specific characteristic of the surveyed installation, not actually a source of variability for the measurement method. Then, the deriving uncertainty is a description of the mean value precision and it cannot be neglected when two road surfaces are compared.

All in all, it has to be noticed that, in most cases, the measurement uncertainty is one order of magnitude lower than the one due to the spatial inhomogeneity of the road surfaces. Anyway, both contribute to the uncertainty related to the L_{CPX}.

The last source of data variability derives from “several factors and processes, which cause and nature of these disturbance are either known, but randomly distributed in an uncontrollable way, or are of a systematic nature, but affect the result in an unpredictable way” (as declared in Annex K of the ISO 11819-2). Thus, during a single measurement session, the effects due to these sources of error, well described in the ISO, affect systematically the measures. Anyway, their influence must be considered random, when results obtained in different measurement sessions, carried out in different days and/or with different set-up or instrumental chains, are compared, and it leads to a combined standard uncertainty of 0.5 dB, with k = 1 coverage factor.

3.2 Pass by methods

The SPB method is described by the ISO 11918-1 and it involves measuring the noise levels from vehicles cruising-by at constant speed and with the engine operating at the usual condition for that speed. The method relies on a great number of vehicles from the normal traffic, i.e. without any constraint on tyre or vehicle. Measure is the maximum A-weighted level $L_{A,Max}$ that reaches the microphone positioned 7.5 m far from the middle of the road lane, at 1.2 m height. A working hypothesis can be done: every vehicles reach the $L_{A,Max}$ at the microphone when passing on the same part of the road, so the propagation path is quite the same for all. Thus, the data dispersion is mainly due to the variety of vehicle model and tyres variety(10).

The CB method, described by the ISO 13325(11) is based on the same principle and microphone configuration, but it requires the engine off and it relies on a single type of tyre to be tested. Also the CB method measures the $L_{A,Max}$. The CPB(3) is a middle way between SPB and CB method, since it is based on the same principle and microphone configuration, but it measures the $L_{A,Max}$ due to a single vehicle mounting a specific tyre and cruising-by at constant speed thanks to the engine on.

On the purpose of comparing two different road surfaces, the $L_{A,Max}$ is a measure that could be easily related to the concept of "road noise emission level", but just when the two surface are laid on the same context and exposed to the same car fleet. Otherwise, the influence of local context on the propagation and the influence of the tyre variety could completely masks the differences between the road surface performances. Moreover, in order to judge if a surface is a good solution as mitigation action, the roadside level just due to the part of the road approximately nearest to the microphone perhaps is not enough, because pass by tails contribute to the equivalent level that has to be reduced.

Born with the aim to study vehicle sources power to be used in modelling, the HARMONOISE and IMAGINE projects configuration adds a second microphone at 3.0 m height and measures the pass by SEL instead of the $L_{A,Max}$. The SEL is usually used as a measure of the energy of the whole event, in this case the pass by. A vehicle passage is considered valid if its tails reach at least 6 dB below the $L_{A,Max}$, preferably 10 dB, as required by the SPB ISO. Anyway the SEL calculus need the definition of the integration time length, which is not strictly defined in the HARMONOISE and IMAGINE projects. In literature, two choices on the definition of integration time length can be found: as the time needed by tails to reach -6 dB below to $L_{A,Max}$; as the time needed by the vehicle to drive a stated distance. The two definitions have different basic ideas: the -6 dB cut aims to describe the whole energy event, whereas the space constant cut produces normalized data.

Within the LEOPOLDO project, the integration time length is the time needed to the sound pressure level to drop 10 dB below the $L_{A,Max}$; in according to the ISO 1996(12). This choice reaches the goal to consider the whole event energy better than the cut at 6 dB below to the maximum, but it increases the probability that a pass by event is rejected due to another close vehicle or to the background noise, so having a minimum set of about one hundred valid event becomes harder.

The $L_{A,Max}$ and the SEL defined with the two integration time length choices above analysed, inspect the pass by event from different point of view about the physical quantity used to describe the phenomenon. Thus, results obtained with different indicators are not comparable. A LEOPOLDO project road surface has been chosen just as simple illustrative case and data obtained in an SPB measurement session has been carried out in terms of both $L_{A,Max}$ and SEL calculated through the -10 dB cut and SEL calculated over a stated distance (35 m). In Figure 1 the analysis of the data set of a measurement session is shown and two observations are worthy to be considered: it can be noticed that the data dispersion is quite the same, whereas the relationship between level and speed is remarkably different between the $L_{A,Max}$ and the two SEL cases.

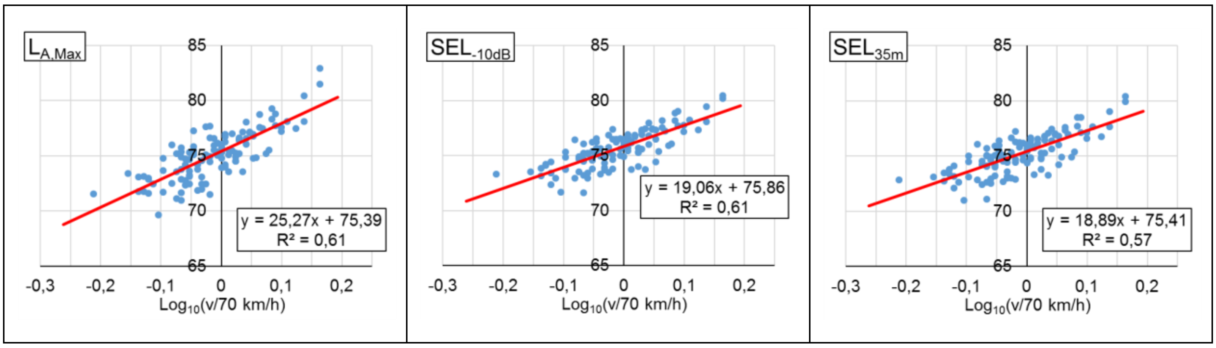


Figure 1 – SPB data obtained in a single measurement session and analysed using three different indicators.

Thus, data correlation is not improved changing a specific indicator and choosing which indicator has to be used is simply up to the researcher and his goals. Instead, the different relationship between data and speed has a clear consequence: having established that the relationship between CPX levels and speed is determined only by the road surface analysed, the comparison with the pass by results leads to different conclusions depending on the indicator used to describe the pass by event.

3.3 Differences between indicators for the CPB analysis

Within the LEOPOLDO project, during each session both pass by and CPX measurements have been carried out. Thus, among all pass by events there are also those due to the CPX vehicle, which during the measurement drove the road stretch in front of roadside microphones. Considering only events due to the CPX vehicle is analogous to the CPB method and it is a solid way to improve the data accuracy, as easily foreseeable and well shown in Figure 2.

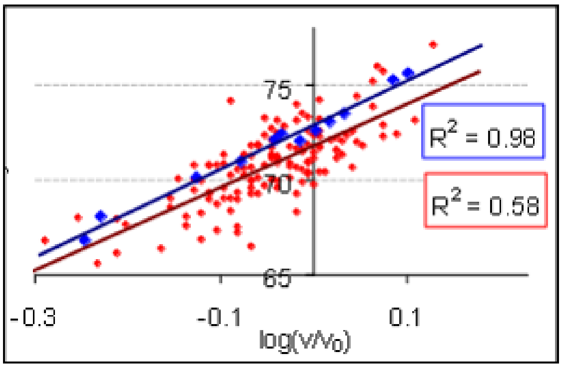


Figure 2 – SPB (red) and CPB (blu) results obtained for the same measurement session

Thus, all further analysis in this work are carried out only on the CPX vehicle pass by events, named for sake of simplicity CPB levels.

The pass by measurement configuration adopted within the LEOPOLDO project positioned microphone at 7.5 m from the centre of the opposite lane ("position 2" described in par. 8 of the ISO 11819-1). In this way microphone is very close to the road surface and the propagation is influenced above all by the road surface acoustical characteristic, and the difference of roadside kind of roadside soil can be considered negligible in a comparison between different sites.

All measurement sessions reported in this work have been carried out on the five road surfaces reported in Table 1.

Table 1 – Road surfaces used in this work

Surface	Road surface
Surf.1	SMA optimized texture gap grade 0/8
Surf.2	Asphalt rubber (wet process) open grade 0/16
Surf.3	Dense grade 0/6 with expanded clay
Surf.4	Asphalt rubber (wet process) gap grade 0/8
Surf.5	SMA 0/16

As first analysis, it is interesting to compare CPB data obtained applying the three measures above described: the $L_{A,Max}$, SEL_{10dB} and SEL_{35m}. In Figure 3 CPB data obtained for each road surface analysed in this work are shown. It can be noticed that for all surfaces the slope of the linear regression levels-log(speed) are significantly different between the $L_{A,Max}$, and the two SEL data. Moreover in case of surface 4 and 5 there is a remarkable difference also between the two SEL data, in particular in case of surface 5 there is a significantly offset, whilst in case of surface 4 also the slope of the linear regression is quite different.

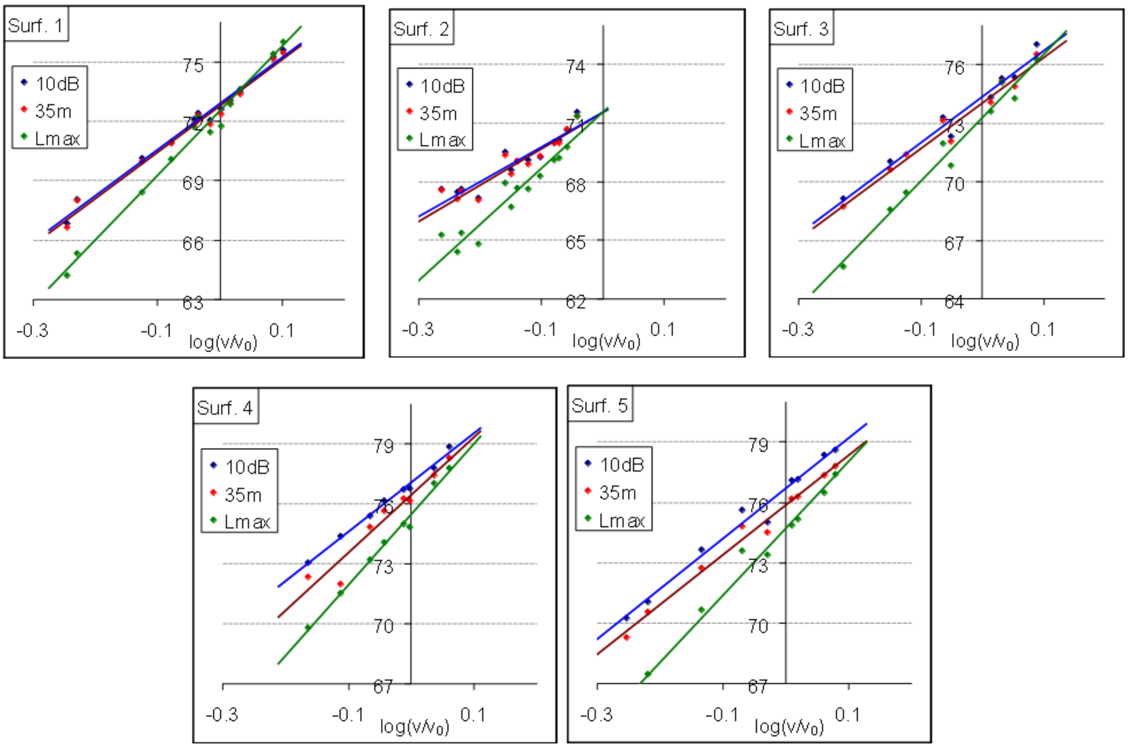


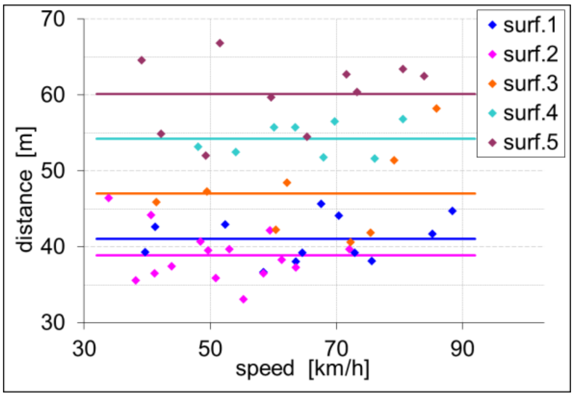
Figure 3 – Comparison of all CPB results obtained using the three different indicators

Differences between SEL_{10dB} and SEL_{35m}. can be well-explained by the comparison of the space lengths driven during the time necessary to achieve the 10 dB decrease in level. As shown in Figure 4a, driven spaces for surfaces 1 and 2 are respectively approximately 39 m and 41 m, not significantly different from 35 m. Surface 3 has a driven space of about 47 m and still no influence on SEL values can be assessed. Surfaces 4 and 5 have a driven space of respectively 54 m and 60 m and the strong difference between 35 m starts to be an issue.

Moreover, in this first analysis the driven spaces calculated for the SEL_{10dB} events are obtained averaging all measures, without searching for any trend in data and assuming that there is no speed dependency. On the contrary, in Figure 4b durations of SEL_{10dB} events are plotted against speed and then are fitted on a power function:

$$\Delta t = {}^{s}\!/_{v^x} \qquad (1)$$

In Table 2 the obtained exponents and R^2 correlation coefficients are reported: the power function exponents are significantly different from 1 and this means the space driven during the time necessary to achieve the 10 dB decrease in not a constant, but it depends on the speed.



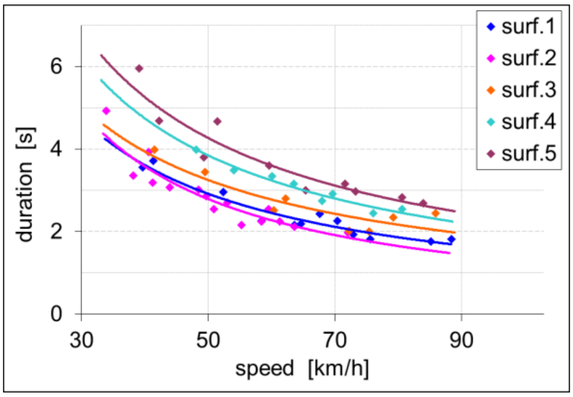


Figure 4 – Analysis of SEL_{10dB} data: a. (left) comparison between the driven space; b. (right) comparison between the pass by event duration.

Table 2 – Best fit between speed and pass by duration event, in case of SEL_{10dB} data

Surface	Power exponent	R^2
Surf.1	- 0.93	0.96
Surf.2	- 1.18	0.88
Surf.3	- 0.93	0.95
Surf.4	- 0.93	0.92
Surf.5	- 0.83	0.96

All these observations lead to consider SEL obtained by the calculus on a stated driven space as data more significant than the SEL_{10dB} data, because the last describe different part of the road surface depending on speed. Thus, further analysis will be carried out using only the $L_{A,Max}$ and the SEL_{35m} indicators.

3.4 Comparison between CPB and CPX results

The comparison between CPX and CPB results obtained in all road surfaces is shown in Figure 5, using both the CPB indicators. Surfaces id have been assigned (Table 1) following the order of L_{CPX} level, so it is easy to argue that the level difference between CPX and CPB depends on the road surface.

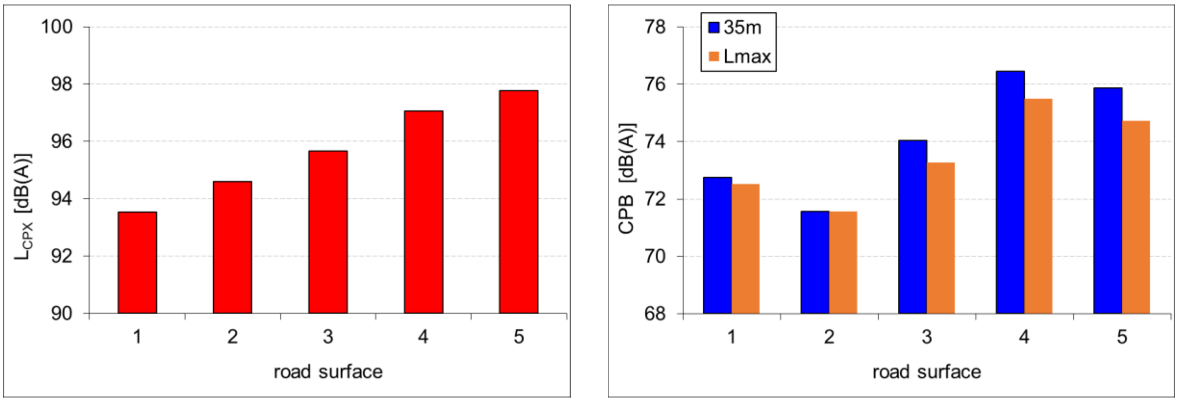


Figure 5 – Comparison between CPX (left) and CPB (right) results.

The difference between CPX and CPB results can be computed also at different speed. In Figure 6 values are shown at 50 km/h, 70 km/h and 90 km/h. The difference is dependent on both speed and type of road surface, with a stronger influence of the first parameter for the difference L_{CPX}-SEL_{35m}.

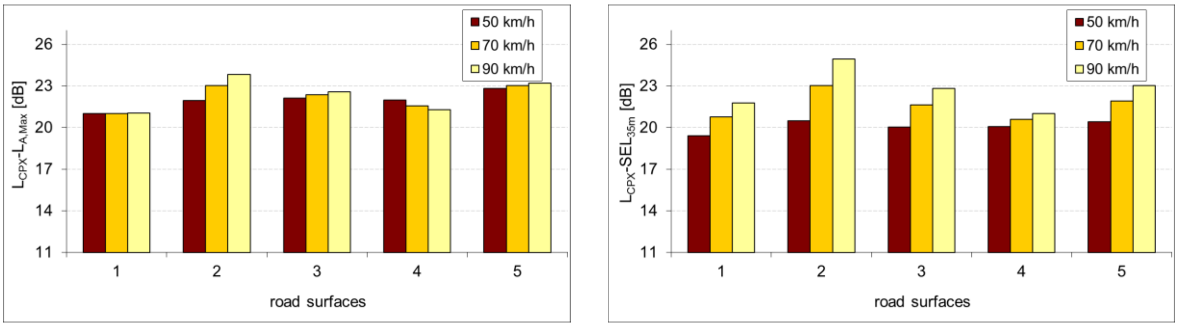


Figure 6 – Difference between CPX and CPB results varying the speed and using both the CPB indicators: the $L_{A,Max}$ on the left and the SEL_{35m} on the right.

In conclusion, it is not possible to estimate a simple mean difference between CPX and CPB results able to work as a propagation filter for all kinds of surface.

3.5 Comparison between CPB and CPX experimental data

Besides the comparing CPX and CPB data between measurement session results, a comparison can be carried out in terms of levels of each pass by event. The CPX vehicle is the CPB noise source, so data must be correlated and the high correlation can be easily highlighted in figure 7 where pass by event are plotted using the L_{CPX} values in abscissa and the CPB ones, as both $L_{A,Max}$ and SEL_{35m}, in the ordinate.

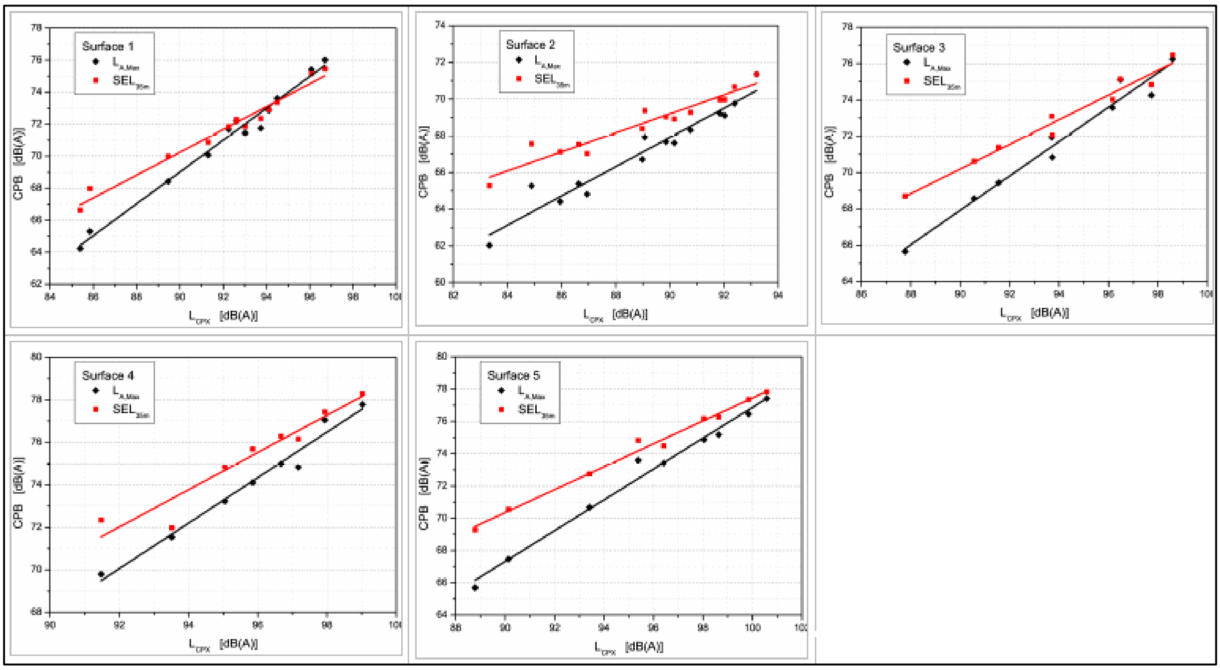


Figure 7 – Comparison between the CPX and CPB data

Besides the high correlation, the most interesting element is the comparison between the slopes of the regression lines. In Table 3 the slope values and the corresponding R^2 correlation coefficients are reported.

Table 3 – Slope values and R^2 coefficients between L_{CPX} values and CPB $L_{A,Max}$ and SEL_{35m}

Surface	$L_{A,Max}$	R^2 ($L_{A,Max}$)	SEL_{35m}	R^2 (SEL_{35m})
Surf.1	0,99 ± 0,04	0,98	0,71 ± 0,04	0.97
Surf.2	0,80 ± 0,06	0,93	0,52 ± 0,04	0.91
Surf.3	0,95 ± 0,06	0,97	0,68 ± 0,05	0.96
Surf.4	1,07 ± 0,07	0,97	0,88 ± 0,11	0.91
Surf.5	0,96 ± 0,04	0,98	0,71 ± 0,03	0.99

Some remarks can be done: for both CPB indicators, the slope is not clearly equal to 1, even if the $L_{A,Max}$ slope is significantly different from 1 only in case of the surface 2, which is the only porous one, whereas the SEL_{35m} slopes are significantly different among the group. This means that CPB values increase differently than L_{CPX} values. Moreover, the slope of SEL data is always lower than the $L_{A,Max}$ one and it depends on the road surface.

4. DISCUSSIONS

Knowing the relationship between CPX and Pass By methods would be useful to use the first method to evaluate also at the receiver the effectiveness of a low noise road surface. Moreover, it would be possible to infer the road surface influence on the propagation. In this work, several CPX and CPB measurement sessions have been analysed in order to improve the knowledge about the relationship between the two methods. First of all, three different pass by indicators have been compared and the differences between them have been shown. In particular, it has been shown that a simple propagation filter useful to correct a CPX result for estimating a pass by one is not possible. Moreover, CPX and pass by data depend differently on the speed, in particular when the SEL is used as pass by indicator. In this case, the pass by event tails have a not negligible contribute.

Further researches are necessary will be developed to define an accurate source model that will use as input parameter the CPX data and will return the roadside time history of sound level, useful to estimate all pass by indicators and to create power level databases to be used in modelling.

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