Anti-vibration pavement: Case of study Novara municipality

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ABSTRACT

The phenomenon of vibrations induced by vehicular traffic is due to several factors including transit speed, irregularity of road surfaces, vehicle mass and type of bituminous conglomerate used. In fact, the vehicular source enters mechanical energy in the pavement which is generated either because of the vehicle and because of the road surface inhomogeneity. These vibrations are instead propagated in function of the constituent materials. Depending on the new production technologies, such road materials may instead be designed to allow the attenuation of vibrations that, in this case, arrives reduced to the surrounding buildings, limiting the disturbance to the inhabitants and the degradation of the Historic Buildings of the territory.

The use of bituminous mixtures containing rubber powder resulting from the recycling of tires at the end of their life (normally used for the reduction of noise emissions) allows concretely the reduction of such vibrational impacts, in all urban environments where vibrations from vehicular traffic, on road or on iron, have a significant impact on human living comfort. The verification of this solution has been developed on a pavement made for the Municipality of Novara. The test involved the analysis of the data detected with the transition vehicle of reference, either on a stretch of anti-vibration pavement, and on one of reference. The signal has been filtered in different bands, obtaining the corresponding SEL. The results showed the anti-vibration level reached.

Keywords: Environment, Noise reduction, Sustainable urban and rural infrastructure, Tyre/road noise

INNOVATIVE SOLUTIONS WITH A COMPOUND OF RUBBER POWDER AND POLYMERS FOR ANTI-VIBRATION ROAD PAVEMENTS.

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1. INTRODUCTION

Especially in urban areas, the factors that can affect the quality of life are different and involve different areas of human activity. Noise and vibration are two elements to which people are more susceptible, as they can sometimes affect physical and mental well-being.
The process of industrialization and motorization can be considered as the main reason for the existence of these two factors. For example, the vibrations generated by road traffic, as well as being a source of trouble for residents, can cause damage to buildings and equipment in the areas close to roads. Sometimes it interferes with activities such as those carried out in operating rooms or in precision laboratories [1] [2].
In recent years, several legislative solutions have been undertaken to decrease road noise, even if the efforts to reduce vibrations are not appropriate to the level of damage done. In the design of public works, it is not always necessary to assess the environmental impact of the work in terms of vibration and Italian legislation is not consistent with the acceptance criteria [1].
Experts and researchers around the world have been studying solutions aimed at mitigating these disturbing elements. Interesting studies have been carried out on road paving construction materials which are be capable of reducing vibrations caused by road traffic [3].
Iterchimica's researchers have developed a special technology based on the use of rubber powder derived from recycled tyres at the end of their service life [4], which alleviate vibration and the resulting rolling noise. In reference to the latter the results of a study conducted in collaboration with iPOOL srl, a spin-off of the Italian National Research Council (CNR) are reported.

2. VIBRATIONS CAUSED BY TRAFFIC

Road traffic generates vibrations and noise, and the causes are: engines, air resistance, tyre motion, as well as braking. In addition, other noises are produced due to irregular paving surfaces [1], due to the laying procedure, the technology used and the presence of surface damage.
The result of these irregularities causes an oscillatory movement in the vehicle, disturbing the people in the vehicles, and the energy waves from the pavement transmit to the structures and people inside them.
In literature there aren't many analytical models studying the vibrations created by traffic to buildings: this failure is mainly due to the poor validity of the models that realistically represent the dynamic behavior of the soil, the geotechnical characteristics, the presence of underground utilities and pipelines that can affect the propagation of the waves [1].
It is also very important to know that the transfer of vibrations from the source to the receiving point happens in different phases, during which the vibrational waves are modified before being retransmitted [Fig. 1].

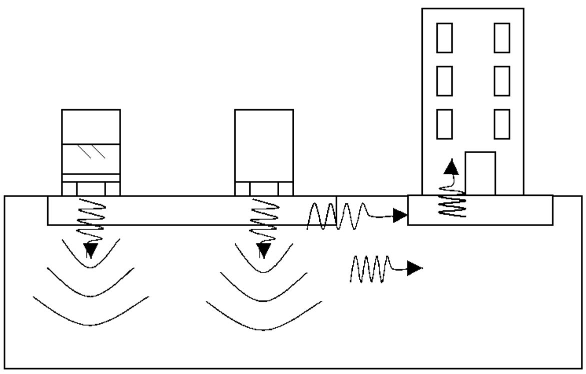

Figure 1: Scheme of the transmission of traffic vibrations

The interaction between road surfaces and vehicles can be considered an emitting source in the range of the low-mid frequency (<1000 Hz approximately). Furthermore, the unevenness of the surface with a wavelength over 0.5 m and the mega-texture of the road surface (50 mm ≤ λ ≤ 500 mm) are responsible for generating the vibrations received by citizens.
Over the past 20 years, some researchers have shown that the structure of the pavement has a strong influence on the vibrations. The more influential physical-mechanical characteristics are stiffness and damping capacities. Therefore, the anti-vibration pavement must be designed considering (and changing) those two elements.

3. ALLEVIATION THROUGH ANTI-VIBRATION PAVEMENT USING RUBBER POWDER

It is possible to reduce vibration pollution thanks to periodic monitoring of surface damage and taking corrective measures (road maintenance) to ensure a suitable road surface, with the aim of reducing the generation of vibrational waves. Otherwise, it is possible to take action against the propagation between source and receiver, studying the design phase.
Further solutions, which allow the reduction of vibrations, are "anti-vibration" pavements using innovative technology. This technological solution avoids the production of excessive vibration and contains the propagation.
The first attempts of anti-vibration pavements in Italy were developed in 1970: pavements with prefabricated plates and beams resting on a concrete slab with rubber pads - Farnesina Palace in Rome; reinforced concrete subbase underneath the binder layers and asphalt binder, placed on panels of rubber surrounded by glass wool, for an urban section of artificial tunnel of State Road 36.
The solutions that involve the development of special bituminous mixtures are more recent. Well established after years of applications, a new technology that consists of the use of a specific compound of suitably treated recycled rubber powder (from End of Life Tyres) and polymers. Such a compound is directly used during the production phase of the asphalt concrete. The technology allows action to be taken on two key issues:

- The surface texture, depending on the particular grading curve designed;
- The coefficient vibration absorption of the pavement, optimized by the presence of the rubber powder.

3.1. Optimization of the pavement texture

Researchers have shown that, in order to reduce the noise emission from rolling and vibration, the texture should be optimized according to the following general characteristics [3]:

a) the micro-texture (λ <0.5 mm) must be increased, in order to reduce the noise due to air pumping (the air will be compressed and expanded inside this micro texture structure);
b) the macro-texture (0.5 <λ <50 mm) must be composed of high amplitudes in the range of wavelengths 1-8 mm, instead the amplitudes should be low in the range 10-50 mm (reduction of the noise component due to the vibratory phenomenon);
c) the maximum diameter of the aggregates in the mixture must not be more than 8 mm in order to obtain a layer with low-noise and vibration (in any case, the maximum diameter should not be more than 10 mm);
d) the aggregates should be crushed in order to increase the texture levels at low wavelengths;
e) the texture must be negative; the road profile has a negative texture when it is characterized by valleys [Fig. 2-3]. A pavement with negative texture contains the deformations of the tyre and, at the same time, enables the drainage of the air trapped between the tyre and rolling surface. Examples of negative textures are present in drainage layer and gap-graded: wearing course is characterized by a discontinuous grading curve in the area of the sands, in order to guarantee to the surface of the pavement the presence of cavities between the aggregate of maximum size;

Figure 2: Positive texture of the road surface

Figure 3: Negative texture of the road surface

f) the pavement must have a homogeneous macro-texture;
g) the aggregates used must have cubic shape so the orientation does not affect the values of mega-texture (50 mm <λ<500 mm) that can influence the vibration.

3.2. Optimization of sound absorption and vibration of road pavement

During the phases of research and design of new anti-vibration materials and with the main goal to optimize performance, it is important to take into account that:

1) The frequency of maximum absorption must lie at the frequency of maximum emission (this frequency is about 1000 Hz for roads with high driving speeds, while it is around 600 Hz for those at low speeds);
2) The vibration wavelengths that affect buildings and their inhabitants are between 10 and 300 Hz;
3) The absorption spectrum must be large enough to dissipate the noise emission in a frequency range that is as wide as possible;
4) Materials such as bituminous mastic and rubber absorb mechanical energy, damping the oscillations induced by the passage of vehicles and the resulting vibrations.

4. ANTI-VIBRATION ASPHALT CONCRETE

As a result of years of research, the bituminous mixture for wearing courses produced with anti-vibration technology is made from a mixture of crushed aggregates, sand, filler, bitumen and normal polymeric compounds containing rubber powder.
It allows the reduction of noise emissions thanks to the optimized texture, aimed at reducing rolling noise generated by the tyre contact with the pavement, and the reduction of vibration transmission in function of the stiffness studied. At the same time it guarantees a lower aging of the binder and a perfect waterproofing of the pavement, thanks to a low content of the voids and high polymer content, in addition to excellent adhesion between tyre and pavement.
The type of bitumen to be used is 50/70 (classified according to UNI EN 12591) in an amount equal to about 6.5-8.5% on the weight of the mixture.
The bituminous mixture is a closed type and it is composed of aggregates of a different nature, which must have the following physical requirements:

- Percentage of crushed surfaces (UNI EN 933-5): 100%;
- Resistance to fragmentation (EN 1097-2 - Los Angeles): ≤ 20%;
- Shape index (UNI EN 933-4): ≤ 20%;
- Flakiness index (UNI EN 933-3): ≤ 20%;

The aggregate grading curve [Tab. 1] is discontinuous (high percentages of gravel) and is linked by a mastic characterized by a high viscosity and composed of bitumen, filler and polymer compounds. It is made of elastomeric polymers and elastomers and must be dosed at 2-4% on the weight of the aggregates.

Table 1: Gradation limits

Sieve Size [mm]	Passing by weight [%]
12.5	100
8.0	82÷100
4.0	25÷52
2.0	15÷30
0.500	8÷20
0.250	6÷15
0.063	4÷9

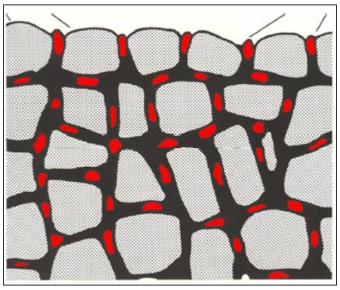

Figure 4: Representative image of the mixture with the added compound

4.1. Mix production

The production technique of this technology is similar to the conventional AC and is indicated as "dry method". In fact, according to the chemical treatment processing, the compound can and should be added directly to the mixer for discontinuous plants, after the hot aggregates; or, for continuous plants, during the final stage of mixing. In order to guarantee the correct dosage of the compound, thermo-melting bags or dosing systems are used. The precautions required are the temperature and the mixing time. In fact, the mixing must take place at temperatures between 170 and 180 ° C to allow the polymeric component to complete its dissolution and facilitate the laying of the modified asphalt concrete, because the presence of the compound involves the increase of mastic viscosity. Before the addition of the bitumen it is appropriate to extend the mixing time by at least 5-10 seconds to guarantee the distribution of the compound in the mass of aggregates.

5. CASE STUDY: NOVARA (ITALY), ANTI-VIBRATION PAVEMENT

In order to limit the vibration produced by vehicles, the City of Novara has ordered the rebuilding of the wearing course of some stretches of pavement in urban areas particularly prone to this phenomenon, using a special bituminous mixture.

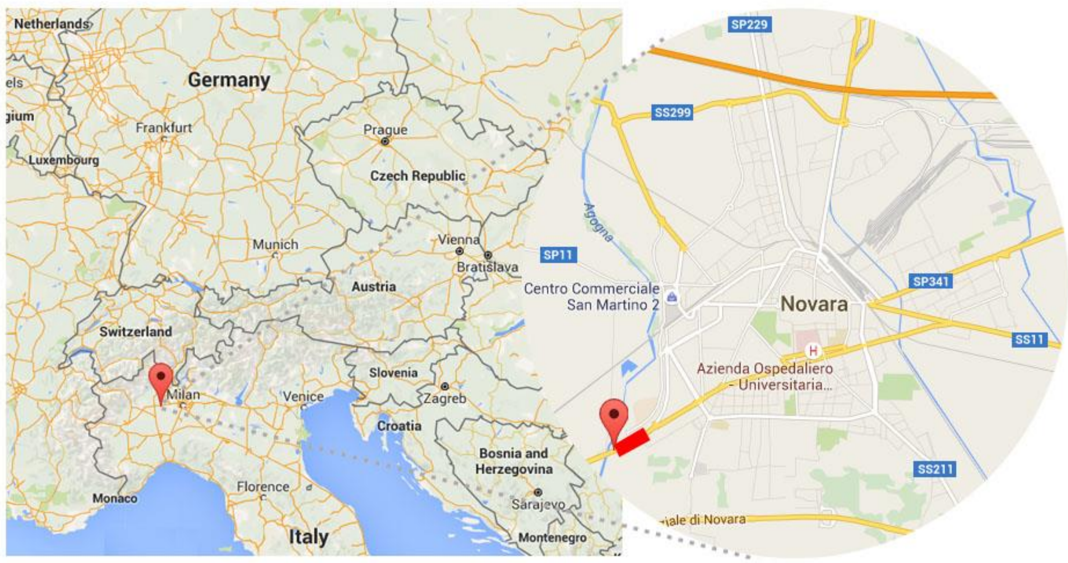

Figure 5: territorial framework

The phases of realization were the following:

- the study of mix design in laboratory;
- Production and laying between April and May 2014;
- Monitoring the anti-vibration performance during November 2014 and March 2015.

5.1. Mix Design

The limestone aggregates taken from the quarry nearest to the production plant were available in only two sizes: 0/4 sand and gravel 4/8. After the tests of physical characterization, the grading curve was analyzed in order to determine the correct proportioning of the aggregates according to the grading reference.

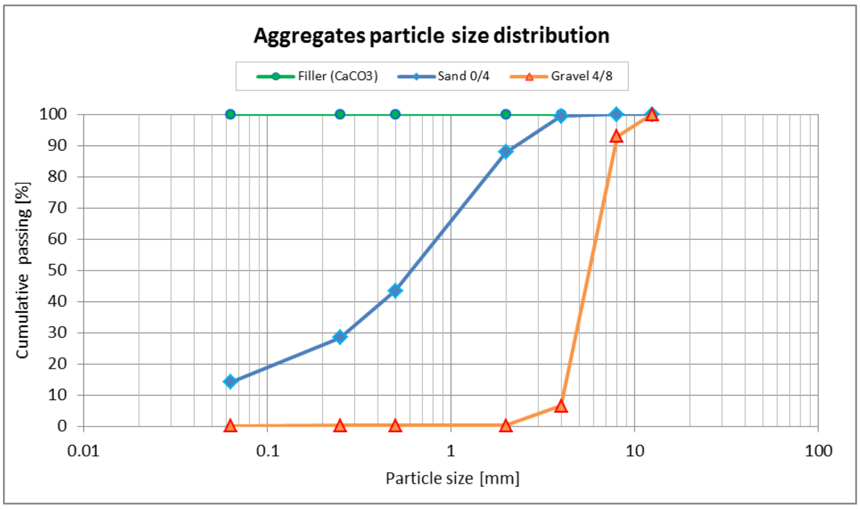

Figure 6: Graph of aggregate particle size distribution

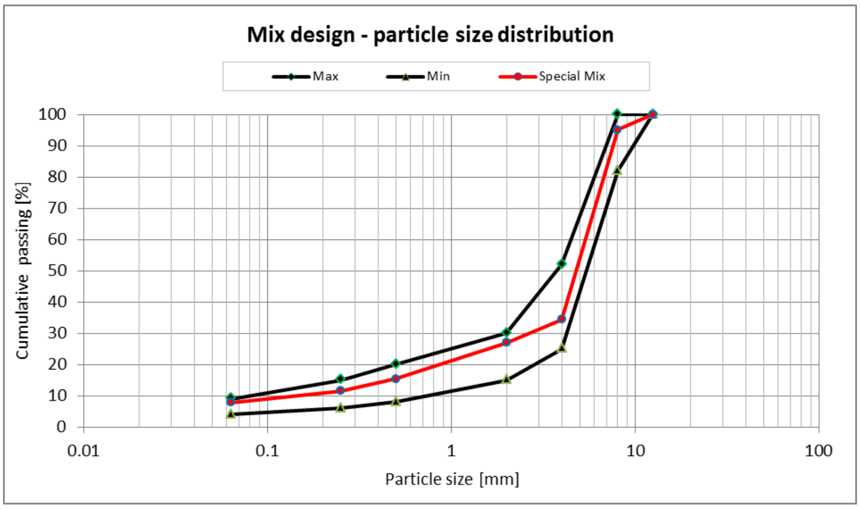

Figure 7: Aggregate particle size distribution resulting from the aggregate proportioning

In order to optimize the bitumen content and to verify the mechanical performance of the mixture in the laboratory (EN 12697-35) three mixtures were produced with different bitumen contents with a fixed percentage of polymeric compound equal to 2.5% of the weight of the aggregates. Using the volumetric method with gyratory compactor, (the characteristics are described in Table 2), it is possible to produce cylindrical specimen (EN 12697-31), and then it was determined the Indirect tensile Strength according to EN 12697-23. Here below the results.

Table 2: Gyratory compaction specifications

Characteristic	Reference Value
Vertical pressure [kPa]	600 ± 3
Rotation angle [°]	1.25
Rotation speed [rot/min]	30
Number of rotations	100
Sample diameter [mm]	100

Table 3: Test results of Indirect Tensile Test

Mixture	Bitumen content	ITS	CTI	Axial displacement	Specific weight	Average voids

	[% on mixture weight]	[MPa]	[MPa]	[mm]	[kg/m^3]	[%]
Limits	6 ÷ 8.5	≥ 0.45	---	---	---	> 2
1	6.39	0.92	53.6	2.613	2428	3.3
2	6.82	0.91	47.5	2.424	2414	3.2
3	7.24	0.88	38.0	3.206	2.411	2.7

Looking at the results of the indirect tensile strength it is possible to observe that the values are nearly equal for all three mixtures (typical behavior of this technology and verified in other tests), the choice of the optimum percentage of bitumen was determined againt the lower percentage of voids, and the greater rigidity: the optimal bitumen percentage is number 3 in the table above.

5.2. Vibration measures

The vibration measurements were made between 23 November 2014 and 31 March 2015 in Corso Vercelli and Via Kennedy located in Novara. The purpose of the measures were to certify the pavement from an anti-vibrational point of view, and then compare it to the standard pavement. Both pavements didn't show any surface damage that could generate abnormal vibration after the passage of vehicles.

Figure 8: a photo of Corso Vercelli - Anti-vibration Technology

Figure 9: a photo of Via Kennedy - traditional wearing course

Despite the lack of standard references, there are technical standards which describe the analysis of the vibrations caused by road infrastructure on the buildings close by. This reference determines the maximum speed of signal PPV (Peak Particle Velocity), but this measurement was not possible because the two pavements are located in two different places.

Therefore, the method of measurement adopted follows a protocol currently under development that consists of the acquisition of the vibration signal with an accelerometer station, which is connected solidly to the road surface being analyzed. The passing of a vehicle creates vibrations on the road, that are transmitted to the edge of the road, where they are evaluated through acceleration measurements devices against the time.

To overcome the inability to control the variables connected to the source (real traffic), it was chosen to analyze the signal resulting from the passage of two well-known and constant vehicles. The tests were carried out considering the temperatures of the air and of the pavement.
The adopted measurement protocol established that, during a single session, the vehicle used as reference drive along the lane close to the accelerometer at different speeds. These conditions allow the operator working at the roadside to record several steps, in order to average (in a post-processing analysis) the different conditions of transit and interaction between tyre / surface. The same pattern was applied to both pavements.
During the phase of post-processing the accelerometric signal of each passage was analyzed, choosing appropriate frequency bands used to evaluate the energy content. The frequency bands have been chosen depending on the energy content of the signal analyzed in narrowband, and following the literature data [Tab. 4] [5].
[1]

Figure 10: placements of an accelerometer

Table 4: The frequency bands chosen for the analysis of the accelerometric signals, the first band can be considered a broad band , including the top 5 narrow bands used .

Index	1	2	3	4	5	6	7	8
Band (Hz)	8 - 1.5k	10 - 100	100 - 200	200 - 400	400 - 800	800 - 1.5k	1.5k - 2k	2k - 3k

The band between 10 Hz and 100 Hz is the most interesting bandwidth from a structural point of view for the vibrations of the pavement, because it can be influenced by the materials used. The two successive bands are equally important, in fact according to the standard (UNI 9916: 2004) the upper limit of the frequency range affected by the vibrations from road traffic is 300 Hz. The increase of the frequency is caused by the macro-texture of the pavement and the internal structure.
The upper frequency bands are investigated because they are reported in the literature. Instead, the first band 8 ÷ 1500 Hz is the analysis in broad band.
For each band, the total energy of a single event (SEL_A) was estimated and calculated in a similar way to the acoustic phenomena.
Then the average of the values in SEL_A was calculated, obtained for each event for each band, and the dispersion around the peak represents the variability of the phenomenon [5].

1

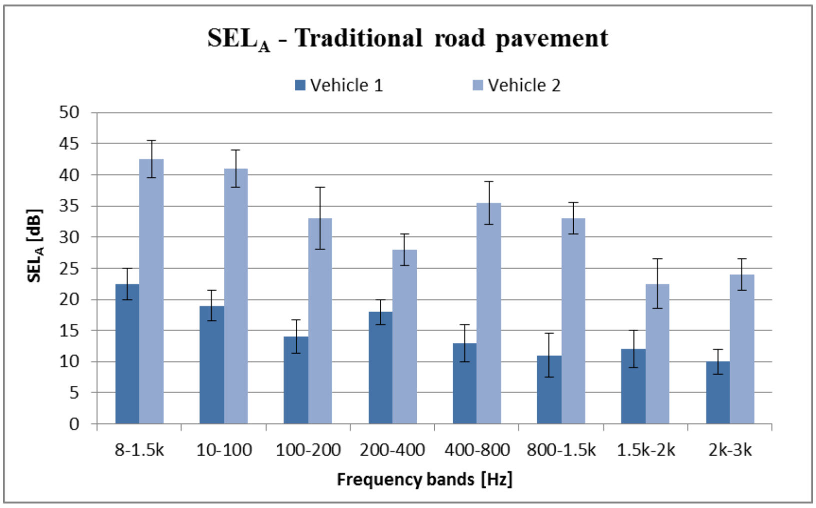

Figure 11: comparison between the SEL$_A$ obtained from the traditional pavement for both vehicles

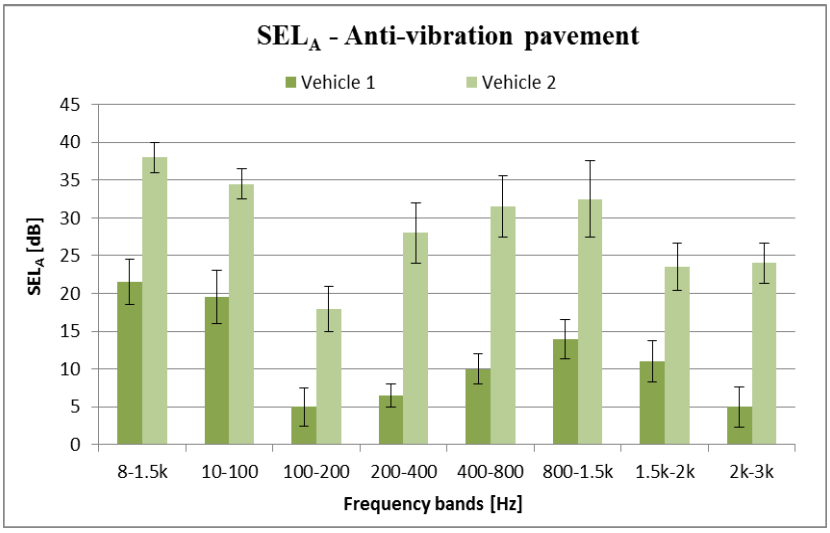

Figure 12: comparison between the SEL$_A$ obtained from the anti-vibration pavement for both vehicles

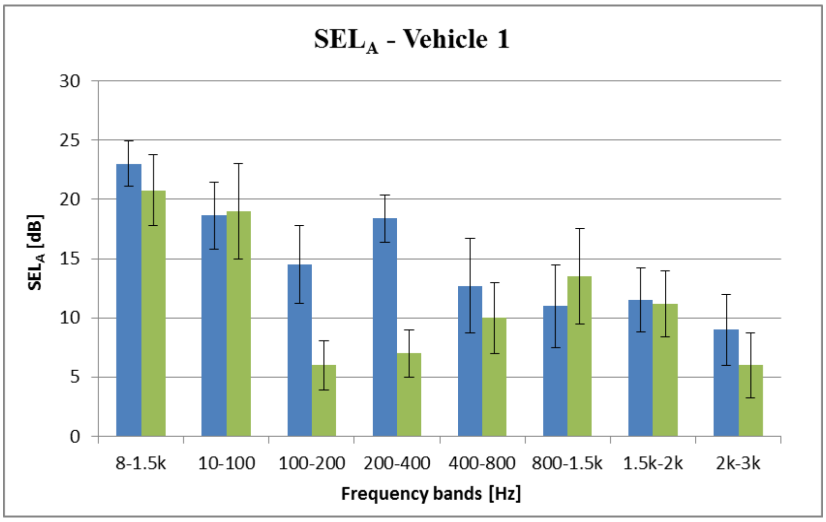

Figure 13: comparison between the SEL$_A$ obtained from the Anti-vibration and Traditional pavement for vehicle 1

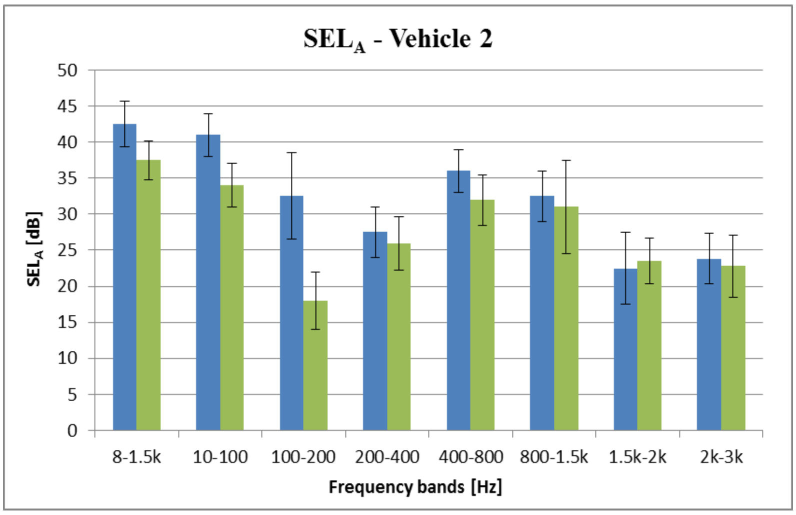

Figure 14: comparison between the SEL$_A$ obtained from the Anti-vibration and Traditional pavement for vehicle 2

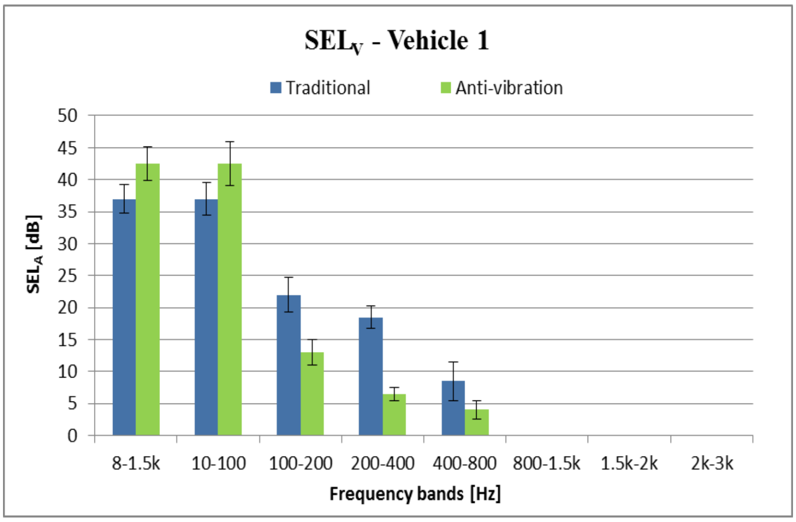

Figure 15: comparison between the SEL$_V$ obtained from the Anti-vibration and Traditional pavement for vehicle 1

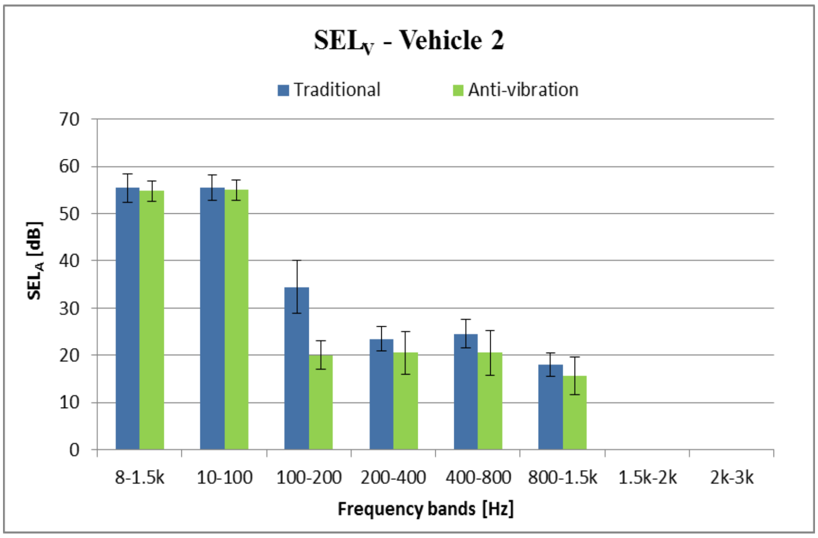

Figure 16: comparison between the SEL$_V$ obtained from the Anti-vibration and Traditional pavement for vehicle 2

The uncertainties associated with the values are big, due to the reduced number of steps, which caused an increase in spread of the results.

Figure 2 shows for each vehicle, the comparison of the SEL_A results, between the special pavement and the reference one. Figure 3 shows the same comparison obtained from the parameter SEL_V.
After the analysis of the results, some conclusions regarding the relationship between the two pavements investigated can be done:

1) for the band 10-100 Hz and for the SEL_A, the two asphalt pavements have the same behavior regarding vehicle 1, while with vehicle 2 the pavement used as a reference showed different values in comparison to the pavement with polymeric compound, in fact the difference is about 6.6±3.5 dB;
2) for the band 10-100 Hz and for the SEL_V the behavior is the opposite, in fact the pavement with polymeric compound have lower results than the reference pavement. The difference is about 5.6±4.0 dB, considering only the vehicle 1;
3) for the band 8-1.500 Hz there is a discordant similar behavior between parameters and vehicles;
4) for the band 100-200 Hz the pavement with the anti-vibration compound has a lower value compared to the reference one for both indicators and vehicles;
5) for the band 200-400 Hz the pavement with the compound has a lower value compared to the reference one for both indicators, but only for vehicle1, because for vehicle 2 the pavements are not so different;
6) all bands which cover the frequency ranges higher than 400 Hz have values not so different between the two pavements, using both parameters for both vehicles.

In table 5 the differences between the values of SEL_A, for both vehicles, are reported, while in Table 6 the differences for the parameter SEL_V [5]are shown.

Table 5: Difference in SEL_A values beetween Special and Reneference pavements

Band [Hz]	8 ÷ 1.5k	10 ÷ 100	100 ÷ 200	200 ÷ 400	400 ÷ 800	800 ÷1.5k	1.5k ÷ 2k	2k ÷ 3k
Vehicle 1	-1.7 ± 3.7	0.2 ± 4.3	-9.4 ± 3.5	-12.1 ±2.2	-2.9 ± 3.6	3.8 ± 4.5	-0.2 ± 4.2	-4.3 ± 3.5
Vehicle 2	-4.9 ± 3.8	-6.6 ± 3.5	-13.8 ±6.7	-2.5 ± 4.8	-4.2 ± 5.5	-0.6 ± 5.3	-0.6 ± 5.9	-0.4 ± 4.2

Table 6: Difference in SEL_V values beetween Special and Reneference pavements

Band [Hz]	8 ÷ 1.5k	10 ÷ 100	100 ÷ 200	200 ÷ 400	400 ÷ 800	800 ÷1.5k	1.5k ÷ 2k	2k ÷ 3k
Vehicle 1	5.8 ± 3.5	5.6 ± 4.0	-8.3 ± 3.8	-12.7 ±2.6	-5.0 ± 5.4	NA	NA	NA
Vehicle 2	-0.9 ± 4.1	-0.6 ± 3.8	-14.5 ±7.4	-3.3 ± 5.0	-4.1 ± 4.7	NA	NA	NA

CONCLUSIONS

As result of years of research, the compound containing rubber powder can reduce the vibration caused by vehicles.
Using the road with the modified wearing course, the users appreciate the advantages. In fact the anti-vibration component can be seen as direct benefit, but also noise reduction is an indirect benefit.
Tests made on the pavement in Novara, in collaboration with iPOOL, a spin-off of the Italian National Research Council (CNR) have showed, in objective way, the anti-vibration performance.
Due to the different frequencies and different power of vibrations, for a more precise study, for the future, we suggest using more accurate methodology.
For example, thanks to sessions of measurement it is possible to evaluate the influence of the different parameters used and it is also possible to evaluate the effect of the crumb rubber on the vibration behavior of the pavement.
In particular, it would be useful to compare two different pavements with the same age, with the same characteristics of texture, and in particular with one of these having rubber powder. It would also be interesting to compare the results obtained using the vibrations caused by normal traffic and not only by known vehicles. In this way it would be possible to investigate the phenomena in a statistical way and to limit the effects due to a particular type of vehicle.

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