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DOCTORAL THESIS:

Evaluation of the superficie of asphaltic mixes: Texture and acoustics absorption related to tire/ road noise.

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Thesis director:
Santiago Expósito Paje

Dedicated to my families,
once has and once makes.

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Summary

The acoustic contamination preoccupation grows every day. In urban areas, the higher noise source comes from road traffic, and for speeds up to 40 km/h tire/road noise prevails over any other source emitted by the vehicle. The mechanisms involved in the noise generation or noise propagation are reflected on the sound emission spectra as impacts or vibrations related to surface texture, or as acoustic absorption, which depends on the asphalt mix characteristic (air voids content, percentage of binder). This work deals with measurements and analysis of the noise emitted in proximity using the CPX methodology on different types of pavement, as well as with factors of influence such as texture or absorption, to characterize and obtain technological advances in the field of sound-reducing pavements.

Equipments used in this investigation, in the Laboratory of Acoustic Applied to Civil Engineering (LA^2IC) of the University of Castilla-La Mancha, have been tuned for measurements, calculus and analysis of tire/road noise parameters. On one hand, new design pavement have been studied, solution to reduce sound emission, as mixes with high viscosity binder with crumb rubber, increasing elasticity and so reducing impact mechanisms. Methods surface texture auscultations have been developed, using lasers in dynamic or static mode. During this period of investigation, I realized a 3 months stay in the IFSTTAR Acoustic Laboratory where I learned how to obtain characteristics parameters of surface texture from the texture profile, as the MPD and the texture spectra. Thus, surface texture correlation with experimental data of tire/road noise is possible.

On the other hand, asphalt intrinsic parameters influence on acoustic absorption has been studied on compacted samples. A Matlab model has been applied. It allows determining parameters related to asphalt mix design from experimental measurements (realized with the impedance tube) and acoustic absorption coefficient simulation.

Finally, an environmental labelling has been proposed for bituminous mixes with capacity to reduce sound emission, depending on sound emission, acoustic absorption and surface texture.

Luckily the wheel was invented before the car,
the road traffic noise would have been unbearable. H.P. Martz

1 INTRODUCTION

According to preliminary results from the Environmental Burden of Disease (EBD) in Europe project [13] traffic noise was ranked second among the selected environmental stressors evaluated in terms of their public health impact.

The European Union (EU) enacted a directive, 2002/49/EC [10], on the management of environmental noise. This directive defines environmental noise as “unwanted or harmful outdoor sound created by human activities, including noise from road, rail, airports and from industrial sites”. It is a common experience that noise is unpleasant and affects the quality of life. It disturbs and interferes with activities of the individual, including concentration, communication, relaxation and sleep. Besides the psychosocial effects of community noise, there is concern about the impact of noise on public health, particularly regarding cardiovascular outcomes.

To determine the most up-to-date and accurate exposure/response relationship between community noise and myocardial infarction, a meta-analysis was carried out [16, 15, 21]. By 2005, a total of 61 epidemiological studies had been recognized as having either objectively or subjectively assessed the relationship between transportation noise and myocardial infarction [13]. 30000 cases of myocardial infarction are attributed to traffic noise in Germany. [13]. Figure 1 shows how myocardial infarction risk increases with an increasing noise equivalent level.

Sleep disturbance is one of the most common complaints raised by noise-exposed populations, and it can have a major impact on health and quality of life. Studies have shown that noise affects sleep in terms of immediate effects (e.g. arousal responses, sleep stage changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g. sleepiness, daytime performance, cognitive

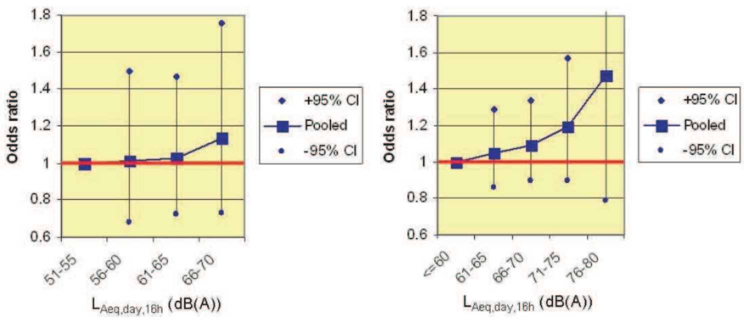

Figure 1: *Combined effect of road noise/myocardial infarction association [13].*

function deterioration) and long-term effects (e.g. self-reported chronic sleep disturbance).

Environmental noise may reduce the restorative power of sleep by means of repeatedly occurring activations (so- called sleep fragmentation). Acute and chronic sleep restriction or fragmentation has been shown to affect, among other things, waking psychomotor performance, memory consolidation, creativity, risk-taking behaviour, signal detection performance and risk of accidents.

WHO defines health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Therefore, a high level of annoyance caused by environmental noise should be considered as one of the environmental health burdens.

40% of Europeans are exposed to sound levels superior to 55 dB(A), about 20% of people are exposed to sound levels up to 65 dB(A) and 30% of the population try to sleep with sound levels above 55 dB(A). Finally, adding the growing appearance of ear illnesses, it has been estimated that 1 million of years of healthy life are lost every year to road traffic noise.

On the other hand, studies show environmental noise is one of the primary reasons people move from town to suburbs. Apart from generating more road traffic noise, the moving of so many people involves a risk for the city income, since in most countries fiscal fees are directly linked to the number of inhabitants [11].

Noise generates public expenditures. Those costs are related to health (medical treatments). Housing prices decrease with increasing environmental noise. It has been calculated that the social cost of European road noise oscillated between 30.000 and 46.000 millions of Euro per year(about 0.4% of the Europe GDP).

A Dutch study [26] calculated benefits from measures to fight noise in the Netherlands, applying the reduction of the housing market value in urban areas as consequence of the noise caused by traffic and rail network, reaches almost 10.800 million of Euro.

The Dutch government Innovation Program [1] against the noise calculated that per every decibel reduced at its source, 100 millions of Euro could be saved from terminal measures (acoustic barrier, building insulation).

In 2002 the European Parliament endorsed directive 2002/49 [10] on the evaluation and management of environmental noise. The main objective is to supply commune basis to deal with the noise problem in the European Union, with 4 principal bases:

- Supervise the environmental issue elaborating noise map,
- Inform and consult the public,
- Deal with questions about local noise,
- Develop a long term commune strategy.

The urban development and the increase of sound level are closely linked. Thus, ground use planning and urban development can contribute significantly to increase or reduce the inhabitant exposure to noise. Avoiding the noise generation is the more efficient way to reduce noise, and, in a first step, involves influence on the urban development.

The noise produced by road traffic results from the sum of different sound levels generated by rolling vehicles. Principally, it comes from motor car transmission systems, and the tire/road interaction, as well as from friction between vehicle and the air. The tire/road interaction dominates the other noise sources above 50 km/h [2]. Furthermore, with the development of electric motors, vehicles are more and more silent, thus it can be assumed tire/road noise dominates the other noise sources generated by vehicles rolling at lower speed.

Increases in speed of circulation and the fleet of country vehicles [12], as well as the deterioration of the wearing courses, increase the sound level generated. Hence the type of courses and the state of road conservation can be considered as determining the final acoustic behaviour of the pathways.

The European Green book [8] on future noise policy published in 1996 mentions that traffic road noise reduction will occur via the use of "low noise road surface". Tire design is an important factor which influences tire/road noise sound emission (tread pattern, the material, the width).

However, apart from the speed influence, other parameters associated with road surface can influence sound emission. The design and construction of the road can affect sound generation and propagation. Surface texture and acoustic absorption are the main factors that contribute to sound generation and propagation.

Nowadays, different "sound reducer" pavements exist and have laid for various years, since low noise pavement tends to be safer, more comfortable, cheaper, and more durable.

The most famous of these is the porous pavement. The first was extended in the United States in the 1930s. The purpose was to improve the important sealed layer of the traffic bearing road. At the beginning of the 1970s a lot of states extended this type of course to improve friction resistance. Porous pavement began to be called open courses (Open Graded Friction Courses). The open graded courses were designed with interconnected voids allowing for rainwater drainage. In Europe, draining asphalt was developed at the end of the 1950s for airport tracks, and in the seventies for public road. The first porous layer common public road was extended in the M40 in the United Kingdom in 1967. Originally, this course was developed to reduce the water level when raining. Then engineers realized that this type of surface offered acoustic benefits as well. Consequently, experiments with porous asphalt were carried out all over Europe, and many other parts of the world. The use of porous layer is very common on Dutch highways, and about 60% of the road network is, now, a porous layer.

Ultrathin layers have been used a lot as well, replacing surface treatments for road restoration. The thin layers used to be hot bituminous mixes extended in a 20 mm to 40 mm layer. They have been developed in Germany, France, Scandinavia, Netherlands and United Kingdom as an answer to the need for sustainable road, safe and durable under increasingly heavy traffic. It is difficult to say when and where these thin layers have been developed, but it is usually attributed to Germany in the 1970s having carried out the development and the extension of the first Stone Mastic Asphalt (SMA) mix. In the 1980s various prototypes emerged in France, with ultrathin layers. These courses present a few more air voids than the former materials developed in Germany, improve water drainage, and provide a significant tire/road noise reduction.

The SMA mixes, already mentioned, used to be related to dense pavement but also can be used as a thin layer. However, they present advantages that dense pavements do not, such as reduced sound level for their open texture. The SMA mixes are essentially bituminous material characterized by a high proportion of thick aggregate forming a stone-stone skeleton. This mineral skeleton is refilled with binder, filler, sand and fibres. The role of this skeleton is to bear the weight, and create high deformation resistance. The binder supplies pavement durability.

On the other hand, now “Green” road tends to be extended, because they are environmentally friendly due to having a reduced carbon print once produced and extended. One of the residues that most characterize developed modern society is wasted tires. Wasted tires are considered non-dangerous residues despite being flammable.

Although, used tires do not generate any immediate danger, their disposal in an inappropriate way or production in high quantities can contaminate seriously the environment. Designed to resist tough mechanic and climatic conditions, they are resistant to ozone, light and bacteria; thus they are almost indestructible. Further, storage in landfills does not allow for retrieval of energy or material. In 2000, the EU member states approved directive 2000/53/CE [9], establishing measures to prevent residues from vehicles and propose recycling and reuse as a way to increase the value of a vehicle and its components at the end of its useful life. A way to recycle is, once processed, to integrate crushed material used in the pavements, to be mixed with the binder of a bituminous mix (wet way) or to be part of the aggregate of a surface treatment (dry way).

Understand one of the major source of noise so that it can be reduced is a common utility and presents a high scientific interest. The sound emission generated by the tire/road contact is a new field of investigation, in which much is left to discover. The mechanisms involved in sound generation are not entirely defined. The role of the pavement surface texture in the noise is the subject of diverse speculation. Furthermore a sound reducing pavement happens to be a safer road.

The main objective of this thesis is to characterize on an acoustic level different road layers, in order to understand the mechanisms involved in road noise generation and thus participate in its reduction. The sound pressure level generated by tire/road interaction is principally caused by two mechanisms: at low frequency, texture influences mainly the sound generation, and at higher frequencies up to 1000 Hz, aerodynamics mechanisms such as acoustic absorption are more present.

From the above mentioned, this investigation aims to achieve some specific objectives:

- Select, acquire and tune up equipments for the characterization of the pavement surface from the road profile measured in a geo-referenced way.
- Develop a methodology to calculate parameter as the MPD (Mean Profile Depth) and a possible correlation with measurements realized with the sand patch method [3].
- Develop a methodology to calculate texture spectra from the pavement texture profile.
- Characterize different types of pavement, on an acoustic level, and textural level and try to correlate both.
- Measure and simulate acoustic absorption in bituminous mixes to determine intrinsic parameters of a porous material.
- Establish a system to label environmentally bituminous mixes from the acoustic point of view.

The first chapter presents the experimental techniques used to develop this research. Among other equipment, the trailer tiresonic has been used to measure exclusively tire/road noise. The texture measurements have been carried out with different laser equipments, and allow for characterization of the pavement macrotexture. Finally, the importance of acoustic absorption is shown, as a parameter which influences sound propagation on certain courses.

The second chapter shows the results and analysis of geo-auscultation realized on different pavements. For every studied pavement, the sound pressure level is presented, as well as the sound pressure spectra and texture data; thus the correlation can be studied. Surface treatments with crumb rubber, bituminous mixes extended in an ultrathin layer with a high viscosity binder, and SMA mixes have been evaluated.

The third chapter deals with acoustic absorption models to simulate acoustic absorption, and through a program developed in Matlab the intrinsic parameters for a porous material are determined.

Finally, the last chapter presents an idea of an asphalt mix labelling, which may enable the constructor and city hall to be able to fight together with knowledge against the noise.

6 CONCLUSIONS

At the beginning of this investigation the main purpose was to analyse the mechanisms involved in road noise generation and propagation, directly at contact level, and indirectly with acoustic absorption and surface texture. With this aim, measurement equipment and analysis methods, presented in the experimental techniques chapter, were developed. In a first part, the Close ProXimity geo-auscultation method has been introduced. Measurements have been realized with the trailer Tiresonic Mk4, a semianechoic chamber, with inside a reference tire. Two microphones measure sound pressure on/at the tire/road contact patch. This equipment allows measuring exclusively road noise, without wind contribution, reflections, or motor noise, as can happen with other measurement methods (SPB, basic CPX). In addition, experimental measurement analyses have been realized, using an instrumented vehicle, in the acoustic laboratory IFSTTAR (Nantes).

For both equipment, speed and temperature are key parameters, as well as the tire state of conservation. A 20000 km wheeled tire can generate 4 dB(A) more than a new tire when contacting with pavement. Sound level behaviour function of the speed has been analysed, for different types of pavements, showing higher speed results at higher sound emission levels. Sound level behaviour as a function of temperature has also been studied. On the contrary, an increasing temperature results in a decreasing emitted noise, losing around 0.06 dB(A) for Celsius grade and depending on the pavement type [19]. Road noise is a direct result of tire/road contact. One of the principal aims has been, besides the texture equipment acquisition and tune-up, the study of surface texture influence on sound emission.

Macrotexture depends on maximum aggregate size used in the bituminous mix.

Macrotexture has wavelengths from 0.05 mm to 50 mm. The sound spectrum reflects macrotexture influence. At low frequencies, higher surface macrotexture induces higher noise. More precisely, at low frequencies (< 1 kHz) the noise increases with macrotexture for wavelengths above 10 mm. Conversely, for frequencies above 1 kHz, noise decreases with an increasing macrotexture for wavelength below 10 mm.

The MPD (Mean Profile Depth) characterizes macrotexture. Surface profile measurements are used to determine macrotexture. Several texture lasers have been used to measure road surface profiles. Texture lasers have been chosen for qualities of portability, speed and precision, and possible post-data treatments. The Ames texture scanner is a portable equipment which scans the surface pavement along multiple lines inside a rectangular area of 7.5 x 10 cm, in situ or in the laboratory. The so-called LaserDynamic has been used, as well. Hooked on the rear part of a vehicle, this profilometer allows high speed (> 120 km/h) surface texture profile measurements. MPD is determined from the road texture profile. Surface texture data and noise measurement can be analysed in parallel. For texture spectrum, the LaserStatic has been used; this scanner is another configuration of the LaserDynamic. The laser is moved along a rail, and texture profile measurements are made every 0.1 mm, the optimal resolution to determine texture spectra. The IFSTTAR laser presents a similar running to the LaserStatic.

The developed methodology to determinate MPD index opens a wide results field. Depending on the filter used, grade and cut wavelength, MPD value can vary by 30%.

Acoustic absorption is another indirect parameter which can have a strong influence on road noise propagation. Acoustic absorption has been measured in the laboratory with an impedance tube on compacted testubes or samples extracted from the road, and depends on structural parameters such as thickness and intrinsic parameters such as porosity, tortuosity and air flow resistance.

This experimental techniques development allowed road noise and surface texture geo-auscultation from several pavements, ones with high technological values.

For every different pavement auscultation, tire/road noise has been measured with the trailer Tiresonic, surface texture has been evaluated and, when possible, the correlation between these two measurements has been determined. In a first part, results from bituminous slurry with crumb rubber geo-auscultation results have been presented. This kind of surface treatment presents high technological and ecological value. It is interesting to ask if noise can be reduce while keeping a safe course. Measurements in the Ciudad Real region of Spain have been taken on the road CM-4106 and in the Andalusia region on the road A-472.

After acoustic auscultations were carried out at three different times in the course of one year on the CM-4106, it can be concluded that:

- Differences measured at first auscultation, with or without crumb rubber bituminous slurries sound levels, reduced. Initially, a surface treatment with 7% crumb rubber emitted 1.5-2 dB(A) less than a conventional slurry. After 6 months, this gap slightly reduced to 1.3 dB(A). One year after the initial measurement campaign, this difference reduced to 1 dB(A).

- The first auscultation conclusion is reproduced, on an acoustic level, and on a textural level at low and middle frequencies, giving an idea of how impact mechanisms have been reduced by crumb rubber.

- One year after the road was extended, the high value and low frequency sound level (below 1 kHz, linked to vibration and impact mechanisms), maintained its reduction thanks to crumb rubber addition. However, this reduction is smaller than in previous measurement campaigns.

- Results after the third acoustic auscultation show crumb rubber introduction is a good measure to reduce sound emission from contact between bituminous slurries and tire. Environmental condition have been improved in two ways: wasted tire re-use and acoustic contamination improvement.

- A surface texture to noise correlation seems to exist, but this correlation is weak.

Experimental slurries have been studied on the road A-472 as well, in the project Fenix framework. From these measurements it can be concluded that:

- In this case, the surface texture worsened over time, leading to poor sound results for experimental bituminous slurries, especially for a slurry with 10% of crumb rubber in the aggregate.

- Experimental bituminous slurries have evolved poorly on an acoustic level. Sound level registered as increased, in spite of the higher surface temperature registered.

- Experimental data analysis reflects that the sound effectiveness of the experimental test tracks characterized was decreased by traffic and climatological conditions.

- Bituminous slurry with 10% crumb rubber and 2/4 mm aggregate size, emitted less sound during the first measurement campaign. However, the sound level during the second auscultation increased until it reached and exceeded the sound level registered for other experimental tracks even conventional track.

- Finally, no texture influence on noise generated has been observed, regardless of the type of extended slurry.

- Regarding the possible correlation between surface texture and noise generated, none has been found for experimental tracks. However, for conventional bituminous slurries, used as reference pavement, the correlation coefficient is slightly better.

Discontinuous micro agglomerates have been also studied. Two road sections with discontinuous pavement have been evaluated, in which crumb rubber has been mixed with the binder (wet way).

The first studied section has been extended on the road CM-3109 in the region of Ciudad Real. The impact of texture on sound emission has been observed. The experimental test track with higher macrotexture was noisier at middle and low frequencies.

The second study presents the results of the impact of high viscosity binder incorporation (wet way) into a bituminous mix on tire/road noise registered on the road CM-3102. In this case, the introduction of crumb rubber (wet way) reduced sound emission, at middle and low frequencies. Low texture level, and possible muffling on the experimental track with higher viscosity for high binder concentration, can explain this result. In this case, the sound level generated by the experimental track was 4 dB(A) below the conventional track. 6 months after the road was laid, this difference reduced to 2 dB(A). Crumb rubber incorporation into binder seems to led to a decrease in tire/road noise by muffling vibrations. However, long term results seem to deteriorate, since acoustic qualities are not preserved after one year. Surface texture evolution in time has not been studied, since the surface was very smooth and influenced road noise only weakly. Discontinuous pavement without crumb rubber but extended in ultrathin layer has been studied, as well. This pavement presents a high air voids content in order to reduce tire/road contact noise. However, against expectation, an ultrathin layer with 25% of air voids content generated a higher noise level than a conventional pavement (BBTM 11A). In this case, higher noise levels are linked to frequencies from 200 to 1600 Hz. This frequency range is related in part to vibration mechanisms. Regarding MPD index values for experimental and conventional test tracks, it seems that ultrathin layer noise generation is due to surface texture and vibration mechanisms, and to a maximum aggregate size reduction. Thus, surface texture exerts a greater influence than air voids content on sound level, in this case. In theory, the same experimental mix with smaller aggregate size should emit less sound pressure at low frequencies. Discontinuous micro agglomerate with a high air voids content resulted in a less effective method than conventional pavement, in terms of reducing tire/road noise.

Regarding the possible correlation between surface texture and contact noise, the first studied section has given good results.

Finally, SMA mixes have been studied. This type of pavement has been extended for decades in Europe and has been recently introduced in Spain in the framework of an R&D project. Test tracks present a different size of aggregate. The SMA study on the road CV-43 in Valencia shows the importance of aggregate size and track slope. Conclusions are:

- The mix with higher aggregate size, the SMA16, emits slightly more noise than the SMA11.

- A decreasing slope increases the impact of mechanism generation at low frequency.

- Finally, a first correlation between SMA surface texture and sound emission spectra has been realized. The influence of aggregate size has been observed for frequencies above 630 Hz.

Surface texture/ road noise correlation is not speculation. However, it is important to note that measurements have not been realized strictly in parallel, since it is extremely complicated to reproduce the same tracing in successive pathways (lineways) corresponding to acoustic auscultation and texture auscultation. Low correlation levels could be due to this lack of colinearity.

Regarding surface texture auscultation techniques learned during a 3 months' stay in France, several things can be said. First, a Matlab code has been written to determine texture spectra. This code has been used for the post-treatment data of surface texture measurements realized in IFFSSTAR laboratory and for data measured by the LA^2IC.

Texture road noise correlation results show that between 50 and 110 km/h the surface macrotexture has more influence on road noise below 1 kHz and for wavelengths above 10 mm. The best correlation is obtained for 50 km/h and 90 km/h as the reference speed. Importantly, test tracks were separated from the statistic study, in order to prevent overestimating results.

A wavelength threshold value exists (= 10 mm), at which pavement acoustic behaviour changes. For wavelengths above 10 mm and for frequencies below 1 kHz, tire/road noise increases with texture level. For wavelengths below 10 mm and for frequencies above 1 kHz, tire/road noise decreases with increasing texture level. This agrees with results observed in available literature [31],[20]. It seems that wavelength, which influences road noise at low frequencies, tends to decrease with increasing speed.

After the CPX noise study of surface texture and evaluation of the possible correlation, acoustic absorption was the logical continuation in order to fully characterize bituminous mixes. Two theoretical models have been revised which allow simulating porous or semidense material acoustic absorption. With the Berengier phenomenological model, sample absorption could be simulated. Using the least squares method, a fitting on experimental curves in order to determine intrinsic parameters has been carried out. Porosity, tortuosity and air flow resistance of 95% of the treated ultrathin samples and 82% of the porous test tubes have been determined. This study is important, since it can be used as a control method for the extended courses and comes from a simple acoustic laboratory measurement.

Finally, as a proposal, the last chapter presents an acoustic labelling idea for asphalt mixes depending on energetic consumption similar to that which exists for everyday elements such as electrical appliances. This proposal, unique in Spain, is based on measurements carried out on proximity road noise, surface texture and acoustic absorption.

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Projects

Private funding

- Evaluación acústica de nuevas mezclas bituminosas SMA mas sostenibles y medioambientalmente amigables. (03 MAR 2010)(OBSV).
  ARTICULO 83 - CONTRATO DE I+D
  Empresa financiadora: ELSAN S. A.
  enero 2011 - Diciembre 2012
  Investigador responsable: EXPÓSITO PAJE, SANTIAGO

- Investigación en nuevos conceptos de carreteras más seguras y sostenibles. Proyecto Fenix
  ARTICULO 83 - CONTRATO DE I+D
  Empresa a: A.I.E. FENIX – Ministerio de Industria – CDTI
  29 Mayo 2007 - 01 Nov 2011
  Investigador responsable: EXPÓSITO PAJE, SANTIAGO

Public funding

- Clasificación acústica de pavimentos para capas de rodadura con cámara semianecoica
  Entidad financiadora: CONSEJERIA DE EDUCACION Y CIENCIA
  01 Abril 2009 - 31 Marzo 2012
  Investigador responsable: Santiago E. Paje
  Número de investigadores participantes: 5

- Influencia de la capa de rodadura en la generacion y propagacion del ruido. COrrelación ruido de rodadura/textura de pavimento. DPI2008-06212
  Entidad financiadora: Ministerio de Educación y Ciencia
  01 enero 09 - 21 Septiembre 11
  Investigador responsable: Santiago E. Paje

Publications

- S.E.Paje, M. Bueno, F. Terán, U. Viñuela, J. Luong. *Assessment of asphalt concrete acoustic performance in urban streets.* Journal of Acoustic Society of America, 123(3)1439-1445, 2008

- M. Bueno, J. Luong, U. Viñuela, F. Terán, S.E. Paje. *Pavement temperature influence on close proximity tire/road noise.* Applied Acoustics, 72(11)829-835, 2011

- M. Bueno, J. Luong , F. Terán, U. Viñuela and S.E. Paje. *Macrotexture influence on vibrational mechanisms of the tyre/road noise of an asphalt rubber pavement*. Applied Acoustics (under revision)

- J. Luong, M. Bueno, F. Terán, U. Viñuela, and S.E. Paje. *Acoustical study of a asphalt pavement with crumb rubber modified binder*. Construction and Building Materials (send).

- J. Luong, M. Bueno, V. Vásquez, F. Terán, U. Viñuela, S. E. Paje. *Effect of pavement temperature on the macrotexture of a semidense asphalt surface*. Road Material and Pavement Design (send)

Congresses

Oral

- S.E.Paje, J. Luong, M. Bueno; F. Terán; U. Viñuela. *Influencia de la macrotextura de una capa de rodadura delgada en la emisión sonora*, Congreso Ibero-Latino Americano del Asfalto, Lisboa, Portugal,Octubre 2009

- J. Luong, M. Bueno, U. Viñuela, F. Terán, S. E. Paje. *Relationship between road surface macrotexture characteristics and CPX noise of a bituminous gap-graded mixture*. Forum Acusticum 2011, Aalborg, Denmark, Junio 2011

- J. Luong, M. Bueno, F. Terán, U. Viñuela, S. E. Paje. *Impact of the Use of Crumb Rubber ModifiedvBinder on Tire/Road Noise Generation* . Forum Acusticum 2011, Aalborg, Denmark, Junio 2011

Poster

- M. Bueno, S.E. Paje, U. Viñuela; F. Terán, J. Luong. *A First step toward a close proximity noise map*. Acoustic08, Paris, France, Julio 2008

- J. Luong; M. Bueno; F. Terán; U. Viñuela; S.E.Paje. *A Study of the correlation between macrotexture and the tyre/pavement close proximity noise* . Internoise 2010, Lisboa, Portugal, Junio 2010

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- J. Luong, V.F. Vazquez, M. Bueno, F. Terán, S. E. Paje. *Influence of texture spectra on CPX noise of SMA Pavements* . Acoustics2012, Nantes, Francia, April 2012