SOUND FEATURE MODELING OF NOISE SUPPRESSION ROAD MATERIALS

Tomislav Keser[1], Ivana Barišić[2], Marija Kovačević[1], Dario Pović[1]
[1]Faculty of Electrical Engineering Osijek, Cara Hadrijana 10b, 31000 Osijek, Croatia
[2]Faculty of Civil Engineering Osijek, Crkvena 21, 31000 Osijek, Croatia

Abstract

Today in urban and rural environments a main and common source of noise and other sound related pollutant is a traffic of various kinds of vehicles. Wheels, squealing tires, rotating engines and any other moving part of vehicle produces air dynamic movement of specific amount of energy that causes a sound pressure on every obstacle in surroundings. That pressure manifests as force on our ear drum and causing unpleasant response of central nervous system causing many side effects, short or chronicle one. In function to reduce a noise level of traffic noise pollutant as one way and solution is to build a noise absorbent or shielding systems. Such systems uses various kind of buildings materials that refers as decent noise manipulators, absorbent or reflectors. In this paper is presented a method for modeling such materials by its sound characteristics. Modeling relies on sound spectral analysis of absorbance and reflectance material features.

1. INTRODUCTION

Traffic and traffic noise are tightly related to today way of life. Not only in aspect of transportation commodity, in human health aspect also. Noise and noise environment can cause various kind of diseases related to living in such “unpleasant” environment. That is massively researched and many studies are written where are proven connection between traffic noises and diseases like cardiovascular, neuro-vegetative and many others, [1, 2]. What is noise? Most easily way to explain is; noise is a psychosomatic manifest of external sound wave pressure that causes unpleasant response of our central neural system. How to avoid, reduce or remove it such kind of sound source? So, there are many ways how to do that, with more or less success. Mainly, if you remove source of noise you are removed the problem. But traffic is essence of today’s way of life so other soundproofing techniques must be used. Soundproofing is a keyword. That means: reduce sound pressure by using materials that absorb or reflect that pressure wave. In traffic, noise can be absorbed by construction materials of road or surrounding objects. Not only absorbed, sound can be reflected or even channeling and redirected from protected areas. For successful soundproofing a right material with right composition must be used for road and other object builds. How to determine and how to design building materials? That is focus of many research projects today. As well, in this paper is presented method for quantitative and qualitative material sound properties measurement and modelling in function to develop new material composition that meets soundproofing demands in today’s road constructions.

2. TRAFFIC NOISE

The traffic noise is a summary result of following noise components; aerodynamic, vehicle propulsion system, tire-to-road contact noise, [3]. Predominant noise sources varies with vehicle speed. The dominant component of traffic noise at low speeds is the sound produced by the propulsion engine. The tire/road noise dominates at speeds exceeding 50 km/h, [3, 4]. Also, noise produced by moving vehicle largely depends on the geometrical properties of the road surface. That is main reason why today researches have been based on finding new methods of reducing noise at its place of origin, road surface, through the observation of the behaviour of different pavement types and composition. Studies have shown that modification of pavement surface type and/or texture can result in significant tire/pavement noise reductions and that the proper selection of the pavement surface can be an appropriate noise abatement procedure, [5].

2.1. Noise and pavement materials

Characteristics of pavement surface, texture, porosity and rigidity seems to have the greatest influence on the noise levels. The surface texture of the pavement has an impact on the noise caused by the tire/road interaction and reducing the unevenness height and spacing contribute to the abatement of tire vibration noise, [6]. Porosity reduces the effects of air pumping so with higher effective porosity and smaller size of the voids, the lower noise can be achieved, [7]. The pavement stiffness is several times higher than stiffness of a pneumatic tire. So reducing the pavement stiffness, reduction of force generated upon rolling tire impact with roadway during the vehicles movement could be achieved which would reduce the vibration and thus noise. Recent studies have shown that in a case of an asphalt concrete mixture, the viscoelastic property has been one of the main factors influencing tyre/pavement noise, [8].

2.2. Measurement techniques

To assess the influence of pavement surface properties on noise reduction a reliable and standardized noise measuring methods are needed. Today, there are several methods for assessing the issue related to road noise and its influence on environment. Generally, all methods can be divided in two groups; ***in situ*** methods for outdoor tyre/road noise measurements and ***laboratory*** methods for determination of noise-relevant pavement surface characteristics.

In situ methods are used for measuring the noise level at the place of origin (tire-road contact point) or measuring noise at the roadside. These, generally preferred methods, are simple and robust, and evaluates the noise performance of a road surfaces and classifies them with great success. Most commonly used methods are *Statistical Pass By* method (SPB, ISO 11819-1) and *Controlled Pass By* method (CPB) for roadside noise measuring, *Close Proximity* method (CPX, ISO/CD 11819-2) and *On Board Sound Intensity* method (OBSI, AASHTO TP76) for measuring tire-pavement noise at the source. The basic advantages of these methods are summarized analysis results of various types of traffic noise sources. That gives "full noise picture" of analyzed case. Long duration measurement, high cost and data-location specific related results are the main drawbacks of these methods.

In laboratory tire/road noise measurement can be done by using test rolling drums (simulates paved road) with diameter as large as possible (often between 1 to 15 m) to make the test pavement surface as flat and realistic as possible, [9]. Problem with this kind of measurement technique is in the influence of the test drum curvature related to distortion of the tyre deflection which can influences on noise picture to some extent. However, years of experience showed that comparison between surfaces is not essentially different than if the drum had an infinite radius, [10]. The other laboratory tire/road noise measurement method relies on pavement material sound properties measurement and qualitative evaluation. Absorbance and impedance, respectively. The acoustic absorbance is a measure of the sound absorption by testing material and is measured in an impedance tube according to ISO 10534-2, [11].

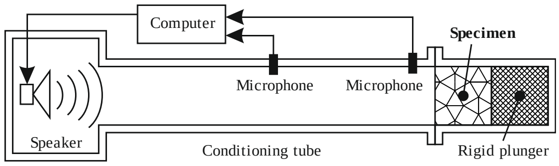

Figure 1. Impedance tube used for measurement of acoustic absorption coefficient, [10].

The acoustic absorption performance of specimens may be affected by the existence of specimen sealant, [10]. The other problem is tube length which must be sufficiently long to present a stable plane-wave sound field to the sample under test.

2.3. Material composition

Materials used for road paving are divided into asphalt and concrete based materials. Asphalt pavements consist of asphalt wearing course and base courses of unbound, mechanically compacted granular material or granular material bound with hydraulic or bitumen binder. As asphalt based pavement a **porous asphalt** shows as the most efficient road surface technology in terms of noise reduction, [7]. The main characteristic of this material is high porosity with void content between 12-30%, [12]. Concrete pavements are composed of concrete slabs as a wearing course placed on the base of stabilized and/or unbound mechanically compacted granular materials. Due to its high rigidity they are often called rigid pavement structures while structures with asphalt wearing course are called flexible pavement structures.

2.4. Material modeling

Material porosity is shown as key factor for noise absorption. Porosity is created by mixing aggregates of different sizes to form structural skeleton of material with a lot of empty space between aggregate granules. By investigating more than 200 hot-mix asphalt surfaces using CPX method, it was discovered that void content and thickness affects to the noise component of the higher frequencies (>1200 Hz), while the particle size distribution has a greater impact on the lower frequency range (<800Hz). Finer grain size and a higher void content have a positive effect on the reduction of traffic noise, [5].

3. SOUND FEATURE MODELING

As aggregate particle size and void content of paving mixture affects on noise absorption differently, a more precise measurement method for material noise absorption figure forming is needed. In situ method can't offer satisfactory sound analysis especially by separate sound spectral components. Laboratory methods are often focused on overall sound suppression results but without deepen analysis of sound feature of analyzed material. This paper presents a method that creates full, hearable, sound spectral image of analyzed material and gives spectral model of tested material.

3.1. Sound spectral analysis

For targeted noise suppression material development in road paving noise suppression techniques a full, hearable, sound spectrum analysis is needed. Full spectrum image should show a material sound properties and makes their development cycles significantly shortened. Theory behind full spectral sound analysis relies on measuring a sound level pressure absorbance ratio of tested material for several sound spectral testing reference components (sinusoidal sound waves). The signal suppression rate if often called *system transfer function*, (1).

$$G(s) = X(s)/Y(s), \tag{1}$$

where, X(s) is excitation function and Y(s) is relevant system output. So, G(s) represents a spectral model of analyzed system regarded. The *s* represents spectral analysis domain and it can be considered as $j\omega$, where ω is frequency of excitation function and *j* shows it complex nature.

By applying a *chirp* excitation signal of amplitude *A*, (2), on test system, fig 2, absorbance image of tested material can be determined.

$$x(\omega) = A \cdot sin(\omega t) \tag{2}$$

That kind of analysis in theory of signal and system analysis is called system spectral response. A setup for conducting tests for system spectral response measurement is shown in fig 2.

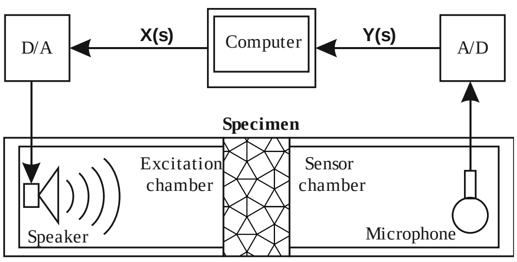

Figure 2. Test setup for sound spectral analysis.

System consists of excitation chamber where sinusoidal waves of different frequencies are generated, measurement chamber where noise measurement sensor is placed and specimen holder where specimen is placed. This setup configuration is used to measure level of transported noise pressure through material, transmittance respectively.

3.2. Sound features

The ratio between excitation and measured signal directly gives *G(s)* function of specimen, called suppression model. According test setup configuration that refers only one measurement sensor, just one aspect of measurement can be considered at the time. Several sound properties of such analysis can be defined but with this configuration only sound conductivity can be considered as truly measured. Other property that can be defined is absorbance ratio. **Sound conductivity**, *C(s)*, is a rational measure of reference signal $Y_{ref}(s)$ and measured $Y_m(s)$. $Y_{ref}(s)$ is referent output function of testing setup where *G(s)=1*, without test specimen respectively. **Absorbance ratio**, A(s), is measure of difference between $Y_{ref}(s)$ and *C(s)* for given specimen, (3).

$$C(s) = \frac{Y_m(s) \cdot 100}{Y_{ref}(s)},\ A(s) = 1 - C(s) \tag{3}$$

As tested material is better sound conductor that refers to its poorer absorbance ability and vice versa.

4. MEASUREMENT AND RESULTS

To validate theoretical claims and confirm right way of research a laboratory tests are conducted. Measurements are conducted on concrete based paving materials with known sound properties and overall characteristics. These materials carries marks CP_1 and CP_2, where CP_1 is standard concrete mix for road paving that uses only dolomite aggregate and binding solution. The CP_2 mix is more advanced and is based on mixture of dolomite aggregate, as CP_1, and addition of very porous aggregate of steel production leftover, called ***slag***. By previous laboratory tests the CP_2 is proven as better sound absorber than CP_1. Test setup consists from; PC based computer as sound generator and data logger, excitation chamber with integrated speaker, measurement chamber and specimens. As measurement sensor is used professional noise measurement device and manual reading of results.

Due manual nature of data/results readout there is no practical way to correctly readout noise measurement of tested specimen excited with chirp signal. So, as replacement for chirp signal a spectral vector of several characteristic frequencies of excited signal *x(ω), ω∈[0.5,…,16 kHz]* is used.

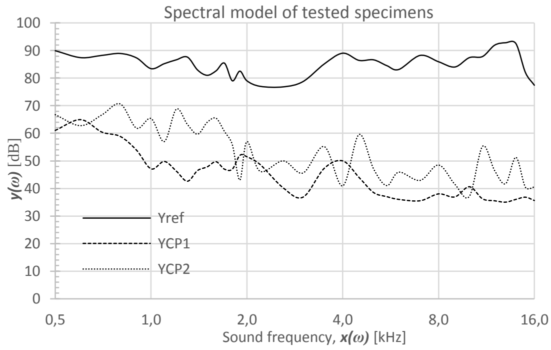

Figure 3. Spectral response of tested specimens.

By applying excitation signal *x(ω)* on specimens the spectral response is registered for both specimens as is shown on fig 3. From shown responses it could be seen that specimen CP_2 is better sound conductor than CP_1. In practice that means that CP_2 will absorb and channels more of traffic noise from road surface toward road construction bed. Other properties also could be seen in manner of spectral conductance selectivity. From CP_1 and CP_2 responses also could be seen that CP_2 material varies its conductance property according test frequency. On some frequencies it is better conductor than CP_1 and on other is poorer one. That is result of aggregate granularity and thickness of tested specimen.

5. CONCLUSION

As traffic noise is unavoidable in today way of life. The only way to reduce it is soundproofing roads and traffic surroundings. For that purpose a suitable paving materials are needed. Until today there are various kind of methods developed for on-field and laboratory measurements. All of these methods relies on traffic-like sound properties measurement without separate spectral components analysis. Here proposed method introduces spectral component analysis of paving material sound properties and method for modeling it. Model of tested material is represented as spectral response curve what identifies analyzed material according its spectral absorption/conductance properties. It is shown that tested materials not only behaves as noise suppressor, like noise conductor on some frequencies respectively. Such models can helps to develop suitable and specialized paving material that will suppress or conduct traffic noise of specific frequency ranges to specific absorbent/reflecting materials of modern roads.

6. LITERATURE

[1] Welch, D; Shepherd, D; Dirks, KN; McBride, D; Marsh, S., *Road traffic noise and health-related quality of life: A cross-sectional study*, Noise Health 2013;15:224-30.

[2] Sørensen, M; Andersen, ZJ; Nordsborg, RB; Becker, T; Tjønneland, A; Overvad, K; Raaschou-Nielsen, O., *2013. Long- Term Exposure to Road Traffic Noise and Incident Diabetes: A Cohort Study*, Environ Health Perspect 121:217–222.

[3] Sangiorgi, C.; Bitelli, G.; Lantieri, C.; Irali, F.; Girardi, F., *A study on texture and acoustic properties of cold laid microsurfacings*, Procedia - Social and Behavioral Sciences, 53 (2012): 223 – 234.

[4] Žmavc, J., *Hrup na cestah*, 7. Slovenski kongres o cestah in prometu. 2004., Portorož, Slovenija. Ed. Vilhar, M., Družba za raziskave v cestni prometni stroki Slovenije

[5] Hanson, D.I.; James, R.S., *Colorado DOT tire/pavement noise study*, 2004., Colorado Department of Transportation, Report No. CDOT-DTD-R-2004-5

[6] Fujikawa, T., Koike, H.; Oshino, Y.; Tachibana, H., *Definition of road roughness parameters for tire vibration noise control*, Applied Acoustics, 66 (2005): 501–512.

[7] Praticòa, F. G.; Anfosso-Lédée, F., *Trends And Issues In Mitigating Traffic Noise Through Quiet Pavements*, Procedia - Social and Behavioral Sciences. 53 (2012): 203 – 212.

[8] Prapoorna Biligiri, K., *Effect of pavement materials' damping properties on tyre/road noise characteristics*, Construction and Building Materials, 49 (2013): 223–232.

[9] Bernhard, R., Wayson, R.L.: *An introduction to tire/pavement noise of asphalt pavement*. http://www.asphaltroads.org (13.8.2014.)

[10] Sandberg, U.; Świeczko Żurek, B.; Ejsmont, J.A.; Ronowski, G., *Tyre/road noise reduction of poroelastic road surface tested in a laboratory*, Proceedings of Acoustics 2013 – Victor Harbor. Victor Harbor, Australia. Australian Acoustical Society

[11] Kim, H.K.; Lee, H.K., *Influence of cement flow and aggregate type on the mechanical and acoustic characteristics of porous concrete*, Applied Acoustics. 71 (2010): 607–615.

[12] Seybert, A. F., *Notes on Absorption and Impedance Measurements*, http://www.engr.uky.edu/ (13.8.2014)

[13] *Guidance manual for the implementation of low-noise road surfaces*, SILVIA Sustainable road surfaces for traffic noise control, European National Highway Research Laboratories. Report 2006/02.

[14] Paje, S.E., Bueno, M., Terán, F., Miró, R., Pérez-Jiménez, F., Martínez, A.H., *Acoustic field evaluation of asphalt mixtures with crumb rubber*, Applied Acoustics, 71 (2010): 578-582.