Construction and Building Materials 49 (2013) 223–232

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of pavement materials' damping properties on tyre/road noise characteristics

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HIGHLIGHTS

- The effect of vibroacoustical damping properties of asphalt surfaces on tyre/road noise characteristics were quantified.
- A total of 168 asphalt mixtures covering 5040 data points were used in the study.
- The damping capacities of different asphalt mixtures with respect to classic acoustical control regions were established.
- Excellent correlations were found between the various tyre/pavement damping acoustical parameters of the asphalt mixtures.

ARTICLE INFO

Article history:
Received 27 March 2013
Received in revised form 7 August 2013
Accepted 9 August 2013
Available online 11 September 2013

Keywords:
Pavements
Pavement noise
Vibroacoustics
Damping
Phase angle
Damping ratio
Asphalt
Asphalt-rubber

ABSTRACT

The objective of this study was to investigate and quantify the effect of fundamental pavement vibroacoustical damping properties of two different asphalt surfaces on tyre/road noise characteristics. A total of 159 conventional dense graded asphalt (CONV) and 9 asphalt rubber friction course (ARFC) mixtures, resulting in over 5000 data points were utilized to estimate the various physical damping parameters. Previously, viscoelastic phase angle properties were obtained for these complex modulus materials and relationship between phase angle and highway noise was established. Damping ratios, dynamic magnification factors, and transmissibility at resonance were estimated for these mixes. The calculations indicated that ARFC mixes provided higher noise-damping response than the CONV mixes due to the extra binder, higher porosity, rubber inclusions, which respectively rendered extra viscodamping effect, higher noise-absorption potential, and higher vibroacoustical damping capacity. Overall, this study is envisioned to aid in the discernment of the variants of asphalt pavement materials' noise damping capabilities in a fundamental form based on the relationships between vibroacoustical and mixture materials' properties.

1. Introduction

Rapid urbanization has myriad outcomes such as societal development, building of new and heavy structures such as highways, generation of new jobs, improvement in quality of life standards, and so forth; but, at the same time, it creates a host of effects on the environment such as energy and water demands, need for sustainable materials, and generation of noise. One of such a sustainable aspect: highway noise and in particular, tyre/pavement noise has become a growing problem in urban areas, especially, in the neighborhoods of highways and arterial roads. More so, a significant increase in traffic volume has continually been adding more noise pollution. As per the World Bank, even when it is not perceived consciously, chronic exposure to road noise can affect human welfare in varying degrees, both physiologically and psychologically [1].

The wider use of "quieter" pavements across the globe has been an important quality of life interest in reducing the overall noise exposure due to high cost of other mitigation strategies such as noise barriers [2]. Several studies have indicated that tyre/pavement interaction noise contributes significantly to the overall roadway noise, i.e., at vehicle speeds greater than 40 km/h (25 mph) as indicated by [3,4]. Researchers across the world have listed a multitude of factors influencing tyre/road noise such as pavement material type and properties, porosity, texture, pavement age, thickness, tyre rolling resistance and vibration, and pavement friction [5–8].

In case of an asphalt concrete mixture, the viscoelastic property has been found to be one of the main factors influencing tyre/pavement noise [9–11]. The study also concluded that Asphalt Rubber Friction Course (ARFC) mixes reduce tyre/pavement noise (comparing to the conventional dense graded asphalt mixtures) because they act as an acoustic absorber due to the increased viscoelastic nature of the asphalt mix. The increased viscoelastic characteristics of an ARFC come from much higher asphalt binder content (9–10%

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0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.08.016

by weight of the total mix) and, possibly, the inclusions of crumb rubber (20% by weight of the asphalt binder).

Field evaluation of the effects of material properties such as texture, porosity and durability on the measured noise levels in California, USA indicated a relationship of pavement surface texture with frequency related acoustic impact and shock mechanisms; the same studies also indicated that the rubberized asphalt concrete surfaces had lower tyre/pavement noise levels than conventional asphalt mixes by about 2–3 dB [12,13].

The aforementioned studies have been directed towards characterizing road noise by means of evaluating and establishing the relationships of the influence of pavement materials' properties on noise levels either by performing laboratory experiments or field measurements. However, understanding the fundamental vibroacoustical elements of pavement materials' noise-damping parameter(s) that attenuate/generate noise from a purely science perspective needs quite an amount of research and development.

One parameter that is extensively used in the design process of heavy machines and large structural members to study the effect of damping is the "damping ratio". Research studies have made use of the damping ratio parameter in embankments and bridges to distinguish between two different materials' vibration attenuation capacity [14,15]. Furthermore, damping ratios of the asphalt mixtures (including asphalt overlays for rehabilitation) were estimated in various other studies to understand damping and vibratory mechanisms along with the estimation of moduli (or stiffness) of those mixtures [16–18]. Damping ratio has also been well-utilized in railway track beds and foundation designs. Zeng et al. and Zeng conducted resonant column tests to measure stiffness and damping ratio of rubber-modified asphalt with different rubber contents, and concluded that rubber-modified mixtures can potentially be used as a foundation material for high-speed railway track-beds owing to their higher damping capacities than a conventional mix and soil subgrade [19–21]. Zhaoyu et al. also reported that an increase in rubber content from 30% to 80% increased damping by about 20% in waste granular rubber and cement soil mixtures [22]. Researchers also have utilized the concept of damping ratios as a means to calculate asphalt mixtures' temperature and frequency related material properties [23,24].

It is noteworthy that although many studies have made use of "damping ratio", a fundamental vibroacoustical parameter to determine damping capacities of different structural members, no similar work has been undertaken in tyre/road noise areas. A careful understanding and determination of the basic fundamental principles of physical acoustics such as damping ratio and its associated parameters would lead to an analogy where the acoustic wave traversing through the roadway material and hence generating noise in a pavement system is akin to a vibratory system such as heavy structures, bridges, dams, railway track beds, and foundations. This noise generating pavement system is potentially capable of storing (mass-storage capacity) and dissipating (damping or magnifying capacity) acoustical energy. Both physical and mechanical science aspects behind noise generation and attenuation in the different pavement systems are not fully understood. Therefore, this paper provides thrust to understanding the science of noise generation at source that is aimed at investigating the effect of pavement system's damping capacity on tyre/road noise characteristics. The approach taken in this study is first of its kind within the framework of tyre/road noise research and development.

The major objective of this study was to investigate and quantify the effect of fundamental pavement vibroacoustical damping properties of two different asphalt surfaces on tyre/road noise characteristics. This study is envisioned to aid in the discernment of the variants of asphalt pavement materials' noise damping (reduction) capabilities in a fundamental form based on the relationships between vibroacoustical and mixture materials' properties. The research scope of work included four distinct parts:

- Conduct literature search regarding the various basic theories about acoustics, damping, and vibrations, and develop theoretical understanding of the salient parameters involved in estimating or quantifying the damping capacity of the different materials (Section 2).
- Collect the historical asphalt pavement material characterization database (commonly known as Arizona State University (ASU) ϕ–E^* database), which includes a wide range of asphalt mixtures representing conventional and asphalt-rubber (Section 3).
- Calculate and quantify the fundamental acoustical damping parameters of all the mixtures in the ϕ–E^* database, and develop relationships for the different acoustical damping parameters estimated for various temperatures and frequencies (Section 4.1).
- Develop a final relationship of the damping capacity parameters of the asphalt mixtures with already established field highway noise measurement (Section 4.2).

2. Theoretical background

This section documents the general basic vibroacoustical theories and analogy, and the test methodology used in this study to characterize asphalt mixtures' fundamental damping properties and their influence on road noise characteristics.

2.1. General basic acoustics for engineers

In a single degree of freedom vibration system, three different quantities, namely, mass (m), viscous damping coefficient (c) and stiffness (k) characterize vibration (displacement or transmission, x) of an acoustic component [25,26]. This analogy can be as well applied to the transmission of an acoustic wave through the pavement material and the noise damping response can be characterized by mass and stiffness of the material along with its inherent viscous damping characteristics. Fig. 1 presents the schematic of a fundamental theoretical vibration model which may look different in practice. The quantities can be modelled in terms of a homogeneous differential equation whose solution is given by:

$$x(t) = e^{-\zeta\omega_1 t} X \sin(\omega_d t + \phi) \quad (1)$$

where ζ is the damping ratio, X is the amplitude constant for motion, ω_d the damped natural frequency and ϕ is the phase angle or lag.

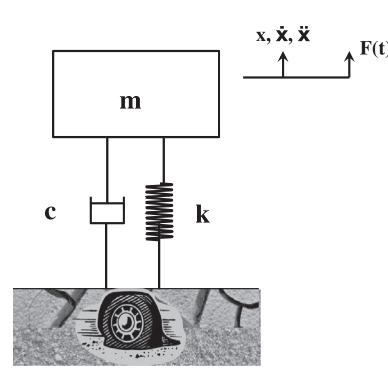

Fig. 1. Schematic of the fundamental theoretical vibration model.