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Pavement stiffness measurements in relation to mechanical impedance

Mingliang Li [a,b], Wim van Keulen [c], Halil Ceylan [d], Dongwei Cao [a,*], Martin van de Ven [b], André Molenaar [b]

[a] Research Institute of Highway Ministry of Transport, No. 8 Road Xitucheng, Haidian District, Beijing 100088, PR China
[b] Section of Road and Railway Engineering, Faculty of Civil Engineering & Geosciences, Delft University of Technology, PO Box 5048, 2600 GA Delft, The Netherlands
[c] VANKEULEN advies bv, Multatulistraat 5, 5251 WV Vlijmen, The Netherlands
[d] Department of Civil, Construction and Environmental Engineering, Iowa State University, Ames, IA 50011-3232, USA

HIGHLIGHTS

- Relationship between mechanical impedance and stiffness of road surface is investigated.
- Mechanical impedance and stiffness of different types of pavements are measured.
- Mechanical impedance is measured by an impedance hammer method both in laboratory and on field.
- Statistical relationship between impedance and stiffness of road surface is developed.
- Suggestions are given for noise reducing pavement development by considering mechanical impedance.

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ABSTRACT

The mechanical impedance is a measure of the ability of a structure to resist motion when subjected to a given force. It has been considered related with tyre–road noise level of road surface. However, this parameter is seldom used to characterize mixtures in asphalt mixture design. In this study, the relationship between the mechanical impedance and the pavement stiffness is investigated based on laboratory and in-situ measurements. Mechanical impedance is tested by an impedance hammer device, while the stiffness is measured by the indirect tension test (ITT) method. Different types of road surfaces are taken into account, including thin layer noise reducing surfacing, dense surface and poro-elastic road surface. The influences of mixture compositions on mechanical impedance and stiffness are discussed. Statistical relationship between the stiffness and the mechanical impedance is developed based on the measurement results. Advices for noise reducing road surface design by considering mechanical impedance are given according to the research findings.

1. Introduction

Mechanical impedance is defined as the ratio of the force acting on a structure to the resulting displacement velocity of the system [1]:

$$Z = \frac{F}{v} \quad (1)$$

where F is the complex force vector and v the complex velocity vector. Mechanical impedance measures the ability of the structure to resist motion caused by the force.

In road engineering, mechanical impedance has received increasing attention as a parameter which influences the tyre–road noise in the medium frequency (630–1600 Hz) [2,3]. In an experiment undertaken by Dutch researchers, coast-by noise measurements were carried out on a concrete surface and on an elastic layer with similar surface texture glued on the same type of concrete surface. A substantial noise reduction from 3 dB to 5 dB was found in the 800–1600 Hz frequency range by adding the elastic layer [4]. Mechanical impedance is also considered as input for predicting tyre–road noise in hybrid models, such as Acoustic Optimization Tool (AOT) [5,6].

In previous research, the influence of the mechanical impedance on tyre–road noise has been investigated [7]. However, in pavement engineering and asphalt mixture design, the mechanical impedance is never used to characterize mixtures. The commonly used parameter for denoting the mechanical properties is stiffness (S) which is defined as the ratio of applied force (F) to resulting displacement (D) and given in Eq. (2):

$$S = \frac{F}{D} \quad (2)$$

* Corresponding author.
E-mail address: caodongwei@vip.126.com (D. Cao).

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It is of importance to relate the mechanical impedance with the stiffness. In this way, the mechanical impedance can possibly be related to stiffness tests which are regularly done in mixture design and evaluation. Such a relationship would be very useful and helpful for pavement engineers, as they can deduce the mechanical impedance from the given stiffness without carrying out special test work.

In this research, laboratory measurements and in-situ measurements were performed for investigating the mechanical impedance and stiffness on different types of road surface. The relationship between the stiffness and the mechanical impedance was the discussed. In the end, it came up with an advice on how to achieve the tyre–road noise reduction based on mechanical impedance in pavement design.

2. Materials and measurement methods

2.1. Materials

2.1.1. Thin layer surfacing

In this study, most of the work was taken on thin layer road surfacing. Thickness of this type of road surface is generally between 20 mm and 30 mm. It is a typical noise reducing pavement which aroused concern in Europe in recent years [8,9]. It was considered to be a replacement of the commonly used porous asphalt, noise reduction ability of which decreases significantly due to clogging of the air voids [10,11]. In this research, the thin layer surfacings for measurements were from two sources:

(1) Laboratory produced slab samples with different mixture composition. The size of the samples is 700 mm × 500 mm, with a thickness 30 mm. The mixture compositions of the slab samples are given in Table 1. The binder used in P06 is colorless bitumen Sealoflex Color with addition of Bayferrox synthetic iron oxide pigments. All the other mixtures were made of Cariphalte DA. Properties of the two types of bitumen are given in Table 2.
(2) Kloosterzande trial sections in The Netherlands: These trial sections are located in the most northern part of the N60 road in The Netherlands. 40 sections with different surface types were laid in the year 2005 and 2007 respectively [12]. The thin surfacings involved in this study are shown in Table 3. The designed thickness is 25 mm.

2.1.2. Other materials

In addition to thin layer surfacing, the tests were carried out on a dense asphalt surface layer and a poro-elastic surface (Roll Pave) in Kloosterzande sections [11]. Material properties of these two surfaces are quite different from the thin layer surfacings. The dense layer is a standard ISO surface with a coarse aggregate size of 0/8 mm and a designed thickness of 30 mm. The poro-elastic surface comprises fine aggregate and rubber particles, which works in increasing elasticity of the surface. The air voids content is around 30% [11].

2.2. Measurement methods

2.2.1. Mechanical impedance measurement

As mechanical impedance is a newly considered influential parameter on tyre–road noise, there is no existing standard method to determine this parameter. Generally speaking, it can be measured by applying an impact to the road surface and recording the response of the material in terms of its vibration. In existing studies, test with an impedance hamper was commonly used [4]. The method is also introduced in this research. A measurement on the road surface is illustrated in Fig. 1. The measurement process and data proceeding methods are described in a previous work by the authors [13]. The tests are conducted at an ambient temperature around 20 °C. It should be noted that the velocity is tested at different positions

Table 1
Mixture compositions of laboratory produced thin layer surfacings.

	Coarse aggregate content (% by mass)	Max. Aggregate size (mm)	Air voids content (% by volume)	Binder content (% by mass of mixture)	Aggregate type
Ref.	78	2/6	12	6.1	Bestone
P01	78	2/6	8	6.1	Bestone
P02	78	2/6	18	6.1	Bestone
P03	72	2/6	8	6.1	Bestone
P04	68	2/6	8	6.1	Bestone
P05	78	4/8	12	6.1	Bestone
P06	78	2/6	12	6.1	Tillred
P07	78	2/6	12	6.1	Irish Greywacke
P08	78	2/6	12	7	Bestone

Table 2
Binder properties of the investigated thin layer surfacings.

Items	Cariphalte DA	Sealoflex color
Penetration, at 25 °C, unit: 0.1 mm	85–130	70–100
Ring and ball softening point, unit: °C	⩾80	50–56

Table 3
Basic information of the mixtures used in the Kloosterzande test sections.

Trial section no.[a]	Coarse aggregate content (% by mass)	Air voids content (% by volume)	Binder content (% by mass of 100% aggregate mass)	Thickness (mm)
2	47	12	7.2	25
3	65	8	7.8	25
4	74.8	12	7.5	25
5	72.5	12	6.6	25
9	86	>20	6.0	25
15	78.8	>20	6.0	25

[a] Numbers of the sections are in accordance with the original numbers of the trial sections.

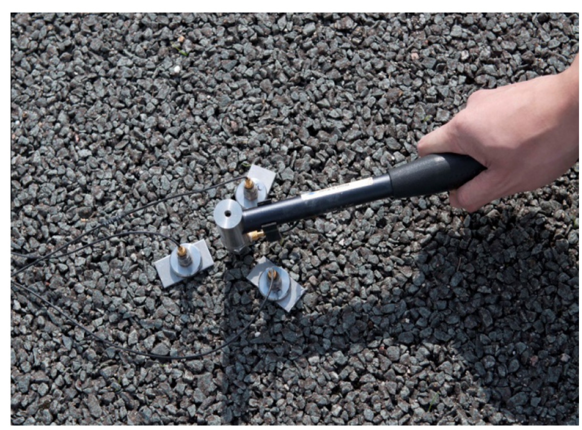

Fig. 1. Impedance hammer test on the road surface of trial sections.

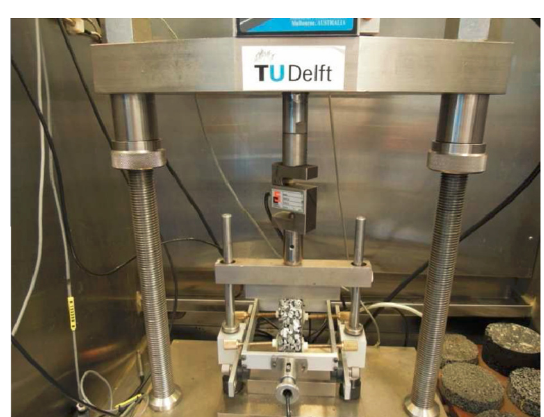

Fig. 2. Setup of the cyclic ITT in the laboratory.