Construction and Building Materials 151 (2017) 848–858

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation into temperature- and frequency-dependent dynamic properties of high-speed rail pads

Kai Wei, Qilu Yang, Yinling Dou, Feng Wang, Ping Wang *

MOE Key Laboratory of High-speed Railway Engineering, Southwest Jiaotong University, Chengdu 610031, China
School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China

HIGHLIGHTS

- Rail vehicle's loads on rail pads involve quasi-static load and random dynamic load.
- Loss factors of high-speed rail pads at wide temperatures are within 0.05–0.35.
- Glass transformation temperatures of high-speed rail pads are between −40 and −45 °C.
- Dynamic property of rail pad under random dynamic load is time-variable.
- Rail pad's dynamic property under random dynamic load depends on quasi-static load.

ARTICLE INFO

Article history:
Received 17 April 2017
Received in revised form 7 June 2017
Accepted 8 June 2017

Keywords:
High-speed railway
Rail pad
Dynamic performance
Temperature-dependence
Frequency-dependence

ABSTRACT

In order to investigate the temperature- and frequency-dependent dynamic properties of high-speed rail pads excited by rail vehicle's large-amplitude quasi-static loads due to bogie interval and wheelset spacing, the soft pads from WJ-7, WJ-8 and Vossloh 300 fasteners frequently used in China's high-speed railway track systems are taken as test subjects. At first, a series of dynamic tests of the three high-speed rail pads at a specific frequency of 0.3 Hz and under various low temperatures ranging from −60 to 20 °C are carried out. Then, the Time-Temperature Superposition (TTS) and Williams-Landel-Ferry (WLF) formula are used to predict their dynamic performance at frequencies higher than the test frequency, and the Fractional Derivative Kelvin-Voigt (FDKV) model is proposed to represent their frequency-dependent dynamic properties. Finally, the frequency-dependent dynamic performance of the three high-speed rail pads under rail vehicle's small-amplitude dynamic loads due to the surface roughness of rail and wheel is discussed. It is found that the storage stiffness of WJ-7, WJ-8 and Vossloh 300 rail pads is sensitive to low temperatures, as well as much larger than their corresponding loss stiffness. The glass transformation temperatures of WJ-7, WJ-8 and Vossloh 300 rail pads are −40, −45 and −45 °C, respectively. The FDKV model can basically give a satisfactory fitting with the experimental results within 100 Hz, especially at ordinary temperatures. The dynamic properties of rail pads excited by rail vehicle's small-amplitude dynamic loads are time-variable and related to rail vehicle's large-amplitude quasi-static load values on rail pads. Thus, it is very important that the temperature- and frequency-dependent dynamic parameters of the polymer materials in vehicle-track systems must be measured according to the specific operation conditions, since otherwise an accurate prediction of the broadband train-induced vibration and noise at different temperatures is difficult to achieve.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

With the rapid expansion of high-speed railway infrastructure, conflicts often arise between the interests of local citizens living along the planned tracks and the national interests of governmental authorities. One of the prominent causes of conflicts is the increasing environmental vibrations induced by high-speed railway (HSR). In order to avoid unexpected remediation measures, vibration levels must be accurately predicted by appropriate field tests or accurate theoretical models.

Over the last 20 or 30 years, many field tests have been performed in order to estimate the vibration levels generated by HSR. Connolly et al. analyzed over 1500 ground-borne vibration records at 17 high-speed rail sites with train speeds ranging from

* Corresponding author at: MOE Key Laboratory of High-speed Railway Engineering, Southwest Jiaotong University, Chengdu 610031, China.
E-mail address: wping@home.swjtu.edu.cn (P. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.044
0950-0618/© 2017 Elsevier Ltd. All rights reserved.

72 to 314 km/h across 7 European countries [1–3]. It was observed that the dominant frequency components of ground vibration velocity due to HSR were the quasi-static frequencies due to bogie and wheelset spacing, approximately in the 20–40 Hz range. Zhai et al. performed a field measurement of ground vibrations on the Beijing-Shanghai high speed railway with train speeds from 300 to 410 km/h [4]. It was found that the significant frequencies of ground vibration acceleration due to high-speed trains at speeds over 300 km/h were also the quasi-static frequencies and in the range of 20–60 Hz [4,5]. There has been a consistent view that critical velocity effects have a strong influence on the quasi-static vibrations generated by bogie and axle passages. When trains running close to critical speed, these quasi-static vibrations will be amplified greater in comparison to trains running at lower velocities. Therefore in order to accurately predict ground vibrations caused by high speed trains, it is necessary to first predict the wheel-track coupled vibration levels at quasi-static frequencies.

Under certain conditions, if it is impossible to carry out a field test, a numerical or analytical method is preferable. For such theoretical analyses, the ground vibrations induced by moving train loads were mainly analyzed through coupled track-foundation models [6–10]. Theoretical model of foundation soil have made great progress in recent times, evolving from a monolayer elastomer to a multilayered poroviscoelastic medium. In the numerical simulation, the finite element method (FEM) [11–14], the boundary element method (BEM) [15,16], the hybrid FEM-BEM [17–21], the hybrid FEM-IFEM (infinite element method) [21–23], the hybrid FEM-PML [24], the hybrid FEM-TLM [25] and the hybrid FEM-SBFEM [19] have all been used to investigate environmental vibrations due to railway traffic. Although theoretical or numerical models combined with experimental data have been reasonably sufficient, besides foundation soil properties, the accuracy of the dynamic properties of track pads for use as modelling inputs also need to be considered. Generally speaking, the dynamic parameters of track pads (such as rail pads, under-sleeper pads and bed pads) are regarded as a constant in the above-mentioned models. However, the dynamic parameters of polymer pads in track system actually have a close correlation with environmental temperatures, excitation frequencies and excitation amplitudes. Squicciarini et al. performed a field measurement of the noise from passing trains at temperatures of 0–35 °C [26]. The test results showed an increase of 3–4 dB. Wei et al. used a frequency-domain algorithm to investigate the influence of frequency- and temperature-dependent stiffness of rail pads on the frequency-domain vibrations induced by railway train [27,28]. The frequency- and temperature-dependent stiffness of rail pads can significantly change the frequency-domain distribution of train-induced vibrations. Obviously, for an accurate prediction of environmental vibrations induced by the quasi-static loads of high-speed railway at different train speeds and at different ambient temperatures, it is necessary to measure precisely the temperature- and frequency-dependent dynamic properties of the viscoelastic polymer materials used in high-speed railway track system.

There have been plenty of tests presented to obtain the temperature- and frequency-dependent dynamic properties of rail pads. Thompson and Verheij introduced a laboratory measurement to indirectly test the dynamic stiffness of rail fasteners [29,30]. The so-called indirect measurement method could be used to fully test rail fasteners in the range of 50–1000 Hz, so that not only their material properties but also their geometrical factors could be measured. Kim and Singh presented a new experimental identification method for extracting the frequency-dependent multi-dimensional dynamic stiffness of an isolator [31]. Smutny performed some laboratory measurements on the dynamic parameters of a single rail fastening by mechanical shock simulated with a hammer [32]. Lin et al. showed a simple experimental method to evaluate the frequency-dependent rubber mount stiffness and damping characteristics by utilizing the measured complex frequency response function from impact testing and then using least-square polynomial curve fitting on the data obtained from the test [33]. Maes et al. designed an alternative set-up for railpad testing allowing for the measurement of stiffness and damping values between 20 and 2500 Hz with variable preloading [34]. Kaewunruen and Remennikov developed a non-destructive methodology for evaluating and monitoring the dynamic properties of rail pads based on an instrumented hammer impact technique [35]. Oregui et al. proposed combining dynamic mechanical analysis and the time-temperature superposition principle to determine various railpad dynamic properties [36]. In this dynamic analysis, the dynamic force is 4 kN, which is the loading value of a typical hammer test, and lower than the quasi-static loads. In a word, the dynamic properties of rail pads measured in the above-mentioned tests are their dynamic performance only under rail vehicle's random dynamic loads due to track irregularity or wheel out-of-round. In contrast with rail vehicle's random dynamic loads, rail vehicle's quasi-static loads due to bogie interval and wheelset spacing not only have higher amplitudes but also possibly influence the dynamic properties of rail pads under rail vehicle's random dynamic loads. Thus, for improvement of the prediction accuracy of the environment vibrations caused by high speed railway, the temperature- and frequency-dependent dynamic properties of high-speed rail pads in the large strain region should be also measured.

For experimental investigation into the temperature- and frequency-dependent dynamic properties of China's high-speed rail pads excited by rail vehicle's large-amplitude quasi-static loads, a universal testing machine equipped with a temperature control box (Fig. 1) is used to measure the dynamic properties of the soft pads of WJ-7, WJ-8 and Vossloh 300 fasteners usually used in China's high-speed railway at a specific test frequency of 0.3 Hz and under various low temperatures ranged from −60 to 20 °C (Section 2). Then, the Time-Temperature Superposition (TTS) and Williams-Landel-Ferry (WLF) formula are applied to predict their dynamic performance outside the scope of measurement (Section 3). After that, a Fractional Derivative Kelvin-Voigt (FDKV) model is proposed to represent their frequency-dependent dynamic properties (Section 4). Finally, according to the actual loading progress of rail vehicle's quasi-static and dynamic loads on rail pads during the passage of train, the frequency-dependent dynamic performance of high-speed rail pads excited by rail vehicle's small-amplitude random dynamic loads due to the surface roughness of rail and wheel is discussed. (Section 5). This experimental study is expected to obtain the actual dynamic parameters of high-speed rail pads during the passage of rail vehicle in order to improve the prediction accuracy of the broadband vibration and noise generated by high-speed rail vehicles.

2. A test for the temperature- and frequency-dependent dynamic performance of rail pads

In China, high-speed railway track system are of the non-ballasted type. Their elasticity is mainly provided by rail pads. There are three types of fastenings frequently used in China's high-speed railway, these being WJ-7, WJ-8 and Vossloh 300 fasteners. In the WJ-7 fastener, the soft pad is located under rail, whereas in the WJ-8 and Vossloh 300 fasteners, the soft pad lies under an iron base plate.

2.1. Experimental preparation

In this test, three full-size soft pads, from WJ-7, WJ-8 and Vossloh 300 fasteners respectively, are used as test subjects (Fig. 2). The

Download English Version:

https://daneshyari.com/en/article/4918247

Download Persian Version:

https://daneshyari.com/article/4918247

Daneshyari.com