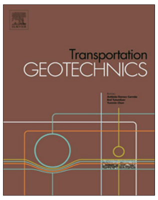
Transportation Geotechnics 4 (2015) 13–27

Contents lists available at ScienceDirect

Transportation Geotechnics

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



Full-scale field testing on a highway composite pavement dynamic responses

Xiaobin Chen [a,b,*], Jiasheng Zhang [b], Xuan Wang [a]

[a] *Central South University, School of Civil Engineering, 22 Shaoshan R., Changsha 410075, China*
[b] *National Engineering Laboratory for High Speed Railway Construction, 22 Shaoshan R., Changsha 410075, China*

ARTICLE INFO

Article history:
Received 15 September 2014
Revised 10 April 2015
Accepted 7 May 2015
Available online 13 June 2015

Keywords:
Composite pavement
Full-scale field test
Heavy traffic load
Mechanical responses
Attenuation coefficient

ABSTRACT

A series of full-scale field tests were conducted to observe the composite pavement's dynamic responses subjected to heavy traffic load. The tire contact pressure beneficially influences the dynamic strains and the dynamic stresses of pavement. A typical "M" shape is observed for the distribution of dynamic responses cross lane. The range of dynamic soil stress on roadbed ranges at 20–50 kPa, and a non-linear model is presented for the dynamic stress attenuation along subgrade depth. Furthermore, the increasing of truck speed decreases the dynamic responses of composite pavement. This is owing to the viscoelastic property of HMA layer and the resonant frequency. At a lower moving speed, the dominant frequency of heavy truck loading is close to the dominant frequency of HMA layer. This would amplify the vibrations of pavements and consequently result in larger mechanical responses. The experimental findings would be helpful to understand the dynamic performance of composite pavement subjected to heavy traffic load.

Introduction

The pavement and subgrade responses are highly affected by the properties of materials and moving trucks. There have been some research studies on the analysis of pavement dynamic response by numerical simulation methods (Cebon, 1986; Yoo and Al-Qadi, 2007; Hu and Walubita, 2011; Grellet et al., 2013; Levenberg, 2013). The use of a 3-D model to investigate the dynamic responses become a great interest (Zaghloul et al., 1994; Al-Qadi et al., 2008; Al-Qadi et al. 2010a; Wang and Al-Qadi, 2009; Liu et al., 2011; Yin, 2013; Liu and Shalaby, 2013; Wang and Brill, 2013). De Beer et al. (2002) found the vertical load shape and distribution have obvious effects on the pavement responses of thin HMA pavements. Al-Qadi and Yoo (2007) highlighted that the effect of surface tangential contact stresses on flexible pavement response is also remarkable. By the full-scale pavement test, Kim and Tutumluer (2006) made a comparison between the measured and predicted permanent deformations of a developed granular base–subbase layer permanent deformation model. Xue and Eric (2011) conducted a series of controlled loading tests on the US-23 testing road in hot weather conditions, and developed a method for consistent comparison of variable field sensor data. Yang and Dai (2013) developed a three dimensional dynamic finite-element model to evaluate the mechanistic responses in the pavement under different traffic characteristics, namely uniform speed, acceleration and deceleration. They found that the traffic characteristics have significant effects on the distributions of the maximum principal strain and the maximum shear stress at the pavement surface. Although the pavement's dynamic response is well simulated by the 3D finite element method, the

---

* Corresponding author at: Central South University, School of Civil Engineering, 22 Shaoshan R., Changsha 410075, China. Tel./fax: +86 731 82656812.

E-mail addresses: chenxb@illinois.edu, chen_xiaobin@csu.edu.cn (X. Chen).

http://dx.doi.org/10.1016/j.trgeo.2015.05.002
2214-3912/

field responses still remain uncertain because of the testing conditions.

Field tests to evaluate the impacts of vehicle loading on pavement responses are particularly important to assess performance of pavements to identify mechanisms of pavement response, and to provide information for a new design (Tholen et al., 1985; Brandon et al., 1996; Perkins and Cortez, 2005; Al-Qadi and Yoo, 2007; Warren and Howard, 2007; McCartney et al., 2013; McCartney and Cox, 2013). After a field testing, Kim and Tutumluer (2006) explained the in situ mechanistic responses of pavement by principal stress rotation effects. Al-Qadi et al. (2010b) presented experimental measurements on a runway flexible pavement to better understand how the pavement responds to airplane traffic loading. In their tests, a truck was used to simulate the effects of speed and load magnitude on the responses of runway pavement. Their results showed that the speed has no effect on the magnitude of the transmitted pressure under the HMA surface, but the loading pulse periods vary. McCartney and Cox (2013) reported an investigation into the deformation response of geosynthetic reinforced soil layers, and they evaluated the level of strain required to mobilize reinforcement mechanisms due to traffic loading. Many studies have been performed to infer the contribution of truck load on pavement mechanical response, among them a number of researchers found that the effect of tire contact pressure on pavement mechanistic response is important (Wang and Al-Qadi, 2009; De Beer et al., 2002; McCartney et al., 2013). However, few literatures have focused on the effect of traffic speed on dynamic response of a composite pavement, and the relationship between the traffic speed and the pavement response is still uncertain.

To assess the composite pavement's mechanical responses adequately, a series of full-scale field tests on composite pavement were carried out. Presented here are the experimental results subjected to heavy truck load conditions, namely the truck speed and tire contact pressure. The objective of this research is to investigate the effects of truck speed and tire contact pressure on dynamic responses of a composite pavement. This study would be helpful to understand the dynamic performance of composite pavement under heavy traffic loads.

Experimental tasks

Material properties of pavement

This paper is aimed to better understand the effects of speed and tire contact pressure on pavement mechanistic responses. To achieve this goal, a field site, as shown in Fig. 1(a), was used for the field testing in Hunan province, China. The site is a new-built four-lane highway, and each lane is 3.75 m in width. The structure of composite pavement is shown in Fig. 1(b), and the basic mechanical parameters of each layer are listed in Table 1. Among them, the 150 mm thick pavement surface is a standard hot mix asphalt (HMA) layer. This HMA includes a 40 mm thick upper layer used by gap-graded stone matrix asphalt (SMA) and a 110 mm thick sub-layer used by AC20–25 for bottom rich binder courses hot mix asphalt. The usage of SMA is to enhance the rutting resistance and durability. The sub-layer HMA has 5.1% asphalt content, and the SMA layer has 5.4% asphalt content. The base course includes three layers of cement treated bound bases below the pavement HMA surface: a layer of 160 mm thick surface base with 5% cement (by weight), a layer of 160 mm granular middle base with 4% cement and a layer of 180 mm thick stabilized subbase with 4% cement. Each base course uses a well-graded crushed limestone with 7–10% fines (No. 200). Before testing the roughness of pavement surface was measured, and the roughness assessment results are plotted in Fig. 1(c).

The fills in subgrade is the red residual soil and the height of the subgrade is 18 m. The fills are derived from the weathering and decomposition of red mud stone. Its median grain size diameter (d_{50}) is 5.5 mm and the uniformity coefficient (C_u) is 33, indicating well-graded soil. The optimum moisture content and the maximum dry density are also obtained using Proctor compaction test of ASTM D1557. The grain size distribution is plotted in Fig. 2, and the physical and mechanical parameters are summarized in Tables 2 and 3.

Installation of sensors

The position of each sensor was carefully chosen based on the type of data to be collected, and the arrangement of instruments is shown in Fig. 3. The strain gages (longitudinal and transversal) were used to measure the dynamic strains at the bottom of HMA, and the dual diaphragm dynamic soil pressure sensors (vertical) were respectively instrumented on the surface of upper base, middle base, sub-base and in the subgrade. Totally, 55 sensors were installed, and 30 of them survived to acquire the dynamic stresses and strains. During the construction one back-up gage was installed for each asphalt strain (namely, LS- and TS-), as well as the dynamic soil pressure sensors in the pavement (namely, PP-). Only one soil pressure sensor was installed for each location in subgrade (namely, PS-), since the sensors were protected by soil cover. Approximately, the 80% of the instruments survived during the construction phase, and 60% were still functional by the end of testing. Fig. 3 shows the survived instruments arrangement, plotted the vertical stress gauge PP on base surface, the vertical stress gauge PS on subgrade surface, transverse strain gauge (TS) at the bottom of HMA and longitudinal strain gauge (LS) at the bottom of HMA. As mentioned by Bian et al. (2014) that the incorrect calibration coefficients of soil pressure sensors would be encountered due to the different stiffness of fills. So, before the installation of these soil pressure sensors they were calibrated in a large steel chamber with fine sands and fills of subgrade. The results of calibration were presented in Fig. 4, and the calibration coefficients were used to calculate the measured vertical stresses in the test. The manufacture supplied calibration coefficient of strain gages is used for the measured asphalt strains at the bottom of HMA.

When the soil pressure sensors were installed at the location of pavement, a hole was firstly excavated. Then the fine sand was paved and compacted to level the sensors. After that, the sensors were covered with a layer of