Construction and Building Materials 73 (2014) 261–270

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of daily temperature variations on the continuous deflection profiles of airfield jointed concrete pavements

Boo Hyun Nam [a], Jung Heum Yeon [b,*], Zachary Behring [a]

[a] Department of Civil, Environmental, and Construction Engineering, University of Central Florida, Orlando, FL 32828, USA
[b] Department of Civil and Environmental Engineering, Gachon University, Seongnam 461-701, South Korea

HIGHLIGHTS

- The effect of daily temperature variations on the continuous deflection profiles of airfield JCP was evaluated using RDD.
- The continuous deflection profiles of JCP varied considerably as the time elapsed from the early morning to noon.
- The effects of other affecting parameters on the curling behavior of JCP were numerically investigated.
- The temperature effect needs to be considered for adequate evaluations of in-situ pavement/subsurface conditions.

ARTICLE INFO

Article history:
Received 21 June 2014
Received in revised form 22 September 2014
Accepted 25 September 2014

Keywords:
Daily temperature variation
Continuous deflection profile
Airfield jointed concrete pavement
Curling
Rolling dynamic deflectometer
Finite element analysis

ABSTRACT

Compared with highway roads primarily damaged by repeated vehicle loads, airfield pavements suffer more from heavier aircraft loading, along with environmental factors. In particular, a pavement temperature is one of the critical factors affecting the behavior and response of airfield jointed concrete pavements (JCP). Temperature variations cause curling and expansion/contraction of a slab, which may ultimately influence the in-situ deflection measurements. Along with the pavement temperature, it is well known that other parameters such as subsurface conditions (i.e. stiffness of base/subbase layers), setting temperature of concrete, slab dimensions, and joint/crack width also affect the behavior and response of JCP. The main objectives of this paper are to characterize: (1) the behavior of airfield JCP due to temperature variations in terms of pavement "deflections" (defined as the dynamic movements of a pavement induced by dynamic loading); and (2) the effects of various affecting parameters on the vertical displacement profile of JCP slabs. The primary research means include in-situ pavement deflection measurements at different times of a day. For this purpose, a rolling dynamic deflectometer (RDD) which measures the continuous deflection profiles along a selected pavement section (100% coverage of a tested path) was employed. Also, extensive two-dimensional numerical simulations were performed to provide supporting evidence for the behavior trends generated by RDD.

1. Introduction

1.1. Background and state-of-the-art

Maintaining and rehabilitating aging concrete pavements is one of the major tasks for transportation authorities. For example, the importance of maintaining and rehabilitating in-service pavements is clearly shown in Texas by the annual expenditures in this area, with approximately $2.7 billion to maintain and rehabilitate its 128,750-km roadway system [1]. Among the 128,750 km of roads, rigid pavements are total more than 11,265 km while jointed concrete pavements (JCP) are about 1448 km [2]. With the aging of the highway infrastructures, pavement engineers need a reliable means of assessing the condition of JCP. The most common nondestructive tool to assess the structural condition of JCP is a falling weight deflectometer (FWD), which is operated in a "stop-and-go" manner. Thus, the testing coverage is quite limited so there would be a potential to miss the assessment of critical features such as cracks and joints. On the other hand, a continuous deflection measurement device such as a rolling dynamic deflectometer (RDD) is a powerful alternative in evaluating the structural condition of JCP because it measures continuous deflection profiles along the section of interest. The continuous deflection profile provides 100% coverage of the tested path and evaluates the load bearing and load transfer conditions of all slabs as well as joints [3–5]. In

* Corresponding author. Tel.: +82 31 750 5498.
E-mail address: jyeon@gachon.ac.kr (J.H. Yeon).

http://dx.doi.org/10.1016/j.conbuildmat.2014.09.073
0950-0618/

this test method, the deflection measured at the slab center (midslab deflection) represents the load bearing capacity of subsurface layers while the one measured at joints (joint deflection) indicates the load transfer condition of joints.

It is well known that a pavement temperature is one of the most critical parameters related to the behavior and response of JCP. In Texas, however, pavement deflection tests are performed in a wide range of pavement temperatures, commonly between 10 and 40 °C during a day in the fall season. With the temperature variations, the behavior of JCP slabs may substantially vary; for example, the deflection measurements in the morning and in the afternoon would be somewhat different. As a result, load transfer conditions at joints, midslab deflections, and deflection basin evaluated by in-situ deflection tests would be inconsistent, even for the measurements at the same locations. It is apparent that inadequate evaluations of pavement conditions will cause a wrong selection of pavement rehabilitation treatments, which is quite undesirable for state highway agencies (SHAs).

Traditionally, deformation behavior of a concrete slab due to temperature differential along its depth is referred to as curling. Many researchers have made an effort to evaluate the temperature gradient (or termed temperature differential between the top and bottom of a slab) during daily times and the corresponding motions of curling in actual concrete slabs [6,7]. Khazanovich and Gotlif [8] reported that joint load transfer efficiency (LTE), a deflection ratio between the upstream and downstream across a transverse joint under a specified mechanical load, are largely affected by various factors such as pavement temperature (season), loading position, and load transfer measurement device. Especially, their result identified that the LTE increases with an increased surface temperature. Shoukry et al. [9] also observed a decrease in joint deflections and increase in LTE across transverse joints with an increased pavement temperature. They found that, at the wheel path, the LTE increased from about 81 to 92% as the slab surface temperature varied from 4 to 28 °C.

The main parameters influencing the behavior and response of JCP include: (1) temperature and moisture gradients; (2) modulus of subgrade reaction; (3) setting temperature of concrete; (4) slab dimensions; and (5) width of transverse joint cracks. The findings of the existing literatures are summarized as follows:

Temperature and moisture gradients: Several former studies [10–12] have shown that temperature and moisture (or internal relative humidity) gradients along the slab depth are typically nonlinear, with greater daily temperature fluctuations at the top surface than at the bottom. If the temperature and moisture gradients are nonlinear, the slab tends to deform in accordance with its compensation plane (or a sectional average plane) as each concrete element along the depth should meet the linear continuity condition [11,13].

Modulus of subgrade reaction: Modulus of subgrade reaction controls the degree of contact loss (or release of contract pressure) between the slab and the underlying layer. A former study [14] found that the vertical displacement varies depending on the modulus of subgrade reaction even with the same amount of curling.

Setting temperature: Final setting of concrete relates to the point where stresses and stiffness begin to develop in concrete. Several research studies reported that the distribution of setting temperature is non-uniform along the slab depth, resulting in built-in curling [12,15,16]. Yeon et al. [17] conducted in-situ measurements of setting temperature differential in a 22.8 cm-thick continuously reinforced concrete pavement (CRCP) and found about 3.3 °C built-in curling gradient.

Slab dimensions: The amount of curling is determined by temperature differential between the top and bottom of a slab [10–13,18]. Al-Nasra and Wang [19] reported that a thicker slab exhibits a greater curling movement whereas Leonards and Harr [20] stated that the upward corner movement decreases as the slab thickness increases. Such conflicting conclusions resulted because the former studies assumed either a fixed temperature differential regardless of slab thickness or a constant temperature increase per unit thickness, which do not account for the actual field conditions. Another study [14] revealed that, in a finite slab, the slab length (joint spacing) has a substantial effect on the amount of curling; the amount of curling movement tended to decrease as the slab length decreased.

Transverse joint crack width: Hansen and Jensen [21] revealed that an apparent width of transverse joint cracks in JCP typically ranges from 0.3 to 0.6 mm, but in some cases, the actual width of joint crack can be further reduced due to infiltration of incompressible materials such as gravel, stone, and sand into crack opening as the joint filling materials wear out.

1.2. Objective and scope

The primary goal of this study lies in comprehensive understanding of the behavior changes in airfield JCP caused by temperature variations and resulting effects on the in-situ deflection measurements. The scope of this study includes evaluation and quantification of the temperature effect by means of in-situ nondestructive testing (NDT) and numerical investigations into the general behavior trends of JCP. In-service airfield JCP slabs with different temperature conditions were characterized in terms of pavement deflections; RDD testing was conducted at different daily times. Furthermore, a series of finite element (FE) simulations was conducted to review the effects of slab temperature conditions as well as other affecting parameters on the curling movements of JCP, and in turn, the continuous deflection profiles. The outcomes of this study are expected to provide meaningful information on adequate interpretation of continuous deflection profiles generated by RDD.

2. In-situ measurements of pavement deflections

2.1. Descriptions of the testing method and site

The RDD is a truck-mounted device on a modified vibroseis platform. The RDD continuously loads pavements dynamically and simultaneously measures pavement deflections while the truck moves along the pavement section at a speed of 1.6 km/h [3]. The continuous deflection profiles measured by RDD have been extensively used for delineation of problematic areas to be repaired, pavement forensic investigations, and evaluations of load-transfer conditions of joints in JCP [4,5,22–24].

The RDD unit is composed of four major components, which include: (1) dynamic loading system; (2) array of rolling sensors; (3) distance measurement device; and (4) integrated data collection and processing systems. For typical highway projects, a 35-kN static force and a 26-kN peak-to-peak dynamic force with an operating frequency of 30 Hz are most often used. The rolling sensors are composed of three-wheel rolling carts with a 15.2-cm wheel diameter and 2-Hz geophone placed on the cart in the geometric middle of those three wheels. The typical configuration of the RDD rolling sensors is in a linear array with four sensors, which is the same way the FWD sensors are situated. The details of RDD can be found in Bay and Stokoe [3]. For travel distance measurements and recording, a rotary optical encoder attached to the rear tire of the truck is used. Sensing and data processing techniques of RDD have been enhanced, and the details are documented elsewhere [25–27].

The testing site was a JCP section at the Texas Department of Transportation (TxDOT) Flight Service Facility (FSF) in Austin, Texas. The JCP at this facility had three different slab thicknesses