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Effect of Dynamic Aircraft Gear Loads on Asphalt Concrete Strain Responses

ABSTRACT: Asphalt strain gauges were installed in both the longitudinal and transverse directions at the Federal Aviation Administration's National Airport Pavement Test Facility (NAPTF) to measure the load-induced Asphalt Concrete (AC) tensile strains during full-scale traffic testing with a dual-tridem Boeing 777 gear configuration and a dual-tandem Boeing 747 gear configuration. The results are presented for four flexible test sections; two sections with 127 mm of AC and two with 254 mm of AC. An axisymmetric finite element pavement analysis software was used to model the NAPTF flexible test sections and compute the AC strain responses. The measured AC strain magnitudes were significantly influenced by AC temperature variations. Dramatic increase in peak strain responses were observed as the NAPTF flexible test sections approached structural failure. There was a good agreement between the field-measured and computed strains during the early life of the test sections.

KEYWORDS: Asphalt Strain Gage (ASG), Asphalt Concrete (AC), NAPTF, flexible airfield pavement, finite element modeling, multiple-wheel heavy aircraft gear loading

Introduction

In a mechanistic-empirical flexible pavement design procedure, the thrust is to design pavement layer thicknesses sufficient to limit the development of pavement distresses to acceptable levels for anticipated traffic loading conditions. Distress modes normally considered in flexible pavement analysis and design are fatigue cracking, rutting, and low-temperature cracking [1]. Classical flexible pavement design procedures are based on limiting the vertical compressive strain on top of the subgrade (subgrade rutting failure criteria) and the horizontal tensile strain at the bottom of the lowest Asphalt Concrete (AC) layer (AC fatigue failure criteria).

According to the 1989 American Society of Civil Engineers survey results [2] and the 1999 Federal Aviation Administration's (FAA) Pavement Condition Index survey results [3], AC fatigue cracking and rutting are among the most common distresses in airport flexible pavements. In AC fatigue algorithms, fatigue failure of the AC layer is primarily related to the magnitude of tensile strains at the bottom of the layer. It is therefore important to measure AC strains so that pavement response and fatigue cracking performance can be properly evaluated.

In this paper, the AC tensile strains measured in the flexible pavement test sections during full-scale traffic testing at the FAA's National Airport Pavement Test Facility (NAPTF) are discussed. During the first round of traffic testing, referred to as the Construction Cycle 1 (CC1) traffic testing, the NAPTF flexible pavement sections were subjected to dual-tridem Boeing 777 (B777) gear trafficking and dual-tandem Boeing 747 (B747) gear trafficking to study and compare their effect on pavement structural responses and rutting performance.

During NAPTF trafficking, Heavy Weight Deflectometer (HWD) tests were conducted at various times to monitor the effect of time and traffic on the structural condition of the pavements. Rut depth measurements were made at periodic intervals throughout the traffic testing. Multidepth Deflectometers, Pressure Cells, and Asphalt Strain Gages (ASGs) embedded within the test sections were used to record the pavement structural responses. After the completion of traffic tests, forensic trench studies were conducted on all of the flexible pavement sections to investigate into the failure mechanism of the pavement structures.

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Objectives

The primary objective of this study is to evaluate the horizontal strains measured in the AC layers of four flexible pavement sections during full-scale traffic testing at the NAPTF. The other objectives are to compare the field-measured AC strains with those computed using a flexible pavement finite element structural model and assess the relative severity effects of six-wheel and four-wheel gear configurations on AC strain responses.

AC Strain Measurements Using Asphalt Strain Gages: Literature Review

Numerous studies in the past have utilized ASGs for AC strain measurements [4–10]. Many of these studies focused on analyzing the effect of speed of load application on the strain responses in the AC layers. Results showed the dependency of AC strains on speed and AC temperature. For instance, Sebaaly and Tabatabaee [6] reported a reduction of 50 to 70 % in the measured AC strains as a result of increasing the vehicle speed from 32 to 80 km/h (20 to 50 mph). Most of these studies report test results for highway-type loading conditions with wheel loads less than 9 tons (20 000 lbs).

Use of Accelerated Pavement Testing (APT) has become one of the most important methods of testing performance of pavements around the world. A large amount of data have also been extracted from APT studies conducted around the world and analyzed for modeling stress/strain, deformation (rutting), surface deflection, fatigue and layer equivalencies [11].

Groenendijk [12] reported the use of longitudinal and transverse AC strain gauges under wheel track of LINTRACK APT facility in Netherlands. The data indicated the presence of higher magnitude of strain and larger effect of permanent strain in the transverse direction than in the longitudinal direction. It was shown in the study that nontransient or permanent strains in transverse strain gauges were dependent on previous loading, peak strain level, temperature, and orientation and locations of strain gauges. On the other hand, very little non-transient strain was observed in the longitudinal direction because of tension-compression effect in that direction [13].

Edwards et al. [14] compared dynamic pavement responses from four Long-Term Pavement Performance Specific Pavement Studies test sections in the field and in the Accelerated Pavement Loading Facility (APLF) in Ohio. Using pavement moduli backcalculated from the Falling Weight Deflectometer (FWD) tests and the APLF dual tire load configuration, an elastic-layered program was used to compute the surface deflections and AC strains. In general, computed deflection was slightly higher than measured deflection and computed AC strain was slightly lower than measured AC strain.

Erlingsson and Ingason [15] compared the performance of two thin pavement structures during APT using a Heavy Vehicle Simulator. Both linear and nonlinear elastic analyses using multilayer elastic theory and finite element (FE) techniques were carried out to simulate the tested structure and compare the computed results with actual field measurements. The results showed that analyses where nonlinear unbound base behavior is taken into account gives better agreement with field measurements compared to linear elastic analyses.

ASG responses were also measured and analyzed during NAPTF pavement testing. The NAPTF pavement testing was conducted in two phases: response test program and trafficking program.

The objectives of the response test program, conducted during August 1999 to September 1999, were to determine the effects of static (HWD), monotonic, and slow-rolling (0.34 mph (0.5 ft/s)) gear configurations (dual, dual-tandem, and dual-tridem) on pavement responses (deflections, stresses, and strains).

Hayhoe et al. [16] presented typical pavement responses, including AC strain measurements, obtained during the NAPTF slow-rolling (0.34 mph) response tests. Gomez-Ramirez and Thompson [17] evaluated the NAPTF response test results for the slow-rolling response tests to study the multiple-wheel load interaction effects. Garg and Hayhoe [18] summarized results from supplemental tests conducted to study the NAPTF ASG responses at low vehicle speeds and high wheel loads. The results from NAPTF traffic testing are discussed in the current paper.

National Airport Pavement Test Facility

The NAPTF is located at the FAA's William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. It was constructed to generate full-scale test data needed to develop pavement design

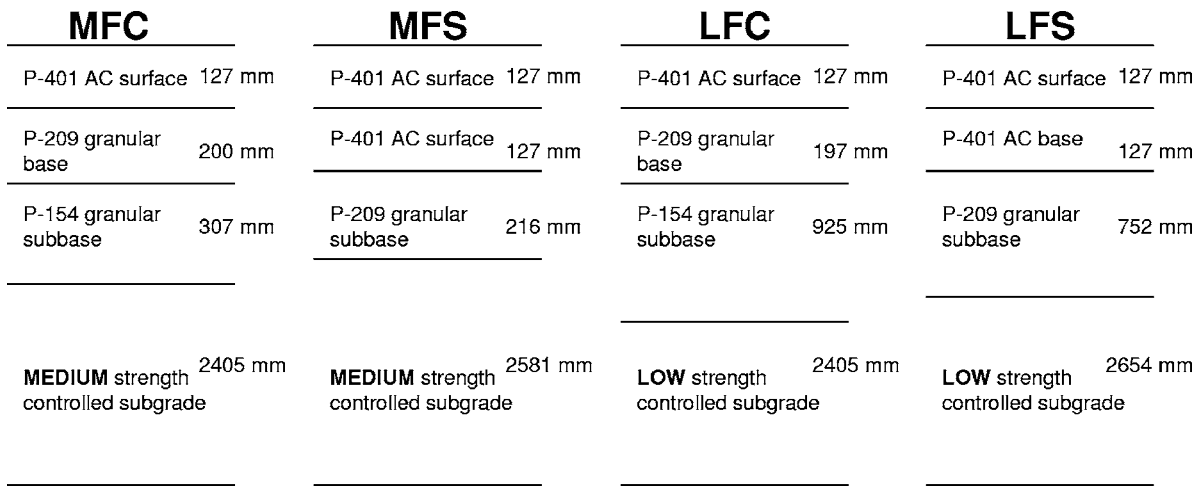

FIG. 1—*NAPTF flexible test sections.*

procedures for the new generation of large civil transport aircraft, including the Boeing 777 (B777) and Boeing 747 (B747).

The NAPTF test pavement area is 274.3 m (900 ft) long and 18.3 m (60 ft) wide. The first set of test pavements included a total of nine test sections (six flexible and three rigid) built on three different subgrade materials: low-strength (target California Bearing Ratio (CBR) of 4), medium-strength (target CBR of 8), and high-strength (target CBR of 20). Two different base sections were used: conventional (granular) and stabilized (asphalt concrete).

Trafficking tests were conducted with Boeing 777 (B777) gear in one lane and Boeing 747 (B747) gear in the other lane using a 5340-kN (1.2 million-lb) pavement test machine. The vehicle is equipped with six adjustable dual-wheel loading modules. A hydraulic system applies the load to the wheels on the modules. Trafficking continued until the test sections were deemed failed. Per NAPTF failure criterion, this is reflected as 25.4-mm (1-in.) surface upheaval adjacent to the traffic lane.

Flexible Pavement Sections

Each NAPTF test section is designated using a three-character code (MFC, LFS, etc.), where the first character indicates the subgrade strength ("L" for low, "M" for medium, and "H" for high), the second character indicates the test pavement type ("F" for flexible and "R" for rigid), and third character signifies whether the base course material is conventional (C) unbound granular material or asphalt-stabilized (S).

The conventional-base flexible test sections (MFC, LFC, and HFC) have 12.7 mm (5 in.) of AC thickness each, while the asphalt-stabilized test sections (MFS, LFS, and HFS) have 25.4 mm (10 in.) of AC thickness. Note that the high-strength subgrade flexible test sections (HFC and HFS) were not considered in this study.

Cross-sectional views of the as-constructed NAPTF flexible test items considered in this study are shown in Fig. 1. The items, P-209 (crushed stone), P-154 (gray quarry blend fines), and P-401 (asphalt concrete) are as per standard specifications detailed in the FAA Circular No. AC 150/5370-10A.

A MH-CH soil classification (ASTM Unified Soil Classification System) material known as County Sand and Stone Clay (CSSC) was used for the low-strength subgrade while DuPont Clay (DPC) (CL-CH soil classification) was used for the medium-strength subgrade. Target strengths of the low-strength subgrade and medium-strength subgrade were 4 and 8 CBR, respectively. The naturally occurring sand layer underlying the NAPTF subgrade layers was classified as a SW-SM soil with a target strength of 20 CBR.

AC Materials Characterization

The P-401 Plant Mix bituminous pavement is composed of mineral aggregate and bituminous material mixed in a central mixing plant and placed on a prepared course. The mixture was spread, finished, and compacted in accordance with FAA Circular No. AC 150/5370-10A for Item P-401. It is noted that the

P-401 material was used as surface layer (made of two lifts) throughout the NAPTF flexible test sections and also as stabilized base course in the LFS and MFS test sections.

The Marshall Test properties of the P-401 mixtures from the truck were measured during production using the Asphalt Institute MS-2 method. The field densities of P-401 cores extracted from NAPTF flexible test sections were measured using ASTM D 2726 procedure. The NAPTF database is available for download or direct access on the FAA Airport Pavement Technology web site [19].

Resilient modulus tests (ASTM D 4123) and fatigue tests (AASHTO TP 8-94) were conducted at the University of Illinois (U of I) Advanced Transportation Engineering Laboratory (ATREL) facility for characterizing P-401 AC mix. A total of about seven cores were extracted from the NAPTF flexible test sections for resilient modulus testing at the U of I ATREL facility. The average laboratory measured P-401 AC resilient modulus at 25°C (77°F) was 2940 MPa (426 ksi).

Ghuzlan [20] performed fatigue analysis of NAPTF P-401 AC mixes as a part of a comprehensive laboratory test program to verify the traditional phenomenological approach as well as the dissipated energy approach. Strain-controlled fatigue tests at a test temperature of 20°C were performed on the NAPTF AC fatigue specimens.

The most frequently used AC fatigue algorithm or transfer function in mechanistic-empirical design procedures is of the form:

$$N_f = K_1(1/\varepsilon_{AC})^{K_2} \tag{1}$$

where N_f is the number of load repetitions to fatigue failure; ε_{AC} is the AC tensile strain at bottom of AC beam; K_1 and K_2 are statistically determined constants. The fatigue coefficients K_1 and K_2 vary from one model to another. Usually, K_2 varies in a range between 3 and 6 while K_1 may vary by several magnitudes [21].

Based on the results of a comprehensive laboratory test program, Myre [22] derived the following relation between K_1 and K_2:

$$K_2 = 1.332 - 0.306 \log_{10} K_1 \tag{2}$$

Carpenter et al. [23] noted that AC mixtures which satisfy the unique phenomenological relationship between K_1 and K_2 will have satisfactory fatigue resistance to support the existence of a fatigue endurance limit for highway and airport pavements. The following relationship was obtained for NAPTF AC mixes between K_1 and K_2 [22]:

$$K_2 = 1.720 - 0.270 \log_{10} K_1 \tag{3}$$

AC Strain Gage Installation

The Asphalt Strain Gage (ASG) is one of the most difficult dynamic sensors to install with a high survival rate. This is primarily due not only to the exposure to high temperatures, but also the subsequent rolling/vibratory impact on these gages after installation.

To insure a high survival rate, manufacturers through the years have developed a robust sensor combined with installation procedures that increase gage survival rate [24].

At NAPTF, H-bar-type Asphalt Strain Gages (ASGs) fabricated by Construction Technologies Laboratories, Inc. were installed at the bottom of the surface asphalt layer of conventional and stabilized-base test sections and at the bottom of the stabilized-base asphalt layer of the stabilized-base test sections. The thickness of the AC surface layer is 12.7 mm (5 in.) in all test sections. In the LFS and MFS sections, an additional 12.7 mm (5 in.) of P-401 AC is included as asphalt-stabilized base layer. The ASGs were installed in both the longitudinal and transverse directions. A total of 96 H-bar type ASGs (transverse and longitudinal) were installed at the time of NAPTF pavement construction.

Strain gages were applied at mid-length on round polyester bars between end flanges. Four 350-ohmgages, two axial and two transverse (rotated 90° from the active gages), are used on each bar. They are connected electrically in a full Wheatstone bridge circuit and arranged on the polyester bar so that the longitudinal strain of the bar is measured [18]. The principal features of the design and construction of the ASGs installed at the NAPTF are shown in Fig. 2.

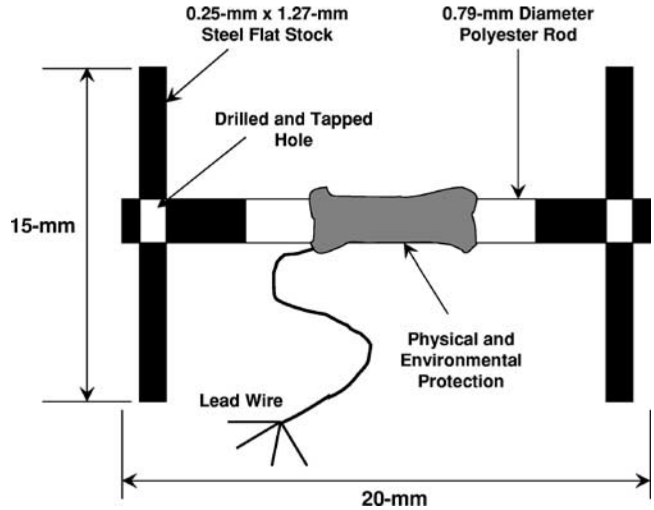

FIG. 2—*Details of Asphalt concrete Strain Gage (ASG) used at NAPTF.*

The strain gage is encapsulated in polyamide with large, rugged copper-coated solder tabs. The strain gage sensor circuitry is encapsulated in wax and epoxies for physical and environmental protection [18]. According to manufacturer specifications, the ASG instrument had an accuracy of 1 microstrain and a resolution of 0.1 microstrain. The measurement range was 2000 microstrain and the temperature range was 0 to 150°C. As noted previously, the ASGs were installed in both the longitudinal and transverse directions. The ASG locations in NAPTF flexible test sections are illustrated in Fig. 3 with reference to traffic test lanes.

NAPTF Traffic Testing

A six-wheel dual-tridem gear configuration (B777) with 1372-mm (54-in.) dual spacing and 1448-mm (57-in.) tandem spacing was loaded on the north wheel track. The south side was loaded with a four-wheel dual-tandem gear configuration (B747) having 1118-mm (44-in.) dual spacing and 1473-mm (58-in.) tandem spacing. The wheel loads were set to 20.4 tons (45 000 lbs) each and the tire pressure was 1295 kPa (188 psi).

In the low-strength subgrade test sections (LFC and LFS), the wheel loads were increased from 20.4 tons (45 000 lbs) to 29.4 tons (65 000 lbs) after 20 000 initial load repetitions. The traffic speed was 8 km/h (7.33 ft/s or 5 mph) throughout the traffic test program. To realistically simulate transverse aircraft movements, a fixed wander pattern was performed during NAPTF traffic testing [25].

According to the FAA, the primary objective of the NAPTF trafficking tests was to determine the number of load applications to cause shear failure in the subgrade. Per NAPTF failure criterion, this is reflected as 25.4-mm (1-in.) surface upheaval adjacent to the traffic lane.

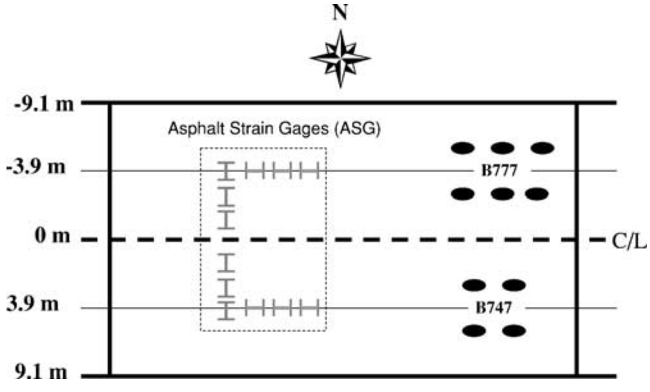

FIG. 3—*AC strain gage installation at NAPTF.*

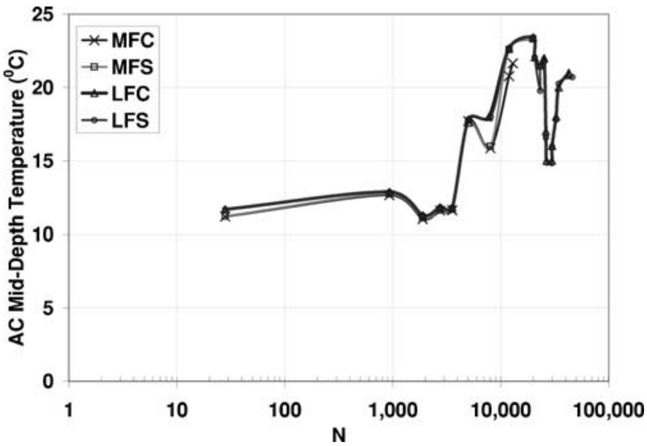

FIG. 4—*Variations in AC temperature during NAPTF trafficking.*

The low-strength sections (LFC and LFS) showed few signs of genuine distress even after 20 000 passes and therefore the wheel loading was increased from 20.4 to 29.4 tons.

The NAPTF traffic testing was started in February 2000 and was completed in September 2001. The AC temperature varied between 11 to 23°C (51 to 73°F) over the duration of traffic testing. The temperature of the AC layer during traffic loading has a significant influence on the pavement structural responses.

During the NAPTF construction, static temperature sensors were installed at different depths along the test sections to record the pavement temperatures at different times of the day. Pavement temperatures in the AC layer were monitored using Omega Thermistor temperature gages [18]. The temperature gages were placed at 13 mm (0.5 in.), 64 mm (2.5 in.), and 114 mm (4.5 in.) below the AC surface.

The seasonal variations in average daily pavement temperatures computed per depth during traffic testing were analyzed. The temperature measurements indicated that the temperatures in the AC layer show no significant variation with respect to depth [25]. It should be noted that the NAPTF is an indoor testing facility. The variations in AC layer mid-depth temperatures during traffic testing are plotted against the number of load repetitions (*N*) in Fig. 4.

Effect of NAPTF Traffic and Temperature on AC Strains

In studying the ASG responses from NAPTF slow-rolling response tests (0.34 mph), Gomez-Ramirez and Thompson [17] reported a wide range of values for the AC horizontal strain, at the bottom of the surface asphalt layer as well as the asphalt-stabilized base course. In stabilized-base test sections, the responses were higher at the bottom of the surface asphalt layer than the bottom of the AC stabilized base. For example, in the MFS section, horizontal strains at the bottom of the AC surface layer ranged from 1700 to 3500 microstrain; whereas strains ranged from 900 to 1700 microstrain at the bottom of the AC stabilized base course.

These inconsistencies were attributed to the slow rate of loading during the response tests. The authors noted that more consistent measurements could be obtained during the NAPTF traffic tests conducted at 8 km/h (5 mph).

Garg and Hayhoe [18] observed significantly higher peak strain values (ranging from 500 to 2000 microstrain) in the high-strength subgrade flexible test sections. Due to longer duration of loading at slow speeds, the ASG measured responses were about 2 to 3 times higher than the values predicted by layered elastic analysis pavement analysis programs.

To study the effects of speed of load application on the strain responses in the AC layers, Garg and Hayhoe [18] conducted additional tests on the high-strength subgrade flexible pavements. Garg and Hayhoe [18] clearly observed the effect of vehicle speed (load duration) and temperature on the measured AC strains. Higher speeds (lower load durations) produced lower strains. An increase in the AC temperature (mid-depth of the AC surface layer) from 11.1°C (52°F) to 22.2°C (72°F) resulted in an increase in AC strains ranging from 100 to 120 % (for the three load levels at all speeds). The effect of increasing

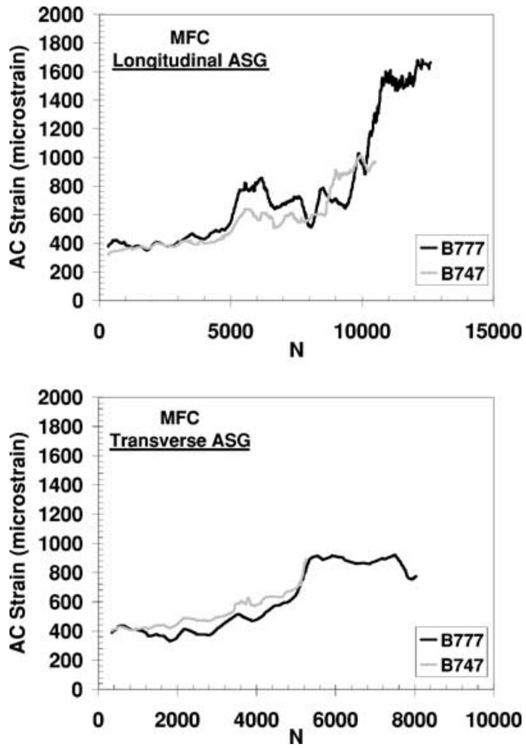

FIG. 5—*Peak AC strains in MFC section during trafficking.*

temperature was also to increase the proportion of viscous deformation relative to the elastic deformation [18].

The NAPTF traffic testing was started in February 2000 and was completed in September 2001. Although there were six longitudinal ASGs and six transverse ASGs, equally divided between the two traffic lanes, in each test section, not all the ASGs were fully functional during the entire duration of the traffic testing. Those ASGs that reported inconsistent measurements were considered unreliable and were not considered in the analysis.

The development of longitudinal and transverse peak AC strains in NAPTF test pavements with number of load repetitions (*N*) during traffic testing are shown in Fig. 5 and Fig. 6 for MFC and MFS sections, respectively. As expected, the peak AC strain magnitudes are strongly influenced by variations in AC temperatures. The drastic increase in AC strains between 4000 and 5000 passes with the increase in AC temperature from 12.8°C (55°F) to 20.6°C (69°F), is evident. By normalizing the effects of AC temperature, the effects of traffic loading alone on AC strain responses could be studied. The AC strain magnitudes increase at a drastic rate as the test sections approach failure. The steady rise in B777 AC strains after 8000 passes is consistent with the other dynamic sensor response results [25].

In Fig. 7 and Fig. 8, the development of AC strains with *N* are displayed for LFC and LFS sections, respectively. The drastic increase in AC strain magnitudes with the introduction of 29.4-ton (65 000-lb) wheel load at around 20 000 passes is clearly seen in the LFS section. For example, the B777 transverse AC strain gradually increased from 400 to 800 microstrain during 20 000 passes of 20.4-ton (45 000-lb) wheel loading. However, as the wheel load magnitude was increased to 29.4-ton (65 000-lb), the transverse AC strain increased from 800 to 1300 microstrain in a few thousand passes although the temperature remained more or less constant. These results are consistent with the trends in HWD-backcalculated AC moduli variations with *N* [26–28].

The transverse/longitudinal AC strain ratios were computed for each section. The transverse AC strains, in general, were equal to or higher than the longitudinal AC strains. Except for the MFS section, the AC strain ratios for both B777 and B747 gears remain between 1.0 and 1.5 for all sections. In the MFS section, the AC strain ratio is greater than 2.0 throughout the duration of trafficking.

Finite Element Modeling of NAPTF Flexible Pavements

Structural analyses of NAPTF flexible pavements were performed using the ILLI-PAVE flexible pavement finite element (FE) software [29]. Numerous research studies have shown that the ILLI-PAVE model

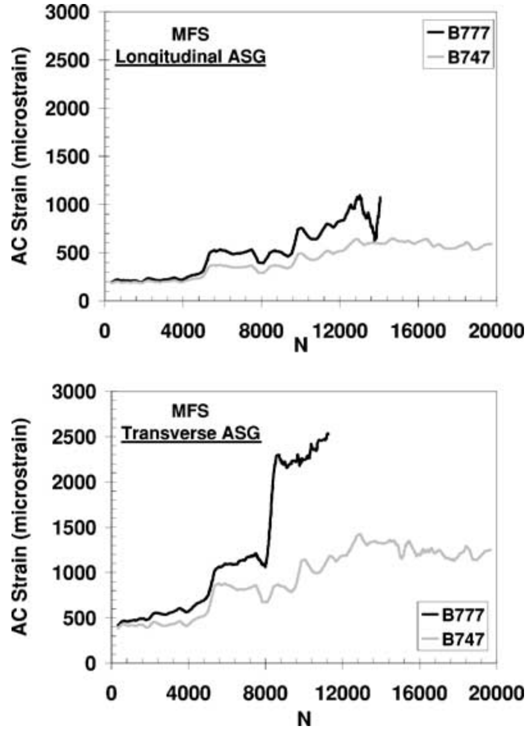

FIG. 6—*Peak AC strains in MFS section during trafficking.*

provides a realistic pavement structural response prediction for both highway and airfield pavements by incorporating nonlinear stress-dependent unbound material modulus models and Mohr-Coulomb failure criteria to limit material strength [17,21]. Thus, by incorporating realistic pavement geomaterial resilient modulus models, ILLI-PAVE can produce solutions for the dynamic analysis of flexible pavements.

Using the NAPTF response test results from the original flexible test sections, Gomez-Ramirez and Thompson [17] have shown the presence of unbound material nonlinearity at NAPTF. Garg and Marsey [30] have also observed the stress-dependent nature of underlying layers at NAPTF. Therefore, the use of

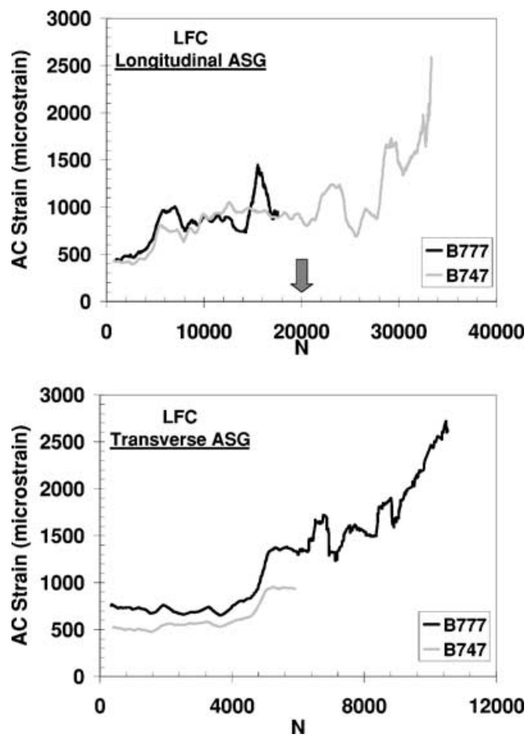

FIG. 7—*Peak AC strains in LFC section during trafficking.*

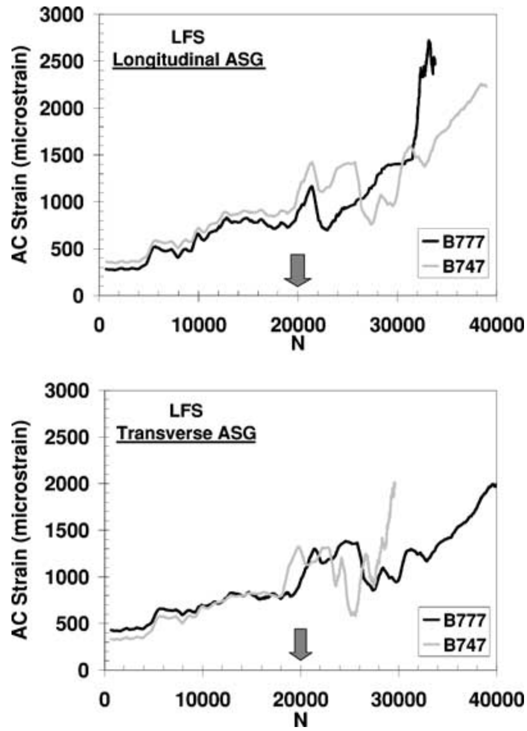

FIG. 8—*Peak AC strains in LFS section during trafficking.*

a pavement structural model like ILLI-PAVE, which can accommodate nonlinear stress-dependent materials, is more appropriate for performing NAPTF pavement structural analysis.

ILLI-PAVE is capable of considering only a single wheel load in contrast to Elastic Layer Programs that are capable of handling multiple wheel loads. Using the pavement response test results from the NAPTF and ILLI-PAVE structural models, Gomez-Ramirez and Thompson [17] verified the principle of superposition for six-wheel B777 and four-wheel B747 landing gear configurations.

Thompson et al. [31] have enhanced the ILLI-PAVE FE program to characterize flexible pavement response and performance under MWHGL aircraft using mechanistic-empirical concepts.

Using ILLI-PAVE, the NAPTF flexible pavement sections were modeled as two-dimensional, axisymmetric FE structures with as-constructed layer thicknesses. The P-401 AC layer and the natural sand layer were treated as linear elastic material with constant moduli and Poisson's ratio, whereas stress-dependent elastic models along with Mohr-Coulomb failure criteria were applied for the unbound pavement layers (P-209, P-154, and subgrade). The assumptions made during ILLI-PAVE modeling and the input parameters used for computing the structural responses are described in Ref. [25].

Comparison of AC Strains

A crucial link in the mechanistic-empirical pavement design process is to relate the critical structural responses (deflections, stresses, and strains) to pavement performance through transfer functions. The most commonly used approach is to relate the early-life pavement structural response to performance measures such as rutting level after trafficking or the number of load repetitions to reach some failure point.

The early-life AC strains measured using the longitudinal ASGs are compared with ILLI-PAVE computed longitudinal AC strains in Fig. 9 and Fig. 10 for low-strength subgrade test sections (LFC and LFS). Similar comparisons are shown for transverse AC strains in Fig. 11 and Fig. 12 for LFC and LFS test sections. Very similar trends were obtained for the medium-strength subgrade test sections (MFC and MFS) [25], but are not shown here due to space constraints.

In the longitudinal ASG strain pulses (Figs. 9 and 10), there was always compression first, then tension as the wheel passed over the ASG. Compression was always observed between the axles in the case of both B777 and B747 loading. The same behavior was observed in the ILLI-PAVE results. In general, the longitudinal ASG strains and the ILLI-PAVE computed values agreed well. In the conventional test sec-

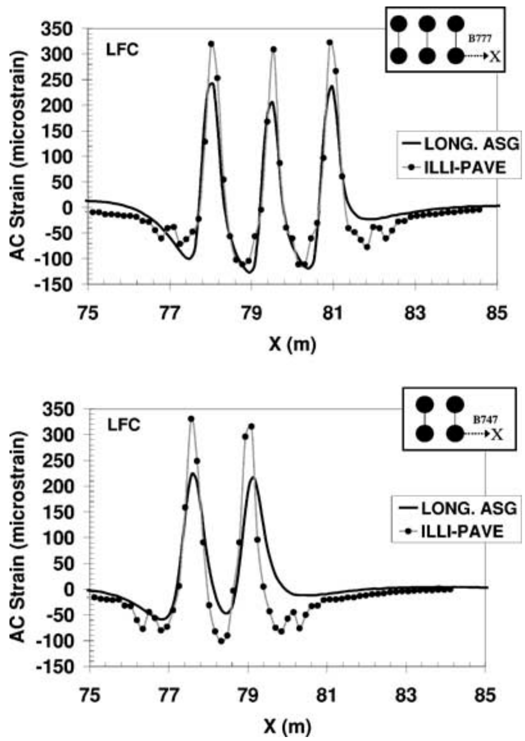

FIG. 9—*Comparison of early-life longitudinal AC strains in LFC section.*

tions (MFC and LFC), the ILLI-PAVE strains were higher than ASG strains whereas in the asphalt-stabilized test sections (MFS and LFS), the opposite is true. In general, the longitudinal ASG strains were approximately equivalent for both the dual-tridem (B777) and dual-tandem (B747) landing gears. This was more evident in the asphalt-stabilized test sections (MFS and LFS).

In contrast, there was no compression in the transverse ASG strain pulses (Figs. 11 and 12), but only tension. The tension accumulated as the test gear passed over the sensor. In studying NAPTF AC strain

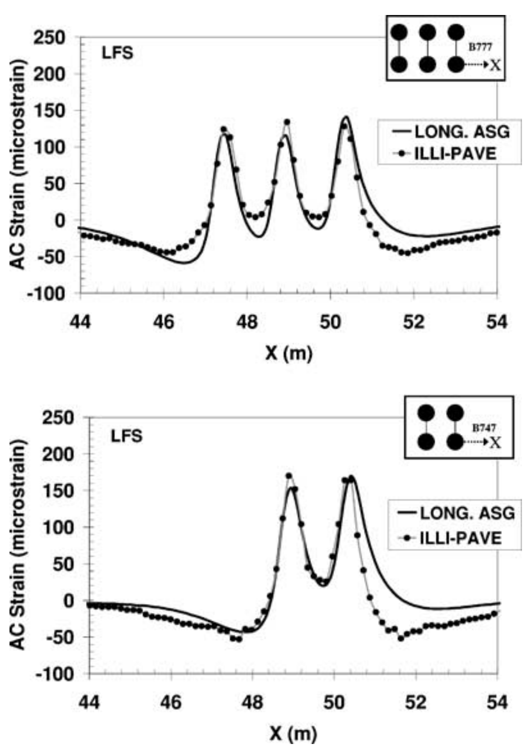

FIG. 10—*Comparison of early-life longitudinal AC strains in LFS section.*

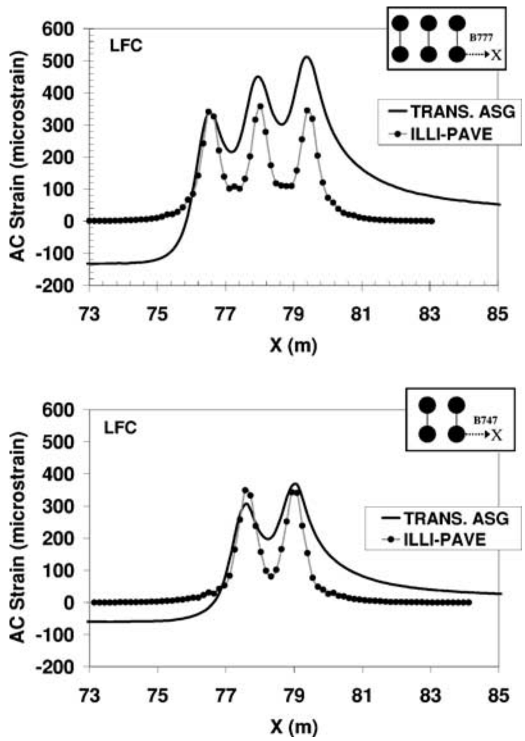

FIG. 11—*Comparison of early-life transverse AC strains in LFC section.*

responses at high loads and low speeds, Garg and Hayhoe [18] observed that this tension accumulation was higher at higher temperatures. Except for the B777 traffic lane in the MFC test section, the transverse ASG strain responses were higher than the ILLI-PAVE computed transverse strains in all four test sections.

The transverse-longitudinal AC strain ratios were calculated for both cases (ASG and ILLI-PAVE) and the results are compared in Fig. 13. Using ILLI-PAVE, the ratio is close to unity for all sections. In the case

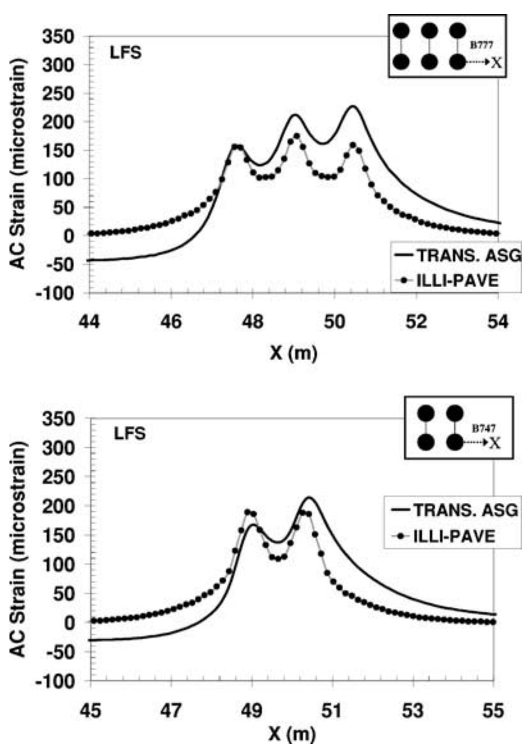

FIG. 12—*Comparison of early-life transverse AC strains in LFS section.*

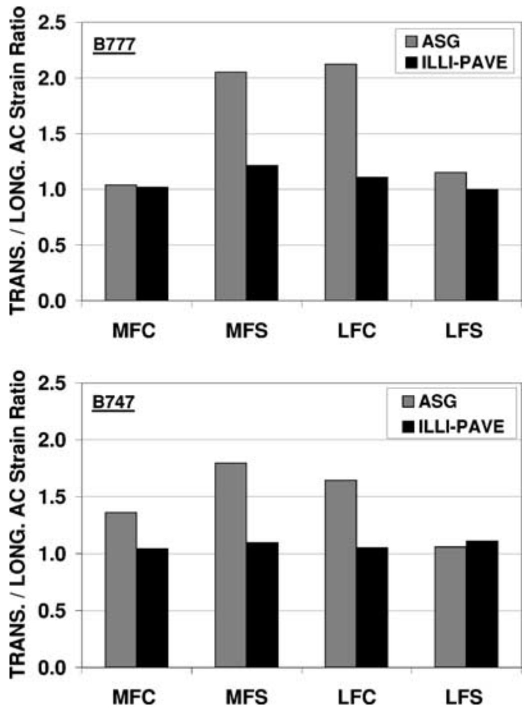

FIG. 13—*Comparison of transverse-longitudinal AC strain ratios.*

of ASG measured values, the ratio is greater than 1.0, and sometimes greater than 2.0. Further research using a mechanistic approach is required to model and compare the effects of longitudinal and transverse AC strain pulses on the fatigue behavior of AC pavements.

Pavement Performance

AC fatigue cracking and rutting are among the most common distresses in airport flexible pavements. The main focus of the NAPTF traffic test program was to evaluate these two pavement performance characteristics: rutting and AC fatigue cracking.

During NAPTF traffic testing, Transverse Surface Profile (TSP) measurements were to monitor the progression of rutting in the test sections. The NAPTF rutting study results showed that the mean rut depths obtained under B777 and B747 trafficking did not differ significantly between the two test gears in all four test sections [32].

Fatigue in asphalt concrete pavements appears as cracking at the surface of the pavement. The Strategic Highway Research Program Project A-003A made significant advancements in testing and evaluating the fatigue resistance of asphalt concrete mixes [33].

Unfortunately, AC surface cracking data as a function of the number of load repetitions was not collected during NAPTF traffic testing. The only surface cracking information available are the weekly distress observations recorded manually during NAPTF traffic testing. Significant observations were recorded regarding the development of distresses, such as the number of load repetitions to appearance of the first crack (N_{fc}), location of cracking, etc. were recorded.

The observations revealed that all the cracks in NAPTF test pavements were top-down cracks rather than bottom-up cracks. Most of the cracks appeared in the longitudinal direction parallel to the centerline of the pavement. No meaningful relation could be obtained between the early-life ASG/ILLI-PAVE AC strain values and N_{fc} in this study.

Top-down cracking in AC pavements is a phenomenon that has not yet been fully understood and has recently received a lot of attention [34]. The literature review indicated that the top-down cracks usually appear in the traffic path. However, in NAPTF test sections, most of the cracks appeared near the edge of the traffic path parallel to the centerline. One of the possible reasons for the cracks to appear at this location could be due to the high magnitudes of rut depths experienced by the NAPTF test sections.

Trench Study Findings

After the completion of NAPTF traffic testing, trench studies were conducted to investigate the failure mechanism of the pavement structures.

In the medium-strength flexible test sections (MFC and MFS), rutting was primarily contributed by the subgrade and P-154 subbase layer. Subgrade intrusion into the P-154 subbase layer was observed. In both the low-strength subgrade test sections (LFC and LFS), rutting was observed in the P-401 AC layer, P-209 base layer, and P-154 subbase layers in both the traffic paths. Shoving occurred in the P-401 AC layer [35–38]. The trench study findings also confirmed that the surface cracks in the NAPTF test pavements were all top-down cracks.

While the medium-strength subgrade test sections were declared to be failed at the subgrade level as per NAPTF failure criterion, the LFC and LFS sections failed in the surface layers, signifying tire pressure or other upper layer failure effects, but not subgrade level failure [36]. According to Hayhoe [38], full structural failure did not occur in the LFC and LFS test sections, probably because the subgrade material contained a significant amount of silt and the upper layers of the subgrade dried somewhat over the long period of time between construction and starting of traffic testing.

Summary/Conclusions

Asphalt Strain Gages (ASGs) were installed in both the longitudinal and transverse directions at the Federal Aviation Administration's National Airport Pavement Test Facility to measure the load-induced Asphalt Concrete tensile strains during full-scale traffic testing.

The primary objective of this study was to evaluate the horizontal strains measured in the AC layers of four flexible pavement sections during full-scale traffic testing at the NAPTF. The other objectives are to compare the field-measured AC strains with those computed using a flexible pavement finite element structural model (ILLI-PAVE) and assess the relative severity effects of dual-tridem Boeing 777 (B777) and dual-tandem Boeing 747 (B747) gear configurations on AC strain responses.

The peak AC strain magnitudes were strongly influenced by variations in AC temperatures during NAPTF traffic testing. The AC strain magnitudes increased at a drastic rate as the test sections approached failure. The drastic increase in AC strain magnitudes with the introduction of 29.4-ton (65 000-lb) wheel load at around 20 000 passes was evident in the LFS section. The transverse ASG AC strains, in general, are equal to or higher than the longitudinal AC strains.

The ASG measured early-life AC strains were compared with ILLI-PAVE computed AC strains. The agreement between ASG strains and ILLI-PAVE estimated strains was better for longitudinal strains. The transverse-longitudinal AC strain ratios were computed and the results were compared. In the case of ILLI-PAVE computations, the ratio is close to unity for all sections. In the case of measured values, the ratio is greater than 1.0, and sometimes greater than 2.0.

Analyses of NAPTF traffic test results indicated that there was no relation between the early-life AC strain values and the number of load repetitions to appearance of first crack, N_{fc}. The surface cracks observed in the NAPTF test pavements during trafficking were all top-down cracks. In general, the longitudinal ASG strains were approximately equivalent for both the dual-tridem (B777) and dual-tandem (B747) landing gears.

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