Mechanical Response of Unbound Materials in Perpetual Pavement Sections at the National Airport Pavement Test Facility

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ABSTRACT

During Construction Cycle 7 (CC7) at the FAA National Airport Pavement Test Facility (NAPTF), instrumentation to monitor the mechanical response of unbound materials was installed in four perpetual test pavement items. These items had different structures but were trafficked under relatively constant heavy aircraft loads using a uniform gear configuration. Earth pressure cells (PC) and multi-depth deflectometers (MDD) captured vertical stresses at the top of the subgrade and permanent deformation in the subbase material, respectively. Also, temperature profiles in the hot mix asphalt (HMA) layer were obtained from thermocouples embedded at different depths. This unique full-scale test experiment gives insight into the influence of pavement structure and aircraft loads upon the unbound materials behavior and overall structural performance. Stresses at the top of subgrade show a decrease with increasing thickness of the HMA layer. A relatively significant effect of the interaction between HMA layer thickness and temperature on the seasonal variation of subgrade stresses was observed. The benefits of increasing the thickness of HMA layer to limit the permanent deformation in both the subbase and subgrade layer were assessed. Forensic evidence confirming that most of the permanent deformation took place in the subbase layer is presented.

Keywords: Perpetual pavement, vertical stress, permanent deformation, heavy aircraft load, pressure cell and MDD.

1. INTRODUCTION

The Asphalt Pavement Alliance (APA) introduced the concept of Perpetual Pavements in 2000 [1]. Perpetual pavement is defined as an asphalt pavement designed and built to perform for 50 years or more without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement [2]. With perpetual pavements, the potential for traditional fatigue cracking is reduced, and pavement distress is typically confined to the upper layer of the structure. This concept is an appealing alternative to airport pavements where minimizing rehabilitation and reconstruction costs as well as closures to traffic operations is critical. In order to study the effect of HMA layer thickness and support the development of perpetual pavement design criteria for airfields, four perpetual pavement test items were designed, constructed, and fully instrumented as a part of Construction Cycle 7 (CC7) at the FAA National Airport Pavement Test Facility (NAPTF) [3].

The main objective of the study presented in this paper was to evaluate the effect of varying HMA layer thickness on the mechanical response and performance of the unbound materials in the perpetual pavement test items.

2. BACKGROUND

2.1 Pavement Structure and Instrumentation

Four perpetual test pavements were designed using FAARFIELD [4]. A 3D (3 Duals in Tandem) gear configuration was considered for design with 245 kN (55,000 lb) wheel load. In the design, a fatigue failure mechanism was induced whereas subgrade failure was prevented. The test items designated LFP1, LFP2, LFP3 and LFP4; were constructed on a FAA specification P-152 [5] low-strength subgrade with target California Bearing Ratio (CBR) of 5.5. As-built thicknesses of FAA specification P-401 HMA [5] and FAA specification P-154 granular subbase [5] for all test items are detailed in Figure 1(a). Thermocouples were installed within the HMA layer at multiple depths. MDDs at various depths and PCs on top of the subgrade are some of the dynamic sensors installed in each test item as seen in Figure 1(b). The MDD components capture deflections at multiple depths: E and F at different depths within P-152, B to D at different depths within P-154, and A near the bottom of P-401. Figure 1(c) shows the approximate location of sensors within each test item.

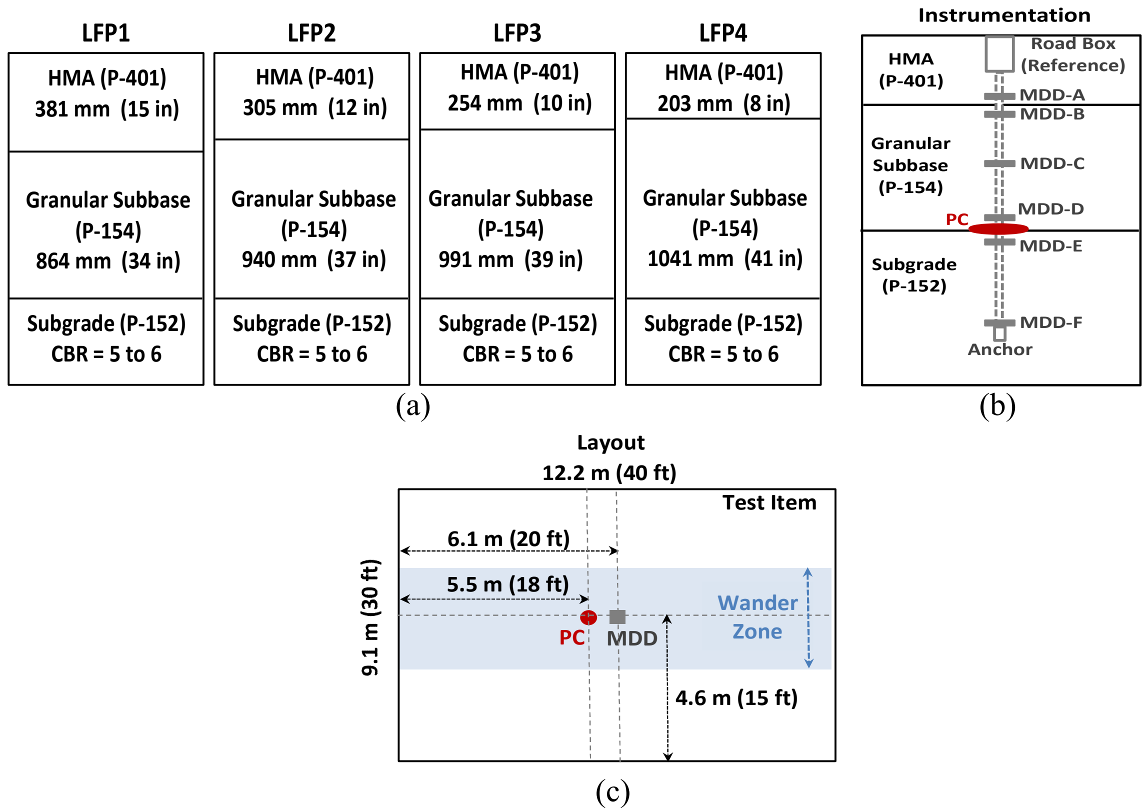


FIGURE 1 Structure and Instrumentation: (a) Perpetual Items, (b) Instrumentation Cross Section, (c) Instrumentation Layout

2.2 Traffic Test

Full-scale traffic test was conducted using a 3D (three duals in tandem) gear configuration (245 kN per wheel) at a vehicle speed of 4 km/h (2.5 mph). The wheel load was increased to 289 kN (65,000 lb) after 30,030 passes on LFP1 and LFP2. The wander pattern consisted of 66 repetitions arranged in 9 wheel tracks to simulate a taxiway normal distribution. Surface rut depth (SRD) measurements were conducted at various intervals during trafficking. Similar to the criteria used by the U.S. Army Corps of Engineers for the multiple wheel heavy gear load test series [6], the CC7 perpetual sections were deemed failed if surface cracking developed to the point that the pavement is no longer waterproof. Traffic test was terminated on LFP1 and LFP2 after completion of 37,686 passes with no evidence of any fatigue cracks. Due to severe fatigue cracking observed on LFP3 and LFP4, trafficking was stopped after completion of 35,046 and 27,192 passes, respectively.

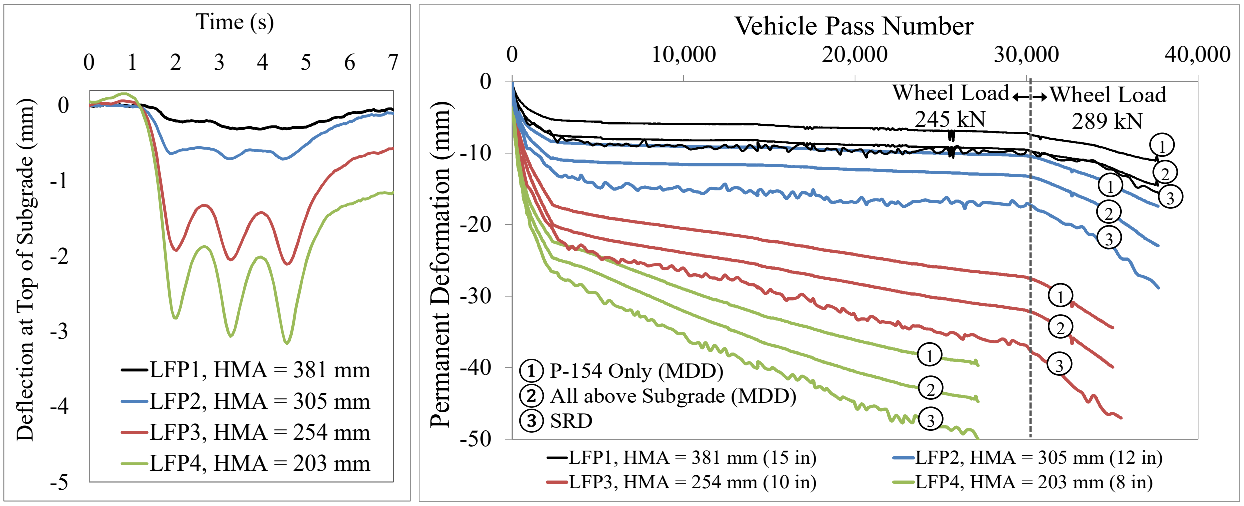
3. MECHANICAL RESPONSE OF UNBOUND MATERIALS

The dynamic data analysis in this section is based on the critical responses observed for each sensor. This response corresponds to the wheel track (transverse position) of the landing gear that produced the maximum sensor response value. Although only key findings are summarized herein, elaborated discussion on the analysis can be found elsewhere [3].

3.1 Vertical Deformation of Unbound Layers

Inspection during CC7 post-traffic trenches revealed structural damage in the lower part of corrugated tubes of MDDs and clay intrusion that restricted vertical movement. This was believed to be the cause of the irrationality observed in the subgrade MDD data. Hence, MDD subgrade data was not considered for the CC7 dynamic data analysis. Figure 2(a) shows that the MDDs captured the effect of HMA thickness on the pavement deflections pulse measured at the top of subgrade. These responses were recorded during a vehicle pass that took place when the HMA layer temperature was 11°C (52°F). As the HMA thickness increased, better protection to unbound materials against the wheel loads was provided resulting in flatter response curves of lower magnitude. In Figure 2(b) a direct comparison of permanent deformation accumulation with traffic across perpetual sections is shown. A notable increase in the rate of accumulation of permanent deformation in response to the increase in wheel load from 245 kN to 289 kN after 30,030 vehicle passes is noticeable in items LFP1, LFP2, and LFP3. MDD permanent deformation curves for the P-154 subbase only and all material above subgrade are provided for each section. The discrepancy between these curves is most likely attributed to confined shallow HMA permanent deformation that was not captured by MDDs. The third curve in each set shows the SRD measurements during trafficking. The discrepancy between measured SRD and MDD permanent deformation of all material above subgrade can be attributed to the subgrade contribution to the total permanent deformation.

In Figure 2(b) a negligible discrepancy was observed between the SRD and MDD permanent deformation of all material above subgrade for LFP1, which indicates that the 381 mm of HMA completely isolated the subgrade from detrimental levels of load-induced stress. Note that as the HMA thickness decreased, the discrepancy between SRD and MDD permanent deformation for all material above subgrade increased indicating increasing subgrade exposure to load-induced stresses and thus, increasing subgrade damage. Also, the MDD data in Figure 2(b) revealed that the major contributor to permanent deformation was unquestionably the P-154 subbase material. This is consistent with findings reported in prior experiences at the NAPTF [7, 8]. Regardless of the dataset used to compare the performance of perpetual sections, increasing the HMA thickness resulted in decreasing the load-induced stresses imparted to the unbound materials and hence, minimizing the total permanent deformation.

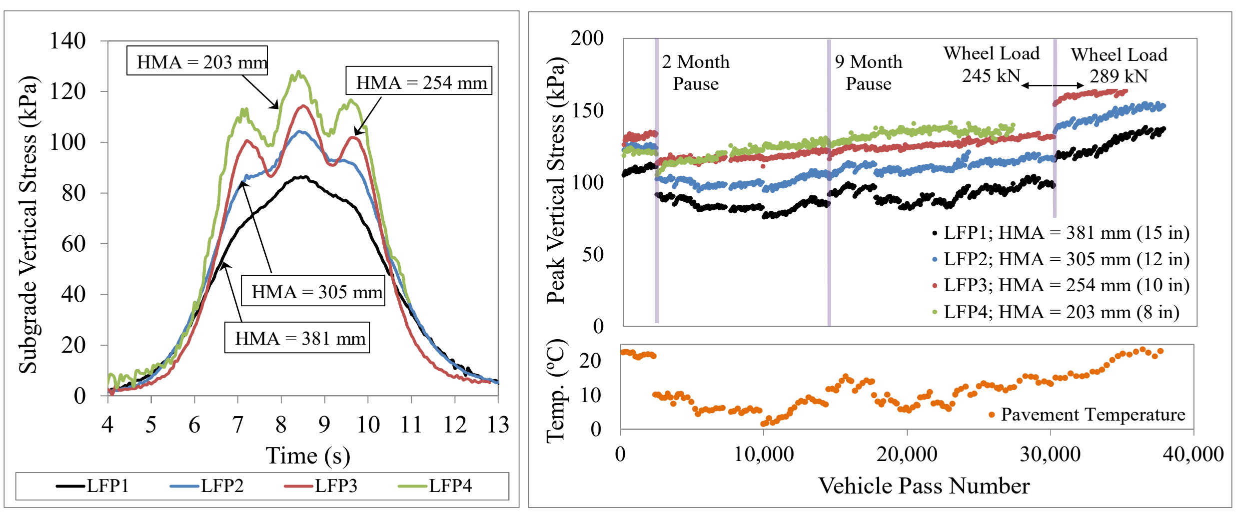


(a) (b)

FIGURE 2 Vertical Deformation: (a) Deflection Pulse at Top of Subgrade, (b) Permanent Deformation Comparison across Perpetual Sections

3.2 Subgrade Vertical Stresses

Figure 3(a) shows how the PCs captured the effect of HMA thickness on the vertical stress pulse measured at the top of subgrade in a single vehicle pass (at average temperature conditions). Similar to the MDD deflection pulses, as the HMA thickness increased, the protection for unbound layers against the wheel loads improved resulting in flatter response curves of lower magnitude. In Figure 3(b), both the peak vertical stresses and corresponding average HMA layer temperature are plotted. By increasing the HMA thickness, peak vertical stresses on top of the subgrade decreased. Trafficking pauses and the wheel load change after 30,030 vehicle passes are also indicated by purple vertical markers.



(a) (b)

FIGURE 3 Vertical Stresses at Top of Subgrade: (a) Full Stress Pulse Comparison, (b) Peak Vertical Stress Comparison across Perpetual Sections

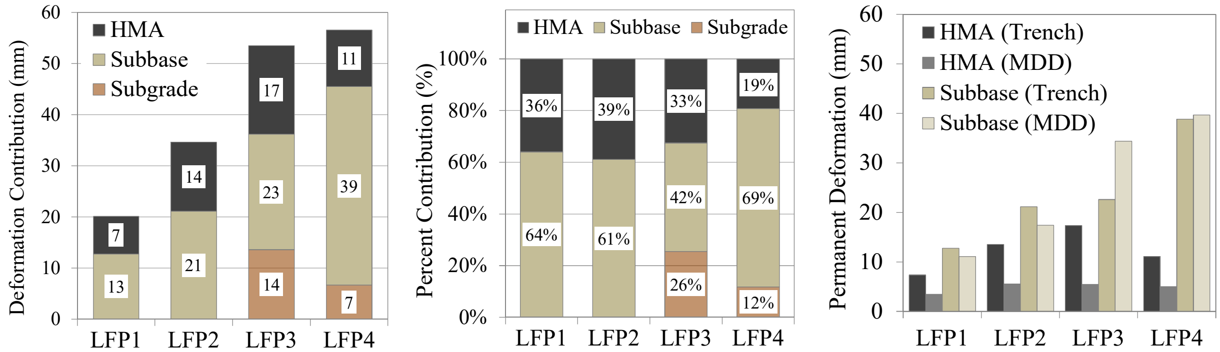
In Figure 3(b), a strong correlation between the HMA layer temperature and subgrade vertical stresses that further strengthened with increasing HMA thickness is observed. For instance, perpetual sections LFP1 and LFP2 showed more sensitivity to seasonal temperature changes than LFP3 and LFP4 due to the temperature dependency of the HMA stiffness. Although forensic investigation showed no subgrade permanent deformation in LFP1 and LFP2, the potential for seasonal fluctuation of vertical stresses on unbound materials was evidenced and its relative significance in the design of perpetual pavements may need to be assessed as part of future research efforts. In general, regardless of pavement temperature, increasing the HMA thickness resulted in a decrease of the vertical stresses on top of the subgrade.

3.3 Post-traffic Forensic Study

CC7 forensic study is currently underway. Trenches were excavated in all perpetual sections. When the MDDs were exposed, severe damage was observed in the portion installed within the subgrade. This is consistent with the subgrade data irrationality encountered when extensive MDD data analysis was conducted [3]. Layer profiles were also measured in the trenches. As seen in Figures 4(a) and 4(b), layer profiles confirmed that the major contributor to permanent deformation in all perpetual sections is the P-154 subbase layer, with a percent contribution ranging between 42% and 69%. Although not all perpetual sections were subjected to the same number of load repetitions, Figure 4(a) shows that in general, less HMA thickness resulted in more P-154 subbase and total permanent deformation; same as concluded from the MDD data analysis. Figure 4(b) indicates that regardless of the HMA thickness, the HMA contribution to permanent deformation approximated a third of the total deformation. Even though a discrepancy between SRD and MDD permanent deformation for all material above the subgrade was encountered for LFC2 (i.e.; suggesting subgrade deformation), layer profiles showed that actually no rutting developed in the subgrade. Thus, perpetual sections with HMA thicknesses over 305 mm were very effective at protecting the subgrade from traffic-induced vertical stresses. A comparison of estimated permanent deformation between layer profiles and MDD data is presented for the HMA and subbase layer in Figure 4(c). Generally, the estimates for the P-154 subbase were fairly consistent regardless of the data source whereas, for the HMA layer, MDD based deformations are clearly inconsistent with field measured values. This is due to the fact that a rigid road box containing the MDD electronics is embedded within the top 51 to 76 mm of the HMA layer, which prevents the MDD from properly capturing confined shallow HMA permanent deformation.

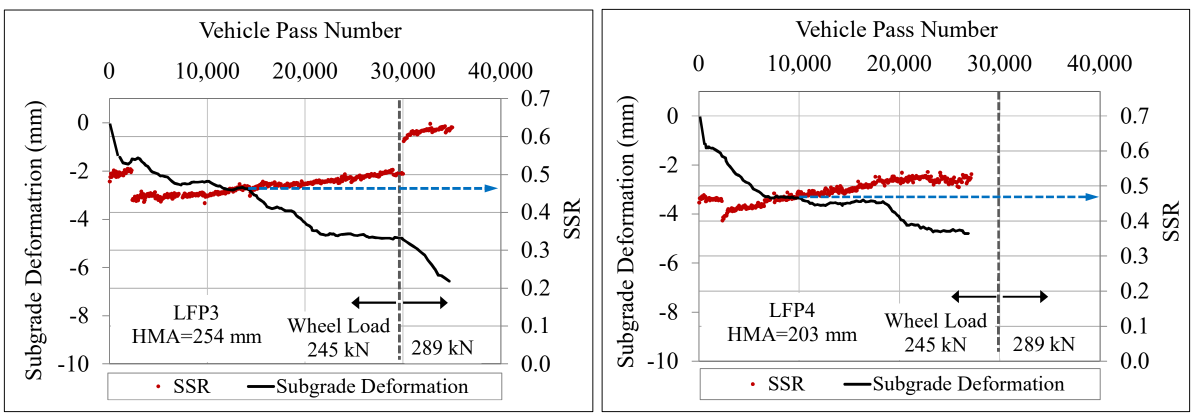
3.4 Performance and Mechanical Response

Preliminary analysis aimed at relating the development of permanent deformation in the subgrade to the stresses measured by PCs on the top of subgrade was conducted. Subgrade reconstituted specimens were tested for unconfined compressive strength (UCS). Using PC data, subgrade stress ratios (SSR) relative to an average UCS of 262 kPa were estimated for all perpetual sections. The permanent deformation in the subgrade was estimated as the difference between the measured SRD and the MDD permanent deformation of all material above subgrade, for LFP3 and LFP4 only. Figure 5 shows the correlation between SSR and permanent deformation in the subgrade for these perpetual sections. Although the estimated subgrade permanent deformation values in Figure 5 did not necessarily match the layer profile measurements in Figure 4, it is believed the deformation accumulation trends were adequately captured. SSR values above 0.5 appear to accelerate the accumulation of permanent deformation. In-depth analysis integrating CC7 instrumentation, performance and forensic data is currently underway to evaluate the potential of using SSR as a pavement design parameter.



(a) (b) (c)

FIGURE 4 Permanent Deformation from Layer Profile: (a) Layer Contribution in Deformation Unit, (b) Layer Contribution in Percent Unit, (c) Layer Profile vs. MDD



(a) (b)

FIGURE 5 Correlation between Subgrade Permanent Deformation and Subgrade Stress Ratio: (a) Perpetual Section LFC3, (b) Perpetual Section LFC4

4. CONCLUSIONS

Perpetual pavements were tested as part of CC7 at the NAPTF. Mechanical responses of unbound materials captured by MDDs and PCs, along with performance data and forensic study results revealed that perpetual sections with a HMA layer thicker than 305 mm completely remove the potential for rutting development in the subgrade and further reduce the permanent deformation in the subbase. The P-154 subbase was confirmed to be the major contributor to the total pavement permanent deformation. A comparison between MDD-based and field-measured permanent deformation showed that the MDDs produced good quality data for intermediate unbound layers but were unable to capture the total deformation in the HMA surface layers due to the way MDDs are configured and installed. An exploratory evaluation of the subgrade SSR as a parameter controlling the development of subgrade permanent deformation was discussed.

5. ACKNOWLEDGEMENT

The work described in this paper was supported by the FAA Airport Technology Research and Development Branch. The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA. The paper does not constitute a standard, specification, or regulation.

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