Investigation of Deformation Trends Observed in Pavement Test Section Unbound Aggregate Layers Due to Heavy Aircraft Loading with Wander

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Abstract

Federal Aviation Administration (FAA) built the National Airport Pavement Test Facility (NAPTF) to investigate airfield pavement responses due to complex gear loadings of New Generation Aircraft (NGA). One of the latest series of full-scale flexible pavement tests conducted with available field data is referred to as the Construction Cycle 5 (CC5) test, part of which is the subject of the analyses presented in this paper. The NAPTF CC5 test database includes individual pavement responses collected using installed sensors, such as Multi-Depth Deflectometer (MDDs) due to the proximity applications of six-wheel dual-tridem gear. Pavement test sections in CC5 built with a dense graded aggregate (DGA) layer met New Jersey highway specifications, over a low strength subgrade that was selected for the analyses. The unbound aggregate base/subbase MDD data have been analyzed to investigate the layer deformation trends of pavement sections. It was seen that initially shakedown was occurring in the P209 base layers while at the same time the DGA subbase layer was deteriorating. Also, the pavement section did not show an apparent increase in residual deformations due to increased traffic. Upholding an FAA priority for research and development in the area of improved methods for airport pavement damage analyses, this paper focuses on investigating the deterioration behavior of granular layers under heavy aircraft loading.

Key words: Unbound aggregates, base, subbase, airfield pavement, Multi-depth deflectometer, full-scale testing, rutting, load wander

Introduction

Unlike highway pavements which see mostly channelized traffic, airfield pavements experience higher load levels with wander (lateral movement of aircraft). Though wander reduces the number of repetitions of maximum load applied to the most heavily-trafficked pavement location, wander does not necessarily increase the pavement life and can in reality be very damaging to the pavement due to the increased movement and rearrangement of particles in the unbound aggregate layers. Furthermore, with the introduction of New-Generation Aircraft (NGA) combined with rapid growth of airline traffic, an urgent need has arisen for proper understanding of the deformation behavior of pavement layers due to aircraft wander coupled with complex gear landings. Recent research work conducted using full scale test data from the

Federal Aviation Administration's (FAA's) National Airport Pavement Test Facility (NAPTF) has clearly indicated significant effects of wander (offset loads) on the deformation behavior of unbound aggregate layers in asphalt pavement test sections (Garg, 2003; Hayhoe, 2004; Hayhoe et al., 2004). The NAPTF applied a sequential wander pattern covering approximately 82% of all traffic from a standard normal distribution curve of real world taxiway traffic. During a complete trafficking wander pattern, some of the residual deformation caused by a single pass was recovered due to subsequent load applications offset by wander (Hayhoe, 2004; Hayhoe et al., 2004). Figure 1 provides a simple diagram of the observed behavior and shows how the stress in a soil element offset from a load can change with a moving wheel.

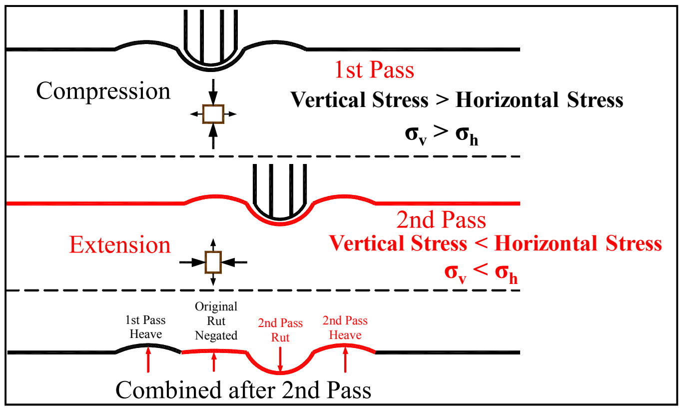


Figure 1. Schematic explaining the rut profile development from an offset wheel

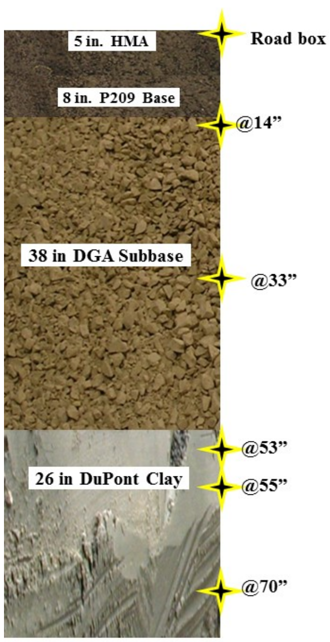
More recent research efforts at the University of Illinois focused on the analyses of the behavior of unbound aggregates to offset wheel loads (Donovan and Tutumluer, 2008, 2008a, 2008b; Donovan, 2009). Essentially, the study of dynamic response data indicated that the unbound aggregate particles move because of the constantly changing load application lane. This movement negated the stabilization or shakedown expected in unbound aggregate layers under repeated loads and the strong stable particle matrix predicted to develop by shakedown theory never materialized. And the application of the wander pattern to the low and medium strength subgrade asphalt pavement NAPTF test sections were found to cause the so-called "anti-shakedown effect" in the unbound aggregate layers. Further, comparison of channelized traffic and traffic with wander indicated that traffic with wander might be more detrimental to the unbound aggregate layers due to the increased movement and rearrangement of particles in the unbound aggregate layers.

This paper presents NAPTF full scale pavement test section findings from the preliminary analyses of multi-depth deflectometer (MDD) data and identifies deformation trends in the unbound aggregate layers due to applied aircraft gear loading with wander. Upholding an FAA priority for research and development in the area of improved methods for airport pavement damage analyses, this paper will focus on investigating the deterioration behavior of granular layers under heavy aircraft loading applied with wander.

NAPTF Testing

Federal Aviation Administration (FAA) built the National Airport Pavement Test Facility (NAPTF) to generate full-scale testing/trafficking data in order to support the investigation of the performance of airport pavements subjected to complex gear loading configurations of new generation aircraft applied with wheel load wander. The NAPTF consists of a 900 ft long and 60 ft wide test track along with a rail-based test vehicle built with two carriages. Each carriage in the vehicle can be equipped with two load axles with each axle capable of carrying 20 wheels with a maximum total load capacity of 1.3 million pounds with various combinations of landing gear and wander sequences. Test sections are trafficked at a travel speed of 5 mph which represents aircraft taxiing from the gate to the takeoff position. Full scale testing conducted at the NAPTF are assessed by construction cycles, and one of the most recent series of full-scale flexible pavement tests conducted with available field data is referred to as the Construction Cycle 5 (CC5) test, part of which are the subject of the results presented in this paper. The CC5 test database included individual pavement responses collected using installed sensors, such as Multi-Depth Deflectometer (MDDs) due to the applications of six-wheel (typical Boeing 777 aircraft like) dual-tridem landing gears. A simulated wander pattern that represented the taxiway distribution for design consisting of 66 repetitions, 33 travelling west and 33 travelling east, arranged in nine equally spaced wander positions (or tracks) at intervals of 10.25 inches was applied to the test sections during the test period (see Figure 2 b and c). The dual wheel spacing used in 6-wheel landing gear was 54 in and the wheel loads were initially set to 59,000 lbs. with a tire pressure of 243 psi. This paper will present the preliminary analysis results using dynamic response data from the CC5 test section that was built using a dense graded aggregate (DGA) meeting the specifications of New Jersey highway agency and the low strength DuPont clay subgrade. Figure 2a shows the configurations of the selected test section along with the locations of MDD sensors along the pavement cross-section.

(a)



(b)

Wander Position	1	-1	0	Sequence 5
Pass Number	61,62	63,64	65,66	

Wander Position	-2	0	2	1	-1	Sequence 4
Pass Number	51,52	53,54	55,56	57,58	59,60	

Wander Position	3	1	-1	-3	-2	0	2	Sequence 3
Pass Number	37,39	39,40	41,42	43,44	45,46	47,48	49,50	

Wander Position	-4	-2	0	2	4	3	1	-1	-3	Sequence 2
Pass Number	19,20	21,22	23,24,	25,26	27,28	29,30	31,32	33,34	35,36	

Wander Position	-4	-2	0	2	4	3	1	-1	-3	Sequence 1
Pass Number	1,2	3,4	5,6	7,8	9,10	11,12	13,14	15,16	17,18	

(c)

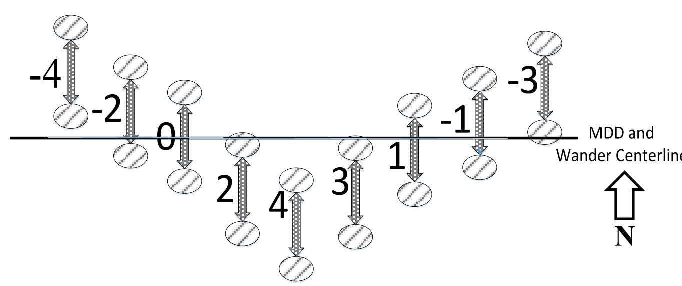


Figure 2. (a) Layer configuration of the dense-graded aggregate (DGA) base, (b) applied wander sequence, and (c) 6-wheel gear centerline position for each wander position

Preliminary Analyses of MDD Data

The initial MDD data provided for the CC5 testing was in a comma separated value format and a code written using Python was utilized to convert the MDD sensor data into individual layer deformation values and residual deformation values. The initial assessment of the collected MDD readings seemed erratic and random; however, when the data were separated by wander position, travel direction, and wander sequence, distinct patterns emerged.

(a)

(b)

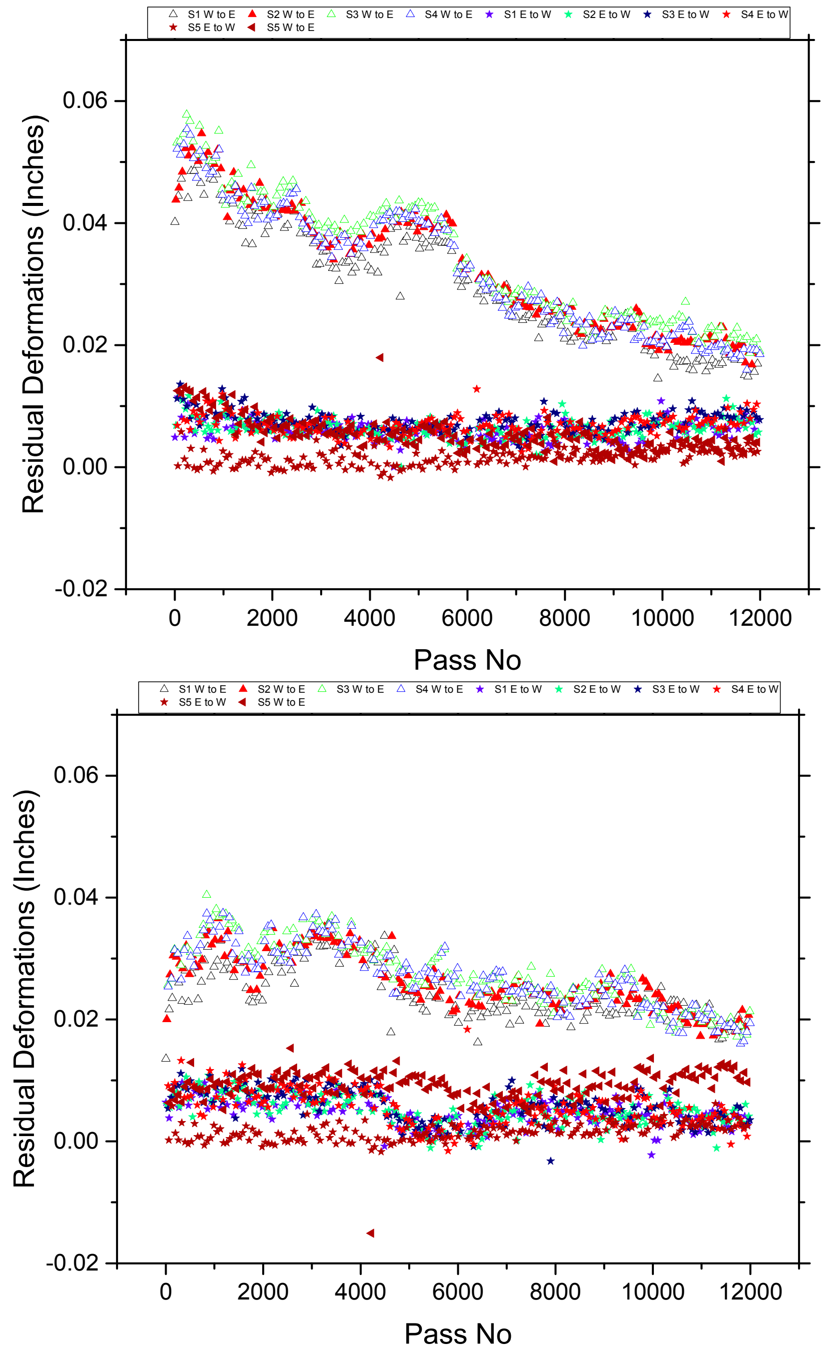
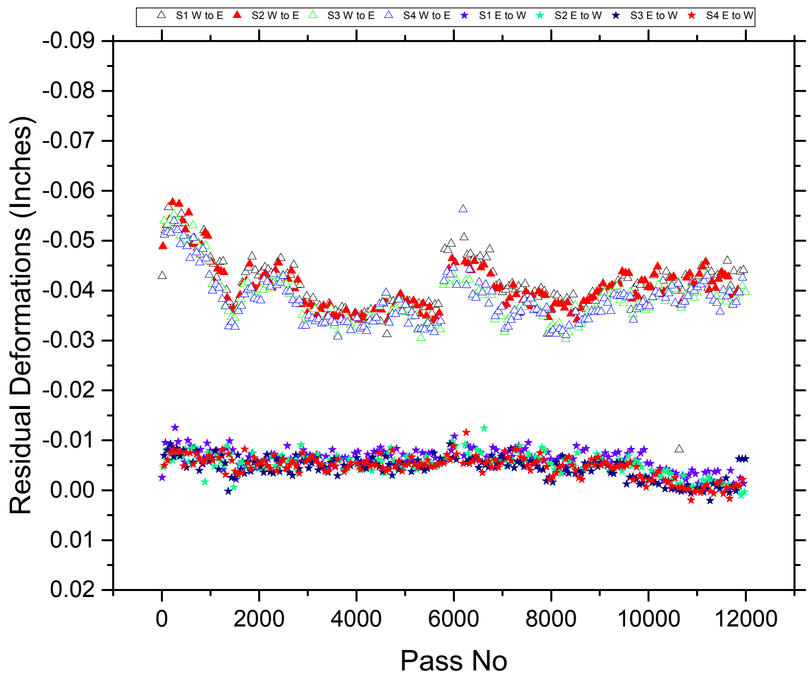


Figure 3: Residual deflections accumulated at wander position 0, a) surface and P209 layers and b) DGA subbase layer

The separation of the residual deflection data for wander position 0 by individual wander positions and sequences for the surface and P209 layer and for the DGA layer are shown in Figure 3a and b respectively. Similar results are presented in Figure 4a and b for wander position 2. Please note that there was no MDD sensor installed at the interface of HMA surface and P209 base layer, hence these two layers were analyzed together.

(a)



(b)

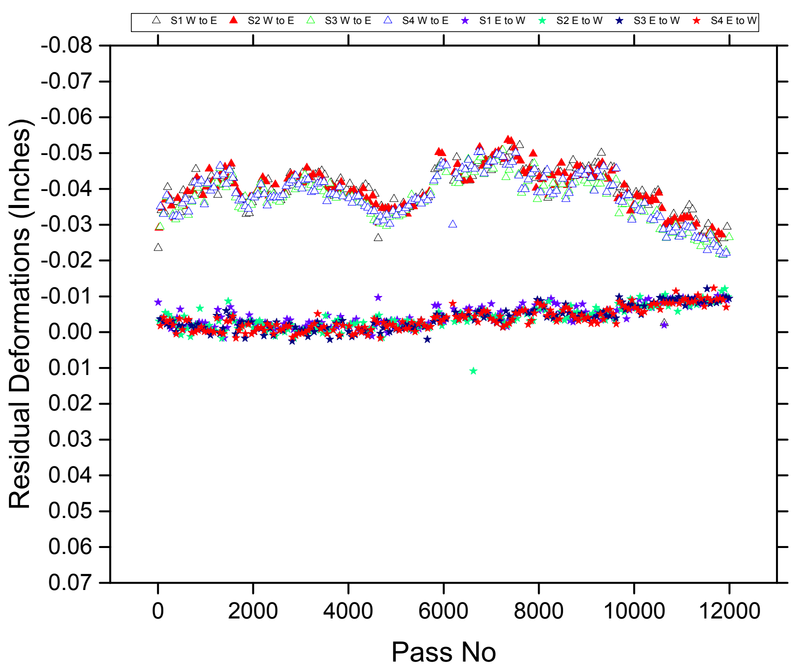


Figure 4: Residual deflections accumulated at wander position 2
a) surface and P209 layers and a) DGA subbase layer

The data separation also leads to an important observation which was that the first pass on each wander position in the West to East direction typically caused the most response and the return pass along the same wander position showed significantly less residual deflection. This finding clearly indicates that shakedown was occurring in the unbound aggregate layers.

- The aggregate shakedown concept as defined by Werkmeister et al. (2001) has identified three zones of shakedown which are dependent on the stress level as following (see Figure 5): Zone A-plastic shakedown: is characterized by a quick decrease in the residual deflections which eventually leads to the layer showing no further residual deformation with additional load repetitions.
- Zone B-plastic creep: initially goes through a decreasing residual deformations but as the number of load cycles increase, the residual deformation rate increases subsequently leading to an incremental collapse.
- Zone C-incremental collapse: shows a slower reduction in the residual deformations than in zones A or B and a quick resurgence of the strain rate after a very limited number of load cycles.

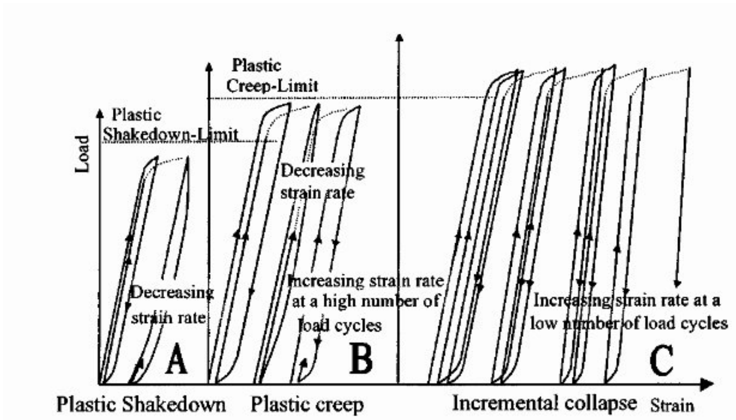


Figure 5: Idealized behavior of granular materials under repeated cyclic pressure load (Werkmeister et al. 2001)

It is also likely that for all shakedown ranges, any particle rearrangement that occurs due to stress will relieve some small amount of the residual compressive stress in an unbound layer that was induced by compaction and preloading of the layer; which in turn will cause additional rutting. Figure 3 and 4 also show that the P209 base and DGA subbase layers consolidated only a little during testing. If the shakedown did occur in the unbound aggregate layer, the percent of residual response by layer would decrease for the surface and P209 and DGA layers. However, as shown in Figure 6, this did not happen with increasing pass number. The percent of the residual response remained relatively constant for each layer as the testing progressed, i.e., 56% for surface and P209, 41% for DGA, and 3% for the subgrade (wander position 0). Though an exception can be seen in the surface and P209 layers (see Figure 6), an apparent shakedown or compaction occurred in the surface and P209 layer as the initial 1000 passes shows a decrease in the percent of residual response from the surface and P209 layer. Interestingly, this compaction in the surface and P209 layers was counteracted by an increase in the percent of residual response by the DGA layer for the same 1000 passes. Due to the excessive movements of the layers, the MDD data are only reliable up to 6500 passes.

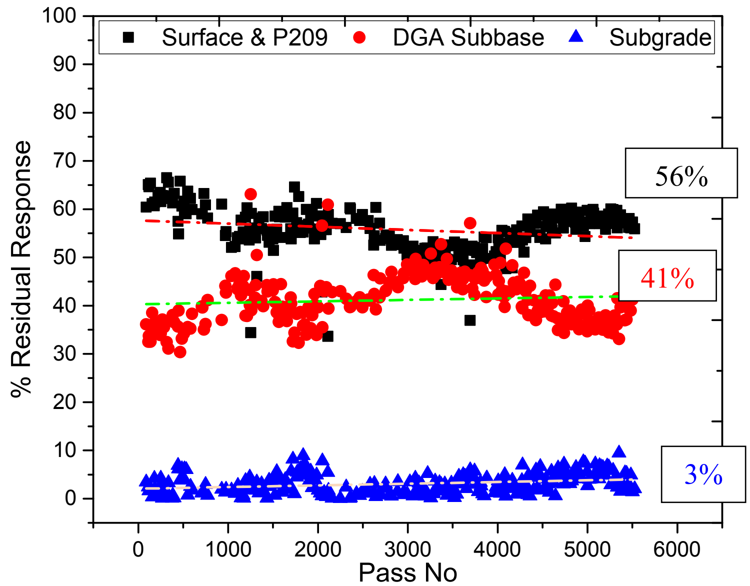


Figure 6: Layer percentage of the total residual response on the B777 lane, west to east loading direction, wander position 0

Figure 7 shows the layer percentage of the total residual response for wander position 2 in west to east direction. Please note that wander position 2 had one gear wheel directly over the MDD. Once again, the percent of residual response in each layer remains relatively constant. It is interesting to note the reduction in percent of residual response from the surface and P209 layers and the gradual increase in the percent of residual response by the DGA layer. This can be attributed to range B behavior where the constant particle rearrangement slowly deteriorated the DGA layer while at the same time the surface and P209 layers consolidated due to traffic.

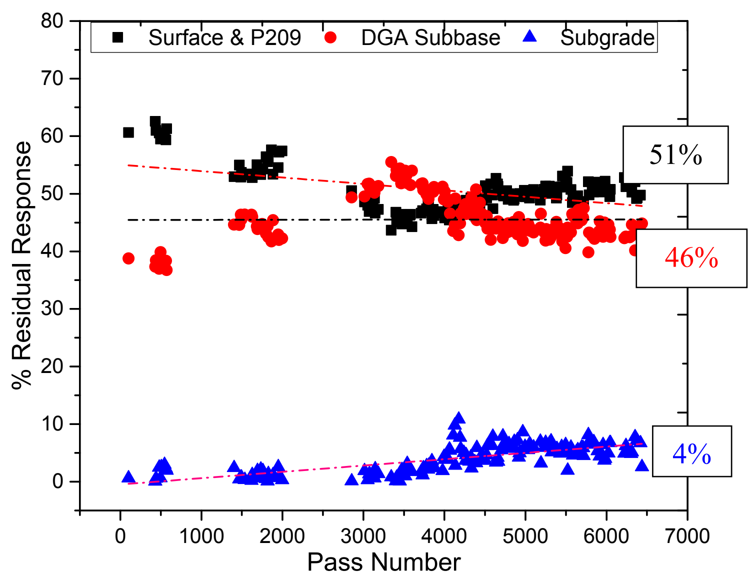
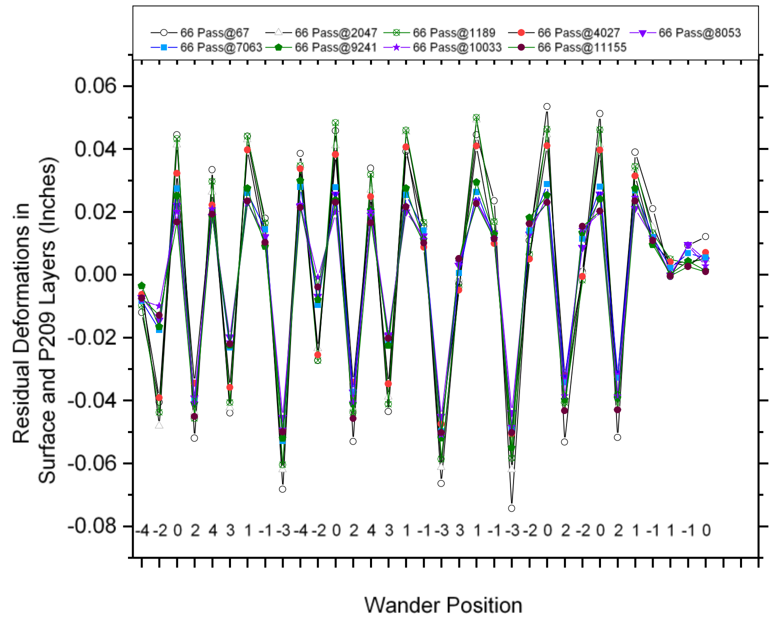


Figure 7: Layer percentage of the total residual response on B777 lane, west to east loading direction, wander position 2

The influence of travel direction, wander position, and wander sequence on the residual response values can also be further evaluated by combining the data into 66 pass wander patterns. The data are separated into 66 pass wander pattern and each 66 pass pattern is presented in the prepared graphs as an individual line. Figures 8a and 8b show 66 pass wander patterns for the Surface and P209 layers and DGA subbase layers respectively.

(a)



(b)

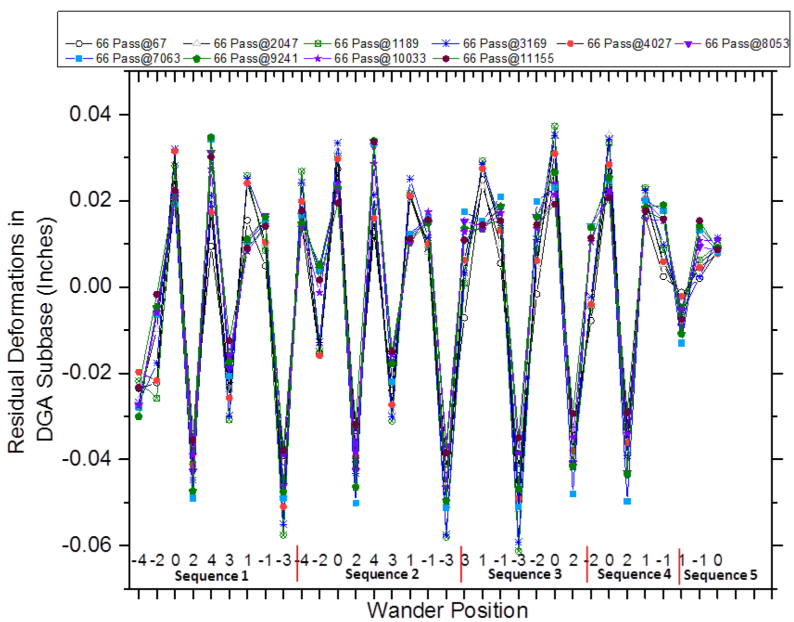


Figure 8: Residual response over 66-pass wander pattern and wander sequence (a) surface and P209 layers (b) DGA subbase layer

As can be seen from Figures 8a and 8b, traffic in the west to east direction on wander position -3 produces the maximum downward residual deformation, which correlates with the maximum load position when a wheel is directly over the MDD centerline. Wander position 2 is the only other wander pattern to produce a consistent downward residual deformation of DGA and is the second closest wheel load. All of the other wander positions contribute various amounts of rutting or heave. Wander position 4 is again highlighted as the offset that causes the most heave of the pavement system and individual layers. Wander position 0 also causes considerable heave to the system. Figures 8a and 8b show that the rut and heave residual deformation values do not increase much with the number of passes. In fact, Figure 8a shows that the residual deformation initially is decreasing from the pass started at 67 to the next wander cycle shown at pass 1189.

Conclusions

In airport pavements, the stability and strength of the unbound granular layers largely depend on the load wander affecting particle rearrangement. Preliminary analyses of the Multi-depth deflectometer (MDD) data of the Federal Aviation Administration's (FAA's) National Airport Pavement Test Facility (NAPTF) low strength conventional flexible pavement (LFC) construction Cycle 5 test sections indicate that the residuals deformations were not increasing much due to increased traffic. However, it also indicated that the percent of residual deflection responses in the surface and granular P209 base and dense graded aggregate (DGA) subbase layers were relatively constant, contradicting with the shakedown theory which predicts the unbound aggregate layers to consolidate and hence decrease their contribution to permanent deformation. Though, initially there was a reduction in percent of residual response from the surface and P209 layers and a gradual increase was observed in the percent of residual response by the DGA layer. This can be attributed to range B behavior where the constant particle rearrangement slowly deteriorated the DGA layer while at the same time the surface and P209 layer consolidated due to traffic. The graphs generated using the residual response trends of complete 66 pass wander pattern can determine where the critical wander positions were and if shakedown was occurring. The blocks of 66 pass wander pattern data indicate that both rut and heave initially decreased with the number of passes.

Further analyses of these findings will lead to a better understanding of the field damage mechanisms that will eventually help improve the development of realistic pavement performance prediction models. This study was completed on only one of the twelve low strength subgrade sections. Further analyses of the other sections are required to validate the findings. The next step in this project is to develop a stress-history analysis based rut prediction tool to allow any combination of wander positions and sequences of load applications to be accounted for their effects on the final surface rut development. With wheel configuration, wander location, speed, and load, along with any post trafficking data the deterioration of unbound materials due to wanders can be quantified by incorporating the apparent random travel paths of aircraft on airport pavements. Also, the ability to predict the future rut profiles will ensure an accurate estimations of remaining pavement life, helping the designers plan an effective maintenance and rehabilitation strategy, subsequently leading to an economic and sustainable airport pavement management system.

References

Garg, N. (2003). "Permanent Deformation Behavior of the Granular Layers Tested at the National Airport Pavement Test Facility," Presented at the 82nd Annual Transportation Research Board Meeting, Washington, D.C. (http://www.airtech.tc.faa.gov/NAPTF/Download/)

Hayhoe, G.F. (2004). "Traffic Testing Results from the FAA's National Airport Pavement Test Facility," In Proceedings of the 2nd International Conference on Accelerated Pavement Testing, University of Minnesota, Minneapolis, U.S.A.

Hayhoe, G. F., Garg, N., & Dong, M. (2004). Permanent deformations during traffic tests on flexible pavements at the National Airport Pavement Test Facility. In *Airfield Pavements: Challenges and New Technologies* 147-169.

Donovan, P.R. & Tutumluer, E. (2008a). "The Anti-Shakedown Effect," In Proceedings of the 1st International Conference on Transportation Geotechnics, Nottingham, England, August.

Donovan, P.R. & Tutumluer, E. (2008b). "Effect of Aircraft Load Wander on Unbound Aggregate Pavement Layer Stiffness and Deformation Behavior," In Proceedings of the Transportation and Development Institute of the American Society of Civil Engineers Airfield and Highway Pavements Specialty Conference, Bellevue, WA, October.

Donovan, P.R. (2009). *Analysis of Unbound Aggregate Layer Deformation Behavior from Full Scale Aircraft Gear Loading with Wander.* Ph.D. Dissertation, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Werkmeister, S., Dawson, A., & Wellner, F. (2001). Permanent deformation behavior of granular materials and the shakedown concept. *Transportation Research Record: Journal of the Transportation Research Board*, (1757), 75-81.