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Rutting prediction in airport pavement granular base/subbase: A stress history based approach

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ABSTRACT

Test data from full-scale aircraft gear loading conducted at the National Airport Pavement Test Facility (NAPTF) by the US Federal Aviation Administration (FAA) were analyzed to investigate the effects of wander (offset loads) and channelized traffic loadings on the deformation behavior of unbound aggregate layers in asphalt pavement test sections. Insights were drawn on the complex rebound (recovered) and residual (unrecovered) deformation trends of granular materials due to passing of each of the 6-wheel Boeing 777 (B777) and the 4-wheel Boeing 747 (B747) gears for various combinations of loading (stress history effects), wander positions, and wander sequences. Measured field layer deformations and the accumulation rates could only be achieved when the magnitudes and variations of stress states in the granular layers, number of load applications, gear load wander patterns, previous loading stress history effects, trafficking speed or loading rate effects, and finally, principal stress rotation effects due to moving wheel loads were properly accounted for. Accordingly, measured transverse profiles and multi-depth deflectometer data were used to create individual pass residual deformation transverse profiles. The created transverse profiles were then combined with stress history effects to predict the residual transverse profiles for the test sections with P209/P154 granular base/subbase layers. The proposed method emphasizes the use of the previous load location and stress history of the pavement element to develop the residual deformation in that element. Calculation of the residual deformation in each element across the pavement surface results in the development of the complete permanent deformation transverse profile. This technique can be applied to estimate the transverse rutting profile of the pavement after trafficking based on any combination of applied wander and traffic direction.

Introduction

The US Federal Aviation Administration (FAA) constructed the National Airport Pavement Test Facility (NAPTF), located at the William J. Hughes Technical Center in New Jersey, in 1999 to generate full-scale testing/trafficking data to support the investigation of the performance of airport pavements subjected to complex gear loading configurations of new generation aircraft. Two gear configurations, a six-wheel tridem landing gear (Boeing 777 type or B777) in one lane and a four-wheel dual-tandem landing gear (Boeing 747 type or B747) in the other lane were tested simultaneously with an applied transverse wander pattern consisting of a fixed sequence of 66 vehicle passes (33 traveling East and 33 traveling West). Sensor installation included multi-depth deflectometers

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(MDDs) and pressure cells to capture pavement responses under traffic loading. Rutting was monitored throughout the traffic test program by transverse surface profile (TSP) measurements, rolling inclinometer and straightedge rut depth measurements, and individual layer rut data collected using MDDs. Individual pavement dynamic response data were collected due to passing of each gear for various combinations of applied load magnitudes, traffic directions, and wander positions. To minimize the interaction of gear loads at the subgrade level, the 6-wheel B777 type and the 4-wheel B747 type gears moved in phase, with both gears moving left and right together rather than towards and away from each other.

The FAA designated P209/P154 aggregate materials were used in the construction and testing of the NAPTF flexible pavement test sections with variable thickness base and subbase courses. The first series of full-scale tests conducted in NAPTF, referred to as Construction Cycle 1 (CC1) tests, found that applying a sequential offset load (wander) pattern to asphalt pavements reduces or even negates the expected shakedown effect possibly due to particle movement and rearrangement. The downward residual deformation (rutting) caused by a pass of heavily loaded landing gear carriage was shown to be reversed by the upward residual deformation (heave) resulting from the pass of the same gear offset by wander (Hayhoe and Garg, 2002). 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. This behavior indicated that, due to aircraft loading wander, individual unbound aggregate particles were moved, rotated, reoriented, and rearranged in relation to one another (Donovan, 2009; Donovan and Tutumluer, 2008a,b). An asphalt surface can provide material confinement and minimize particle movement however, if the applied stress is high enough, particle movement can still occur even under the confinement of an asphalt layer. Fig. 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.

The application of the wander pattern to the low- and medium-strength subgrade asphalt pavement CC1 test sections was found to cause the so-called "anti-shakedown effect" in the unbound aggregate layers. Essentially, study of MDD data indicated that the unbound aggregate particles moved 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. Further, comparison of channelized traffic, as in the CC3 test sections, 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.

To account for the rutting performances of the substantially thick NAPTF granular layers, a comprehensive set of repeated load triaxial tests, considering both constant and variable confining pressure (CCP and VCP) conditions, were conducted on the P209 base and P154 subbase granular materials at the University of Illinois. Based on the laboratory test results, both CCP and VCP type permanent deformation models were developed to predict maximum ruts that occurred at the NAPTF under both 6-wheel and 4-wheel gear loadings applied following a wander pattern. The developed rutting models were first calibrated for the field conditions and then evaluated for predicting the field accumulation of permanent deformations by properly taking into account the NAPTF trafficking data, effects of stress rotation due to moving wheel loads, and loading stress history effects. A comparison of the measured and predicted permanent deformations indicated that a good match for the measured rut magnitudes and the accumulation rates could only be achieved when the magnitudes and variations of stress states in the granular layers, number of load applications, gear load wander patterns, previous loading stress history effects, trafficking speed or loading rate effects, and finally, principal stress rotation effects due to moving wheel loads were properly accounted for in the laboratory testing and permanent deformation model development (Kim and Tutumluer, 1952, 2006, 1913).

The objective of this paper is to demonstrate successful applications of a stress history based approach developed

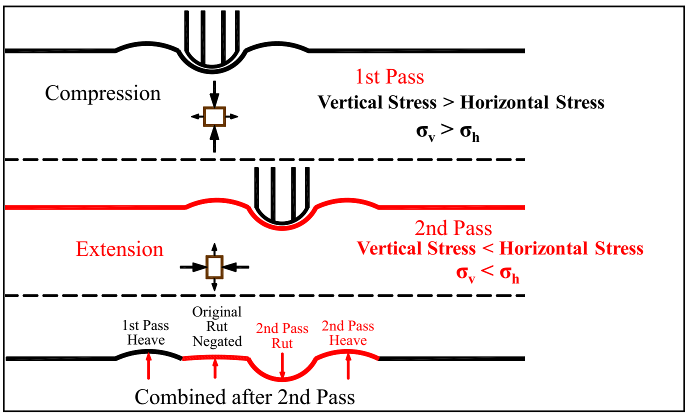

Fig. 1. Schematic explaining the rut profile development from an offset wheel.