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*Ohio Department of Transportation*
*Office of Statewide Planning & Research*
***Research Section***
*1980 West Broad Street, Mail Stop 3280*
*Columbus, OH 43223*
*614-644-8135*
*Research@dot.state.oh.us*
*www.dot.state.oh.us/Research*

# Implementation and Thickness Optimization of Perpetual Pavements in Ohio

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| Research Agency: | Ohio University |
| Researchers: | Shad Sargand, Issam Khoury, Ben Jordan |
| ODOT Technical Liaisons: | Aric Morse, Adam Au |

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## Project Background

Perpetual asphalt pavements are designed to confine distresses to the upper layer of the structure, by eliminating or reducing the potential for fatigue cracking by maintaining the horizontal strains at the bottom of the pavement below a critical fatigue endurance limit (FEL). While there have been a number of successful installations of perpetual pavements, there are still questions to be answered in order to achieve a comprehensive understanding of the design of such pavements. For example, although various endurance limits have been proposed, none have been determined and field validated for efficient design. The National Center for Asphalt Technology (NCAT) suggested the FEL value for most perpetual pavement designs is in the range of 70 to 100 με. However, based on the results of different in-service pavement sections, some researchers suggested the Fatigue Resistance Layer (FRL) can withstand up to 150 με depending on the type of mixture used. In this study, an endurance limit was obtained following the method in NCHRP Project 9-44A report (Witczak et al, 2013).

This research study was aimed at determining a minimum thickness design for perpetual pavements in Ohio. To achieve this objective, pavement sections were constructed and instrumented on the Strategic Highway Research Program (SHRP) Test Road on US Route 23 in Delaware County, referred to as "DEL-23". The four test sections were designed with three different total pavement thicknesses of 11 in (28 cm), 13 in (33 cm) (two sections), and 15 in (38 cm). The response of those sections was monitored under controlled vehicle loads to determine if they met the perpetual pavement criteria, with the exception of one 13 in (33 cm) section that did not conform to the design at the location of the instrumentation, as explained below. In the report, the pavement response data collected through the sensors installed in the experimental test sections are analyzed in order to assess the performance of the pavement and the perpetual nature of the various sections. Furthermore, the relative performance of the pavement test sections were analyzed using the computer programs PerRoad and AASHTOWare Pavement-ME Design.

## Objectives

The main objective of this study was to develop a procedure for the selection of the optimal design for perpetual pavements in Ohio. Other specific objectives of this project included:

- Investigate various perpetual pavement structure alternatives through varying the thickness and material properties of pavement layers in field test sections constructed on DEL-23 and in the Accelerated Pavement Load Facility (APLF).
- Use data collected at the field test sections to verify the analysis results.
- Evaluate typical conventional asphalt pavement designs currently used in Ohio and develop an approach to retrofit existing conventional asphalt pavements in good condition to meet perpetual pavement requirements.

## Description of Work

**DEL-23:** Three perpetual pavement test sections on U.S. Route 23 in Delaware, Ohio (DEL-23) were constructed with AC thicknesses 11 in (28 cm), 13 in (33 cm), 15 in (38 cm) and instrumented to detect strains in Fatigue Resistant Layer (FRL) and base layer, pavement deflections, temperatures, and subgrade pressures. Controlled Vehicle Load (CVL) testing was conducted in November and December 2012 and in July 2013. CVL testing involved placing a known load into a tandem axle truck (approximate axle load 37 kip (165 kN)) and single axle truck with wide-base tire (approximate load 29 kip (129 kN)), and driving each truck over the instrumented pavement at speeds of 5 mph (8 km/h), 30 mph (48 km/h), and 55 mph (89 km/h) with tires inflated to pressures of 80 psi (552 kPa), 110 psi (758 kPa), and 125 psi (862 kPa). Instrument responses were monitored as the truck tires passed over the sensors to find maximum strains, deflections, and pressures in each run. Particular attention was paid to longitudinal strain in the FRL and longitudinal and transverse strains in the asphalt base layer.

Computer simulation of DEL-23 sections were conducted using PerRoad and AASHTOWare Pavement-ME with Level 3 inputs and national calibration as Ohio calibration values for MEPDG did not carry over to the algorithms in the new software. Level 3 inputs were upgraded to measured local values when these were known.

**Highly Modified Asphalt in APLF:** Test pavements were built in the Accelerated Pavement Load Facility (APLF) and instrumented similarly to DEL-23. The sections were thinner, but included Highly Modified Asphalt (HiMA) with Kraton polymer binder in sections of depth 8 in (20 cm), 9 in (23 cm), 10 in (25 cm), and 11 in (28 cm), the last using conventional asphalt in the base as a control with HiMA in upper layers. Instrumentation in each lane was similar to that used on DEL-23. Testing was performed at two temperatures (70°F (21.1°C) and 100°F (37.8°C)). Once temperature had stabilized at the target temperature, three wheel loads (6000 lb (27 kN), 9000 lb (40 kN), and 12000 lb (53 kN)), at various offsets to the centerline of the lane, were applied at 5 mph (8 km/h) to analyze the test section's pavement response via the instrumentation and surface rutting was measured with a profilometer. The pavement was then subjected to 10,000 repetitions of a 9000 lb (40 kN) load wheel. Response measurements, at 6000 lb (27 kN), 9000 lb (40 kN), and 12000 lb (53 kN), and profilometer readings were repeated after 100, 300, 1000, 3000, and 10,000 passes of the load wheel at each temperature.

The fatigue endurance limit was computed for each test section using parameters measured in the laboratory asphalt mixture performance tester (AMPT) from samples collected from DEL-23 and APLF. Endurance limits were computed following the NCHRP Project 9-44A method and MEPDG guide ($E_0$=$E$*). Master curves and temperature shift factor plots were generated for each asphalt mix used on DEL-23 and the APLF.

**Existing pavements:** Ten high-performing existing AC pavements from a previous forensic study (Sargand and Edwards, 2010) were further evaluated as potential perpetual pavements. Follow-up field investigations at selected sites included distress surveys, falling weight deflectometer (FWD) measurements, dynamic cone penetrometer (DCP) data, and Portable Seismic Property Analyzer (PSPA) measurements. Strains at the bottom of the asphalt were back calculated from FWD deflections using the elastic modulus program Evercalc. AC cores were collected and tested for indirect tensile strength and resilient modulus. The pavements were modeled using finite element software Abaqus, which confirmed the Evercalc strain computations.

A brief report on the status of previous perpetual pavement designs built in Stark County (I77) and Wayne County (US30) is given. At each site a distress survey was conducted, FWD drops made and rutting measurements conducted.

## Research Findings & Conclusions

**DEL-23:** All the data obtained from DEL-23 for all the loading conditions, speed, climate conditions, including worst case conditions, such as 5 mph (8 km/h) traffic under high temperature, were analyzed in conjunction with the NCHRP 9-44A endurance limit model. It was determined the thickness of 13 in (33 cm) or greater, constructed on a

6 in (15 cm) aggregate base and stabilized subgrade, met criteria for perpetual pavement, while the 11 in (28 cm) section on the same base and subgrade did not. It was also determined a pavement thickness of 15 in (38 cm) or greater, constructed on an aggregate base and compacted subgrade, also met perpetual pavement criteria.

With stabilized soil, both the stabilized soil and the ODOT Item 304 base will have increased stiffness (Sargand et al, 2014), thus the strains at the bottom of the asphalt pavement will be reduced and the deflection of the base and subgrade will also be low.

The worst case test conditions, 5 mph (8 km/h) heavy load will not produce a major discrepancy with static load. These conditions may lead to rutting in the surface course, but the rutting will be minimal in the base and stabilized subgrade due to their enhanced stiffness.

**Existing pavements:** Using FWD back calculated moduli in elastic layer models predicted strain in bottom layer with reasonable accuracy when compared to finite element modeling, however empirical equations typically predicted lower strains.

Seven of the ten pavements studied met perpetual pavement criteria assuming an endurance limit of 70με, which observations and distress surveys confirmed. One pavement could be made perpetual with added AC layers, and the other two appeared to have damage and would require a substantial overlay to reduce strain to 70με or less.

ODOT can use the recommended technique to evaluate existing pavements to determine if they are perpetual or could be made perpetual with a designed overlay adding sufficient thickness to reduce the strain in the pavement below the endurance limit. If actual material properties data are not available, the 70με endurance limit can be used as a conservative value.

**Highly Modified Asphalt in APLF:** Test lanes were constructed in the Accelerated Pavement Load Facility (APLF) which further evaluated thicknesses and included the use of high-polymer content binder, or highly modified asphalt (HiMA). On the built-up sections in the indoor facility, subgrade was stabilized, moisture increase in the subgrade soil typically experienced in the field did not occur, and construction quality was very high.

In the APLF, based on data collected, all sections satisfied NCHRP Project 9-44A criteria for perpetual pavement (Witczak et al, 2013). The 8 in (20 cm) thick well-constructed HiMA pavement on 304 and stabilized subgrade met perpetual pavement criteria in the highly controlled environment of the APLF.

Very little rutting was observed in the test pavements. Comparing HiMA with control sections there was significant improvement in rutting resistance using the high polymer asphalt.

**Additional major conclusions:** Stabilization of subgrade appeared to have a significant impact on reducing strains in the FRL, based on data from DEL-23, where 13 in (33 cm) section on stabilized subgrade had lower FRL strains than 15 in (38 cm) section on non-stabilized subgrade.

Using the NCHRP 9-44A model, one of the key steps is determining the initial modulus $E_0$ (Witczak et al, 2013). The MEPDG assumes $E_0 = E^*$, while Romanoschi, et al (2006) indicate $E_0 = E^*/2$. All DEL-23 sections satisfy perpetual criteria on the latter assumption; if $E_0 = E^*$ only the 11 in (28 cm) section failed the perpetual pavement criterion, which matches the experimental findings.

For the mixes used on DEL-23 and in the APLF, E* for the fatigue resistance layer and the asphalt base course (ODOT Item 302) were very similar in the laboratory tests. Thus in implementing NCHRP 9-44A, it is concluded the FRL can be replaced with an asphalt base course.

## Recommendations

New pavement designs which result in an asphalt thickness greater than 13 in (33 cm) on a 6 in (15 cm) dense graded aggregate base on stabilized subgrade or 15 in (38 cm) of asphalt on a 6 in (15 cm) dense graded aggregate base on compacted subgrade should be evaluated for perpetual performance using the following equation:

$$SR = 2.0844 - 0.1386*\log(E_0) - 0.4846*\log(\varepsilon_t) - 0.2012*\log(N) + 1.4103*\tanh(0.8471*RP) + 0.0320*\log(E_0)*\log(\varepsilon_t) - 0.0954*\log(E_0)*\tanh(0.7154*RP) - 0.4746*\log(\varepsilon_t)*\tanh(0.6574*RP) + 0.0041*\log(N)*\log(E_0) + 0.0557*\log(N)*\log(\varepsilon_t) + 0.0689*\log(N)*\tanh(0.259*RP)$$

Where:

$SR$ = stiffness ratio = stiffness measured at any load cycle during beam fatigue testing to the initial stiffness of the specimen

$E_0$ = initial flexural stiffness (ksi)

$\varepsilon_t$ = applied tensile strain (με)
*RP* = rest period (sec)
*N* = number of load cycles

The procedure is as follows:

- Measure or estimate the mechanical properties of the pavement layers and foundation soil.
    - The recent ODOT report entitled *Incorporating Chemical Stabilization of the Subgrade in Pavement Design and Construction Practices* (Sargand et al, 2014) provides a procedure for estimating the moduli of stabilized subgrade and compacted subgrade.
- Compute the endurance limit using the equation above, setting SR = 1, and determine $\varepsilon_t$. For the initial stiffness value, $E_0$, use the results of the beam fatigue test to provide the most accurate estimate.
    - If $E_0$ from beam fatigue testing is not available, $E^*$ obtained from the AMPT (asphalt mixture performance test) or the Witczak equation can be used to estimate $E_0$.
- Use elastic layer software to estimate the horizontal strain at the bottom of the asphalt base and compare to the endurance limit determined in the previous step or to the currently used value of 70 με, which appears to be a conservative and reasonable value based on testing completed for this project.

In-service flexible pavements programmed for overlays can be evaluated for perpetual performance by calculating the strain at the bottom of the asphalt layer using back calculated modulus values in elastic layer models. However, a quick estimate using the AUPP equation developed by Kim and Park (2002) may be used by pavement designers, keeping in mind that the AUPP equation results are about 10 με lower than the back-calculated strain on average. Thus, the following steps are recommended for evaluating an existing flexible pavement's perpetual pavement status:

- Perform FWD test.
- Normalize all the deflections to be evaluated to a 9000 lb (40 kN) load.
- Insert deflection values for sensors $D_0$, $D_{12}$, $D_{24}$, and $D_{36}$ into the equation below to calculate *AUPP*.

$$AUPP = (5D_0 - 2D_{12} - 2D_{24} - D_{36})/2$$

- Insert *AUPP* into the equation developed by Kim & Park (2002) to get a quick estimate of the strain at the bottom of the AC base layer, $\varepsilon_{ac}$.

$$\log(\varepsilon_{ac}) = 1.034 \log(AUPP) + 0.932$$

- Add 10 με to obtain adjusted strain $\varepsilon_{adj} = \varepsilon_{ac} + 10$ that matches back calculated value.
- If the adjusted strain $\varepsilon_{adj}$ calculated is below 70 με, then the pavement is considered perpetual.
    - If the adjusted strain $\varepsilon_{adj}$ calculated is above 70 με then the pavement is not considered perpetual, Reevaluate the AC pavement FWD results using Evercalc 5.0. Add thickness to the pavement structure until the strain at the bottom of the AC base layer is less than or equal to 70 με on the Evercalc program.

Further research should be conducted to investigate the relationship between the initial modulus $E_0$ as measured during the beam fatigue test and $E^*$ measured during the simple performance test.

## Implementation

ODOT can use the NCHRP 9-44A procedure to evaluate the endurance limit for an asphalt mix.

When designing perpetual pavement thickness, include global soil stabilization as per current policy. That will result in a significant reduction in asphalt thickness required to meet perpetual pavement design, particularly in combination with ODOT Item 302 base.

A procedure to evaluate the perpetual nature of in-service flexible pavement has been presented. ODOT should use this procedure when the FWD data is available to determine the thickness required to achieve perpetual performance.

An understanding of the $E_0/E^*$ relationship may allow ODOT to reduce the thickness required for perpetual performance with confidence if the relationship developed by Romanoschi is valid for Ohio mixes.

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