Characterization of Two Perpetual Pavements at the NCAT Test Track

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ABSTRACT: Two experimental asphalt pavement sections were built at the National Center for Asphalt Technology (NCAT) Test Track in 2003. Designed according to the 1993 AASHTO Design Guide, they were expected to fail after 10 million equivalent single axle loads (ESALs). However, they performed well throughout the initial 10 million ESALs and have far exceeded their performance expectations with an additional 20 million ESALs applied with excellent performance during the past six years. Though designed as conventional pavements, these sections have performed effectively as perpetual pavements. The main objective of this investigation was to evaluate the long-term structural and performance characteristics of these unexpected perpetual pavements. The investigation included backcalculation of falling weight deflectometer data to monitor in situ asphalt concrete (AC) moduli versus time and traffic. It was found that the AC moduli increased approximately 12 to 20% during the past six years. Weekly monitoring of ride quality, mean texture depth and rutting have shown no appreciable change over time, indicative of a perpetual pavement. Though some minor cracking was observed after 30 million ESALs, forensic investigations indicated it was top-down which was also consistent with a perpetual pavement. Finally, endurance limits determined through laboratory beam fatigue testing were compared against pavement responses measured from embedded strain gauges. The measured strain levels in situ were significantly higher than the endurance limits, approximately double at the 90th percentile, which suggested the need to revise conventional approaches to perpetual pavement design.

KEY WORDS: Perpetual pavement, asphalt, endurance limit.

1 BACKGROUND

In recent years the U.S. asphalt pavement industry has recognized perpetual pavements as a viable and cost-effective flexible pavement option. This pavement type is designed such that the tensile strain at the bottom of the asphalt concrete (AC) and the compressive vertical strain in the subgrade are kept below distress-specific endurance thresholds. Maintaining strain levels below the respective endurance limits prevents distress from occurring deep in the structure which naturally leads to a perpetual pavement that requires only periodic surface rehabilitation such as shallow (i.e., < 50 mm) mill and inlay to mitigate surface distresses.

The perpetual pavement concept first originated in Europe (e.g., Nunn et al., 1997; Simonsen et al., 2004; Ertman, Larsen and Thau, 2004) and has been refined and further developed in the U.S. as described by Timm and Newcomb (2006). Perpetual pavement design is currently facilitated through mechanistic-empirical (M-E) analysis using layered elastic theory to compute pavement responses under load. Though the perpetual pavement design concepts and procedures are now relatively well-established, it is important to recognize that perpetual pavements pre-date the modern design concepts and tools now used for design. A clear example of this are the 80 perpetual pavement awards given by the Asphalt Pavement Alliance since 2001 (Newcomb et al., 2010). To be eligible to receive the award, the pavement must have been at least 35 years old with no structural failures. Since these pavements all pre-date the modern tools and concepts used to design a perpetual pavement, it is warranted to better understand how these high performing pavements were achieved and use them for further refinement of the concept of perpetual pavement.

In 2003, the National Center for Asphalt Technology (NCAT) Pavement Test Track was reconstructed to feature a six-section experiment to evaluate existing pavement design methodologies (i.e., 1993 AASHTO Pavement Design Guide) and also develop the necessary data sets for implementation of M-E Design. As documented in the project report (Timm et al., 2004), the sections were designed according to the 1993 AASHTO Pavement Design Guide to fail within the two year project period, which corresponded to approximately 10 million equivalent single axle load applications (ESALs). Within the six-section experiment, two were designed to fail at approximately 3.3 million ESALs, two were designed to fail after 6.7 million ESALs and two were designed to fail at the full 10 million ESALs. After the initial two-year period, distress was observed in all but the 10 million ESALs sections. These two sections were left in place at the start of the 2006 experiment and monitored over an additional 10 million ESALs. After 20 million ESALs, distresses were still not evident and the sections were again left in place for the 2009 research cycle which was completed in 2011 for a total of 30 million ESALs on the two sections. After 30 million ESALs, well in excess of the design traffic, the sections appear to have performed as perpetual pavements. Thus, there is a need to characterize the in situ behavior of these sections for further refinement of the perpetual pavement design process.

2 OBJECTIVES AND SCOPE OF WORK

The objective of this investigation was to evaluate the in situ characteristics of two perpetual pavement sections at the NCAT Test Track. This investigation focused on backcalculated AC moduli, measured pavement performance over time and measured strain responses relative to laboratory-determined endurance limits.

3 FACILITY, SECTIONS AND TESTING PROGRAM

The NCAT Test Track is a 2.7 km closed loop test facility comprised of forty-six 61 meter long test sections. The Test Track is located in the southeastern U.S. near the campus of Auburn University. The Test Track operates on three year cycles where reconstruction occurs in the first year followed by two years of traffic. Traffic is applied by a fleet of triple-trailer trucks operating sixteen hours per day, five days per week. During each two-year period, approximately 10 million repetitions of an 80 kN standard single axle (ESAL) are applied to each section.

As mentioned previously, this investigation featured two sections built in 2003 pictured in Figure 1. The sections were the third and fourth placed on the north tangent of the track and were referred to as N3 and N4, respectively. Both sections were designed according to the 1993 AASHTO Pavement Design Guide to have 230 mm total AC depth over 150 mm of aggregate base over the subgrade soil (Timm et al., 2004). The primary focus of the original experimental design was to evaluate the effects of full-depth binder modification where N4 used PG 76-22 in each layer modified with and SBS modifier. N3 used an unmodified PG 67-22 binder in each layer. Given the prevailing conditions at the Test Track, these sections were expected to fail after 10 million ESALs.

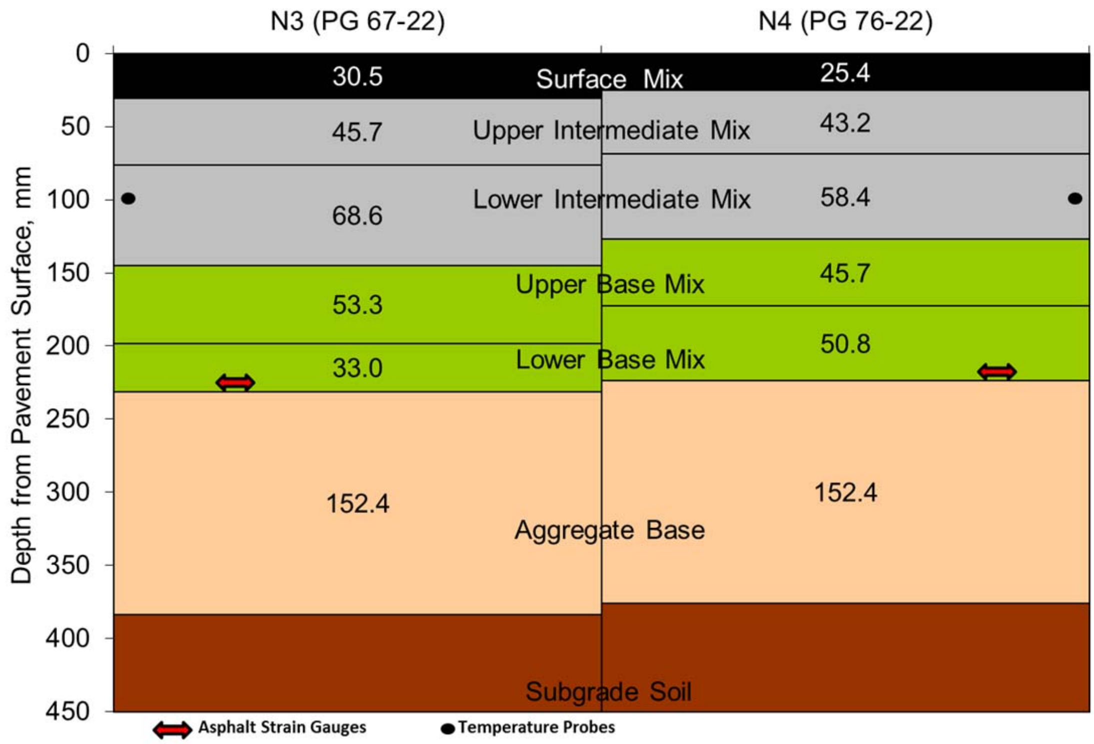

Figure 1: As-built structural cross sections and instrumentation.

4 BACKCALCULATED AC MODULUS

During the 2003 research cycle, falling weight deflectometer (FWD) testing was conducted once per month on each section. In the 2009 research cycle, FWD testing was conducted several times per month. Within each section, twelve locations were tested with three replicates at four drop heights. The data presented below only represent the results at the 40 kN load level using EVERCALC 5.0 to backcalculate layer properties with root mean square errors (RMSE) less than 3%.

Figure 2 shows the strong relationship, as characterized by exponential regression equations, between mid-depth pavement temperature and backcalculated modulus for both N3 and N4. Comparing the regression lines obtained in 2003 versus 2009, there appeared to be a noticeable increase in modulus, caused by aging, during this six-year interval.

To statistically evaluate the aging effect, the moduli for each section were normalized to a 20°C reference temperature using the section-specific regression equations in Figure 2. Note that regression equations were left in the form of their original units with temperature in

Fahrenheit and modulus in units of ksi. Figure 3 summarizes the average and standard deviation of each section at 20°C. Tukey-Kramer statistical testing of the mean values (α=0.05) indicated significant differences between all sections at 20°C. In other words, there was a statistically-discernible aging effect in these sections. Section N3 increased by about 12% during the six year period while N4 increased by 20%. Furthermore, as expected, the PG 76-22 section (N4) had higher moduli than the 67-22 section (N3). The difference between the sections during 2003 was about 7% which increased to 15% difference in average moduli during the 2009 study. It should be noted that had bottom-up fatigue cracking developed during these trafficking cycles, the modulus would in fact have decreased. A modest increase in modulus, as found here, is indicative these sections had not experienced any bottom-up fatigue cracking and were in fact perpetual.

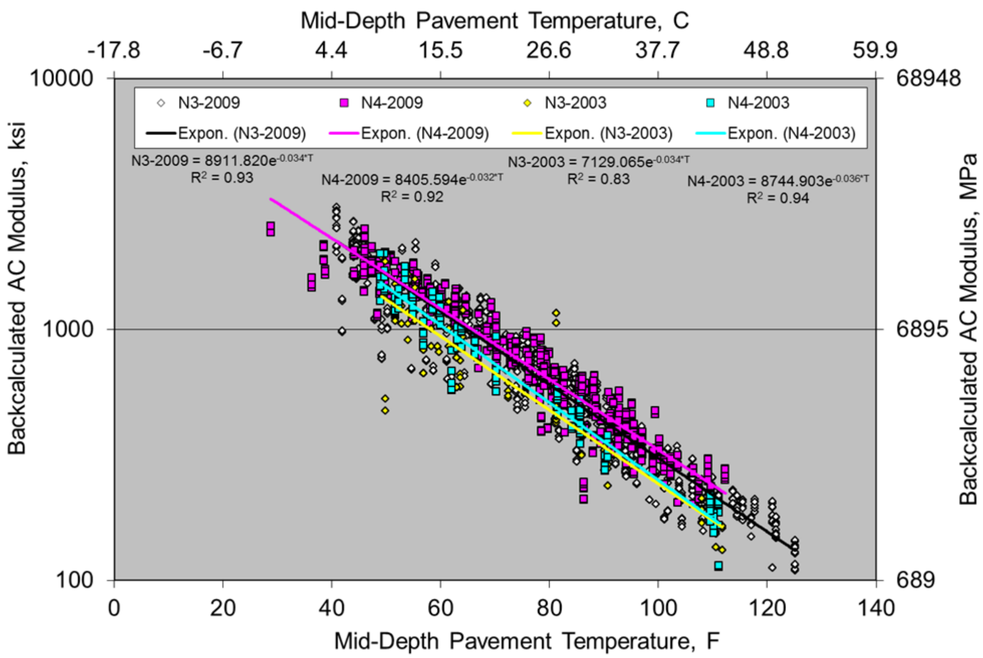

Figure 2: Backcalculated AC modulus versus mid-depth temperature.

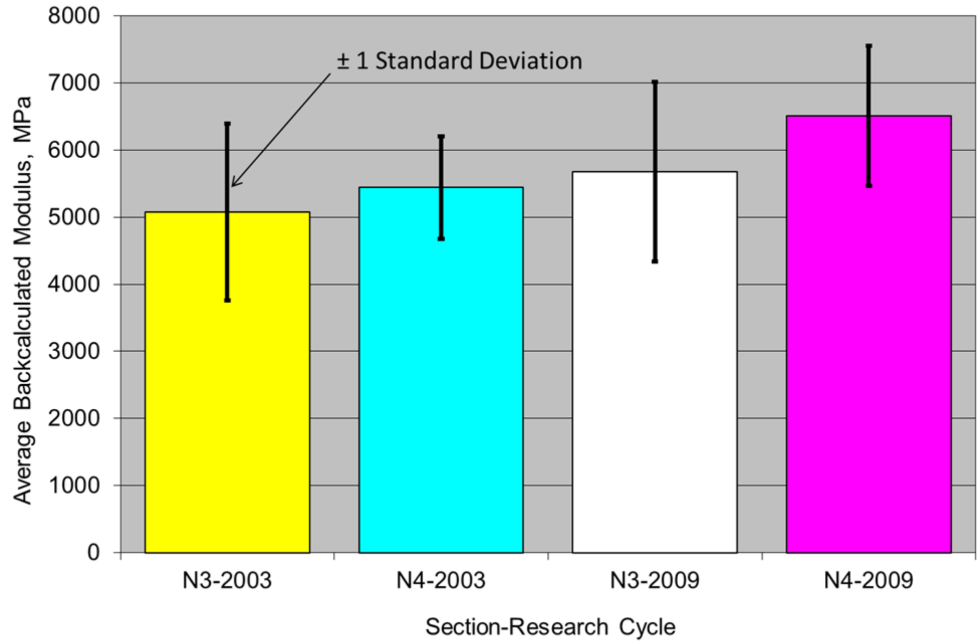

Figure 3: Backcalculated AC modulus at 20^{o}C by section and test cycle.

5 PERFORMANCE

Beginning in 2003, weekly measurements of rutting and ride quality were made using an ARAN van. Furthermore, the sections were visually inspected for cracking. This performance monitoring continued throughout the 2006 and 2009 experimental cycles.

Figure 4 illustrates the rutting progression in each section. The lower x-axis indicates test date while the upper x-axis shows the cumulative applied ESALs over time. Note that the PG 76-22 section (N4) had slightly less rutting over time while neither section exceeded a rut depth of 8 mm. The slightly lower rutting in N4 was consistent with the observation of slightly higher moduli in this section relative to N3 and was expected since it was a polymer-modified material. Both sections were well below 12.5 mm total rutting, a commonly accepted failure threshold. The change in scatter of the rut measurements after the 2003 experiment cycle resulted from a change in the rutting measurement device on the ARAN van.

No cracking was observed during the 2003 and 2006 test cycles in either section. Some minor cracking was observed at the conclusion of the 2009 research cycle as mapped schematically in Figure 5. Forensic trenching and coring were conducted to determine the nature and severity of the cracks. It was found that the cracks initiated at the top of the pavement and were consistent with expected top-down cracking in a perpetual pavement.

Figure 6 illustrates the ride quality of each section over the three test cycles and 30 million ESAL applications. Both sections, having minor amounts of rutting and cracking, were very smooth with international roughness index (IRI) levels below 1 m/km. Neither section exhibited a notable increasing roughness trend; again consistent with the expected performance of a perpetual pavement.

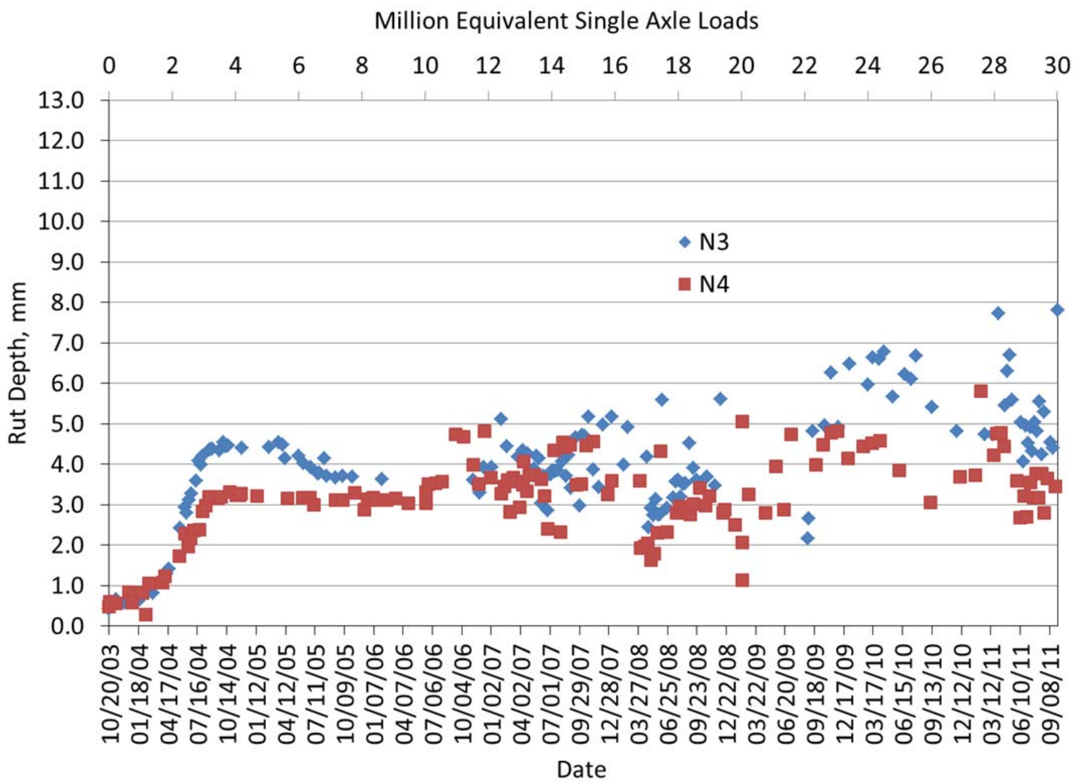

Figure 4: Rutting versus time and traffic loads applications.

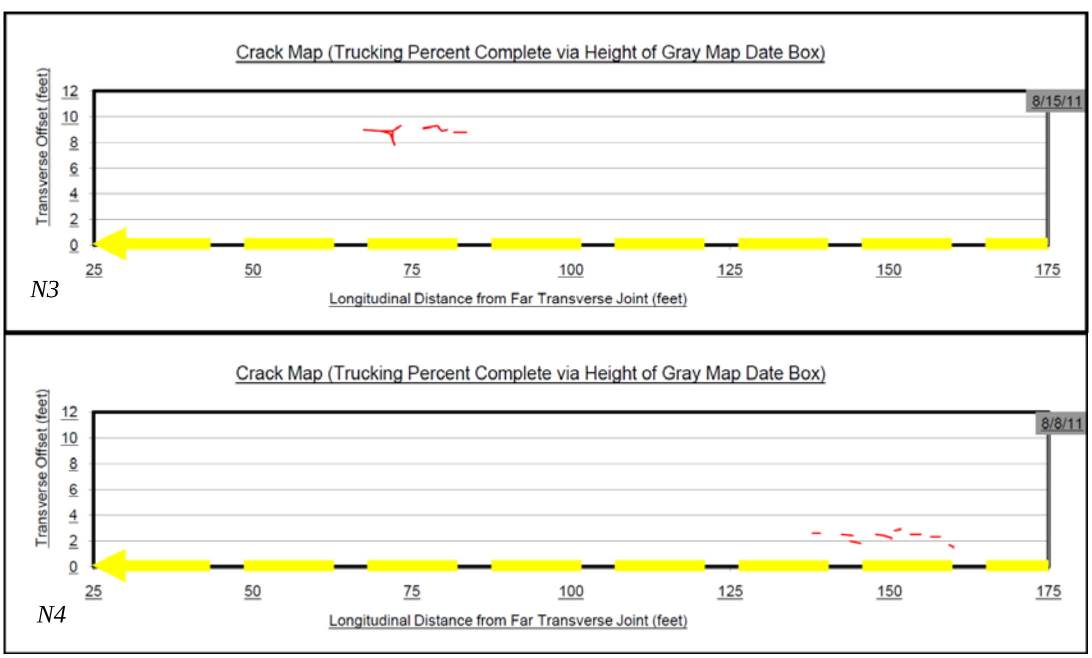

Figure 5: Cracking maps at end of 2009 research cycle.

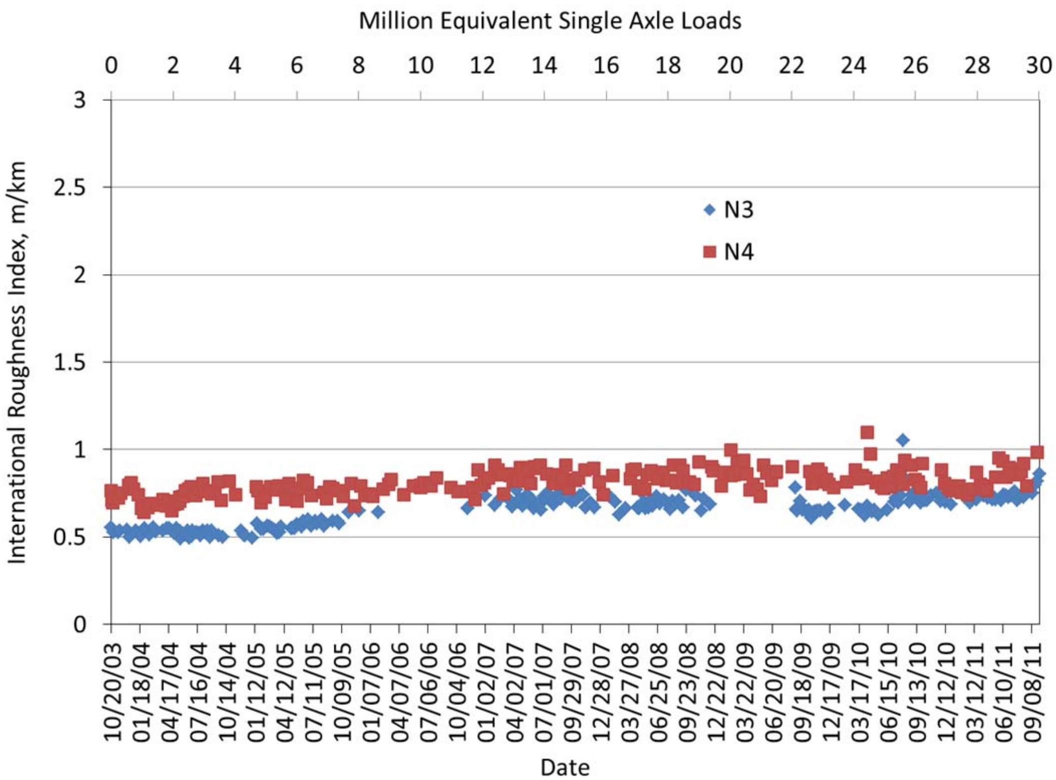

Figure 6: International roughness index versus time and traffic load applications.

6 PAVEMENT RESPONSES

As noted in Figure 1, strain gauges were embedded in each section during construction (Timm et al., 2003). The gauges were monitored during the 2003 and 2006 experiments to measure maximum strain responses under load as the pavements were subjected to changing environmental conditions and increasing traffic. By 2009, there was an insufficient number of operational gauges to continue monitoring during the 2009 research cycle. However, over the two first cycles, cumulative measured strain distributions were created (Willis and Timm, 2010; Willis et al., 2011). These strain distributions, shown in Figure 7, were compared against endurance limits measured through laboratory bending beam fatigue testing on compacted specimens (Willis and Timm, 2010; Willis et al., 2011). The laboratory-measured endurance limit for the base mixture in each section was approximately 150 $\mu\varepsilon$. This was approximately the 35^{th} to 40^{th} percentile measured strain under traffic (Figure 7). In other words, 60 to 65 percent of the strains under traffic in each pavement exceeded the laboratory-determined endurance limit. Clearly, given the performance history described above, the sections were capable of sustaining higher strain levels without compromising their structural integrity. These findings, combined with those of other sections from the three research cycles, led to the development of allowable strain ratios relating field strains to laboratory endurance limits (Willis and Timm, 2010; Willis et al., 2011). It was found that maintaining the 90^{th} percentile field strain below 2.18 times the laboratory-determined endurance limit would ensure a perpetual pavement in terms of fatigue cracking at the Test Track (Willis and Timm, 2010; Willis et al., 2011).

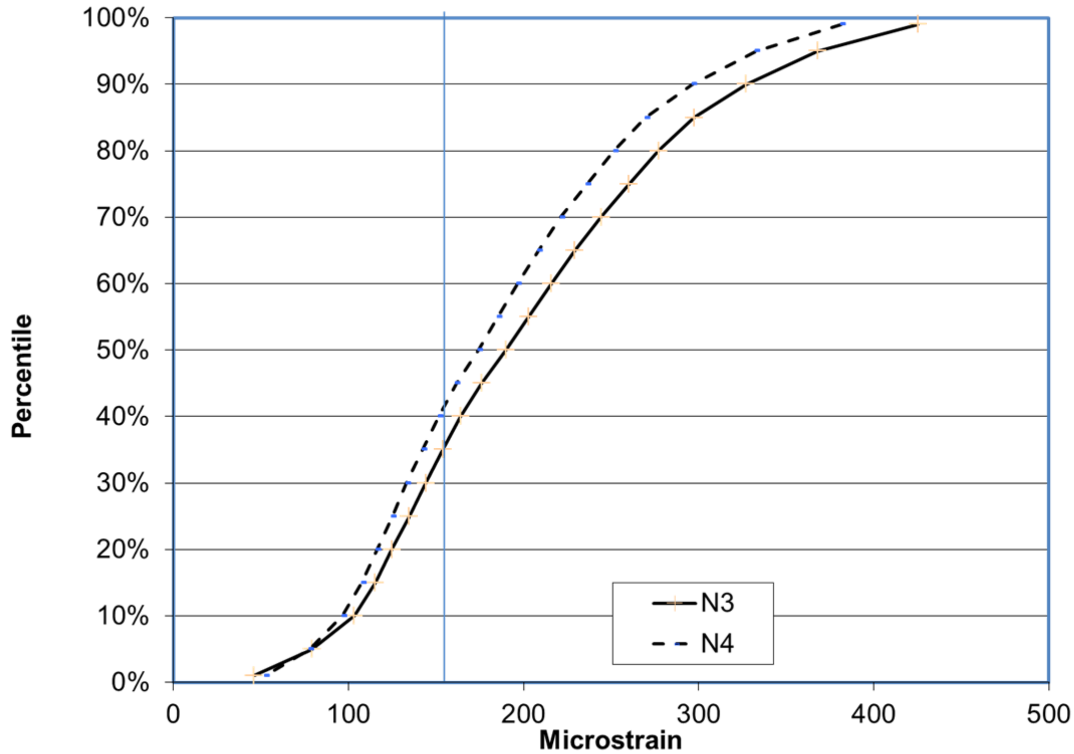

Figure 7: Cumulative tensile strain distributions with laboratory fatigue endurance limit.

7 SUMMARY

This paper characterized the in-situ behavior of two perpetual pavement sections originally designed to fail after only 10 million ESALs at the NCAT Test Track. The fact that the sections exhibited excellent performance after 30 million ESALs demonstrated their perpetual nature. Backcalculated AC moduli showed the sections increased moduli over time indicative of an aging pavement not experiencing any crack development. The performance history of both sections was excellent with very little rutting (<8 mm), very low IRI (<1 m/km) and only minor top-down cracking consistent with the behavior of a perpetual pavement. The measured tensile strain values in each section exceeded the laboratory-determined endurance limits for each base mixture approximately 60% of the time. The strain data were used to develop a controlling strain ratio of 2.18 times the laboratory-measured endurance limit to prevent bottom-up fatigue cracking. These findings should be further validated using perpetual non-Test Track sections to refine design concepts and lead toward more efficient perpetual pavements.

ACKNOWLEDGEMENTS

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