Refined Limiting Strain Criteria and Approximate Ranges of Maximum Thicknesses for Designing Long-Life Asphalt Pavements

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

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Background

Long-life or perpetual pavements are designed and built to last longer than 50 years, requiring only a periodic mill and inlay of the surface layer. The pavement structure is designed using appropriate materials and layer thicknesses to prevent structural distresses that begin at the bottom of the pavement structure, such as bottom-up fatigue cracking and subgrade rutting. To eliminate deep structural distresses, horizontal tensile strains at the bottom of the asphalt layer and vertical compressive stresses/strains at the top of the subgrade must be less than critical thresholds at which damage begins to occur. Additional asphalt thickness above what is required to keep stresses/strains below the critical thresholds is unnecessary to ensure long life. Thus, the goal of perpetual pavement design is to optimize layer thicknesses to sustain heavy loads indefinitely without being overly conservative. Asphalt thicknesses for perpetual pavements have typically ranged from 9 to 16 inches depending on traffic, materials, and site conditions.

Objective

The objective of this study was to establish critical design thresholds and approximate ranges of maximum thickness to improve the cost-effectiveness of long-life pavements.

Refining Limiting Strain Criteria for Perpetual Pavement Design

Existing literature was reviewed to establish historical parameters used in perpetual pavement design. To prevent bottom-up fatigue cracking, perpetual pavements typically have been designed so that strains at the bottom of the asphalt structure are less than the fatigue endurance limit (FEL) of the asphalt mixture in the bottom layer. Typical values for the FEL range from early, conservative estimates of 70 microstrain up to 200 microstrain more recently. To prevent structural rutting, a vertical strain limit of 200 microstrain at the top of the subgrade has been proposed.

In a previous analysis of pavement response data from instrumented sections at the NCAT Pavement Test Track, poor correlations were found between laboratory FELs and field fatigue cracking performance or field-measured strains. Instead, cumulative field-measured strain distributions and fatigue ratios (cumulative strains divided by the FEL of the asphalt base layer) were found to be better predictors of bottom-up fatigue cracking. Because of these promising results, another detailed analysis was conducted in this study using PerRoad simulations to refine the approach investigated in the previous study.

Six test sections built in 2003 and 2006 at the NCAT Pavement Test Track were simulated in PerRoad to predict strain values at the bottom of the asphalt structures. Three of these sections experienced bottom-up fatigue cracking, and the other sections were deemed perpetual without any bottom-up cracking. The predicted strain values were then used to develop a limiting cumulative strain distribution and maximum fatigue ratios that clearly separated the perpetual pavement sections from the others.

The limiting strain criteria were then validated using data from other six sections constructed in 2009 at the NCAT Pavement Test Track. Cumulative strain distributions and fatigue ratios determined using PerRoad simulations for these test sections failed both limiting cumulative strain distribution and maximum fatigue ratios, correctly characterizing the performance of these test sections, as they all experienced bottom-up fatigue cracking.

Table 1 presents the limiting cumulative strain distribution and fatigue ratios refined in this study for future use in perpetual pavement design instead of a conservative limiting strain of 70 microstrain or the laboratory FEL of the asphalt base layer.

Table 1 Refined Limiting Distribution and Maximum Fatigue Ratios for Predicted Tensile Strain

Percentile	Limiting Design Distribution for Predicted Strain	Maximum Fatigue Ratio for Predicted Strain
1%	29	
5%	41	
10%	48	
15%	54	
20%	60	
25%	66	
30%	71	
35%	78	
40%	84	
45%	91	
50%	100	0.68
55%	110	0.74
60%	120	0.81
65%	131	0.88
70%	143	0.96
75%	158	1.06
80%	175	1.18
85%	194	1.31
90%	221	1.49
95%	257	1.73
99%	326	2.19

Estimating Ranges of Maximum Pavement Thicknesses

Based on the refined limiting strain criteria, an analysis was conducted using PerRoad simulations to determine maximum pavement thickness ranges. This analysis was similar to that conducted in SHRP 2 Project R23. The main difference was that this analysis utilized the new limiting strain criteria. The analysis was conducted based on a conservative traffic level within the legal load limits for various combinations of subgrade and base moduli in three climatic conditions to cover the potential ranges of maximum design thicknesses.

The procedure for implementing the refined limiting strain criteria in this PerRoad analysis, described in the following paragraphs, included entering structural information, entering loading information, running the PerRoad simulation, and extracting the output data to compare against the limiting criteria shown in Table 1. The designs were then iterated to achieve the desired output strain distribution.

The structural information was first entered in PerRoad. This information included the number of pavement layers, seasonal material properties, variability of the material properties, and trial design thicknesses. Critical locations in the pavement cross-section were also identified as the bottom of the asphalt concrete (fatigue cracking) and the top of the subgrade (rutting).

The loading conditions were entered next with 100% of the loads as single axle loads set to 20-22 kips, which represents a conservative traffic level consistent with legal axle load limits in the U.S. It is important to note that by its very nature, perpetual pavement design focuses on the heavier axle loads and the strain levels they cause rather than the number of repetitions those axles apply, so traffic volume data are not required.

After entering the pavement cross-section and traffic loading conditions, the simulation was conducted. PerRoad automatically generates an Excel output file containing the simulated strain levels. These strain levels were used to check the fatigue and rutting criteria. For the pavement design to pass, the cumulative tensile strain distribution at the bottom of the asphalt needed to be less than that presented in Table 1 and the vertical compressive strain distribution at the top of the subgrade needed to have at least 50% of values below 200 microstrain. If the pavement design failed either of these criteria, the design was iterated by adjusting the AC thickness accordingly. The resulting approximate ranges of maximum design thicknesses for asphalt pavements are shown in Table 2 for base stiffness of 30, 50, and 100 ksi and in Table 3 for base stiffness of 250 and 500 ksi. Depending on site-specific conditions, the range of approximate maximum asphalt thickness can vary significantly.

As noted in Table 3, further field evaluation and validation are needed for pavement sections built on stiff bases with resilient moduli of 250,000 and 500,000 psi, such as those built on rubblized and cracked and seated pavements. The pavement sections utilized for developing and validating the limiting strain criteria in this study did not include these types of base materials. This is especially important for the very thin sections in Table 3 where the base modulus is 500,000 psi. These sections would likely suffer from reflective cracking that is not accounted for in perpetual pavement analysis.

Recommendations for Implementation

The limiting cumulative strain distribution and fatigue ratios shown in Table 1 should be used in place of the conservative limiting strain of 70 microstrain or the laboratory FEL of the AC base layer in future perpetual pavement design. The limiting cumulative strain distribution was found to be the best indicator of how the structural test sections resisted bottom-up fatigue cracking at the NCAT Pavement Test Track.

Table 2 shows the approximate ranges of maximum AC thicknesses for flexible pavement design with base stiffness of 30,000, 50,000, and 100,000 psi. The design thicknesses for stiff base moduli of 250,000 and 500,000 psi are shown in Table 3, which requires further field evaluation and validation. This is especially important for the very thin sections where the base modulus is 500,000 psi; it is likely that these sections would suffer from reflective cracking that is not accounted for in perpetual pavement analysis. Tables similar to Tables 2 and 3 can be developed based on the procedure described in this synopsis for each state to represent state-specific climate, material, and subgrade conditions.

The maximum AC thickness tables can then be used in conjunction with the agency specific design procedure. When the thickness of a new or rehabilitated pavement designed based on the agency specific design methodology is greater than the maximum thickness, the agency may use the perpetual pavement design approach to optimize the design that can sustain the heaviest loads and provide an indefinite structural life without being overly conservative.

Table 2 Ranges of Maximum AC Thicknesses for Base Stiffness of 30, 50, and 100 ksi

Base Mr (ksi)	Subgrade Mr (ksi)	Maximum Asphalt Thicknesses (in.)					
		6-in. Base		8-in. Base		10-in. Base	
		Average	Range	Average	Range	Average	Range
30	5	14	12.5-15.5	13.8	12.5-15	13.3	12-14.5
30	10	12.2	10.5-14	11.7	10.5-13	11	10-12
30	20	10.5	9-12.5	10.7	9-12.5	10	8.5-11
50	5	13.7	12-15	13.2	11.5-14.5	12.3	11-13.5
50	10	11.8	10.5-13	11.2	10-12	10	9-11
50	20	10.2	8.5-12.5	10.2	8.5-12	9	7.5-10
100	5	13.2	12-14	12.2	11-13	11.2	10-12
100	10	11	10-12	10.2	9-11	9	8-10
100	20	9.7	8-12	9	7.5-10.5	8	6.5-9

Table 3 Ranges of Maximum AC Thicknesses for Base Stiffness of 250 and 500 ksi

Base Mr (ksi)	Subgrade Mr (ksi)	Maximum Asphalt Thicknesses (in.)					
		6-in. Base		8-in. Base		10-in. Base	
		Average	Range	Average	Range	Average	Range
250	5	10.8	9.5-12	9.7	8.5-10.5	8	7-9
250	10	9.2	8-10	7.8	7-8.5	6.5	6-7
250	20	7.3	6.5-8	6	5.5-6.5	4.5	4-5
500	5	8.7	7.5-9.5	6.8	6-7.5	5.2	4.5-5.5
500	10	7	6-8	5.5	5-6	4	3.5-4.5
500	20	5.5	5-6	3.5	3-4	1.8	1.5-2

Authors
Dr. Nam Tran, P.E., Dr. Mary M. Robbins, Dr. David H. Timm, P.E., Dr. J. Richard Willis, Dr. Carolina Rodezno

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