Methodology and Calibration of Fatigue Transfer Functions for Mechanistic-Empirical Flexible Pavement Design

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Problem Statement

Pavement design is shifting toward a mechanistic-empirical framework using engineering principles to design pavement structures that will resist specific distresses, including fatigue cracking and rutting, over the design period. Mechanistic-empirical (M-E) design incorporates material properties and environmental data, and uses mechanical analysis to more accurately model a pavement structure. Pavement response, which is calculated based on expected traffic loading, can then be used to predict pavement performance through empirical correlations or transfer functions. Transfer functions are dependent on pavement materials and climate, requiring calibration to account for local materials and conditions.

While many transfer functions have been developed using laboratory test results, the accuracy of this approach is questionable due to the many discrepancies between laboratory and field performance. Thus, there is a need to develop transfer functions using pavement response and performance measurements from the field.

Figure 1 Fatigue cracking on a structural section on the NCAT Pavement Test Track.

Objective

The objective of this study was to develop fatigue transfer functions using actual field data from the 2003 research cycle at the National Center for Asphalt Technology (NCAT) Pavement Test Track.

Description of Study

The eight 2003 structural test sections used in this study included three hot-mix asphalt (HMA) thicknesses (5, 7 and 9 inches) and two

Figure 2 Taking measurements of the fatigue-cracking area.

asphalt binder types

(PG 67-22 and PG 76-22). All sections were instrumented to monitor pavement response to traffic loading, which was accomplished using a fleet of heavily loaded triple trailers and one legally loaded box trailer. A total of 10 million equivalent single-axle loads (ESALs) were applied over the two-year test period. Pavement response and surface performance data were collected on a weekly basis, while temperature and moisture data were collected continuously.

Embedded strain gauges were oriented in both longitudinal and transverse directions and installed in an array to better capture the wheel wander of the trucks. A procedure was developed to process the raw strain data. Only longitudinal strains were used in developing the fatigue transfer functions, as the most severe strain response was in the longitudinal direction for the majority of the data. Since it was not practical to collect stiffness and dynamic pavement response data continuously, stiffness-temperature and strain-temperature relationships were developed to estimate HMA stiffness and induce strain at any temperature.

In order to establish a relationship between damage and response, the test sections were designed to experience fatigue distress during the two-year test period. However, only three sections—both of the 5-inch sections and the 7-inch section containing a rich bottom layer—reached the failure criterion of cracking covering 20 percent of the lane area. Once cracking became visible, further recorded data for these sections was not included in the analysis.

Fatigue models were then calibrated to most closely relate pavement response to field performance. Preliminary transfer functions were also developed for the sections that did not experience fatigue distress during the two-year test period. The fatigue transfer functions were expressed in the following form:

$$N_f = k_1 \; (1/\varepsilon_t)^{k_2} \, (1/E)^{k_3}$$

where: N_f = Number of load cycles until fatigue failure
ε_t = Horizontal tensile strain
E = HMA mixture stiffness
k_1, k_2, k_3 = Regression constants

Key Findings

Based on the two 5-inch sections that experienced fatigue failure, a fatigue transfer function was developed for thin asphalt pavement sections:

$$N_f = 0.4875 * (1/\varepsilon_t)^{3.031} \, (1/E)^{0.6529}$$

Both sections (one containing PG 67-22 and the other with PG 76-22) exhibited similar fatigue performance.

Based on the 7-inch and 9-inch sections that did not experience fatigue failure, a preliminary fatigue transfer function was developed for thicker asphalt pavement sections:

$$N_f = 0.4831 * (1/\varepsilon_t)^{3.063} \, (1/E)^{0.5992}$$

A fatigue transfer function was also developed for the 7-inch rich bottom section:

$$N_f = 0.4814 * (1/\varepsilon_t)^{3.007} \, (1/E)^{0.6911}$$

Since the rich bottom layer was expected to provide increased fatigue resistance, the premature failure of this section was surprising. However, forensic investigations revealed a substantial loss of bond strength between the rich bottom layer and the overlying layer, contributing to the poor performance of this section.

Recommendations for Implementation

The fatigue transfer functions developed in this study are applicable to public highway design and analysis for states with materials and climatic conditions similar to those at the NCAT test track.

Suggested Further Research

The preliminary fatigue transfer function developed for thick asphalt pavement sections should be revised as necessary to accurately reflect long-term performance of the sections that did not fail during the two-year test period. Further investigation of the rich bottom layer concept is also needed, and the rich bottom fatigue transfer function should be verified, as it was based on the performance of only one test section. Another area of further research should be evaluating the effect of binder modification on fatigue performance.

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