National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

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

RESEARCH SYNOPSIS 06-03

Introduction and Objective

In recent years mechanistic-empirical (M-E) design has been developed to utilize the mechanical properties of a pavement structure, along with information on traffic, climate and observed performance, to more accurately model pavement structure and predict its life. M-E design is used to determine the appropriate materials and layer thicknesses needed to provide the structural capacity for the required performance period. For flexible pavements, this includes considering the main load-related structural distresses – fatigue cracking and structural rutting.

The M-E design and analysis process, shown conceptually in Figure 1., integrates the environmental conditions and material properties of the HMA and underlying layers into the pavement structure. The structure is then modeled using a mechanical analysis program, and the pavement responses are calculated given the axle load and tire configuration. The pavement response is then correlated to performance or cycles to failure (N) through empirically derived transfer functions.

A particularly challenging piece of the design process is developing the transfer function, or performance equation, that is needed to relate the calculated pavement response (stress, strain) to performance (amount of cracking, rut depth). Fatigue cracking is one of the major modes of distress in flexible pavements, along with rutting and thermal cracking. This research focuses on accurately modeling fatigue distress and developing fatigue transfer functions.

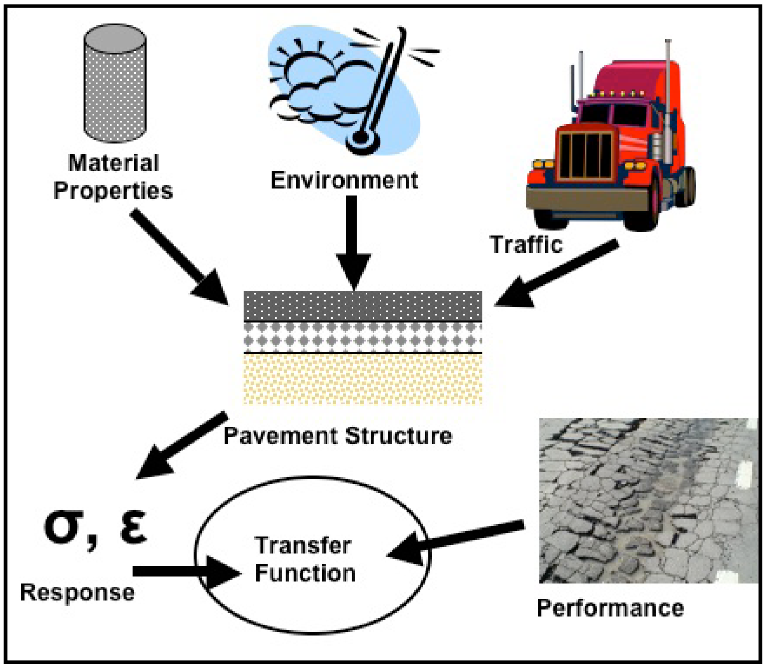

Figure 1. M-E Design schematic

Research Plan

Eight structural test sections were constructed on the 1.7-mile NCAT Test Track – one of the most advanced and comprehensive facilities of its kind in the world. These test sections were subjected to a two-year, 10 million ESALs loading cycle which began in 2003.

Figure 2. Aerial photo of the NCAT Test Track

Figure 2. shows the aerial view of the 2003 NCAT Test Track with eight structural test sections. This test track was suitable for developing transfer functions because it provided full-scale pavement sections, actual tractor-trailer test vehicles, human drivers, pavement instrumentation, environmental monitoring, and the ability to conduct a wide range of performance and material characterization testing.

The eight test sections were designed structurally for varying traffic levels, arriving at a thin, medium, and thick design for three sections using an unmodified asphalt binder (PG 67-22). Three paired sections utilized an SBS polymer modified binder (PG 76-22). The final two sections were designed for the medium traffic level with a one-inch stone matrix asphalt (SMA) surface course. The last section, in addition to the SMA surface course, had a rich bottom layer with an additional 0.5% binder.

Most fatigue transfer functions have been developed using laboratory fatigue tests that are then calibrated or shifted to match observed field performance. However, laboratory-developed performance equations do not accurately predict the fatigue life of asphalt pavements in the field due to several differentiating factors.

The fatigue transfer functions developed from the 2003 NCAT Test Track were derived strictly from field data, without laboratory testing or theoretical models. Therefore, the process was unique and required a massive amount of data collection and synthesis.

Figure 3. Dynamic data acquisition scheme

All inputs shown in Figure 1, including material properties, environment, traffic and the pavement structure, for M-E analysis were measured and quantified, in situ, at the test track. The pavement response was measured from field instrumentation such as strain gauges and pressure plates (Figure 3.) rather than calculated using a theoretical model. And finally, the pavement performance, including fatigue cracking (Figure 4.), was monitored and recorded in the field.

Figure 4. Progressed fatigue cracking

Key Findings

- The strain gauge array was sufficient for the experiment. It successfully captured the wheel wander and maximum strain response and provided adequate redundancy to account for some gauge failures.
- The strain amplitude algorithm developed on the track accurately describes an entire vehicle strain trace and captures the dynamic effects of truck loading.
- The dynamic data processing procedure developed at NCAT is both interactive and efficient.
- The wheel wander at the NCAT Test Track is representative of open-access facilities.
- Both 5-inch (thin) sections, N1 and N2, exceeded their design life of 1.1 million ESALs. The first signs of fatigue cracking were observed at 1.6 and 2.5 million ESALs for Sections N1 and N2, respectively. Based on the very limited data of these two sections, the unmodified PG 67-22 Test Section N1 performed slightly better than its modified counterpart, N2. Although, it can be argued that the two sections were basically the same in terms of fatigue performance.
- All of the 7-inch (medium) test sections outlived their design life of 2.9 million ESAL. Based on the limited test sections, the rich bottom layer did not produce a more fatigue-resistant structure. However, this may be attributed to a poor bond between layers rather than a defect in the rich bottom layer itself.
- No fatigue cracking was observed in the two 9-inch (thick) test sections at the end of the 2-year loading cycle.
- The fatigue transfer function developed for thin asphalt pavement sections (less than 5 inches) based on the data of Sections N1 and N2 was found to be:

$$Nf = 0.4875 * [1/t]^{3.031} * [1/E]^{0.6529}$$

Where: Nf = Number of load cycles until fatigue failure
t = Applied horizontal tensile strain
E = HMA mixture stiffness

- The preliminary fatigue transfer function developed for thicker asphalt pavement sections based on the data from Sections N3 - N7 was found to be:

$$Nf = 0.4831 * [1/t]^{3.063} * [1/E]^{0.5992}$$

- The preceding fatigue transfer functions were developed from a limited number of test sections. The structural test sections were designed using Alabama DOT materials and specifications and, therefore, these transfer functions are directly applicable to the State of Alabama and other states with similar mixture designs and climatic conditions.

Acknowledgements and Disclaimer

The Alabama DOT, the Indiana DOT, and the Federal Highway Administration (FHWA) sponsored this structural study at the Test Track. This research synopsis provides a brief summary of the study's final publication. This document is for general guidance and reference purposes only. NCAT, Auburn University, and the listed sponsoring agencies assume no liability for the contents or their use.