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M-E flexible pavement design: Issues and challenges

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ABSTRACT: M-E flexible pavement design procedures have evolved since the late 50's and early 60's. In the analyses of the AASHO Road Test data it was demonstrated that pavement response (surface deflection) was a good indicator of pavement performance (equally as good as the Structural Number)!! Significant advances have been achieved in the last 50+ years. Current procedures and developments for materials characterization, structural modeling, distress transfer functions, and other issues are considered in the presentation. Emphases are placed on those concepts/approaches that support the development of readily useable/implementable flexible pavement design procedures.

Keywords: Mechanistic-empirical design, flexible pavements

1 INTRODUCTION

The SHELL Pavement Design Manual was presented at the 4th International Conference on Structural Design of Asphalt Pavements [1] and was published by Shell in 1978 [2]. USA interest (AASHTO) in M-E design initiated in the md-1980s. Other agencies and groups have also been engaged in developing M-E pavement design procedures. The development/evolution of the current AASHTO procedure [3] is presented in the following sections.

"Mechanistic-Empirical Design Procedures" is the title of Part IV of the 1986 AASHTO Guide [4]. The Introduction (Section 1.1) of Part IV, states:

> For purposes of this Guide, the use of analytical methods refers to the numerical capability to calculate the stress, strain, or deflection in a multi-layered system, such as a pavement, when subjected to external loads, or the effects of temperature or moisture. Mechanistic methods or procedures will refer to the ability to translate the analytical calculations of pavement response to performance. Performance, for the majority of procedures used, refers to physical distress such as cracking or rutting.
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> However, researchers recognize that pavement performance will likely be influenced by a number of factors which will not be precisely modeled by mechanistic methods. It is, therefore, necessary to calibrate the models with the observations of performance, i.e. empirical correlations. Thus, the procedure is referred to in the Guide as a mechanistic-empirical design procedure.

Activities associated with the development of the revised "AASHTO Guide for the Design of Pavement Structures" [4] prompted the AASHTO Joint Task Force on Pavements (JTFOP) to recommend that research should be initiated immediately with the objective of developing mechanistic pavement analysis and design procedures suitable for use in future versions of the AASHTO Guide. NCHRP Project 1-26 (Calibrated Mechanistic Structural Analysis Procedures for Pavements/J. L. Brown—Texas DOT—Panel Chairman)) was the first NCHRP Project to be sponsored. The M-E principles and concepts stated in the 86 AASHTO Guide were included in the NCHRP Project 1-26 Project Statement.

The University of Illinois cooperated with the Asphalt Institute and the Concrete Technology Laboratories in the conduct of NCHRP 1-26. It was not the purpose of NCHRP Project 1-26 to devote significant effort to develop new technology, but rather to assess, evaluate, and apply available M-E technology. Thus, the proposed processes/procedures were based on the Best Demonstrated Available Technology (BDAT). NCHRP Project 1-26 was completed in December, 1992 and comprehensive reports [5,6,7] were prepared summarizing the study.

2 M-E DESIGN CONCEPTS

Figure 1 illustrates the general concepts of a M-E model as presented in NCHRP 1-26 [7]. The pavement design process is complex. The major components of the M-E procedure are: INPUTS, STRUCTURAL MODELS, TRANSFER FUNCTIONS, and RELIABILITY. These components were comprehensively discussed in the NCHRP 1-26 reports. Three of the most significant components are MATERIAL CHARACTERIZATION, STRUCTURAL MODELS and TRANSFER FUNCTIONS.

Calculated pavement structural responses are for "given time," "given climate," "given pavement structure," "given material properties," and "given loading" inputs. Pavement responses change as these inputs vary throughout the pavement service life. Pavement performance is a long term consideration and mechanistic analysis and design procedures must account for the effect of the varying time-related inputs to the STRUCTURAL MODEL.

3 STRUCTURAL MODELS

A major task in Phase 1 of NCHRP 1-26 [5,6] was the review/evaluation of available mechanistic analysis procedures. It was concluded that the available flexible pavement structural models and computer codes for mechanistic analysis are adequate for supporting the development and initiating implementation of M-E thickness design procedures. Stress dependent finite element programs (like ILLI-PAVE, MICH-PAVE, and Texas ILLI-PAVE) and elastic layer computer programs (like BISAR, WESLEA, JULEA, CHEVRON, ELSYM 5, CIRCLY) were recommended for flexible pavements. The finite element programs are more versatile and can accommodate stress dependent moduli properties (stress-hardening for

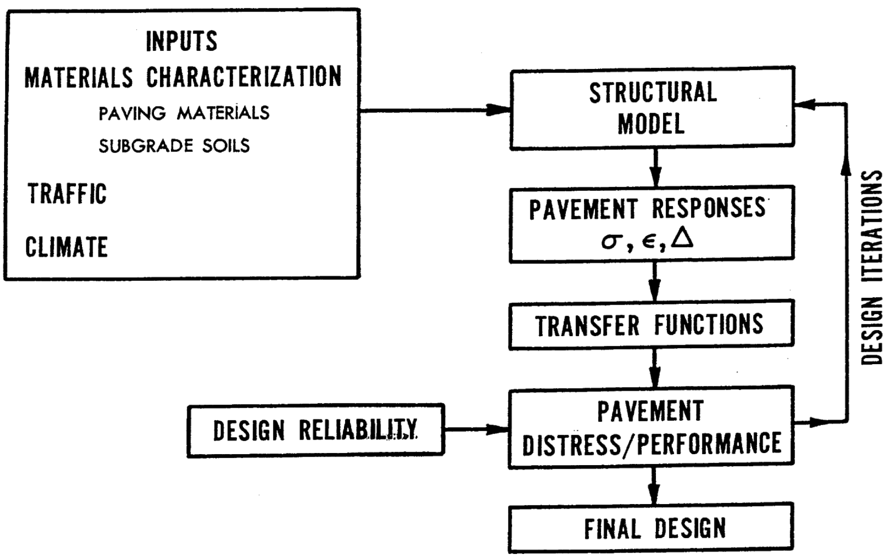

Figure 1. M-E flow chart.

granular materials; stress-softening for fine-grained soils) and also can incorporate failure criteria (such as the Mohr-Coulomb model in ILLI-PAVE).

4 TRANSFER FUNCTIONS

Transfer functions (distress models) relate the pavement responses determined from mechanistic models to pavement performance as measured by the type and severity of distress (rutting—cracking—roughness—etc.). Transfer functions were extensively reviewed in NCHRP 1-26. Modes of distress such as the fatigue and permanent deformation of paving materials and subgrade soils can be characterized from extensive testing of specimens under controlled laboratory conditions. The effects of such factors as stress level, frequency of load repetitions, rest periods, mixture variables, moisture content/density factors, etc. can be readily considered in laboratory-based studies.

The most common flexible pavement TRANSFER FUNCTIONS are a) Asphalt Concrete (AC) flexural strain—fatigue life algorithms, b) subgrade vertical strain—pavement life relations (for a given level of pavement rutting), c) permissible subgrade stress ratios [subgrade stress/subgrade strength] for various ESAL levels, and d) surface deflection—pavement life relations (surface deflection is a reliable indicator of AC flexural strain, subgrade vertical strain, and subgrade stress ratio).

Other flexible pavement distress phenomenon like AC block cracking and AC thermal cracking are more complex and are generally studied/evaluated from actual field performance data. In the field, the significant influencing factors can not be readily controlled/measured as for laboratory-based conditions. Thus, it is more difficult to develop accurate/refined TRANSFER FUNCTIONS for these distress modes.

The NCHRP 1-26 study concluded transfer functions are **weak links** in the M-E design approach. Extensive field calibration and verification are required to establish reliable distress prediction models. The NCHRP 1-26 study indicated:

- Useable flexible pavement transfer functions (distress models) are available for AC fatigue and subgrade rutting.
- The transfer functions for AC and granular material rutting are marginal.
- AC rutting is best considered by material selection and mixture design procedures and practices. (NOTE: The SUPERPAVE Level I Mixture Design procedure is a good example of this approach).
- Granular material rutting considerations can be accommodated by establishing "minimum" AC surface thickness requirements for given classes (based on shear strength and moisture sensitivity) of granular base/subbase materials.

5 NCHRP-1-26/PAVEMENT DESIGN

In NCHRP 1-26 working versions of M-E design processes and procedures were proposed for flexible pavements (Conventional Flexible Pavements, FULL-DEPTH AC pavements, High Strength-Stabilized-Base Pavements). The proposed procedures relate pavement responses (stresses, strains, and deflections) to the development of specific pavement distresses. As opposed to running a PC program, the responses can be predicted from pavement response prediction algorithms [9,10,11] to accomplish routine pavement designs. The pavement response algorithms were developed from comprehensive ILLI-PAVE data bases.

NCHRP 1-26 calibration activities were minimal due to the lack of adequate data. As an alternative, the concept of "Design Confirmation" was suggested. In this approach, the M-E procedure is utilized to explain pavement performance "SUCCESSES" and "FAILURES." (NOTE: Care should be taken to ensure that undue weighting is not given to "long term survivor" sections and inadequate attention provided to "early life" failures.) Modifications and adjustments are made in the M-E procedure to reconcile identified discrepancies.

Confidence and improved accuracy/reliability are thus developed in the M-E procedure. The design confirmation approach can be employed as a "check procedure" for the SHA's current pavement design procedure. In most cases, additional information and data (beyond that required for the current SHA procedure) will be required. Frequently, the pavement FAILURES associated with a section designed by the routine SHA procedure can be explained by M-E analysis and design concepts/procedures.

NCHRP 1-26 emphasized that M-E pavement design is very important, but it is only a segment of a larger scenario. A M-E design process <u>can not</u> realistically adequately address <u>all pertinent factors and issues</u> associated with or related to load responses, distress development, and ultimate pavement system performance. Thickness related factors are most readily addressed by M-E pavement design and that was the emphasis of NCHRP 1-26. AC fatigue and pavement rutting were the distresses that were considered. Some other significant and important factors are material selection practices and material specifications, construction policies and specifications, quality control/quality assurance procedures, maintenance and rehabilitation practices.

6 NCHRP 1-37A

A follow-up project (NCHRP 1-37A—Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II) was initiated in February, 1998 with ARA, Inc.—Eres Consultants Division. The Flexible Pavement Team was led by Dr. Matt Witczak (University of Maryland/Arizona State University). The following excerpts from "The Manual of Practice ([12] present the evolution and development of the MEPDG (Mechanistic-Empirical Pavement Design Guide).

> From the early 1960s through 1993, all versions of the American Association for State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures were based on limited empirical performance equations developed at the AASHO Road Test in the late 1950s. The need for and benefits of a mechanistically based pavement design procedure were recognized when the 1986 AASHTO Guide for Design of Pavement Structures was adopted. To meet that need, the AASHTO Joint Task Force on Pavements, in cooperation with the National Cooperative Highway Research Program (NCHRP) and the Federal Highway Administration (FHWA), sponsored the development of an M-E pavement design procedure under NCHRP Project 1-37A.
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> A key goal of NCHRP Project 1-37 A—Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures: Phase II—was the development of a design guide that utilized existing mechanistic-based models and data reflecting the current state-of-the-art in pavement design. This guide was to address all new (including lane reconstruction) and rehabilitation design issues, and provide an equitable design basis for all pavement types.
>
> The Mechanistic-Empirical Pavement Design Guide (MEPDG), as it has now become known, was completed in 2004 and released to the public for review and evaluation. A formal review of the products from NCHRP Project 1-37 A was conducted by the NCHRP under Project 1-40A. 'This review has resulted in a number of improvements, many of which have been incorporated into the MEPDG under NCHRP Project 1-40D. Project 1-40D has resulted in Version 1.0 of the MEPDG software and an updated design guide document.
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> Version 1.0 of the software was submitted in April 2007 to the NCHRP, FHWA, and AASHTO for further consideration as an AASHTO provisional standard and currently efforts are underway on Version 2.0 of the software. Simultaneously, a group of state agencies, termed lead states, was formed to share knowledge regarding the MEPDG and to expedite its implementation. The lead states and other interested agencies have already begun implementation activities in terms of staff

training, collection of input data (materials library, traffic library, etc.), acquiring of test equipment, and setting up field sections for local calibration.

The NCHRP 1-37A project was much more comprehensive and broad-based than NCHRP 1-26 and considered the development of the following distresses: HMA alligator cracking, HMA longitudinal cracking, HMA transverse cracking, and pavement rutting. A considerable emphasis was placed on predicting pavement IRI (International Roughness Index). An important feature of the MEPDG is that reliability estimates are provided for the distress models and IRI.

The elastic layer program (JULEA—Jacob Uzan Linear Elastic Analysis) is the flexible pavement structural model in the current version of the MEPDG. In the initial versions of the MEPDG, a 2-D finite element program was included. However, the program was not used in the calibration studies and it is not available for use in the current software. AASHTO initially issued the MEPDG as "DARWIN-ME." The most recent version of the MEPDG [3] was issued as "AASHTOWare Pavement ME Design" in 2013. The software is periodically modified as it is utilized.

Comprehensive reports on many topics/issues were prepared by the Flexible Pavements Team during the conduct of NCHRP 1-37A. The major findings and recommendations were presented in the March 2004—NCHRP 1-37A Final Report (Part 1. Introduction/Part 2. Design Inputs/Part 3. Design Analysis/Part 4. Low Volume Roads).

7 NCHRP 1-37A CALIBRATION

GLOBAL CALIBRATIONS for pavement distress were developed in the NCHRP 1-37A project. The calibration results [as presented in Ref.12] for fatigue, rutting, and IRI are shown in Figures 2–4. The statistical summary data shown in the figures (R^2, Se, Sy, Se/Sy) indicate the difficulty in establishing accurate/precise transfer functions on a large scale.

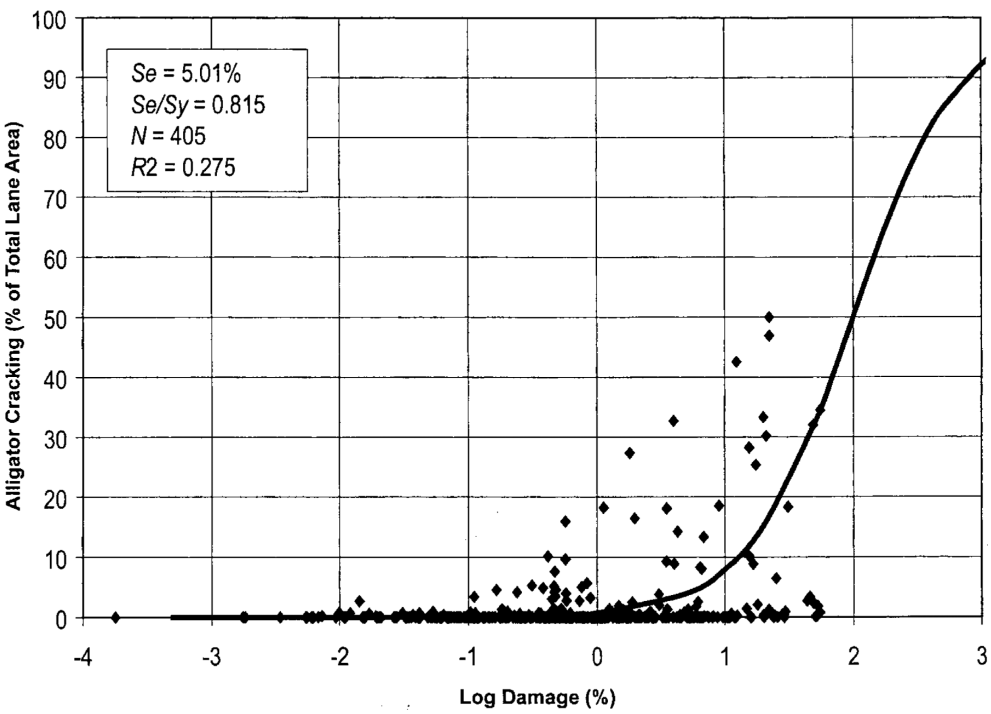

Figure 2. Alligator cracking calibration.

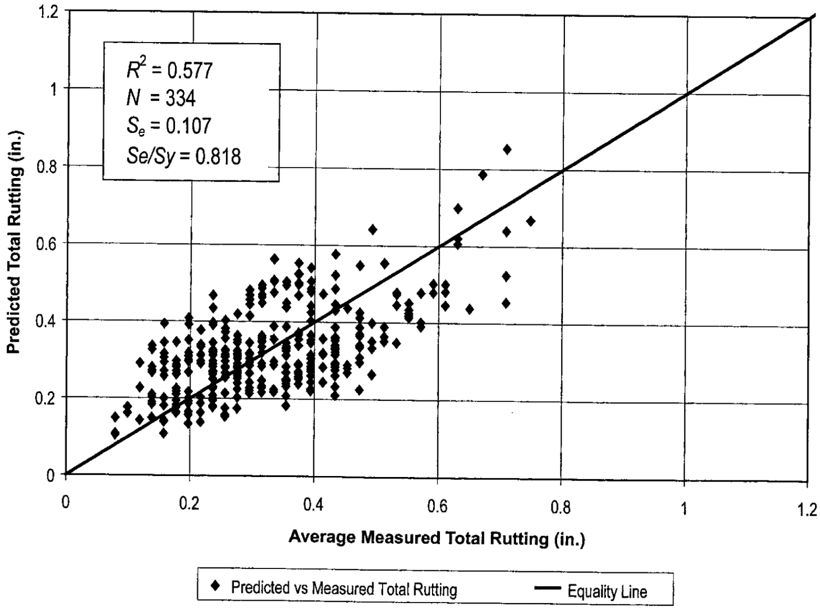

Figure 3. Rutting calibration.

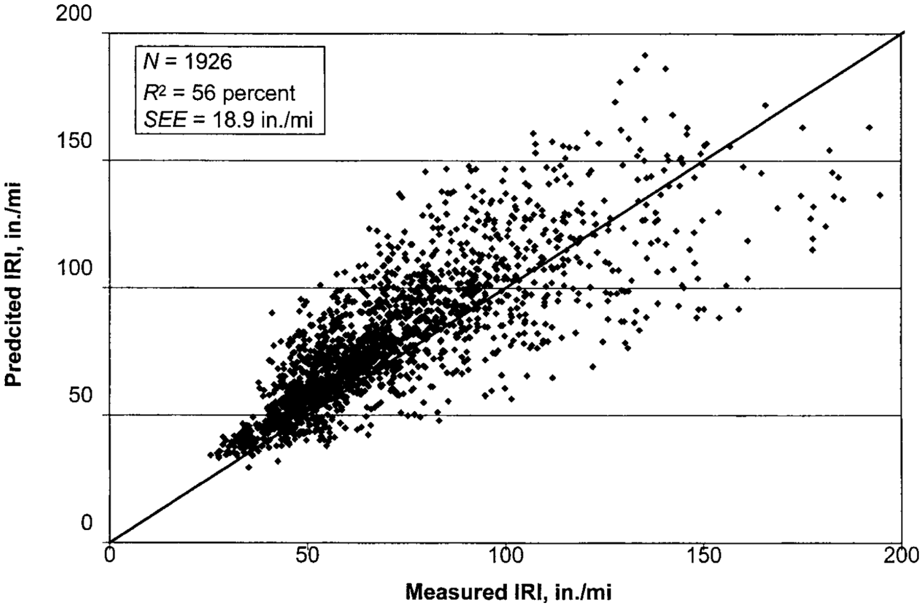

Figure 4. IRI calibration.

AASHTOWare [3] has indicated:

> "AASHTO encourages each licensing agency to calibrate and validate using local materials."

Many agencies have conducted calibration studies and established "typical" input values for routine pavement design. The distress prediction models are "tweeked" by adjusting the model β factors to achieve better model statistics.

8 EXISTING TECHNOLOGY

It is important to note that both NCHRP 1-26 and NCHRP 1-37A were to utilize "currently available technology."

- It was not the purpose of NCHRP Project 1-26 to devote significant effort to develop new technology, but rather to assess, evaluate, and apply available M-E technology.
- A key goal of NCHRP Project 1-37A was the development of a design guide that utilized existing mechanistic-based models and data reflecting the current state-of-the-art in pavement design.

As implementation issues emerge and new technology is developed, there are ongoing efforts to incorporate the developments into AASHTOWare Pavement ME Design.

9 ISSUE AND CHALLENGES

M-E flexible pavement design has made significant progress since the late 50's and early 60's. There are many examples of successful utilization of M-E procedures by various US and international entities. However, as noted in previous sections of this paper, there are still issues and challenges to be addressed that are common to many of the procedures.

Several important (per the author's opinion) issues and challenges are noted below.

- Stress dependent moduli characterization of soils and granular materials.
- Stress dependent finite element models that can accommodate stress dependent soil/material moduli and failure criteria should be further considered for implementation.
- Transfer functions (HMA fatigue/HMA fatigue endurance limit, HMA rutting, granular material and subgrade soil rutting).

Progress continues in addressing these issues and challenges. The resources/ability to develop/provide good inputs, ease of use/complexity, implementation potential, ability to accommodate new technology/developments (particularly new materials and pavement loading conditions) are some key factors that should be considered as M-E flexible pavement design procedures continue to evolve and improve.

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