Use of MnROAD to Support the Development and Further Refinement of the Current Mechanistic Design Guide

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ABSTRACT:
This paper is a review the use of the Minnesota Road Research Project (MnROAD) to support both the adaptation and further refinement of the 2002 Mechanistic-Empirical Pavement Design Guide (ME-EPDG). It shows that the MnROAD facility provided the developers of the M-EPDG very valuable and unique information that was valuable in during the development of the M-EPDG. It is now a valuable asset for pavement researchers to use to refine the M-EPDG for local calibration and validation efforts.

KEY WORDS: MnROAD, Mechanistic-Empirical Pavement Design, Design Guide

1 INTRODUCTION

The recently developed 2002 Mechanistic-Empirical Pavement Design Guide (M-EPDG) (Applied Research Associates, Inc. 2004) represents a major change in the way pavement design is performed. The designer is fully involved in the design process and has the flexibility to consider different design features and materials for the prevailing site conditions. Through the use of mechanistic principles and more detailed input data (material properties of the subgrade and constructed layers, axle load distribution, detailed climatic data), the new design procedure is capable of producing reliable design, even for design conditions that deviate significantly from previously experienced. The M-EPDG is actually an analysis procedure that the designer uses to predict the performance of tentative designs. The designer adjusts various input values relating to materials, thicknesses, and properties to find a pavement structure that is predicted to provide the required performance. However, accurate calibration of the M-EPDG is essential to obtain accurate results.

Accurate calibration and adaptation for local conditions is vital to a mechanistic-empirical design procedure. Currently, there have not been discovered any intrinsic relationship between pavement performance and any of the direct pavement response parameters. For example, for joint faulting of jointed plain concrete pavements, none of the direct pavement response can be used directly to predict the rate of faulting development. Calibration is an integral part of mechanistic-empirical performance model development process, and the models developed under NCHRP Project 1-37A were calibrated using performance data from

Long Term pavement Performance (LTPP) and other available databases. This ensures that the performance prediction models do reasonably good job predicting pavement performance for a wide range of climatic conditions and construction practices. Those predictions can be significantly improved if the models within the M-EPDG are fine tuned for local conditions.

The mechanistic-empirical format of the Design Guide provides a framework for adaptation for local conditions. By adjusting parameters of the performance prediction models, a transportation agency can better describe behavior of pavements under its jurisdiction. The local calibration and adaptation process helps optimize performance prediction capability for given climate, subgrade, and traffic patterns. This creates a demand for high quality pavement performance data that can be used for local calibration and adaptation of the M-EPDG.

To verify and/or improve performance prediction models, the following information should be available:

1. Detailed climatic data
2. Detailed traffic information
3. Detailed construction and materials data
4. Detailed performance information

The MnRoad test facility is an excellent source for this information.

2 MNROAD

Between 1990 and 1994 the Minnesota Department of Transportation constructed the Minnesota Road Research Project (MnROAD). The MnROAD site is located 40 miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments containing 50 test cells, each 152.4 m (500 feet) long. The 5.6 km (3 ½ mile) Mainline Test Roadway (Mainline) is part of westbound Interstate Highway 94 and contains 31 test cells and carries an average of 20,000 vehicles daily. Parallel and adjacent to the Mainline is a Low Volume Roadway (LVR) that is a 4 km (2 ½ mile) closed loop roadway that contains the remaining 19 test cells. Traffic on the LVR is provided by a MnROAD operated 18 wheel, 5-axle, tractor/semi-trailer with two different loading configurations of 454 kN (102 kips) and 356 kN (80 kips). Subgrade, aggregate base, and surface materials, as well as geometric design methods vary from cell to cell. Daily information is gathered via a computerized data collection system that initially monitored more than 4500 mechanical and environmental sensors (many of these sensors are no longer in service). All the data collected is entered into the MnROAD database for Mn/DOT and other researchers use. More information can be obtained from the authors or by visiting the MnROAD web site at http://mnroad.dot.state.mn.us/research/mnresearch.asp

3 MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE

The *Guide for Mechanistic-Empirical Design Of New and Rehabilitated Pavement Structures* – initially referred to as the 2002 Design Guide but now referred to as Mechanistic-Empirical Pavement Design Guide (M-EPDG) - developed under NCHRP Project 1-37A reflects a paradigm shift in pavement design (Applied Research Associates, Inc. 2004). The concepts and methodologies incorporated in developing the procedure reflect the current state of the art in pavement technology. The Guide employs common design parameters for traffic, subgrade, environment, and reliability for all pavement types. It requires an iterative hands-on approach by the designer. The designer must select a trial design and then analyze the design in detail to determine if it meets the performance criteria established by the designer. This involves the following steps:

1. Assemble a trial design for a specific site conditions such as traffic, climate, and foundation—define layer arrangement, asphalt concrete (AC) or portland cement concrete (PCC) and other paving material properties, and design and construction features.
2. Establish criteria for acceptable pavement performance at the end of the design period. The following distresses are predicted for concrete pavements
    a. Transverse joint faulting for jointed plain concrete pavements
    b. Transverse cracking for jointed plain concrete pavements
    c. Number of punchouts for continuously reinforced concrete pavements
    d. Ride - IRI

    Flexible pavements
    a. Rutting
    b. Fatigue cracking
    c. Longitudinal cracking
    d. Thermal cracking
    e. Ride - IRI
3. Select the desired level of reliability for each of the performance indicators.
4. Process input to obtain monthly values of traffic, material, and climatic inputs needed in the design evaluations for the entire design period.
5. Compute structural responses (stresses, strains, and deflections) for each axle type and load and for each damage-calculation increment throughout the design period. For concrete pavements the critical responses are computed using finite element based rapid solution models. For asphalt pavements the responses are computed using either layered elastic analysis program or an axisymmetric finite element program.
6. Calculate accumulated damage at each month of the entire design period.
7. Predict key distresses month-by-month throughout the design period using the calibrated mechanistic-empirical performance models provided in the Guide.
8. Predict smoothness (IRI) as a function of initial IRI, distresses that occur over time, and site factors at the end of each time increment.
9. Evaluate the expected performance of the trial design at the given reliability level for adequacy.
10. If the trial design does not meet the performance criteria, modify the design and repeat the steps 4 through 9 above until the design does meet the criteria.

4 ADAPTATION OF THE MECHANISTIC-EMPERICAL PAVEMENT DESIGN GUIDE FOR MINNESOTA CONDITIONS

The M-EPDG incorporates performance prediction models that were successfully calibrated and validated using design inputs and performance data largely from the national LTPP database, which includes sections located throughout significant parts of North America. Although this effort was very comprehensive, the Design Guide recommends local validation and calibration as a part of implementing this procedure. A validation database should be developed to confirm that the national calibration factors or functions are adequate and appropriate for the construction, materials, climate, traffic, and other conditions that are encountered within the agencies highway system.

Recently, Minnesota Department of Transportation and the University of Minnesota initiated a study aimed to adapt the M-EPDG for Minnesota conditions. The goal of the calibration-validation process is to confirm that the performance models accurately predict pavement distress and ride quality on a national basis. For any specific geographic area, adjustments to the national models may be needed to obtain reliable pavement designs.

The data required for local calibration-validation can be categorized in five general areas:

- Climatic data
- Traffic data
- Detailed construction and materials data
- Pavement performance data, and
- Pavement response data

Data for each of these categories is needed to complete a local calibration. The MnROAD research facility is a valuable resource for the calibration of the M-EPDG for Minnesota. Detailed data in all of the above categories have been collected over the 10 years MnROAD has been in service.

4.1 Climatic Data

Climatic conditions have a significant effect on the performance of both asphalt and concrete pavements. Temperature and moisture distributions in the asphalt layer affect its stiffness and strain distribution. Temperature gradient through the concrete layer thickness causes concrete slab curling. Change in subgrade and granular layers moisture content causes significant variation in their stiffnesses. The M-EPDG recognizes the importance of these effects. As part of the M-EPDG process, the designer executes the Enhanced Integrated Climatic Model (EICM) incorporated into M-EPDG software. Historical (24 to 51 months) of hourly weather data for hundreds of weather stations across the U.S. are included with the software. Information from the weather station located at the MnROAD site is also included with the software.

In addition to the weather data, the following information is collected at MnROAD:

- Temperatures sensors in the pavement, base, and subgrade layers
- Moisture sensors in the underlying base and subgrade layers
- Piezometers that provide water table elevations under each cell
- Frost penetration and the subsequent spring thaws, and
- Precision surface elevation changes measured periodically to monitor the effects of frost heave or other factors that result in changes in pavement elevations.

Temperature profiles through the slab thickness for several of the MnROAD concrete pavement sections were used for verification of the EICM temperature predictions for concrete pavements. The wealth of data collected at the MnROAD for both asphalt and concrete pavements can be used for further validation of the EICM predictions, especially prediction of moisture content of unbound materials and variation of asphalt temperature throughout the asphalt surface thickness. Figure 1 shows an example of temperature measurements for one of the MnROAD asphalt test section.

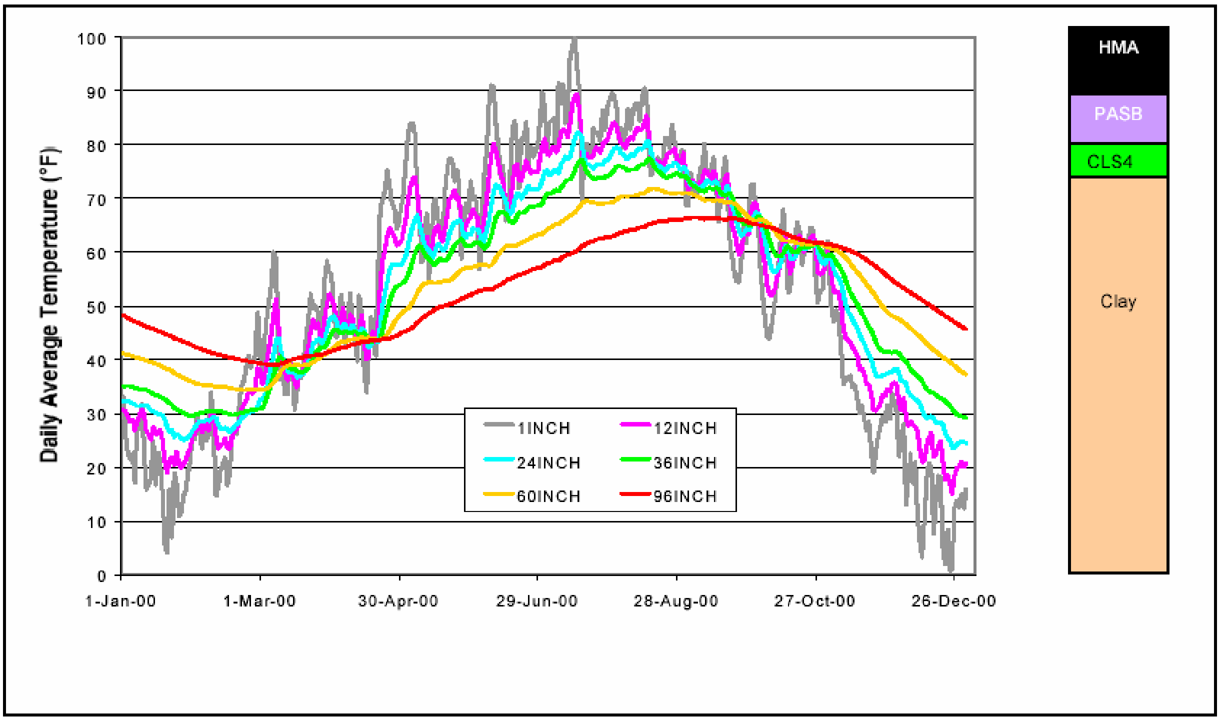


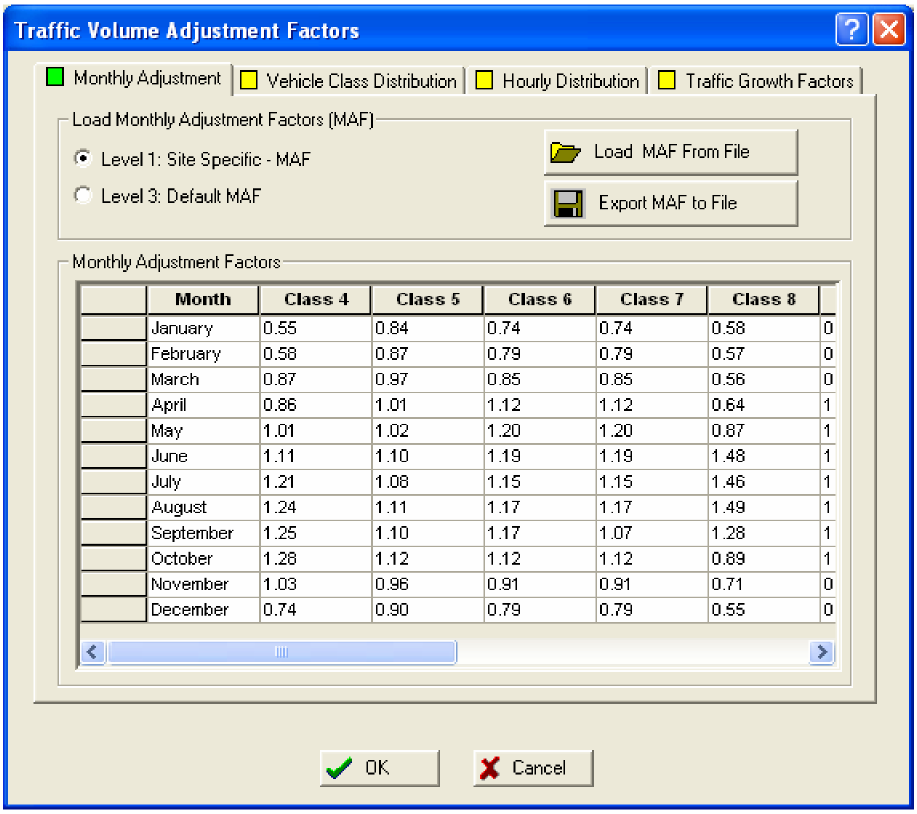
Figure 1: Seasonal variations of temperature for several depths for the MnROAD section with a 240-mm thick asphalt surface layer.

4.2 Traffic Data

Traffic characterization in the M-EPDG is dramatically different from the way it is accounted for in the current AASHTO design procedure. Instead of using number of Equivalent Single Axle Loads (ESALs), the M-EPDG design process requires prediction of the number of axle load applications for each axle type (single, tandem, tridem, or quad) and weight for every month of pavement design life. To predict these distributions, the Design Guide software requires the designer to provide the following data:

- Base year truck-traffic volume.
- Truck-traffic directional and lane distribution factors.
- Truck type and axle load distribution factors.
- Truck lateral distribution factor.
- Truck growth factors.

Weigh-in-motion (WIM) data collected at the Mainline provides crucial traffic data. For example, the Design Guide's software current default assumes that the traffic volume is uniform throughout the year. Analysis of the MnROAD traffic data has shown that it is not the case of I-94 highway where the WIM is located. Figure 2 shows the Design Guide input screen for truck monthly adjustment factors using MnROAD data. Analysis of traffic information for other Minnesota highways has shown that the proposed adjustment factors better described traffic patterns in Minnesota.



Load Monthly Adjustment Factors (MAF)

● Level 1: Site Specific - MAF

○ Level 3: Default MAF

Monthly Adjustment Factors

Month	Class 4	Class 5	Class 6	Class 7	Class 8	
January	0.55	0.84	0.74	0.74	0.58	0
February	0.58	0.87	0.79	0.79	0.57	0
March	0.87	0.97	0.85	0.85	0.56	0
April	0.86	1.01	1.12	1.12	0.64	1
May	1.01	1.02	1.20	1.20	0.87	1
June	1.11	1.10	1.19	1.19	1.48	1
July	1.21	1.08	1.15	1.15	1.46	1
August	1.24	1.11	1.17	1.17	1.49	1
September	1.25	1.10	1.17	1.07	1.28	1
October	1.28	1.12	1.12	1.12	0.89	1
November	1.03	0.96	0.91	0.91	0.71	0
December	0.74	0.90	0.79	0.79	0.55	0

Figure 2: Truck Traffic Monthly Adjustment Input Screen of the 2002 Design Guide Software

4.3 Detailed Construction and Materials Data

MnROAD database contains a wealth of data related to construction and material properties. First of all, it contains detailed information when each layer was placed, so its future performance can be related to construction conditions. MnROAD database also contains design gradations for unbound construction layers as well as mix design for asphalt and concrete layers.

Comprehensive information on as-constructed material properties was collected. The MnROAD data base contains the results of construction control testing which included density, specific gravities, and air voids for asphalt layers, compressive strength and air content for concrete layers. In addition, numerous materials samples were taken from behind the paving machine at the time of construction. These samples were tested to evaluate how the material properties are different from designed properties.

4.4 Pavement Performance Data

One of the advantages of the MnROAD test data is that it allows comparison of the performance of various design features subjected to the same environmental and traffic loading. The MnROAD database contains comprehensive performance data for more than 50 pavement sections for all distresses included in the M-EPDG:

IRI for rigid and flexible
Cracking for rigid
Faulting for rigid
Fatigue cracking for flexible

Thermal cracking for flexible
Rutting for flexible

These data were collected in a consistent manner, many times a year from the time the cells were opened to traffic in 1994 to now for over 10 years of performance data.

Some information is unique to MnROAD. In the summer of 1998 trenches were cut in 8 cells for forensic investigations when the cells reached the end of their serviceable life. The trenches were 4.3 m (14 feet) by 1.2 m (4 feet) wide. The 4.3 m dimension was perpendicular to the centerline and included the 3.65 m (12 feet) of the driving lane and 0.6 m (2 feet) of the shoulder. The 4.3 m (4-foot) dimension was chosen to accommodate the width of the backhoe bucket and to allow access into the trench for in situ testing and sample collection. The cutting was laid out with a string line and spray paint. Each trench was subdivided into 8 individual 0.6 m (2-foot) squares. The pavement was wet sawn with as little water as possible to keep the saw blade cool and limit the amount of moisture entering to the base and subgrade.

In August and September of 2001 trenches were cut in anther 6 HMA cells. These trenches were 3.6 m (12 feet) by 0.9 m (3 feet) wide. The 3.6 m dimension was also perpendicular to the centerline but only included the3.6 m driving lane. A smaller backhoe bucket was used which allowed the width of the trench to be reduced. A special dry cut asphalt blade was used to complete the sawing in order to eliminate any water from infiltrating into the base and subgrade.

Elevations were taken from each forensic trench using a rod and level before the asphalt surface was removed. Once the trench was excavated the face perpendicular to the roadway centerline was cleaned with soap and water and the interfaces of the individual lifts were highlighted with black permanent marker. With the individual lifts highlighted rod and level readings were made by placing the edge of a putty knife against the face of the trench along the lift interface and setting the rod on top of the putty knife. This procedure was completed across the entire length of the trench at 50 mm to 305 mm (2 to 12-inch) intervals for each of the individual lifts within the pavement surface. These measurements provided unique insight onto contribution of rutting of individual layers toward total rutting. This information was invaluable during calibration of the Design Guide and is further discussed in some forensic reports located on the MnROAD web site.

The climatic, materials, and traffic data described above will be inputted into the M_EPGD software to predict development of distresses for each MnROAD pavement section. The predicted performance will be compared with the measured performance. If necessary, adjustments to the national models will be made to obtain reliable pavement designs. This will be done using a non-linear optimization technique. The error function defined as a sum of squares of differences between predicted and measured deflections will be minimized by appropriate adjustments of the calibration parameters of the performance prediction models. The process of verification and adaptation of the M_EPDG model by the MnDOT and the University of Minnesota is expected to be completed in 2006.

4.5 Pavement Response Data

The M-EPDG does not allow the user to modify the structural models. This does not mean, however, that the models incorporated into the M-EPDG do not need improvement. MnROAD database contains wealth of data, which will allow the evaluation the current models, and to determine if there is a need for future development. Although the M-EPDG is was developed to predict pavement performance from calculated responses, the ability of the response models in the M-EPDG to accurately predict actual pavement response is very important. The critical responses for both flexible and rigid pavements are strains in both the bound and unbound layers. MnROAD had a large amount of response type sensors installed during the original construction and for cells that have been reconstructed. The sensors that were installed to measure the dynamic response to moving truck loads as well as to impulse loads generated by a falling-weight-deflectometer allow direct comparisons of measured and predicted responses. In addition, the dynamic strains measured under the live traffic has been and can be correlated to the axle load spectrums measured with the weigh-in-motion equipment, providing a link between observed strain distributions, the predicted pavement strains, and the pavement performance to be made.

5 CONCLUSIONS

The MnROAD facility provided the developers of the M-EPDG very valuable and unique information that was valuable in during the development of the M-EPDG. It is now a valuable asset for pavement researchers to use to refine the M-EPDG for local calibration and validation efforts.

The future use of MnROAD is expected to play a key role in the continued development of mechanistic-empirical design processes and specifically the M-EPDG within Minnesota and likely for other highway agencies with similar climate.

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