LRRB INV 828
Local Road Material Properties and Calibration for MnPAVE

Task 6 Summary Report

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Introduction
Minnesota's M-E design program began as a Mn/DOT-funded research project at the University of Minnesota in the mid 1990's. The outcome of that research was a computer programs called "ROADENT". In 2000, Mn/DOT expanded the ROADENT software into a new design program called "MnPAVE". This software was calibrated using existing R-Value and Soil Factor designs, and validated using MnROAD test sections. A statewide MnPAVE training program was conducted in 2002. The current project was funded by the Local Road Research Board (LRRB) to determine material properties and model calibrations for use on local road designs.

Task 1: Survey of Local Road Officials
A statewide survey was conducted in 1998 to determine the practice of low volume pavement design and maintenance in Minnesota. The results are summarized in Minnesota Low Volume Road Design 1998 [1]. The portions of this survey considered useful in calibrating MnPAVE are those pertaining to pavement performance, such as deflection testing and information about pavement management systems containing pavement condition data. Historical pavement performance data combined with structural and traffic information are essential for calibrating a mechanistic-empirical design procedure. An analysis was conducted to determine which cities and counties may have useable pavement performance data. This data was used to target a follow-up survey to determine if data useful for MnPAVE calibration had been collected since 1998.

A follow-up e-mail survey was submitted through the State Aid office to solicit information useful for the calibration of MnPAVE for local roads. Needed information included structural, traffic, and pavement condition data. While there were several responses from cities and counties with PMS and/or other pavement data, it was either contained in a proprietary database, or was not complete enough to use for calibration.

A pilot project to conduct deflection testing and analysis on Minnesota county state aid highways (CSAH) in 2006 provided sufficient deflection, structural, and traffic data to calibrate MnPAVE. Pavement management data collected on CSAH routes by Mn/DOT in 2006 provided the necessary condition data. Global information systems (GIS) software was used to locate routes with all of the necessary data for calibration.

Task 2: Model Selection

Geographic Information System (GIS) data was used to determine the relationship between soil textural class and modulus. A model was developed to predict soil modulus based on clay and silt content. This model allows moduli to be predicted for any soil textural class. As in the current version of MnPAVE, adjustment factors will be used to correct these optimal values for seasonal changes in moisture and temperature.

Deflections on pavement test sections at MnROAD were used to backcalculate aggregate base moduli. Routine FWD deflections at MnROAD from 1993 to 1996 were analyzed using EVERCALC [2]. The analysis was limited to 3-layer asphalt sections (asphalt over base over subgrade) to avoid ambiguous results caused by multiple base layers. The stiff layer option was used to account for the water table present at MnROAD. Results with root mean square error (RMSE) values greater than 5.0 were filtered out, and the base and subgrade modulus values were plotted by date.

The backcalculated moduli were filtered to remove outliers, and plotted with three successive Spring thaw periods (1994-1996) superimposed in order to determine the default seasonal multipliers for MnPAVE Basic design. MnPAVE calculates the length of each season based on historical temperature data from nearby weather stations. The method of calculating season lengths was developed by Ovik *et al* [3].

There are 11 textural soil classes commonly found in Minnesota. Statewide FWD deflections are available, but without reliable information about the pavement structures, traditional backcalculation analysis cannot be performed for most of these soils. The Hogg model is a forward-calculating model that simulates a thin plate on an elastic foundation. It was originally developed in 1944 and modified in 1983 (Stubstad *et al* [4]).

The Hogg model was validated using MnROAD data and applied to the statewide deflection data. Statewide FWD data used to develop the soil model was screened to exclude interstate and divided highways, which tend to be designed for high traffic volumes. In order to determine default modulus values for different soil textural classifications, GIS technology was used. FWD data collected since 2005 includes global positioning systems (GPS) location data and is easily plotted on a map using ArcGIS software. This data was then superimposed on soil textural class data from the Minnesota Soil Atlas [5] in order to associate the subgrade modulus values with different soil classes. A spatial query was performed using ArcMap software to obtain subgrade modulus statistics by soil type. A 3D model was developed using online data modeling software [6] to relate clay and silt content to average subgrade modulus. The model selected is shown in Equations 1 and 2.

$$E = e^{\mu+\sigma^2/2} \quad (1)$$

Where

E = Predicted subgrade modulus (MPa)

μ = Expected value of ln$E$ (see Equation 2)

σ = Standard deviation of ln*E*
(σ ranged from 0.11 to 0.47 with 0.34 providing the best fit)

$$\mu = 1.93\left(CLAY^{-0.0558} + SILT^{-0.0514}\right) \quad (2)$$

Where

CLAY = Clay content (on a scale of 0-1)
SILT = Silt content (on a scale of 0-1)

The modulus values from the MnPAVE model are somewhat lower than the typical resilient modulus ranges for equivalent soil types from the Mechanistic-Empirical Pavement Design Guide (MEPDG) Final Report (4). Multipliers based on seasonal pore suction resistance factors are applied to modulus values during the MnPAVE design process.

Task 3: MnPAVE Programming

In order to calibrate MnPAVE for local roads, a more accurate subgrade soil modulus model was needed. Other improvements were implemented, and some features formerly available only in "Research Mode" were made available in the standard design mode. Following is a listing of improvements programmed in MnPAVE Version 5.3:

1. The subgrade soil modulus model developed in Task 2 was implemented.
2. The default soil modulus values were updated using Equations 1 and 2.
3. A prototype "Soil Class" view was implemented in the Climate module.
4. The rutting model was recalibrated and validated.
5. The fatigue model from 2002 was re-validated.
6. Two reliability methods were implemented:
   a. Layer thickness and modulus adjustment: The values used to simulate the pavement are reduced according to the level of confidence (50-99%), the mean and coefficient of variation (COV) and distribution type (normal or lognormal).
   b. Monte Carlo simulation: 2,500 simulations are run using thickness and modulus values that are varied randomly within their respective distributions. The reliability is defined as the percentage of simulations that meet or exceed the design life.

All programming was done in Visual C++ using Microsoft Visual Studio Version 6.

Task 4: Model Calibration

Data collected on 29 CSAH routes in 2006 was used to recalibrate the rutting model. There were insufficient fatigue failures recorded to recalibrate the fatigue model so the 2006 CSAH data was used to re-validate the existing MnPAVE fatigue model. Both models were also validated using selected pavements from Minnesota Department of Transportation Investigation No. 183 (Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota) [7].

Task 5: Expand MnPAVE Help Files

The MnPAVE help files are typical of many Windows applications with "Contents", "Index", and "Find" tabs. Many of the Help topics replicate the appearance of the MnPAVE modules, with clickable buttons that jump to the corresponding help topic. The help files have been expanded and updated to encompass the new features and updates in Version 5.3.

The "Contents" feature displays the MnPAVE help topics in a hierarchical format. Major headings can be double-clicked to expand subheadings. The "Index" feature is a way of quickly locating a main topic or subject. As text is typed into the top window, the blue highlight bar automatically jumps to topics that begin with the letters typed. The "Find" feature is used to locate all topics containing the desired keyword. As text is entered the list of keywords is narrowed to those beginning with the letters typed. The user can then click on the desired keyword and a list of relevant topics appears below.

In topics with clickable images, links are indicated when a hand pointer  appears over a portion of the image when the mouse is moved there. Clicking the left mouse button either opens a pop-up description or jumps to the relevant topic.

The newly expanded Help files are intended to serve as a stand-alone manual for the user or as a supplement to the printed User's Guide.

References

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4. Stubstad, R.N., Jiang, Y.J., Clevenson, M.L., and Lukanen E.O., "Review of the Long-Term Pavement Performance Backcalculation Results – Final Report," Report No. FHWA-HRT-05-150, Federal Highway Administration, McLean, VA, February 2006.
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6. Phillips, James R., "ZunZun.com Interactive 2-Dimensional and 3-Dimensional Data Modeling, http://www.zunzun.com
7. Lukanen, E.O., "Application of AASHO Road Test Results to Design of Flexible Pavements in Minnesota," Investigation No. 183 Final Report, Minnesota Department of Transportation, 1980.