Project Summary Report 0-1863-S

Project 0-1863: Evaluate the Use of FWD Data in Determining Seasonal Variations in Pavement Structural Strength

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PROJECT SUMMARY REPORT

Temperature Correction of Backcalculated AC Modulus

The Texas Department of Transportation (TxDOT) uses the falling weight deflectometer (FWD) for pavement evaluation. A common application is the backcalculation of pavement layer moduli by deflection basin fitting. In Texas, pavement engineers use the MODULUS program to provide estimates of pavement layer moduli from measured FWD deflections. These estimates are subsequently used in other applications, such as the FPS-19 flexible pavement design procedure, the Program for Analyzing Loads Superheavy (PALS), and the Program for Load-Zoning Analysis (PLZA).

For pavement applications, engineers must adjust the results obtained from the FWD or correct them to reference or standard conditions of temperature, moisture, and loading frequency. As indicated in the research project statement for Project 0-1863, this problem has been studied by state, federal, and international researchers. What is needed is to use the knowledge gained from previous studies to develop an automated method for correcting FWD data to standard conditions. The scope of the project was limited to asphalt concrete (AC) pavements with unbound base materials, and to the development of an automated procedure for correcting backcalculated AC modulus to user-prescribed reference or standard conditions of temperature and loading frequency.

Research efforts resulted in the development of the Modulus Temperature Correction Program (MTCP), which incorporates procedures for predicting pavement temperature and the seasonal variation of backcalculated AC modulus. MTCP (Figure 1) runs under the Windows® operating system and requires Microsoft Excel®, version 97 or later. By having an automated procedure, TxDOT pavement engineers can more effectively consider seasonal variations in structural strength in the design of pavements, analysis of superheavy load routes, and evaluation of axle weight restrictions.

What We Did...

To identify existing methods for temperature correction of backcalculated AC modulus, researchers initially conducted a literature review of previous investigations in this area. From this review, researchers, in consultation with the project monitoring committee, selected m'ethods to evaluate in this project using available data from the Seasonal Monitoring Program (SMP) sites located in Texas, Oklahoma, and New Mexico that were collected under the Long-Term Pavement Performance (LTPP) program. To supplement the SMP data, personnel from the Texas Transportation Institute (TTI) and TxDOT's Mobile Load Simulator (MLS) crew also collected FWD and pavement temperature measurements on two test sections located at the Riverside Campus of Texas A&M University. Altogether, there were nine sites from which data were taken and analyzed:

- five SMP sites in Texas—481060, 481068, 481077, 481122, and 483739;

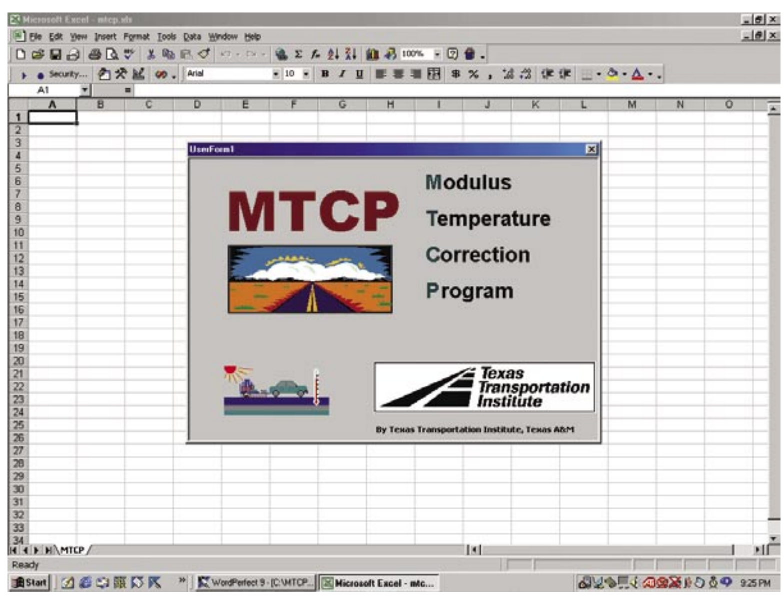

Figure 1. MTCP Title Screen.

- one SMP site New Mexico—351122;
- one SMP site in Oklahoma—404165; and
- two test sections (12 and 21) located at the Texas A&M Riverside Campus.

Researchers used the data to evaluate pavement temperature prediction methods as well as existing procedures for modulus temperature correction. In this evaluation, predictions of pavement temperature were compared to measurements available at the sites to assess the accuracy of temperature predictions from the following methods:

- the BELLS2 equation *(1)* developed in a research project funded by the Federal Highway Administration (FHWA); and
- the Asphalt Institute (AI) equation for predicting mean monthly pavement temperatures *(2)*.

To evaluate methods for temperature correction of backcalculated AC modulus, researchers used the MODULUS program to backcalculate the layer moduli from the measured FWD deflections collected on the project sites at different times and pavement temperatures. The following temperature correction methods were evaluated:

- the Chen equation *(3)* developed by TxDOT using FWD and pavement temperature data collected from MLS investigations conducted by the department;
- the Asphalt Institute dynamic modulus equation *(2)*; and
- the dynamic modulus equation developed by Witczak and Fonseca *(4)* that is a proposed method for predicting dynamic modulus in the 2002 pavement design guide being developed for the American Association of State Highway and Transportation Officials (AASHTO).

Figure 2 illustrates the approach taken by researchers to evaluate modulus temperature correction methods. Prior to correction, the temperature dependency of the backcalculated AC modulus is clearly evident from the figure. After correction, the normalized modulus varies about a given level that corresponds to the modulus at the assumed reference temperature. By examining the variation of the corrected moduli with test temperature and the difference between the reference modulus and the average of the corrected moduli, researchers evaluated the effectiveness of the temperature correction methods identified previously.

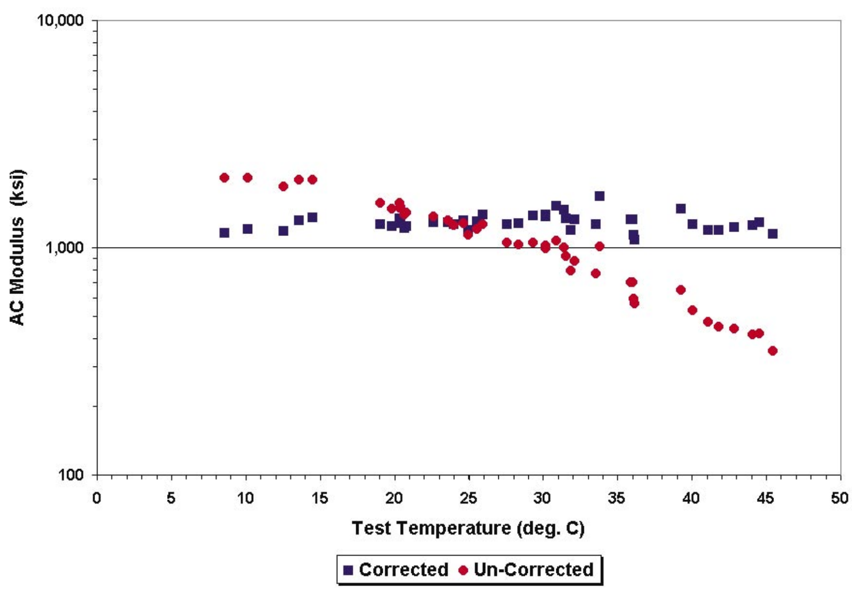

Figure 2. Illustration of Approach Used to Evaluate Temperature Correction Methods.

What We Found...

Prediction of Base Temperature for Modulus Correction

Before correction to a reference temperature may be made, the pavement temperature one is correcting from must first be established. This pavement temperature is referred to as the base temperature for the modulus correction. Research efforts led to the development of the Texas-LTPP equation for predicting pavement temperature that researchers consider to be more applicable for Texas conditions than the existing BELLS2 equation.

Prediction of Seasonal Pavement Temperatures

Researchers also compared mean monthly pavement temperatures predicted using the AI equation against measured temperatures at the SMP sites to assess the applicability of the AI equation for predicting seasonal variations in pavement temperatures. These comparisons showed that:

- for all depths at which pavement temperatures were taken, the predicted mean monthly temperatures generally fall within the range of measured values on the date of the FWD tests for a given month;
- the variation in the predicted mean monthly pavement temperatures over time follows the trend in the measured values for each month; and
- in general, the predictions compare favorably with the averages of the measured temperatures, particularly near the mid-depth and bottom of the AC layer.

Modulus Temperature Correction

Researchers evaluated the three modulus temperature correction methods presented previously. For this evaluation, application of the Witczak-Fonseca dynamic modulus equation required the binder viscosity-temperature relationships for the mixtures placed at the project sites. In practice, the binder viscosity-temperature relationship may be determined from dynamic shear rheometer (DSR) tests conducted at a range of temperatures on the binder used for a given mix. However, this information was not available from the LTPP database. Consequently, researchers evaluated the binder viscosity-temperature relationships based on the backcalculated AC moduli taken at different temperatures.

The results from this evaluation indicate that the functional form of the Witczak-Fonseca equation adequately models the modulus-temperature relationship. The findings obtained are discussed in more detail in Report 1863-1.

The Researchers Recommend...

Based on the project findings, researchers offer the following recommendations for temperature correction of backcalculated AC modulus:

- In the absence of pavement temperature measurements, the Texas-LTPP equation should be used to estimate the base temperatures for the modulus correction. Application of this equation will require infrared (IR) surface temperatures and the previous day's high and low air temperatures in the vicinity of the project. Since only a few of TxDOT's FWDs are equipped with infrared sensors, researchers recommend that TxDOT equip all its FWDs with IR sensors to implement the Texas-LTPP equation. Researchers note that the Texas-LTPP equation is specific to Texas conditions. To make the modulus temperature correction procedure more general for widespread use, the BELLS2 and BELLS3 equations were also included as options in MTCP.
- Prior to the FWD survey, the layer thickness variations along the project should be characterized using ground penetrating radar (GPR) supplemented, as necessary, by coring and/or dynamic cone penetrometer (DCP) measurements. Knowing the surface layer thickness prior to the deflection survey will permit the FWD operator to measure pavement temperatures at the appropriate depth. In addition, the layer thicknesses are required for the modulus backcalculation. Researchers recommend taking pavement temperatures at mid-depth of the AC layer for the purpose of establishing the base temperatures for the modulus correction.
- In the absence of layer thickness information prior to the FWD survey, researchers recommend taking pavement temperatures at a depth of 1.6 inches, unless the base is reached prior to this depth. The FWD operator should observe the material brought up by the drill bit to check for a thin surface.
- For modulus temperature correction, researchers recommend using the Witczak-Fonseca dynamic modulus equation or Chen's equation. The former equation is simply referred to as the dynamic modulus option in MTCP. Researchers recommend that FWD data be collected over a range of pavement temperatures to characterize the modulus-temperature relationship for calculating temperature correction factors using the dynamic modulus option. The engineer should review available information to establish testing requirements, and then run tests accordingly to get the information needed for planning, design, and construction of the given project. In this regard, the costs for running tests are generally small compared to the costs of designing and constructing the pavement.
- In applications where the characterization of the modulus-temperature relationship by laboratory or field tests is not feasible, Chen's equation may be used as an alternative to the dynamic modulus option. Application of this equation requires the mid-depth pavement temperature at the time of testing, the backcalculated AC modulus corresponding to the test temperature, and the reference temperature.
- To estimate the seasonal variations in pavement temperature, researchers recommend using the AI equation for predicting mean monthly pavement temperatures from the mean monthly air temperatures. In this way, the seasonal variation of the backcalculated AC modulus taken at a given time may be predicted as illustrated in Figure 3. For the purpose of estimating seasonal variations, MTCP includes a database of mean monthly air temperatures covering all counties of Texas.

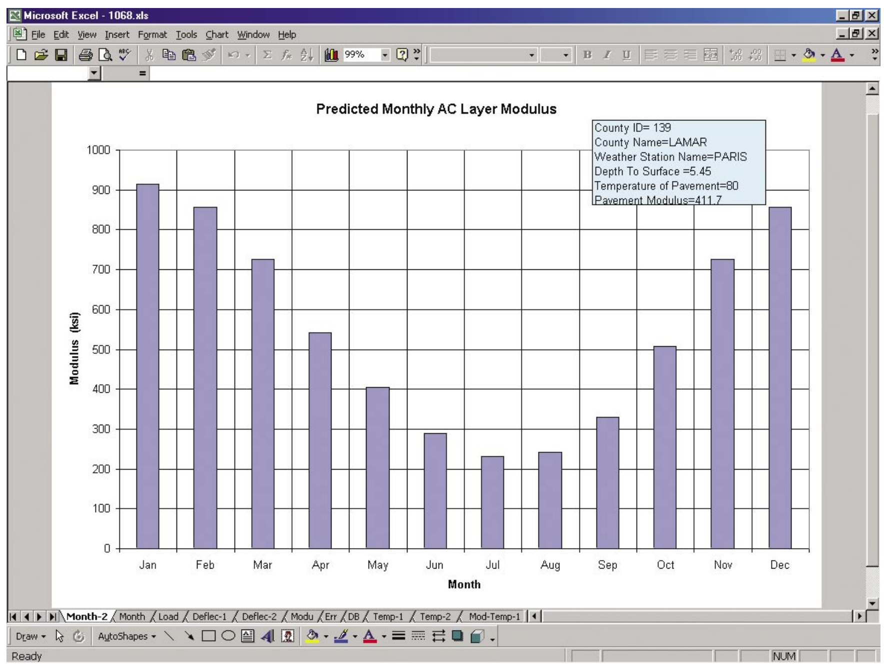

Figure 3. Example Chart of Predicted Monthly Variations in AC Modulus.

References...

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2. Asphalt Institute. "Research and Development of the Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition." Research Report No. 82-2, Asphalt Institute, Lexington, KY, 1982.
3. Chen, D., J. Bilyeu, H.H. Lin, and M. Murphy. "Temperature Correction on Falling Weight Deflectometer Measurements." Transportation Research Record 1716, Transportation Research Board, Washington, DC, pp 30-39, 2000.
4. Witczak, M.W., and O.A. Fonseca. "Revised Predictive Model for Dynamic (Complex) Modulus of Asphalt Mixtures." Transportation Research Record 1540, Transportation Research Board, Washington, DC, pp 15-23, 1996.

For More Details . . .

The research is documented in Report 1863-1, *Development of a Procedure for Temperature Correction of Backcalculated AC Modulus.* Detailed instructions on using the MTCP analysis software are found in Report 1863-2, *User's Guide for the Modulus Temperature Correction Program (MTCP)*.

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TxDOT Implementation Status
November 2003

The MTCP software has been implemented in the Web-based training site at TTI. The URL of this site is http://pavementdesign.tamu.edu/mtcp.htm. Users can access this site to receive training in the use of the software and also to download a version of the software. TxDOT employees will have access to this training through a cross link in the Intranet.

For more information, contact: Dr. German Claros, P.E., Research and Technology Implementation Office, (512) 465-7403 or gclaros@dot.state.tx.us.

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Disclaimer

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Trade names were used solely for information and not for product endorsement.