Using the LWD Simulation module in MnPAVE Flexible

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Background

This module was created to assist in the analysis of light-weight deflectometer (LWD) data at the Minnesota Department of Transportation (MnDOT). It was designed using the best available data at the time. The recommended LWD Resistance Factors may not be accurate for the devices that are available today. Researchers are advised to use the recommended value as a starting point, and to adjust it as needed based on the results of the device in use. For more information, see the Appendix on page 6.

Procedure

1. From the MnPAVE main window, select **View... Mode... Research** (seeFigure 1)

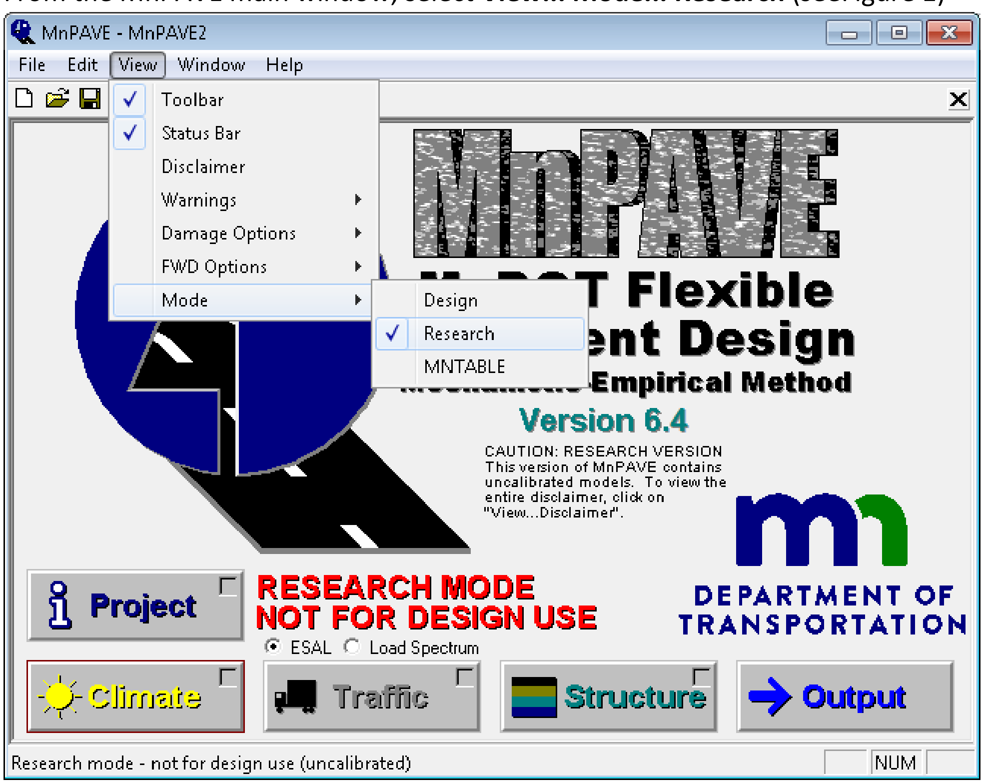

Figure 1 MnPAVE Research Mode

2. Design the pavement, including the HMA layer. **Research Mode** provides many more options than **Design Mode**. The default values for these additional options should be used. Return to Structure and select the Advanced tab (see Figure 2).

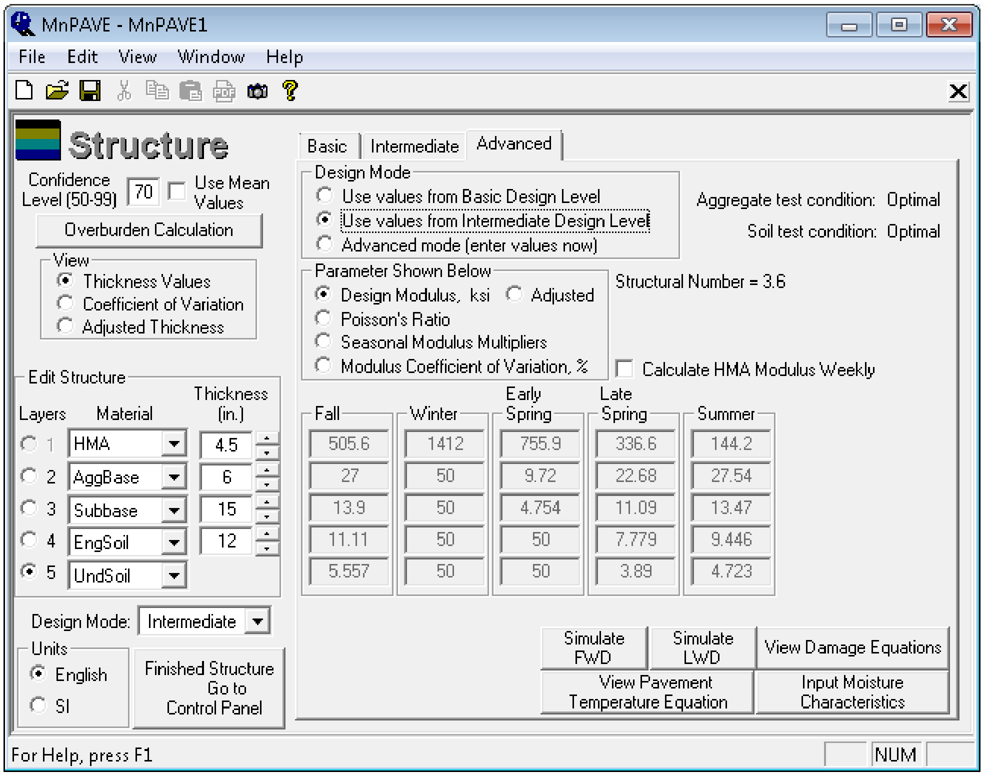

Figure 2 MnPAVE Design (Structure)

3. Click the **Simulate LWD** button at the bottom of the **Advanced Structure** tab. This will open the LWD Simulation window (see Figure 3).

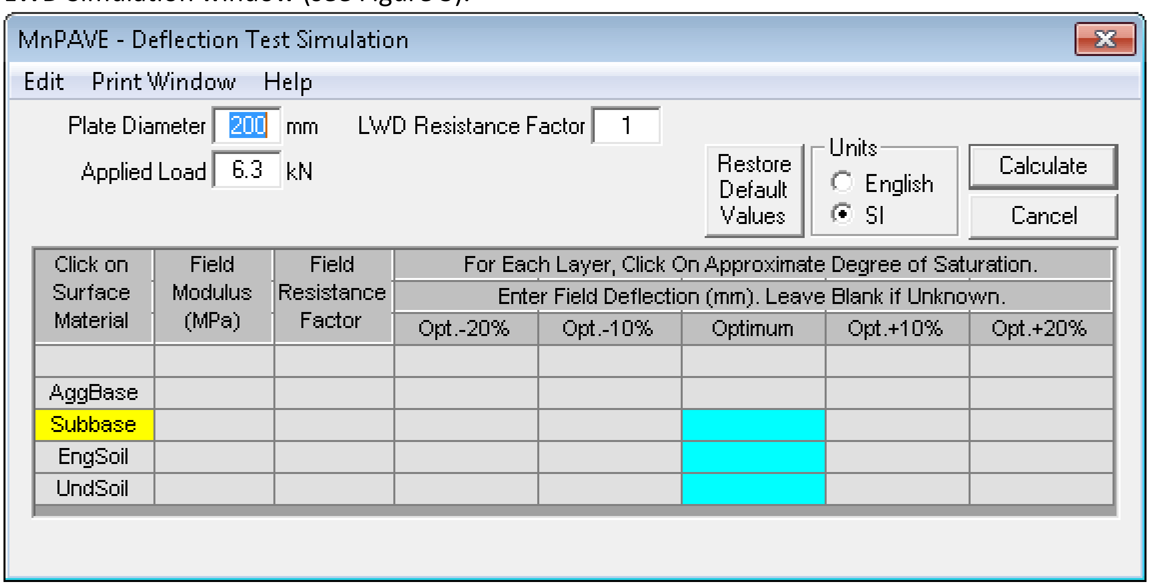

Figure 3 LWD Simulation Window

4. Enter the **Plate Diameter** and **Applied Load** for the current test. The **LWD Resistance Factor** is a value between 0.6 and 1.0. When this module was developed, the recommended values were 1.0 for *Dynatest* devices and 0.6 for *Zorn* devices. For other devices, a value of 1.0 is recommended to start.
   *Note: **Print Window** can be clicked at any time to save an image of the current window.*
5. From the list of layers on the left, click on the current surface layer that will be tested. The currently selected cell is highlighted in blue. After another cell has been clicked it will be highlighted in gold.
6. Estimate the moisture condition in the underlying layers. For each layer, click on the column that is closest to the estimated value. The moisture level for each layer will be highlighted in light blue (see Figure 4).

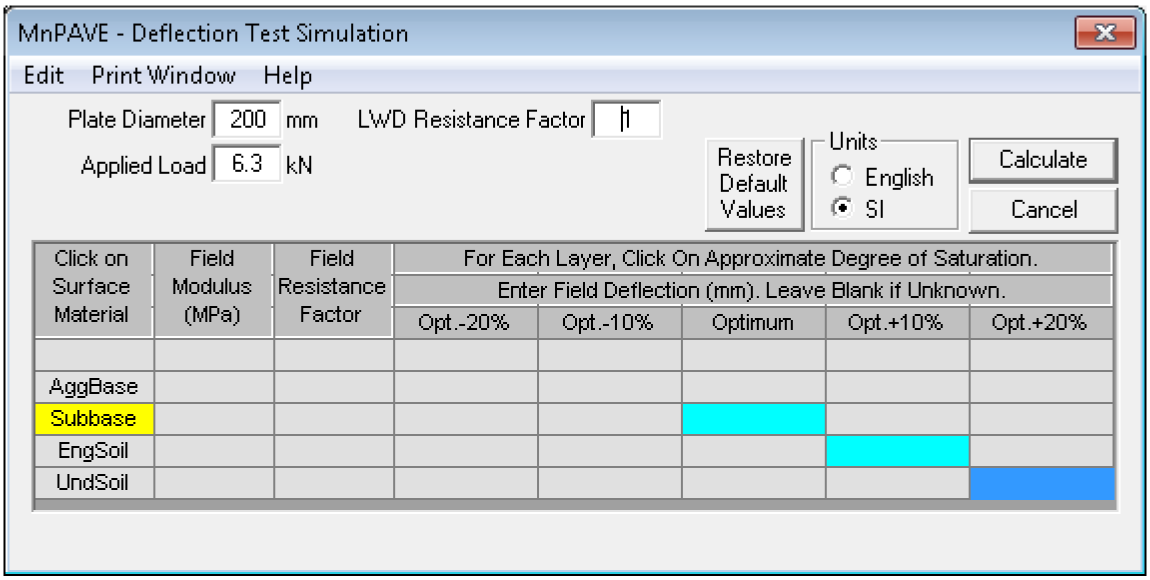

Figure 4 Moisture Conditions

7. If deflection values are available for the underlying layers, enter them in the light blue boxes that correspond to the moisture level at the time of testing. Otherwise leave them blank.
8. Click **Calculate**. If no deflection value was entered, the **Field Modulus** value will be estimated from the design modulus values in MnPAVE and the **Field Resistance Factor** will be 1.0. Otherwise, these values will be estimated from the deflection value.
   The **Field Resistance Factor** is a value that is multiplied by the **LWD Resistance Factor** and the device-generated modulus in order to estimate the MnPAVE design modulus.
   The target deflection values for each moisture condition of the surface layer will also be estimated. If the **LWD Resistance Factor** is correct, the estimated deflections should indicate the target deflections for 95% to 110% standard Proctor maximum density (see Figure 5).

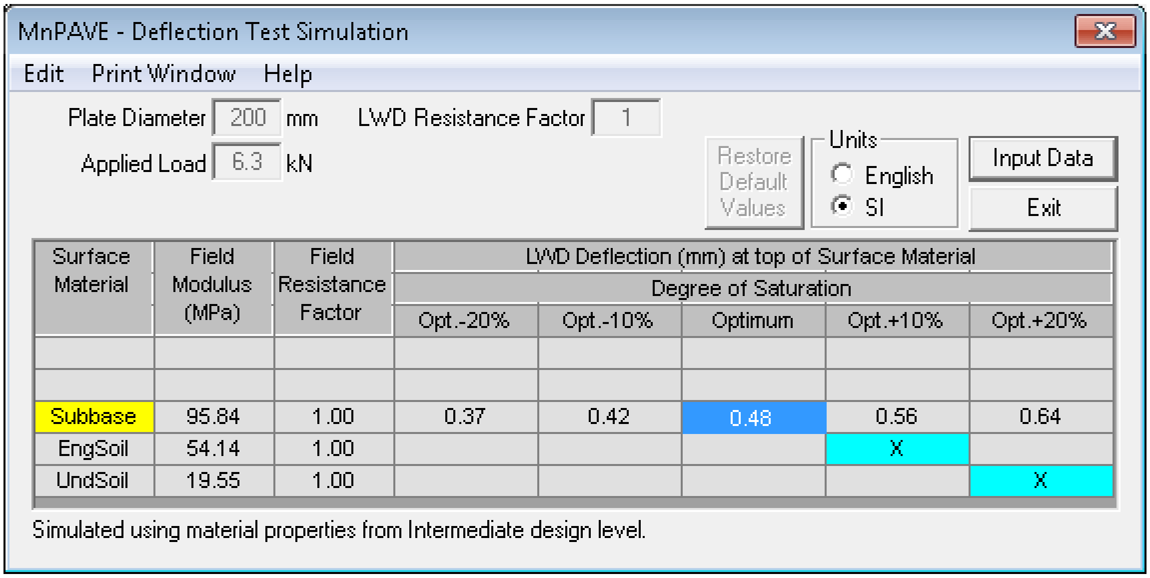

Figure 5 Estimated Target Values for Subbase

9. If LWD tests need to be completed before continuing, you can exit the LWD window and save the MnPAVE file. After deflection data for the current layer has been collected, return to the LWD window. Click **Input Data** if necessary. If the moisture condition for the current layer was not Optimum, select the column that is closest to the moisture condition, click on the box for that layer and enter the measured deflection value (see Figure 6).

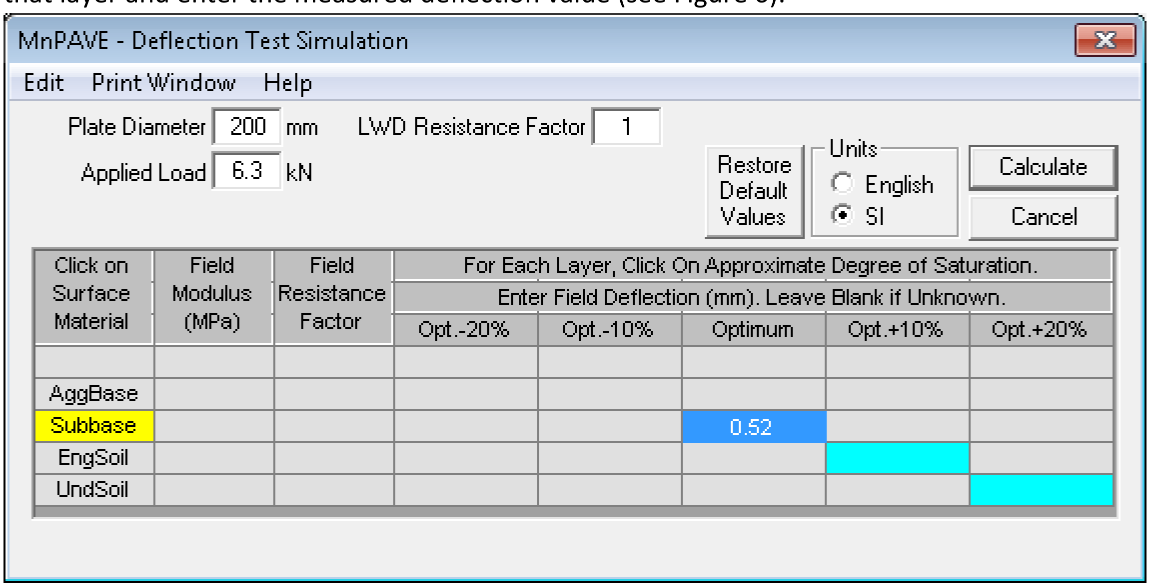

Figure 6 Enter Measured Deflection Value

10. If another granular layer will be placed, click on that layer and then click **Calculate** to estimate target deflections (see Figure 7).

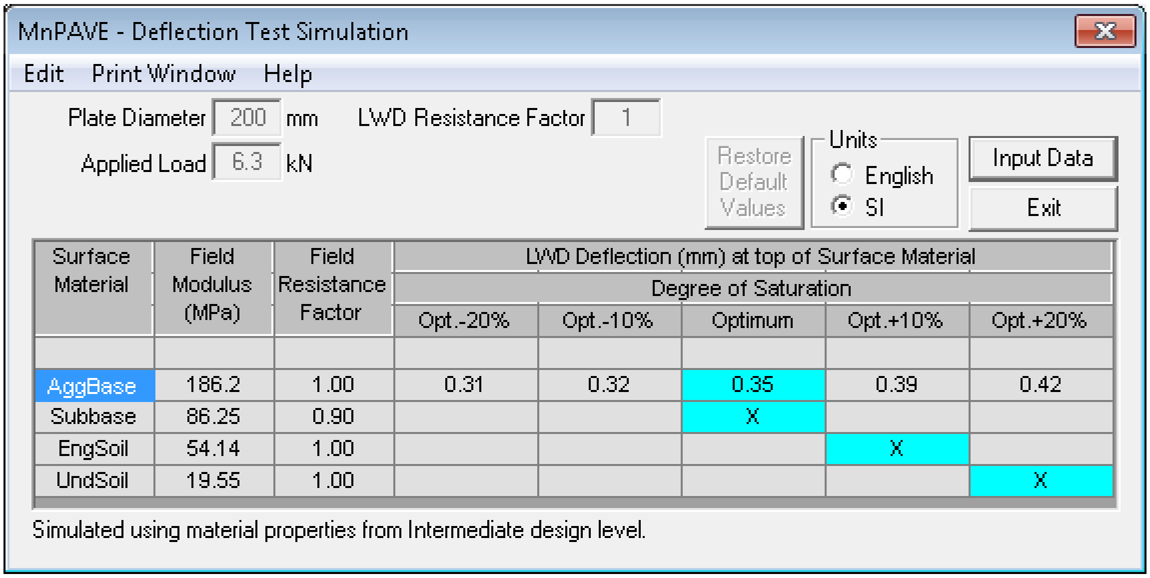

Figure 7 Target Values for Top Granular Layer

11. Repeat step 9 if necessary.

If you have any questions about this procedure or about MnPAVE, contact Bruce Tanquist at bruce.tanquist@state.mn.us.

Appendix

Backcalculation

The backcalculation loops throught the following steps until either the absolute value of *Difference* is less than or equal to 0.1 mil or the number of cycles exceeds 900.

1. Calculate D_{SIM} using WESLEA[1] (Layer moduli E_i, E_{i+1}, E_{i+2}, ... are either previously backcalculated moduli or values from the *MnPAVE Flexible* pavement design, adjusted for moisture. Other inputs are from the *MnPAVE Flexible* pavement design.)
2. Calculate *Difference* = D_{SIM} - D_{LWD}
3. If ABS(*Difference*) > 0.1 mil then adjust the current layer modulus: $E_i = E_i + 100 * Difference$ and go to Step 1.

Where:

D_{SIM} = WESLEA-simulated deflection
D_{LWD} = LWD-measured deflection
E_i = Current layer modulus (psi)

Moisture Adjustment

If the moisture content of a given layer is not optimum, then that layer's modulus is adjusted according to NCHRP[2] (see Equation 1).

$$log\frac{E}{E_{opt}} = a + \frac{b-a}{1+EXP\left(ln\frac{-b}{a}+k_m \times (S-S_{opt})\right)} \tag{1}$$

Where:

E/E_{opt} = Modulus ratio
E = Modulus at the current moisture content
E_{opt} = Modulus at optimum moisture
a = Minimum of log(E/E_{opt}), -0.3123 for coarse-grained, -0.5934 for fine-grained
b = Maximum of log(E/E_{opt}) , 0.3 for coarse-grained, 0.4 for fine-grained
k_m = Regression parameter, 6.8157 for coarse-grained, 6.1324 for fine-grained
$(S - S_{opt})$ = Variation in degree of saturation expressed in decimal

Resistance Factors

The *LWD Resistance Factor* is a multiplier applied to all modulus values from the LWD device in order to align them with design modulus values.

The *Field Resistance Factor* is an additional multiplier applied to modulus value of the current layer from the current LWD deflection in order to align it with the modulus value from the current *MnPAVE Flexible* design.

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[1] Van Cauwelaert, F.J., Lequeux, Delaunnois, "Computer Programs for the Determination of Stresses and Displacements in Four-Layered Systems", **WES Research Contract DAJA45-86-M-0483**, U.S. Army Waterways Experiment Station, Vicksburg, MI, 1986

[2] **Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Final Report, Part 2. Design Inputs, Chapter 3. Environmental Effects**, NCHRP March 2004, p. 2.3.24.