



---

# Test Procedure for Mechanics-Based Assessment of Flexible Base Quality

Product 0-6874-P1

---

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE  
COLLEGE STATION, TEXAS

in cooperation with the  
Federal Highway Administration and the  
Texas Department of Transportation  
<http://tti.tamu.edu/documents/0-6874-P1.pdf>



# **TEST PROCEDURE FOR MECHANICS-BASED ASSESSMENT OF FLEXIBLE BASE QUALITY**

by

Robert Lytton, PhD, P.E.  
Research Engineer  
Texas A&M Transportation Institute

Arvind Devadas  
Texas A&M Transportation Institute

Sajib Saha  
PhD Research Assistant  
Texas A&M Transportation Institute

Yong Deng  
PhD Research Assistant  
Texas A&M Transportation Institute

and

Xue Luo  
Research Engineer  
Texas A&M Transportation Institute

Product 0-6874-P1

Project 0-6874

Project Title: Develop Nondestructive Rapid Pavement Quality Assurance/Quality Control Evaluation  
Test Methods and Supporting Technology

Performed in cooperation with the  
Texas Department of Transportation  
and the  
Federal Highway Administration

Published: September 2021

TEXAS A&M TRANSPORTATION INSTITUTE  
College Station, Texas 77843-3135



## **DISCLAIMER**

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the 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 published herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. Trade names, when mentioned, are only provided for reference purposes and do not imply endorsement.

## **ACKNOWLEDGMENTS**

This project was conducted in cooperation with TxDOT and FHWA. The authors thank the TxDOT technical committee: Gisel Carrasco, Yvette Flores, Miles Garrison, Stephen Kasberg, Enad Mahmoud, Andy Naranjo, Travis Patton, Jimmy Si, and Stacey Strittmatter, and the TxDOT project managers: Sonya Badgley, Chris Glancy, and James Kuhr. Access to field sites was made possible with the help of Brandon Montgomery (TxDOT Bryan District) and Kyle Russell (TxDOT Georgetown Area Office).



---

# Special Specification XXXX

## Modulus of Base Course with GPR (Method)

---



### 1. SCOPE

Use commercially available GPR system and apply the developed methodologies to estimate the modulus of a base layer or estimate pavement layer composition values, including water content or asphalt content, density, percent air or porosity in the asphalt, concrete, base, and subgrade layers using micro-mechanics models.

---

### 2. APPARATUS

#### 2.1. Ground Penetrating Radar

Commercially available air-launched GPR systems operating at a frequency of 1 GHz or 2 GHz can be used. The system should be able to record distance along with the GPR data. GPS could also be incorporated.

- GSSI
  - 2 GHz Horn antenna system
  - 2.5 GHz Pavescan system – only for use on asphalt layers
- Pulse or Wavebounce 1 GHz Horn antenna system

#### 2.2. Supporting Lab Apparatus

- 2.2.1. Apparatus in accordance with Tex-110-E to conduct the Aggregate Gradation test.
- 2.2.2. Aggregate imaging system (AIMS) in accordance with FHWA/TX-05/5-1707-01-1.
- 2.2.3. Apparatus in accordance with Tex-113-E to determine the compaction curve.
- 2.2.4. Apparatus for methylene blue value in accordance with Appendix M FHWA/TX-13/0-6621.
- 2.2.5. Apparatus in accordance with Tex-238-F to determine the percent fines content.

---

### 3. PROCEDURE

- 3.1. Install the GPR system according to the manufacturers recommendations.
- 3.2. Calibrate the GPR system in accordance with the manufacturer's recommendations. This usually involves collecting a metal-plate file and may also require recording an air-launched file depending on the particular GPR system.
- 3.3. Select profile limits to scan the desired pavement test area. Scans may be performed on the pavement in a single pass. Start and stop recording GPR data at the prescribed beginning and ending locations.

- 3.4. To use the LayerMAPP tool for measuring base layer modulus, collect representative sample of the base material in accordance with Tex-100-E or Tex-400-A. Perform the following tests in accordance with the applicable methods:
- Particle size distribution (Tex-110-E)
  - Aggregate form, angularity, and texture (AIMS)
  - Moisture-density relationship (Tex-113-E)
  - Methylene Blue Value (WR Grace method)
  - Percent fines content (Tex-238-F)

3.5. After collecting all the GPR scans, process the GPR data file in accordance with the manufacturer’s recommendations to apply a bounce correction to the GPR data.

3.6. To use LayerMAPP for measuring flexible base course modulus, output a CSV file including:

- Thickness of asphalt layer, if present
- Thickness of base layer
- Dielectric constant of base layer

**Note 1** – it is not necessary for an asphalt layer to be present to use LayerMAPP. However, if an asphalt layer is present, that layer should be at least ¾ in.

**Note 2** – If the thickness of the base layer cannot be determined from the GPR scans, then the LayerMAPP tool cannot be used.

3.6.1. To use LayerMAPP for measuring flexible base course modulus, input the measured lab material properties and the GPR data output into the LayerMAPP tool. See the Appendix for more details on the LayerMAPP operator interface.

3.7. To use PaveSCM for measuring base layer volumetrics, identify two field locations that have different densities. Record the distance in the GPR scan to these ground-truth locations; alternately, perform static scans over ground truth location. Determine the moisture content and dry density at these two locations in accordance with Tex-115-E and Tex-103-E. See the Appendix for more details on the PaveSCM operator interface.

**Note 3** – the PaveSCM tool has built-in functionality for asphalt layers. Analysis of asphalt layers requires two core locations of measured density, asphalt content, and air void content.

## 4. CALCULATIONS

4.1. If using LayerMAPP, determine the PFC as follows:

$$PFC = \frac{\% - 2\mu m}{\% - 75\mu m} \times 100\%$$

where

$\% - 2\mu m$  = the percent of materials smaller than  $2\mu m$ .



% – 75  $\mu m$  =the percent of materials smaller than 75  $\mu m$  .

- 4.2. The LayerMAPP tool uses the dielectric constant and thickness measured from the GPR, along with the material properties measured in the lab, to calculate the modulus according to the octahedral shear stress and the 1<sup>st</sup> invariant. See the Appendix for more details on using the LayerMAPP tool. These calculations are performed automatically according to the following equation:

$$E_{y[kpa]-cal} = k_1 \cdot P_{a[kpa]} \left( \frac{I_{1[kpa]} + 3 \cdot \theta_w \cdot f \cdot Suction_{var[psi]} \cdot 6.89475729}{P_{a[kpa]}} \right)^{k_2} \times \left( \frac{T_{oct[kpa]}}{P_{a[kpa]}} \right)^{k_3}$$

- 4.3. The PaveSCM tool calculates pavement composition. The calculations for PaveSCM require a calibration to be performed at two data points, and then these calibration parameters will be applied automatically in the other GPR scans. See the Appendix for more details on using the PaveSCM tool. The volumetric calculations are determining automatically according to the self-consistent equation:

$$f = \theta_s \times \left( \frac{\varepsilon_s - \varepsilon}{\varepsilon_s + 2\varepsilon} \right) + \theta_w \times \left( \frac{\varepsilon_w - \varepsilon}{\varepsilon_w + 2\varepsilon} \right) + \theta_a \times \left( \frac{\varepsilon_a - \varepsilon}{\varepsilon_a + 2\varepsilon} \right) \doteq 0$$

For asphalt layers the equation is:

$$f = \theta_s \times \left( \frac{\varepsilon_s - \varepsilon}{\varepsilon_s + 2\varepsilon} \right) + \theta_{as} \times \left( \frac{\varepsilon_{as} - \varepsilon}{\varepsilon_{as} + 2\varepsilon} \right) + \theta_a \times \left( \frac{\varepsilon_a - \varepsilon}{\varepsilon_a + 2\varepsilon} \right) \doteq 0$$

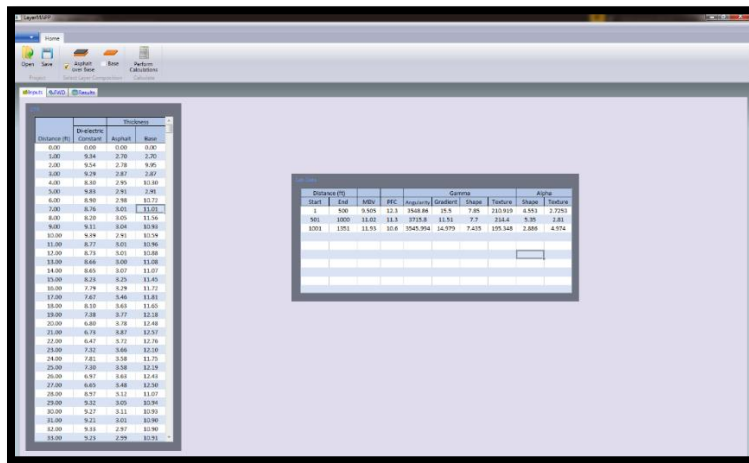


## APPENDIX: LayerMAPP and PaveSCM Operator's Guide

Both the LayerMAPP tool and the PaveSCM tool can be used on the same GPR scans. The LayerMAPP tool requires the GPR scans and lab-measured material properties. The PaveSCM tool requires the GPR scans and two field ground-truth reference values.

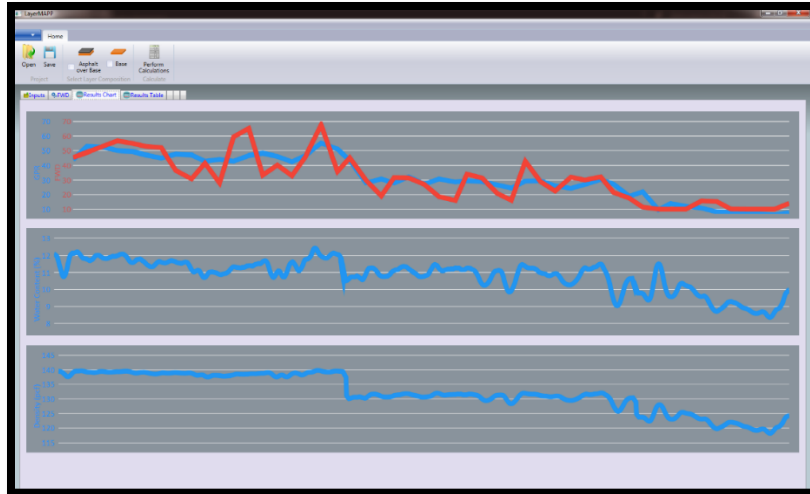
### Using LayerMAPP

Enter the dielectric constant and thickness of the base layer by pasting in from the CSV file output from GPR. If an asphalt layer was present, include the thickness of the asphalt layer in the CSV file. Enter the material properties from the lab analysis. If there were different base materials within the GPR scan distance, which requires multiple soil samples to be analyzed, then that information can be entered in multiple sections for the same scan. If available, enter FWD data in the FWD tab. Figure 1 shows the interface for inputs.



**Figure 1. LayerMAPP Inputs.**

Press the button to perform calculations. Figure 2 shows example output; the top plot shows the modulus with distance, the middle shows the volumetric water content, and the bottom plot shows the density. If desired, save result output in a CSV file.

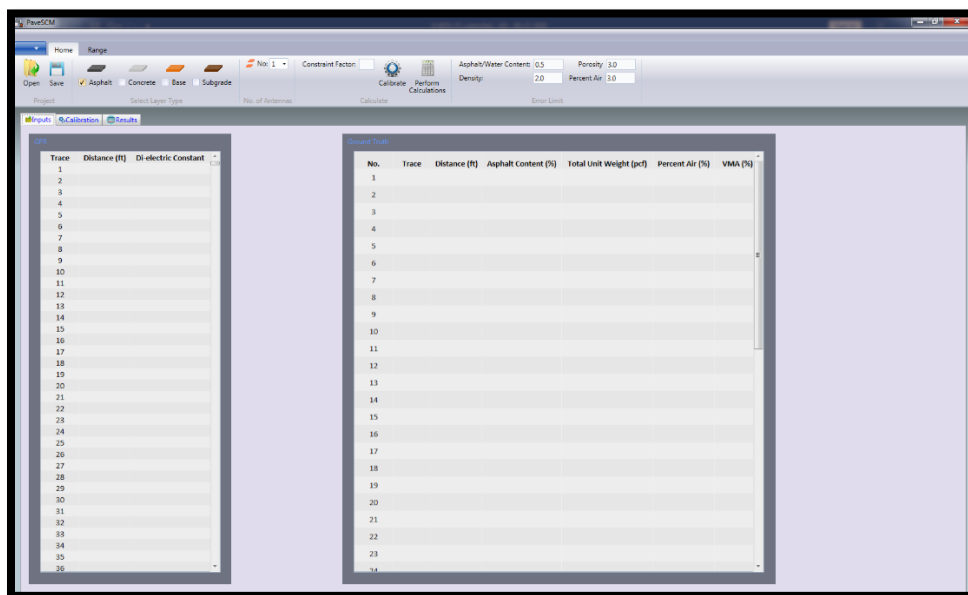


**Figure 2. LayerMAPP Outputs.**

### Using PaveSCM

Select the pavement layer type in the ribbon bar. If the GPR system contains multiple antennas, then select the number of antennas. Enter the dielectric constant and the distances in the table on the left in the input screen. If there is more than one antenna, enter this information for each antenna. The GPR data can be copied and pasted into the tables from the CSV GPR file output.

Enter the ground-truth information from the core or density gauge measurements. PaveSCM uses the first ground-truth location in the calibration. Note that any number of ground-truth locations can be entered. Figure 3 shows the PaveSCM input screen.



**Figure 3. PaveSCM Input Screen.**

Press the *Calibrate* button. One parameter that can be controlled in the calibration is the *calibration factor*, which can be set from 0 to 10. Normally set this value around 2.0; however, by using the second ground-truth location, this value can be adjusted to perform a better calibration.

The calibration generates two sets of results for each ground-truth location. The first set, upper row in table, shows the calculated results using the GPR data located at the distance entered in the ground-truth location. In the second set of results, the GPR data located near the distance entered for the ground-truth location that would have the dielectric constants from GPR that closely agree with the ground-truth measurements are used. This second set of calculation in the calibration is done because some of the GPR antennas have a foot print of 2 to 3 ft, and also there can be errors in the distances of the ground-truth locations. So, in choosing the GPR signal for the ground truth location, a signal within this distance is chosen. When doing the full-scan analysis of the GPR data, either of the two calibration sets can be chosen.

Figure 4 shows the results of the calibration. The table shows the ground-truth data and the results of the calibration. The absolute difference between the ground-truth and the PaveSCM calculations are also listed.

Click on the *Perform Calculations* button to perform the full analysis on the entire GPR scan. Figure 5 presents example output of calculated layer composition with distance. The results can be saved to a CSV file.

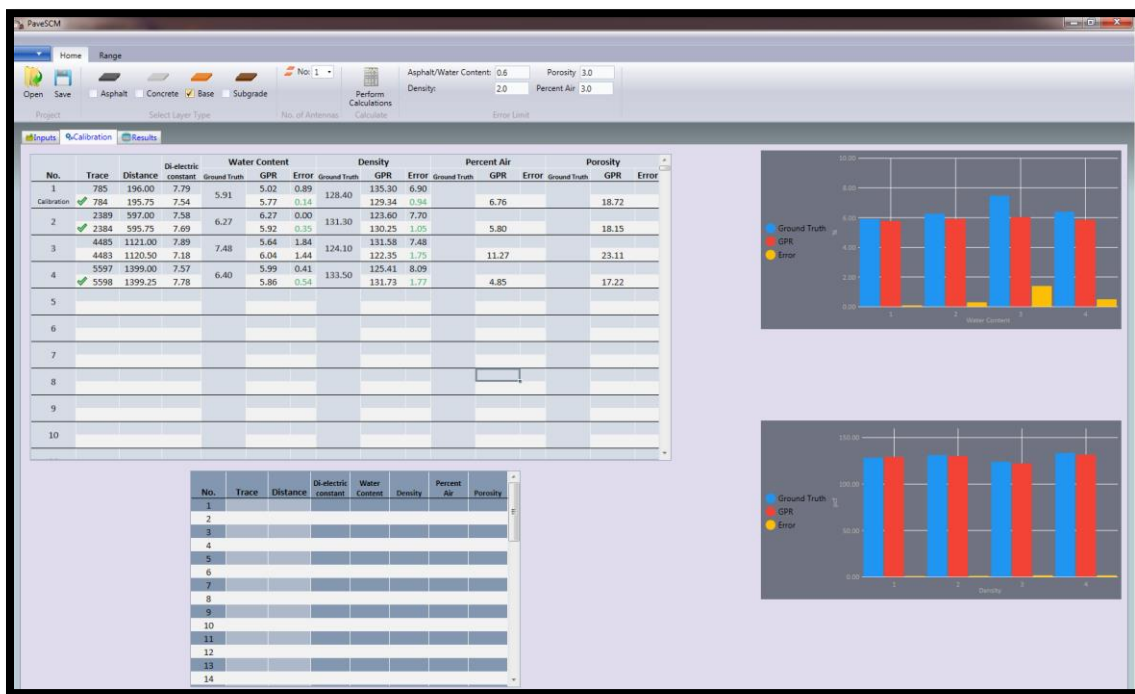
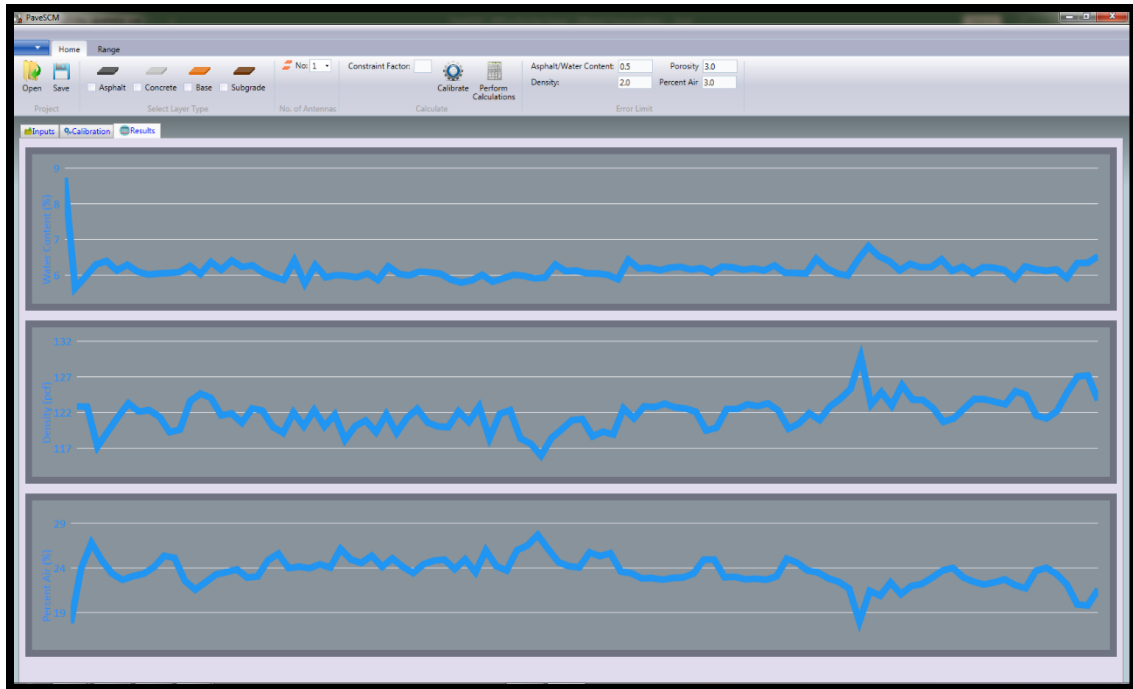


Figure 4. PaveSCM Calibration Screen.



**Figure 5. Water Content (Top), Density (Middle), and Percent Air (Bottom) Line Profiles from PavementSCM.**