Pavement Design Basics

Darlene Goehl, P.E.
Texas A&M Transportation Institute

2018 Transportation Short Course
October 16, 2018

Overview

History

- TxDOT established 100+ years ago
- Pavement design largely concerned with protecting the subgrade until the end of WWII
- Initiation of highway road tests following WWII
- AASHO develops relationship between repetitive axle loads and pavement damage/serviceability
- AASHO Empirical design is developed based on Road Test; formalized in early 1970's.

History

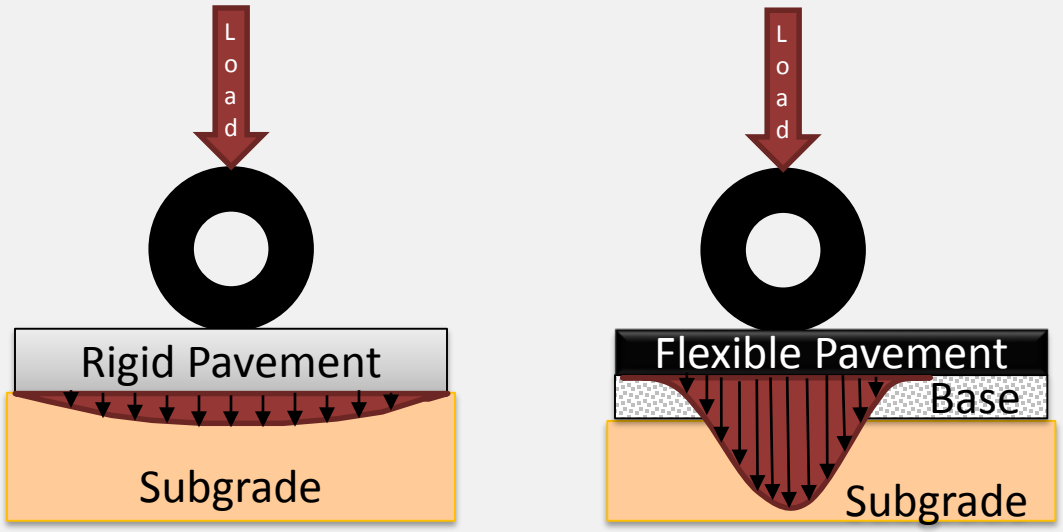
- **TxDOT initializes research into developing own empirical flexible design system early 1970s into 1980s.**
- **FPS-19 introduced early 1990s using material moduli and elastic layer theory**
- **AASHTO ME design released 2006**
- **TxME development continues . . .**

Pavement

- **<u>Pavement Structure</u>**. Combination of surface course and base course placed on a subgrade to support the traffic load and distribute it to the roadbed
- The primary structural difference between a rigid and flexible pavement is the manner in which each type of pavement distributes traffic loads over the subgrade.

Rigid vs. Flexible Pavement

- A rigid pavement has a very high stiffness and distributes loads over a relatively wide area of subgrade –
  - a major portion of the structural capacity is contributed by the slab itself.
- Flexible pavement's load carrying capacity is dependent on the layers.
  - load-distributing characteristics of the layered system is critical



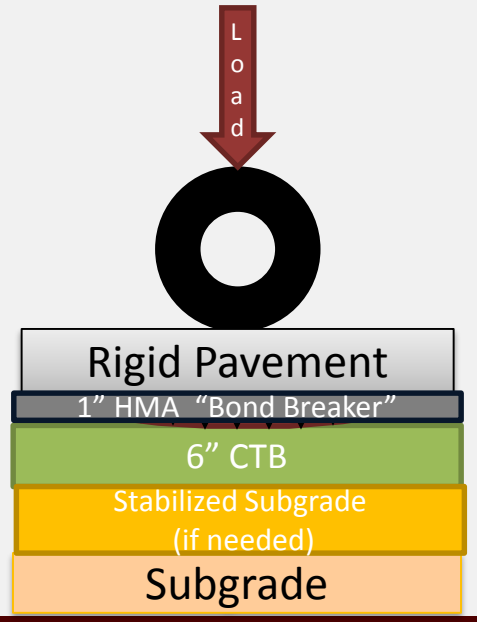
Load distribution for a typical flexible pavement and a typical rigid pavement.

Overview of Rigid Pavement Thickness Design

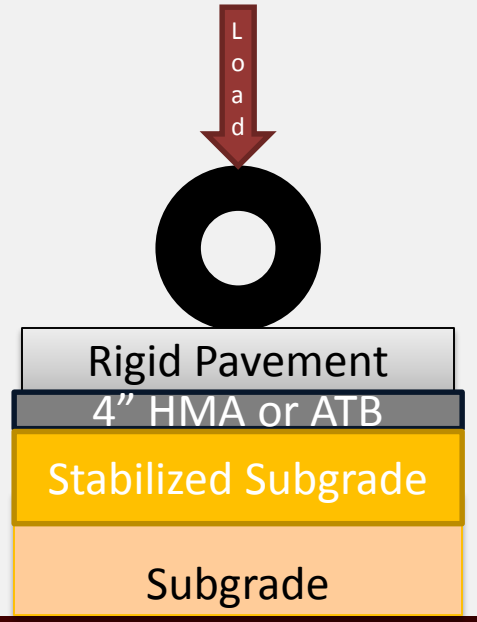
- TxCRCP-ME Design Program for CRCP Developed under department research project 0-5832, “Develop Mechanistic/Empirical Design for CRCP.
  - Uses Punchouts as main distress
- AASHTO Rigid Pavement Design Procedure for CPCD
  - The 1993 AASHTO *Guide for Design of Pavement Structures*

Overview of Rigid Pavement Subbase Design

- Base layer combinations for concrete slab support (CRCP or CPCD):
  - 4 in. of hot-mix asphalt (HMA) or asphalt treated base (ATB), or
  - a minimum 1 in. hot-mix asphalt bond breaker over 6 in. of a cement treated base



These are non-erodible subbases. TxDOT chose this strategy instead of requiring subbase drainage designs.



Rigid Pavement Design Inputs -TXCRCP-ME

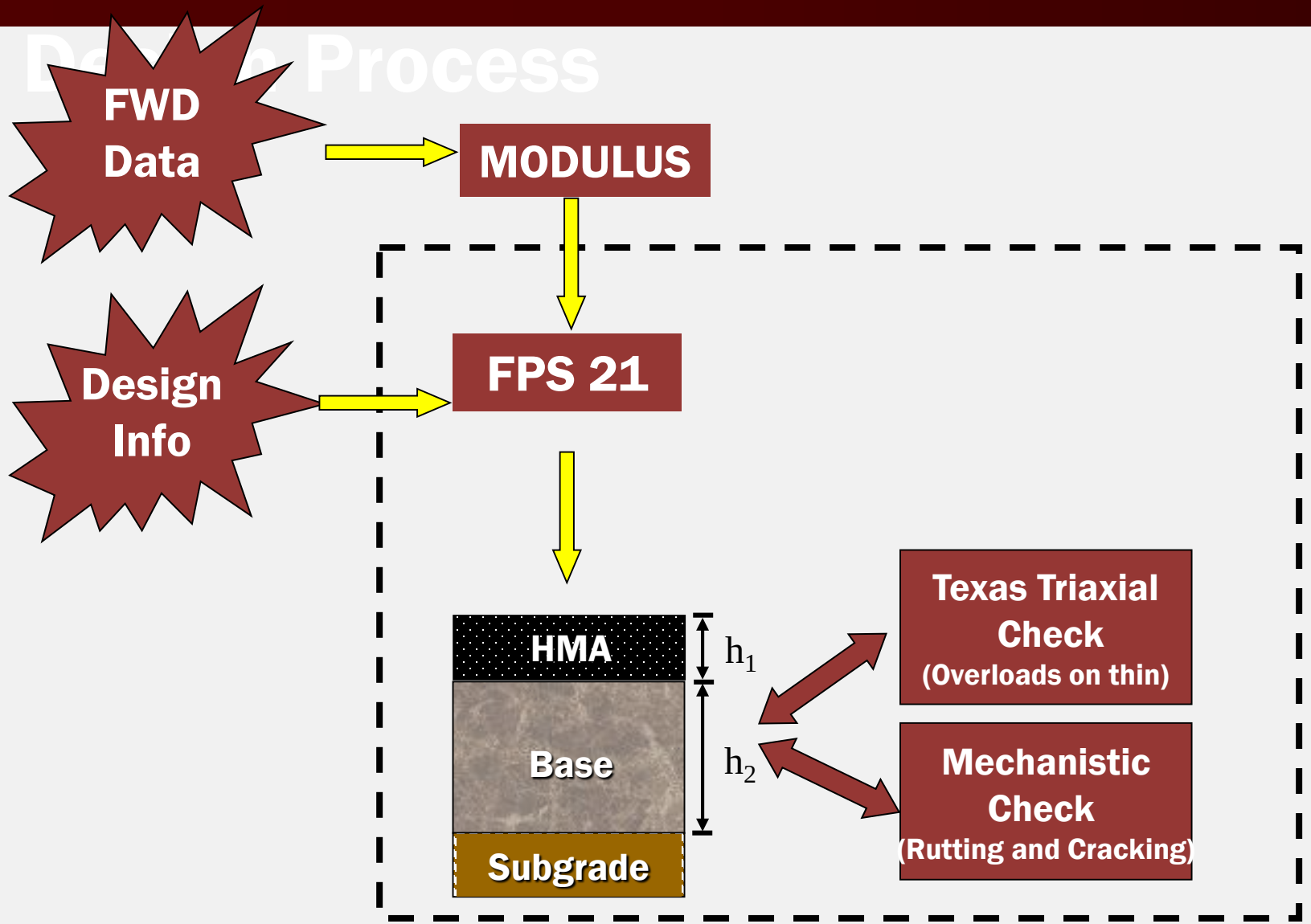
Rigid Pavement Design Inputs - New Pavement			
Parameter	**Range**	**Usual Input**	**Comments**
Design Life (years)		30	
Punchouts per Mile		10	May lower depending on Roadway.
Thickness of Concrete	7" to 15"	Estimated depth	TxCRCP-ME program will evaluate depth entered to determine if it is adequate, however this may be a trial and error process to determine the minimum thickness required.
Number of Lanes		in One Direction	Refer to Typical section
Design Traffic		One-Way total 18-kip ESALs	
Soil Classification of Subgrade	GW, GP, SW, SP, GM, SM, GC, SC, ML, OL, MH, CL, CH, OH	Determine from subgrade testing	Refer to Unified Soil Classification System
Base Layer Requirements	Asphalt treated base (ATB), hot mix (HMA) or cement treated base(CTB)		Select most cost effective base layer
Modulus of Base Layer (ksi)	100-700	HMA or ATB use 400	
		CTB use 500	

Rigid Pavement Design Inputs – 1993 AASTO Formula

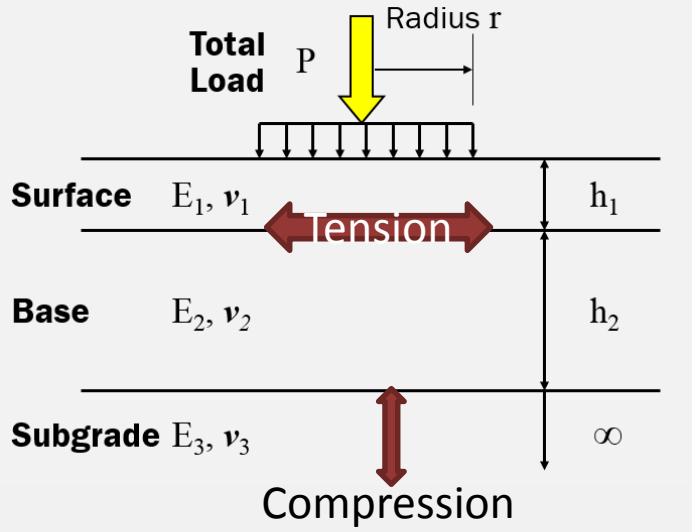
Rigid Pavement Design Inputs - New Pavement, CPCD			
Parameter	**Range**	**Usual Input**	**Comments**
Design Life (years)		30	
Thickness of Concrete	7" to 15"	Estimated depth	AASHTO equation can be used with trial and error process to determine depth or depending on equation calculator program may be able to calculate thickness needed.
28-day Conc. Modulus of Rupture, psi (MOR)	620 - 680	620	
Reliability, %	90% - 95%	90% or 95%	Use 90% when <= 5 M ESALs Use 95% when > 5 M ESALs
Overall Standard Deviation		0.39	
Load Transfer Coefficient (J)	2.5 – 2.9	2.9	JCP with tied concrete shoulder
28-day Concrete Elastic Modulus, psi		5,000,000	
Serviceability Indices		Initial: 4.5	
		Terminal: 2.5	Difference: 2.0
Design Traffic		One-Way 18-kip ESALs	Can apply lane distribution factor(LDF) when total lanes are >4 lanes. For 6 lanes, LDF=0.7, >=8 lanes, LDF=0.6
Effective Modulus of Subgrade Reaction, psi (k)	300 - 800	300	Assuming 4" of ACP or 6" of CTB + 1" ACP
Drainage Coefficient	Annual Rainfall (in.)	Drainage Coefficients	Select Drainage Coefficient based on annual rainfall.
	58-50	0.91-0.95	
	48-40	0.96-1.00	
	38-30	1.01-1.05	
	28-20	1.06-1.10	
	18-8	1.11-1.16	

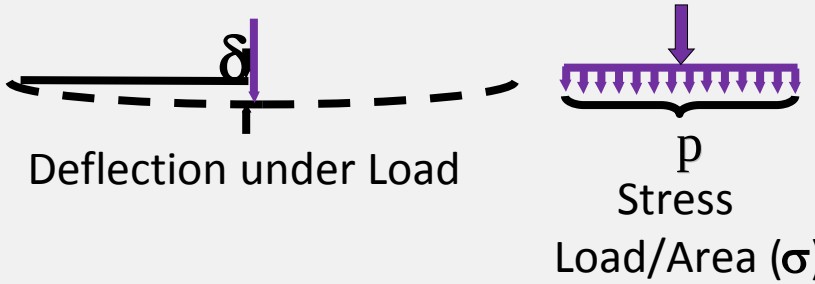
Overview of Texas Flexible Pavement

Design Process

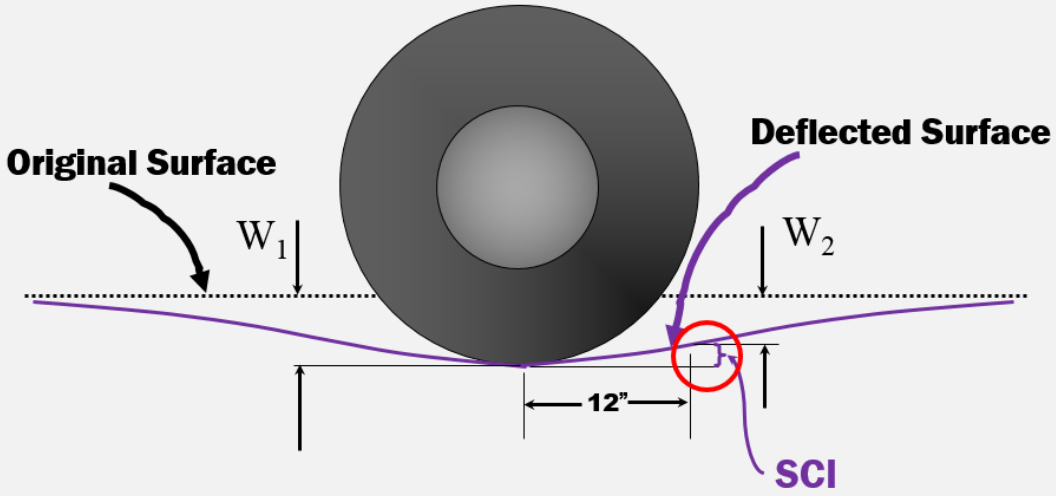


Flexible Pavement Loading and Response

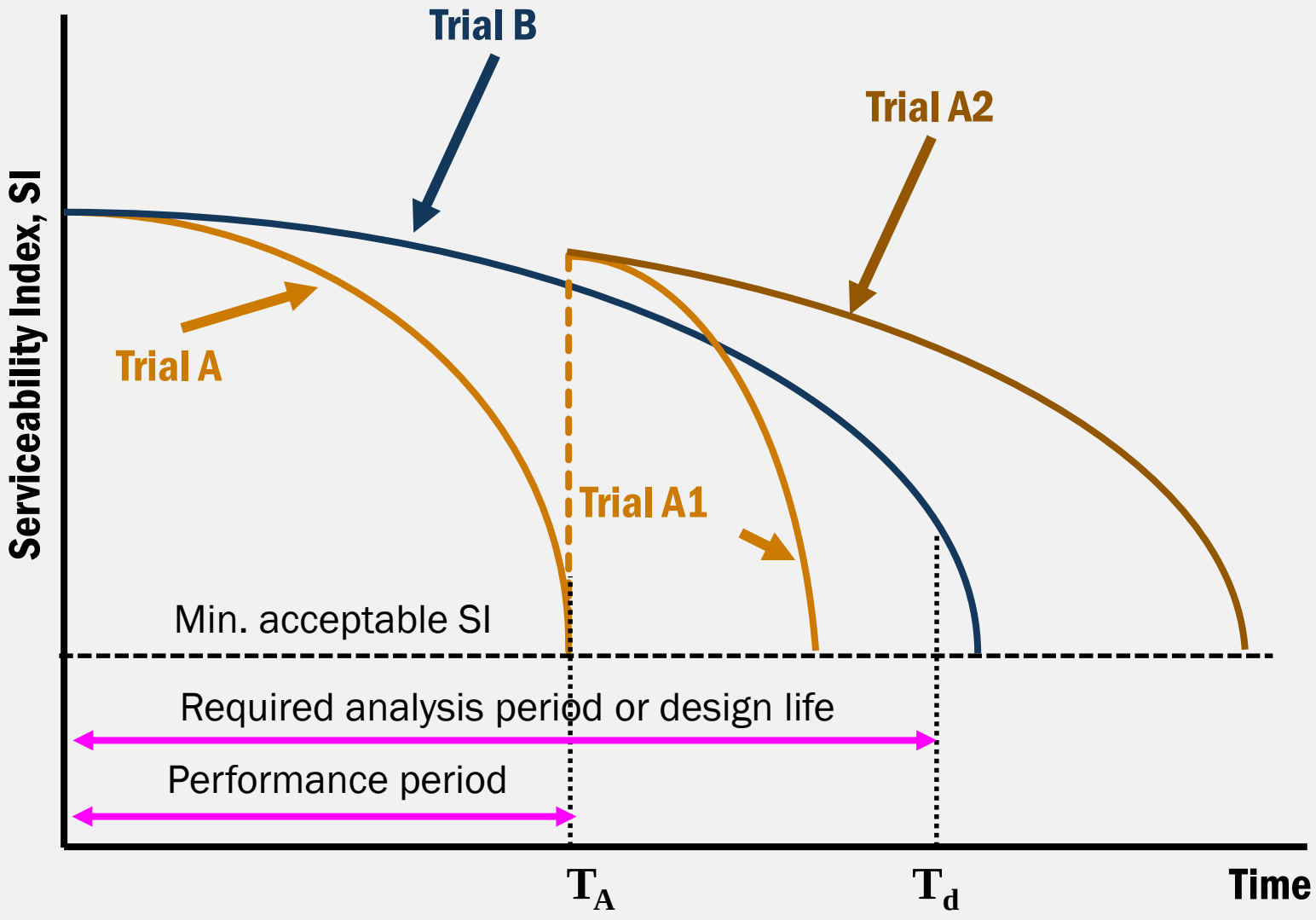




Strain
Deformation (ε)



Service Histories of Several Trial Designs

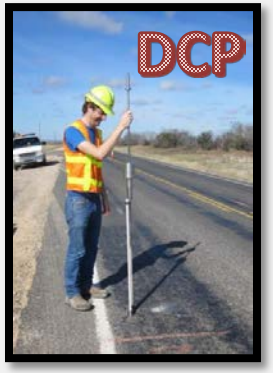


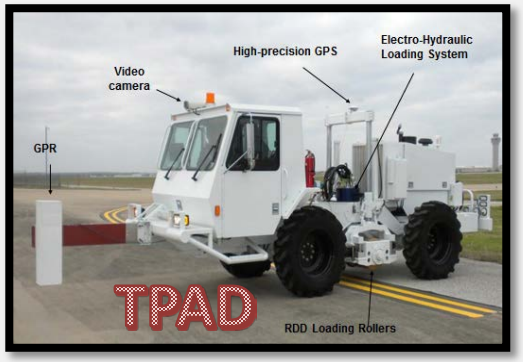
Failure & Serviceability

- Structural
  - Material fails to point can no longer function to distribute loading.
  - May require complete rehabilitation
- Functional
  - Loss of Ride
  - Loss of Friction
  - May only require repair of riding surface
- Serviceability
  - Can be correlated to pavement roughness
    - Initial should be a good smooth ride
    - Final will be rough ride

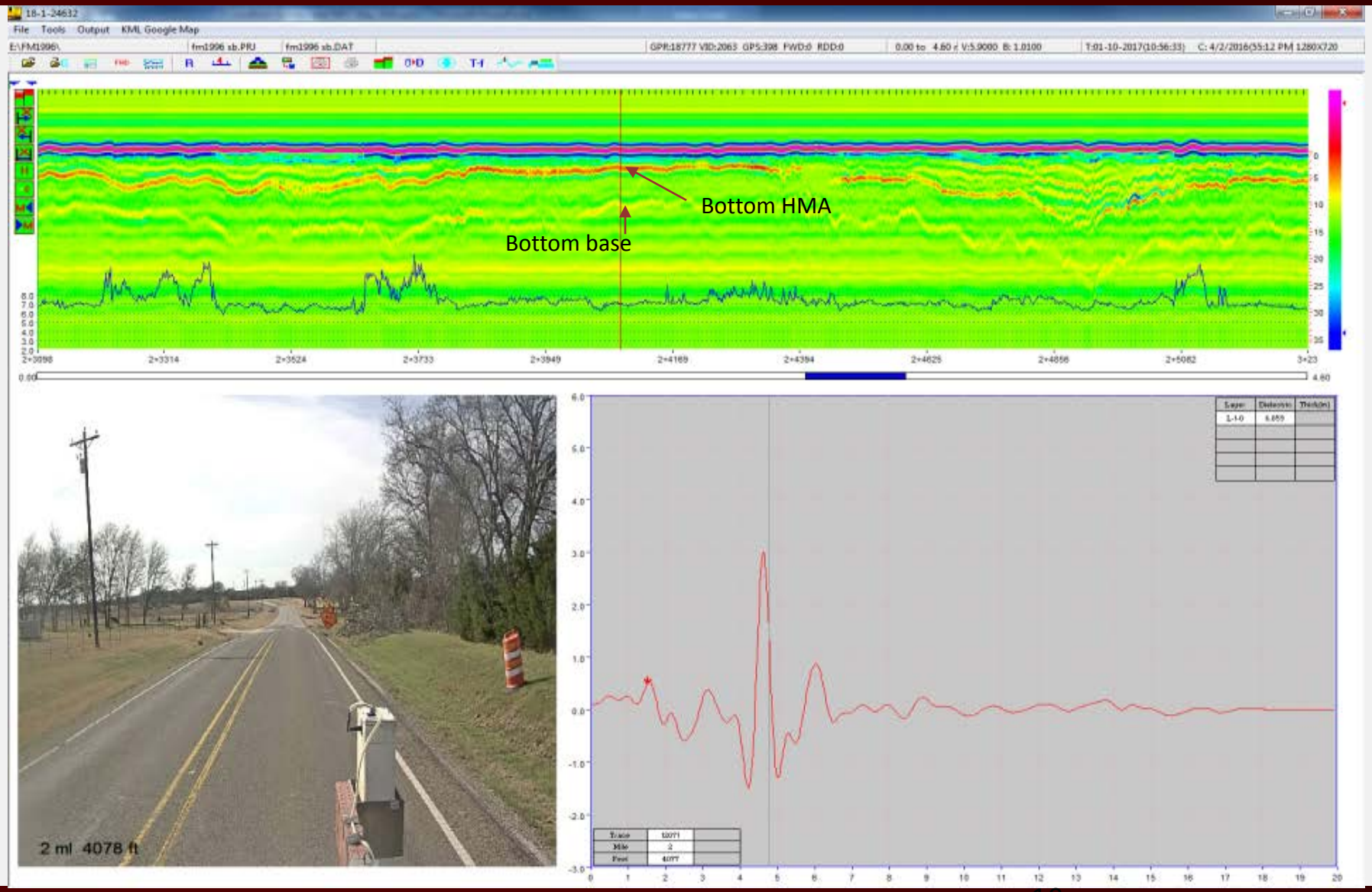
Available Pavement Evaluation Tools

- **FWD** structural strength, including subgrade
- **GPR** thickness variability; identify major problem areas; sampling locations
- **DCP** in-site strengths of lower layers
- **TPAD** structural strength of concrete pavement, weak subgrades, poor load transfer
- **LIDAR** ditch depth; horizontal and longitudinal slopes; drainage evaluations





GPR data



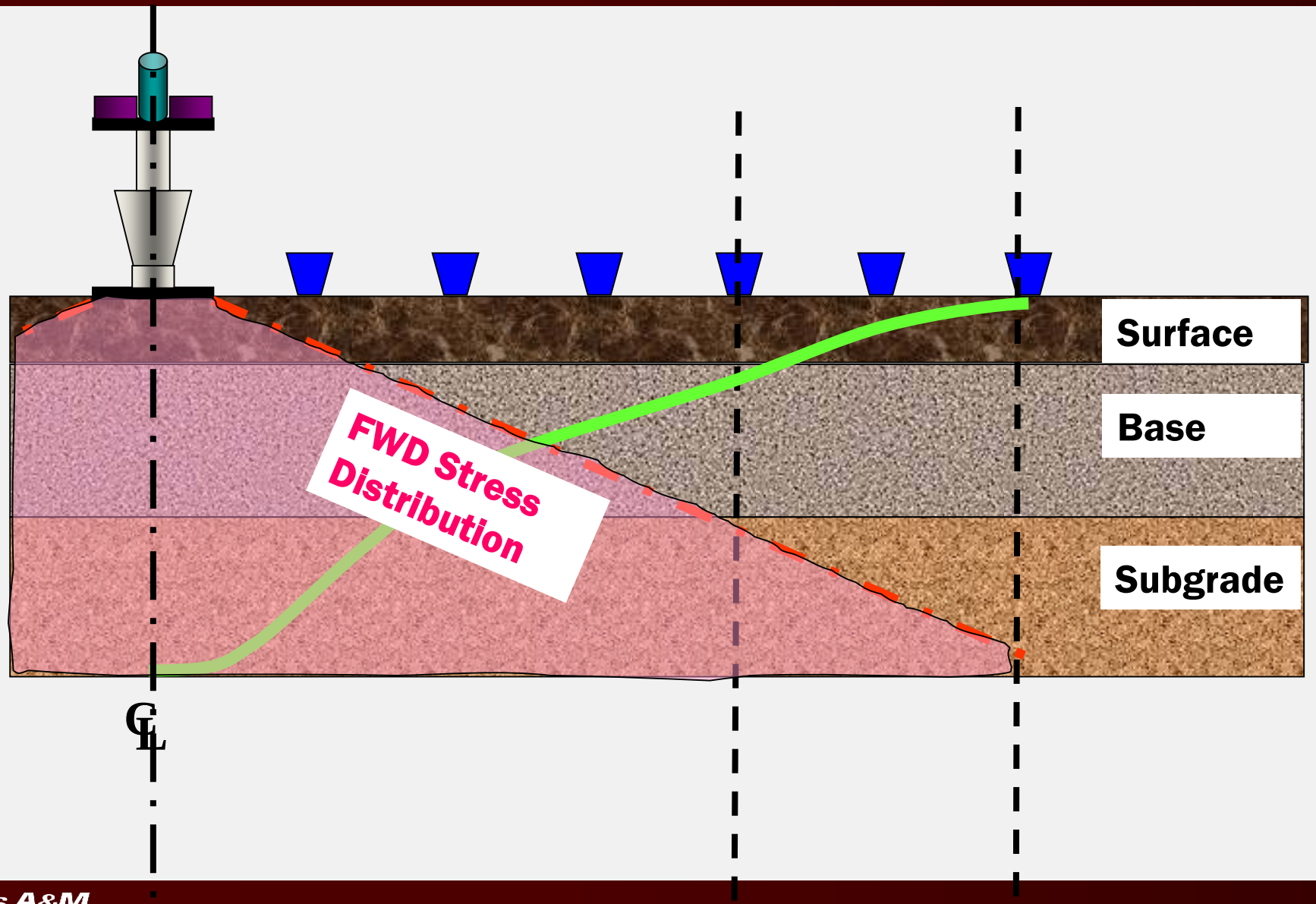
Rolling Deflectometer in Action

TPAD DATA

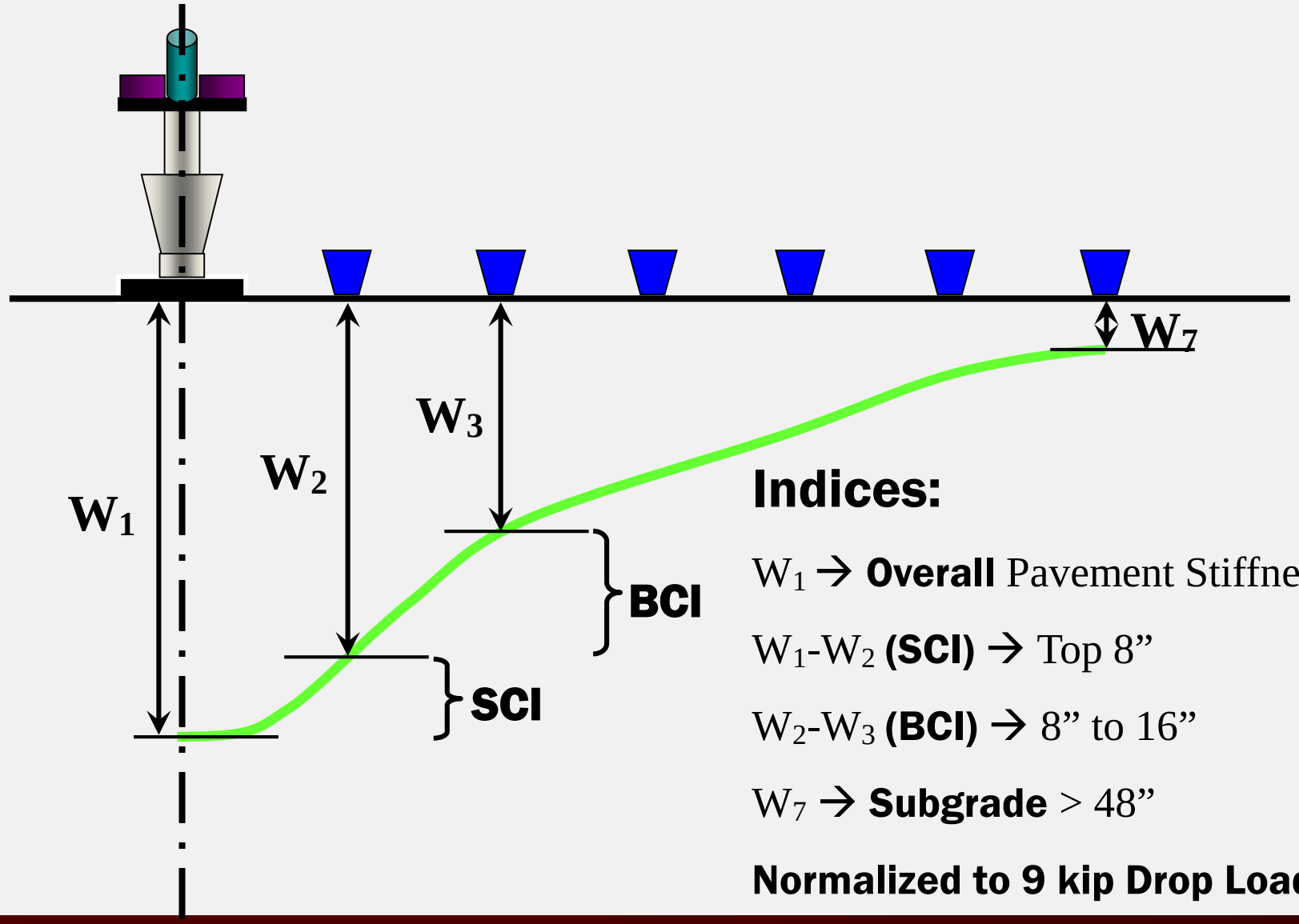

Deflection (mils/10-kips)
Center Geophone
Front Geophone
Rear Geophone
Lat. 29.6771993 Lot. 95.5399649 DMI 5771.9 Value 0.33
Deflections
Sensors 1 and 2
1 mi 455 ft

Falling Weight Deflectometer - FWD

Stress Distribution and Deflections Under FWD Loading



Raw Deflection Data Indices



Indices:

W_1 → **Overall** Pavement Stiffness

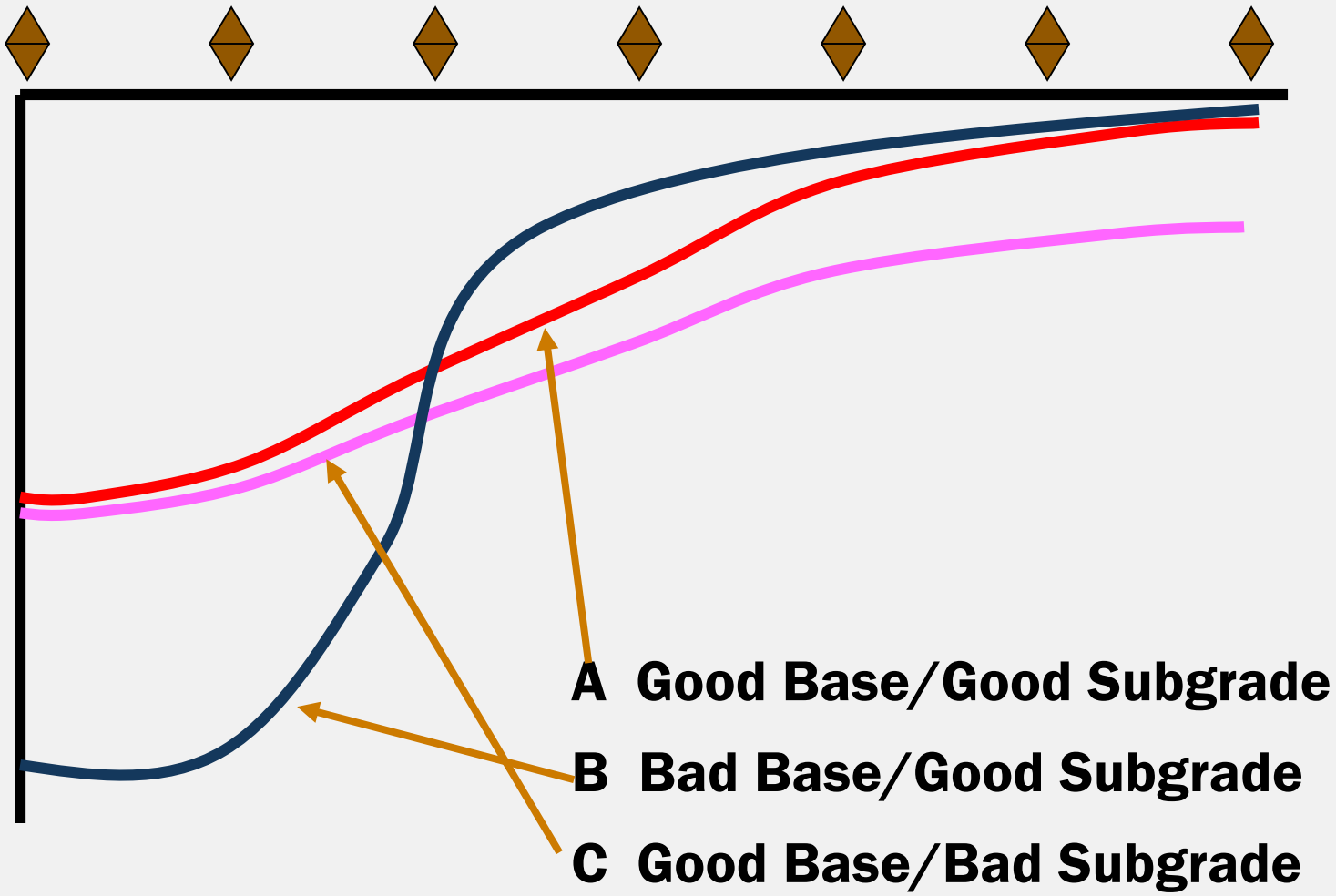
W_1-W_2 **(SCI)** → Top 8”

W_2-W_3 **(BCI)** → 8” to 16”

W_7 → **Subgrade** > 48”

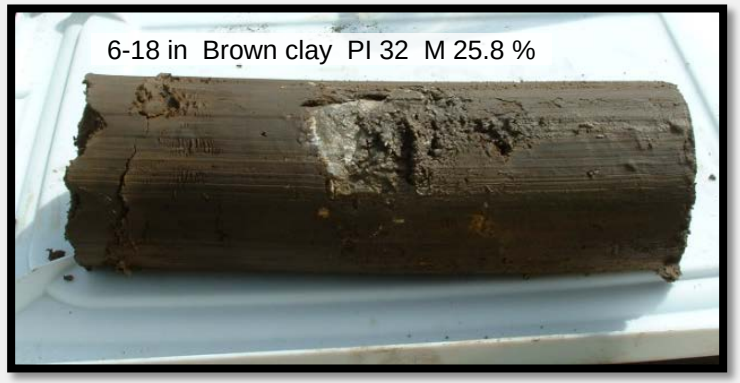
Normalized to 9 kip Drop Load

Interpreting Relative Deflection Bowl Shape



Subgrade Evaluation

- http://websoilsurvey.nrcs.usda.gov/app/
  - USDA soil information webpage
- Sample and Test Subgrade



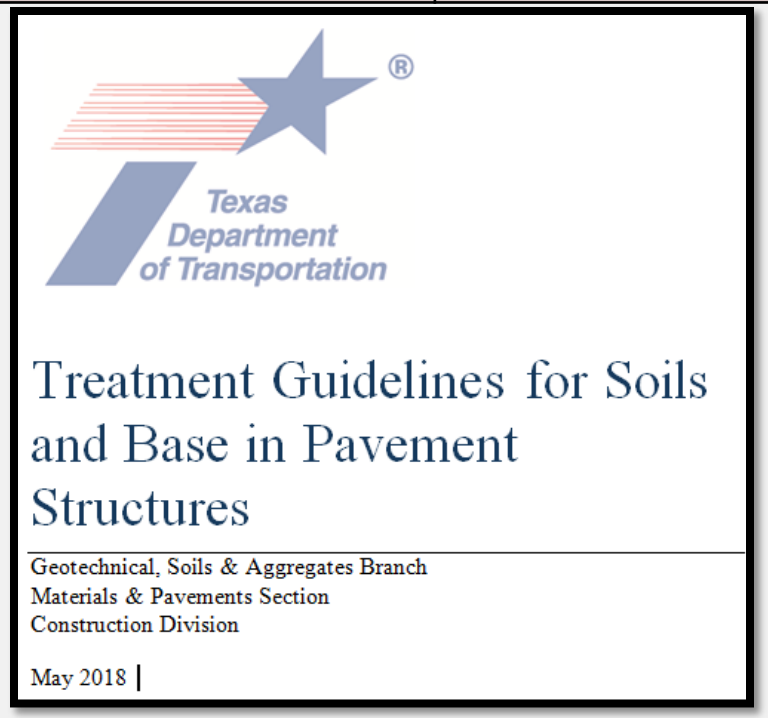
Site Coring validating defects - additional testing

Subgrade and Existing Pavement Layers

- FPS
  - Priority should be to use the project-specific backcalculated subgrade modulus.
  - Defaults by county are available in the FPS design program.
  - Typical Design Modulus range is 8-20 ksi.
  - Typical Poisson's Ratio range is 0.35-0.45
    - Wetter or more highly plastic materials warrant higher Poisson ratios.
  - New location construction
    - deflection testing on an adjacent highway, or
    - intersecting highways can provide data for backcalculation.
    - Alternatively, elastic modulus correlations to field or laboratory derived CBR or the program default may be used.

Stabilized Subgrade

Material Type	2014 Spec	Design Modulus	Poisson's Ratio
Lime or Cement Treated Subgrade	Item 260, 275	30 - 45 ksi	0.30
Emulsified Asphalt Treatment (Subgrade)	Item 314, various special specs	15 - 25 ksi	0.35


Texas Department of Transportation

Treatment Guidelines for Soils and Base in Pavement Structures

Geotechnical, Soils & Aggregates Branch
Materials & Pavements Section
Construction Division

May 2018

Base

Material Type	2014 Spec	Design Modulus	Poisson's Ratio
Asphalt Treatment (base)	Item 292	250 - 400 ksi	0.35
Emulsified Asphalt Treatment (Base)	Item 314, various OTU special specs	50 - 250 ksi	0.35
Flexible Base	Item 247	If historic data not available, modulus shall be no greater than 3-4 times the subgrade modulus or use FPS default, whichever is lower. Typical range 40-70 ksi.	0.35
Lime Treated Base	Item 260, 263	60 - 75 ksi	0.30 - 0.35
Cement Treated Base	Item 275, 276	80 - 150 ksi	0.25 - 0.30
Fly Ash or Lime-Fly Ash Treated Base	Item 265	60 - 75 ksi	0.30

Guidance FDR projects

Material Description		Modulus Value	Poison's Ratio	Cohesiometer Value for MT check
Existing Material (not reworked, including Subgrade)		500 ksi or Back-calculated from FWD data,	0.35	na
Existing Pavement – Scarified, Reshaped and Compacted		~3 times the subgrade modulus	0.35	na
Stabilize Blend of Existing Pavement & Subgrade	**mostly granular base** (75% or more base)	100 ksi	0.3	800
	blend subgrade & base (50% to 75% base)	65 ksi	0.3	650
	mostly subgrade (<50% base)	35 ksi	0.35	300
New Flexible Base over Stabilized Subbase (mostly granular base)		70 ksi	0.35	na
1st 6" lift of new flexible base (when multiple lifts are required)		~3 times the subgrade modulus, but not > Districts default modulus value (40-70 ksi)	0.35	na

Sampling Projects for FDR or CIR

- HMA Sections > 2 ins

  Keep HMA and Base Samples Separate

TxDOT new Small Sample Mix Design procedure

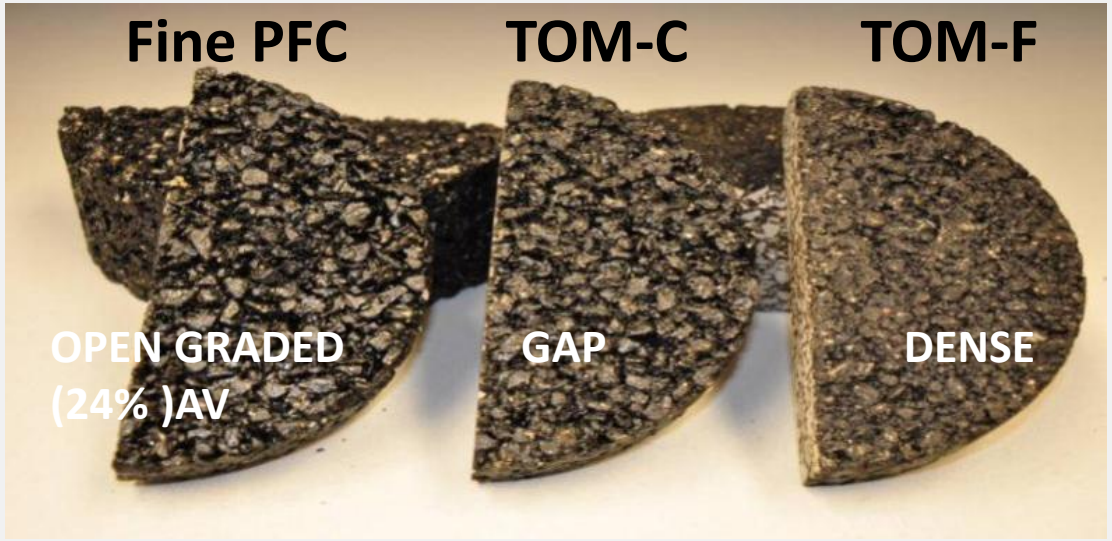
"Traditional" vs "Small" Sample Sizes

- **Traditional sample sizes**
  - **110 pounds per design**
- **Small samples**
  - **15 pounds per design**
- **Oftentimes 4 to 8 different mixtures under consideration**
- **Complete lab design in 5 working days**

HMA

Material Type	2014 Spec	Design Modulus	Poisson's Ratio
Seal Coat (nonstructural layer)	Item 316	200 - 250 ksi	0.35
Limestone Rock Asphalt Pavement	Item 330	200 - 350 ksi	0.35
Hot-Mix Cold-Laid ACP	Item 334	300 - 400 ksi	0.35
Dense-Graded Hot-Mix Asphalt	Item 340, 341	Combined HMA thickness:	0.35
		≤ 4 in. use 500 ksi	
		> 4.0 in. use 650 ksi	
Permeable Friction Course	Item 342	300 ksi	0.35
Superpave Mixtures	Item 344	Combined HMA thickness:	0.35
		≤ 4.0 in. use 650 ksi	
		4 in. < T ≤ 6 in. use 750 ksi	
		> 6.0 in. use 850 ksi	
Stone-Matrix Asphalt	Item 346	Same as Item 344	0.35

Hot Mix



- **THIN MIXES**
  - **30% Cost savings over traditional mixes - lifts of 1 inch or less**
  - **Must pass Rutting (HWTT) and Cracking (OT) performance tests**
  - **Min 6% PG 76-22 SAC A Rock, 100% passing 3/8" NO RAP or RAS**

Pavement Design Report – Supporting Documentation

- Background Material
  - As-Built PS&E
  - Sitemanager Construction Records
  - Maintenance History
  - PMIS data
  - 4 year Plan scope of work
  - Traffic Data
  - Previous Pavement Design Reports
- Drainage analysis
- Design exceptions and approvals
- Document Assumptions
- Existing Material testing Reports
- Core Report
- Life-cycle cost analysis
- PG binder selection criteria
- Surface Aggregate Selection Form 2088
- Traffic Data
- Results of NDT to characterize the existing structural condition
  - Falling Weight Deflectometer (FWD)
    - MODULUS, including the backcalculation summary
  - TPAD
  - Ground Penetrating Radar (GPR)
- Soils Report
  - Material Description: Tex 141-E, 142-E
  - PI: Tex 104-6-E
  - Sulfate Content: Tex-145-E, Tex-146-E
  - Organic Content, Tex-148-E
  - PVR: Tex-124-E
- Material Designs
  - Treatment: Tex 120-E, 121-E, 127-E, 122-E
- Design Program Inputs and Results
  - FPS 21 summary,
    - modified Texas Triaxial check,
    - mechanistic checks,
    - stress analysis, etc.,
  - Alternate pavement design
    - AASHTO (DARWin® 3.1) design summary for CPCD rigid pavements.
    - TxCRCP-ME Design summary for CRCP rigid pavements.

Report Content – Summary Page

- Clearly define the pavement layers
  - Description, thickness, and materials with estimate rates(if applicable)
    - Note: An underseal, Prime Coat, etc. will not be modelled in the design software. It needs to be shown on the summary and proposed typical section, don't assume the designer knows that it is needed.
  - Controlling specification item for each layer
- Proposed Typical Section
  - Changes within the limits of the project (more than one typical section)
    - Frontage Roads vs. Mainlanes
    - Cross overs and intersections
    - Widening details
    - Stage Construction and detours.
    - Undercut areas or Soil mitigation areas (include details for replacement or treated materials)
    - Include special details such as widening, hot mix tapers, stage construction details
- Summary Cost Analysis
  - Comparison of alternates considered
  - Life cycle cost analysis

Questions


Seal
Coat


Flex Base


FDR
24.08.2005 14:20


FDR- Foamed AC


Hot Mix
CATERPILLAR
18.05.2007 10:40


Rubblization


Concrete
16.08.2006 15:26