



Re-Evaluation of Current TxDOT PVR Procedure with A New Suction-Based Approach

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**Foundation Performance Association
Houston, Texas
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TxDOT Project Background (2002-2004)

TTI Project Name: Design Procedure for Pavements on Expansive Soils (3 Volumes)

- *Volume I – Theoretical Background*
- *Volume II – Experimental Protocols,
Case Studies Site Descriptions*
- *Volume III – Computer Programs Manuals*

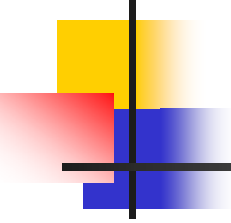
PI: Dr. Robert L. Lytton

Co-PI: Dr. Charles P. Aubeny



Outline

- *TxDOT PVR Assumptions*
- *Analysis Program (Flodef)*
- *Design Program (Winpres)*
- *Laboratory Testing (Diffusion Coefficient)*
- *TxDOT Case Studies*
- *PVR Comparison*
- *Implementation*



TxDOT PVR Tex-124-E Assumptions

- *Soil at all depths has access to water in capillary moisture conditions*
- *Vertical swelling strain is one-third of the volume change at all depths*
- *Remolded and compacted soils adequately represent soils in the field*
- *PVR of 0.5 inch produces unsatisfactory riding quality*
- *Volume change can be predicted by use of the plasticity index alone*

Analysis Program - Flodef

FLODEF

Sequentially Coupled Unsaturated Flow and Deformation Analysis Program

**Robert Lytton
Derek Gay
Charles Aubeny
Xiaoyan Long**



Analysis Program - Flodef

Two-Dimensional Transient Analysis For the Effects of:

- *Vertical Moisture Barrier*
- *Subgrade Material (Lime Stabilized / Inert Soil)*
- *Median Condition (Paved / Non-Paved)*
- *Shoulder Condition (Paved / Bare)*



Analysis Program - Flodef

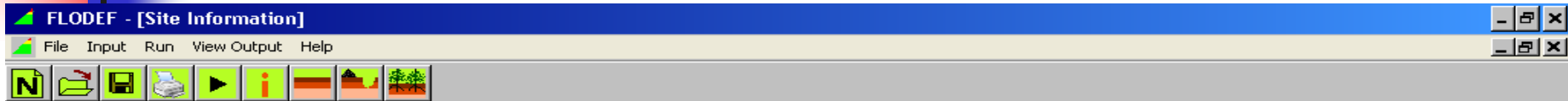
Input

- *2D Cross Section*
- *Soil Index Properties*
- *Geographic Location*
- *Vegetation*
- *Moisture Controls*
- *Drainage Conditions*

Output

- *Shrink-Swell versus Time*
- *Suction versus Time*

Analysis Program - Flodef



Project Name

PRES

Project Engineer

Project Location/Initial Weather Condition

Region

- El Paso
- Snyder
- Wichita Falls
- Converse
- Seguin
- Dallas
- Ennis
- Houston
- Port Arthur

Initial Condition

- Wet
- Equilibrium
- Dry

Duration (years)

- 5
- 10
- 15
- 20

Vertical Moisture Barriers

- No
- Yes

Barrier Depth (ft)

Special Soil Layer?

- No?
- Yes? Types

Horizontal Moisture Barriers?

- No ?
- Yes?

Paving Shoulder Width ft

Drainage Condition?

- Good?
- Poor Drainage?

Ponded Water Depth in Ditch ft

Median Condition

- Paved Median
- Bare Median (With Grass)

Map

Analysis Program - Flodef

FLODEF - [Layers Properties 1]

File Input Run View Output Help

Surface Course
 Asphalt
 Concrete

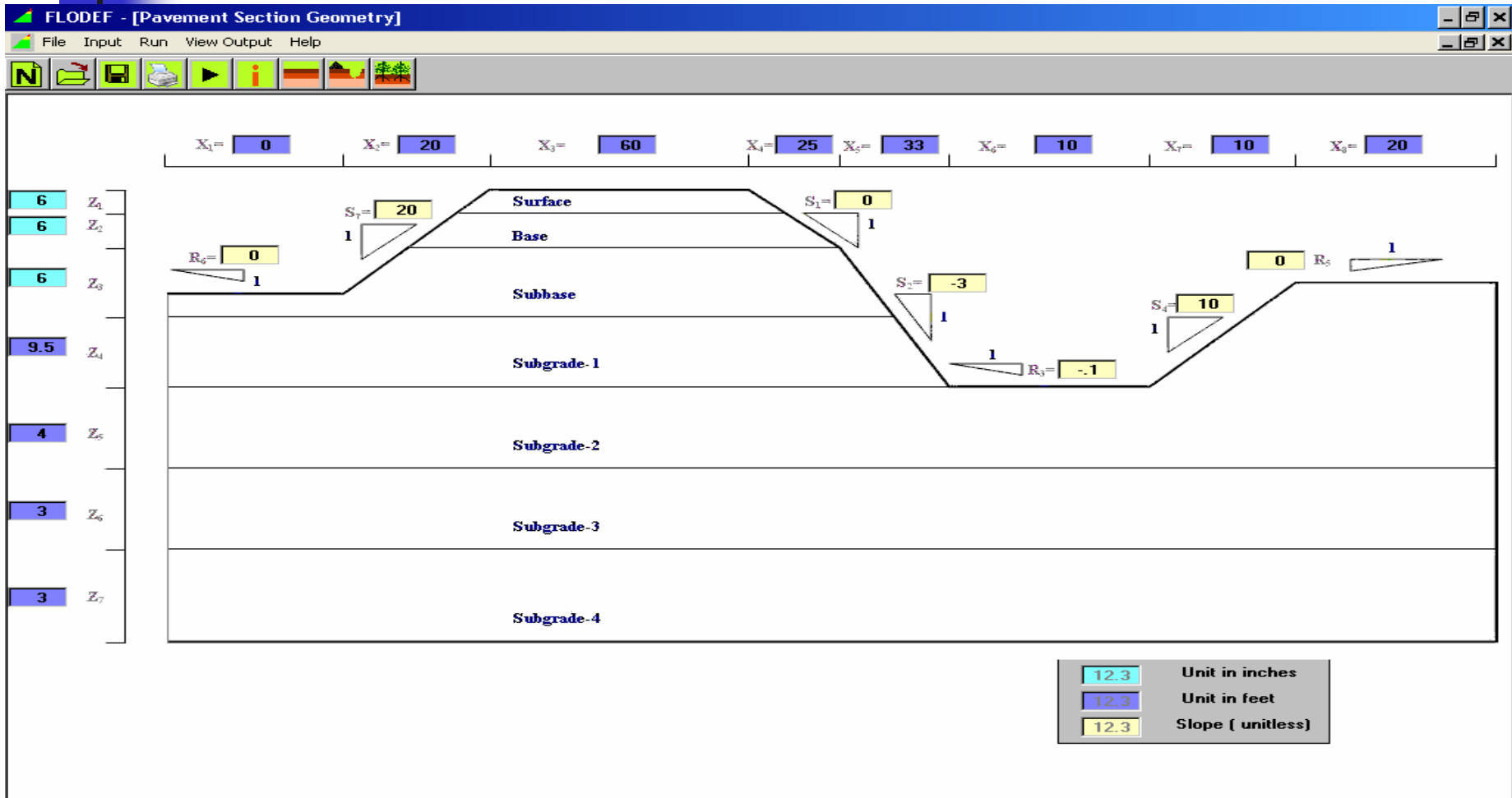
Base Course
 Untreated Granular
 Lime Stabilized
 Cement Stabilized
 Asphalt - Treated

Subbase Course
 Untreated Granular
 Lime Stabilized
 Cement Stabilized
 Asphalt - Treated

	Poisson's ratio	Dry Unit weight (pcf)
Surface Course	<input type="text" value=".3"/>	<input type="text" value="110"/>
Base Course	<input type="text" value=".3"/>	<input type="text" value="110"/>
Subbase Course	<input type="text" value=".3"/>	<input type="text" value="110"/>

Subgrade layers	Soil Type	LL (%)	PI(%)	-200#	-2um	Poisson's ratio	Dry Unit weight	% Lime Content	% Cement by weight
Subgrade-1	Natural Soil	<input type="text" value="63"/>	<input type="text" value="30"/>	<input type="text" value="93.57"/>	<input type="text" value="30"/>	<input type="text" value=".3"/>	<input type="text" value="110"/>		
Subgrade-2	Natural Soil	<input type="text" value="45"/>	<input type="text" value="21"/>	<input type="text" value="99.44"/>	<input type="text" value="37"/>	<input type="text" value=".3"/>	<input type="text" value="110"/>		
Subgrade-3	Natural Soil	<input type="text" value="45"/>	<input type="text" value="21"/>	<input type="text" value="99.44"/>	<input type="text" value="37"/>	<input type="text" value=".3"/>	<input type="text" value="110"/>		
Subgrade-4	Natural Soil	<input type="text" value="45"/>	<input type="text" value="21"/>	<input type="text" value="99.44"/>	<input type="text" value="37"/>	<input type="text" value=".3"/>	<input type="text" value="110"/>		
Vertical Barrier Soil Properties						<input type="text" value=".3"/>	<input type="text" value="110"/>		

Analysis Program - Flodef



Analysis Program - Flodef

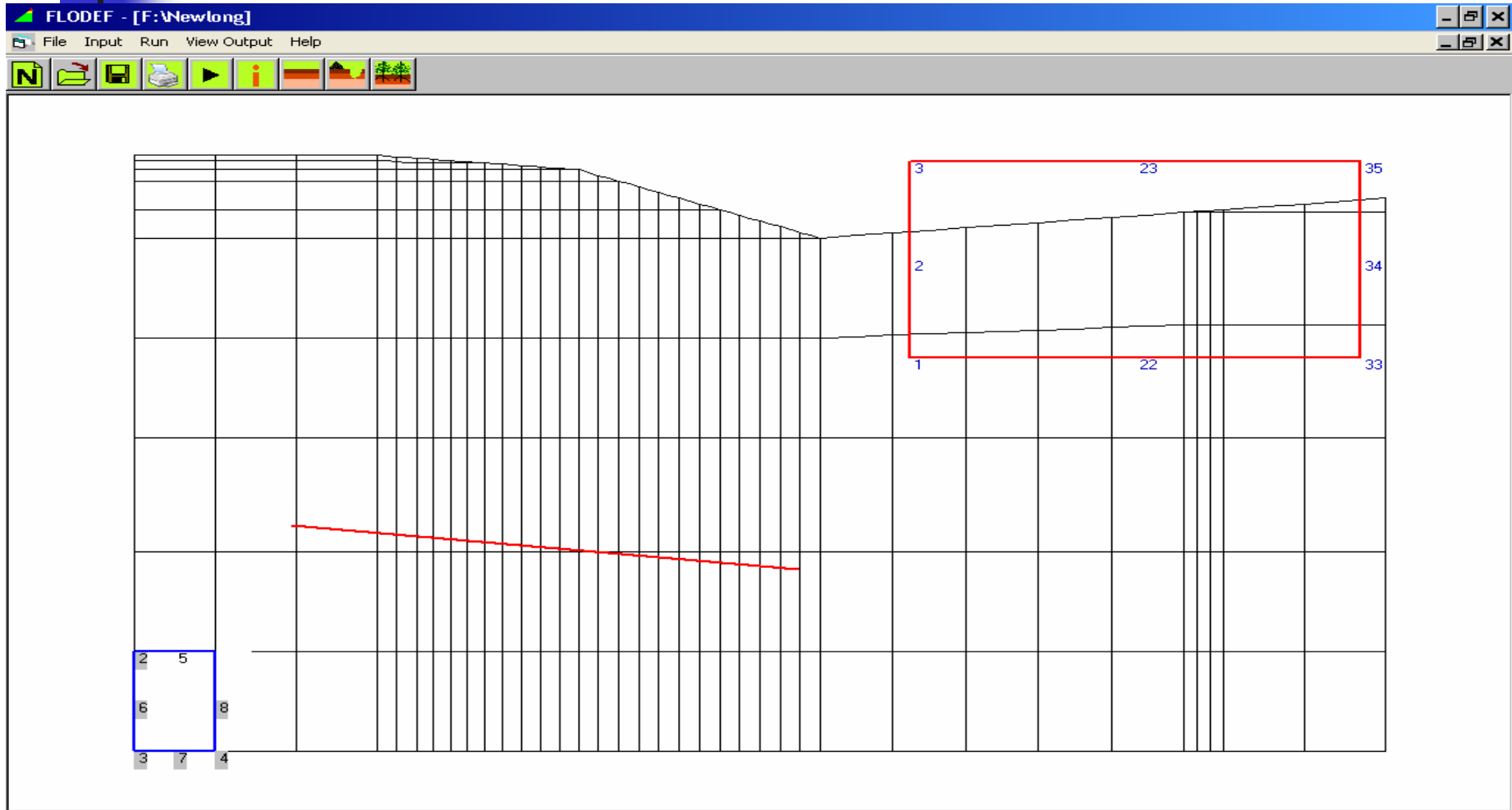
The screenshot displays the FLODEF software interface for a "Tree Root Zone" analysis. The window title is "FLODEF - [Tree Root Zone]". The menu bar includes "File", "Input", "Run", "View Output", and "Help". The toolbar contains icons for navigation and simulation.

The main interface is divided into three sections:

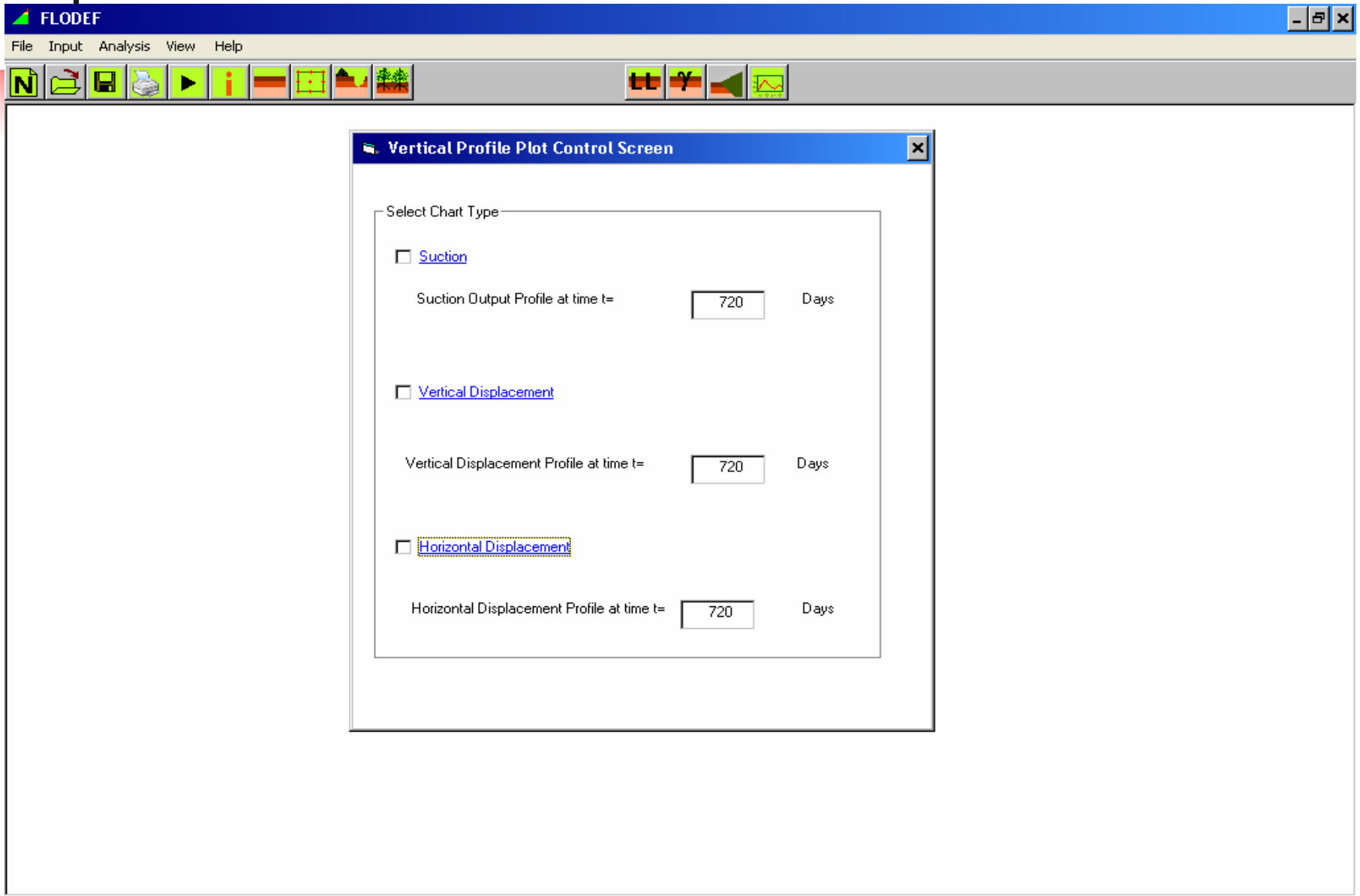
- Vegetation:** Contains buttons for "Tree" and "Grass".
- Tree:** Parameters include:
 - Root Transpiration Rate: 5 in/day
 - Left location: 33.63 (feet)
 - Right location: 61.79 (feet)
 - Root Depth: 14 (feet)
- Grass:** Parameters include:
 - Root Transpiration Rate: 5 in/day
 - Left location: 33.87 (feet)
 - Right location: 61.63 (feet)

A 3D visualization shows a cross-section of the ground with a line representing the root zone boundary. A row of trees is shown on the surface, with vertical blue lines indicating the left and right boundaries of the root zone. A coordinate system in the top right shows the x-axis pointing right, the y-axis pointing down, and the z-axis pointing out of the page.

Analysis Program - Flodef

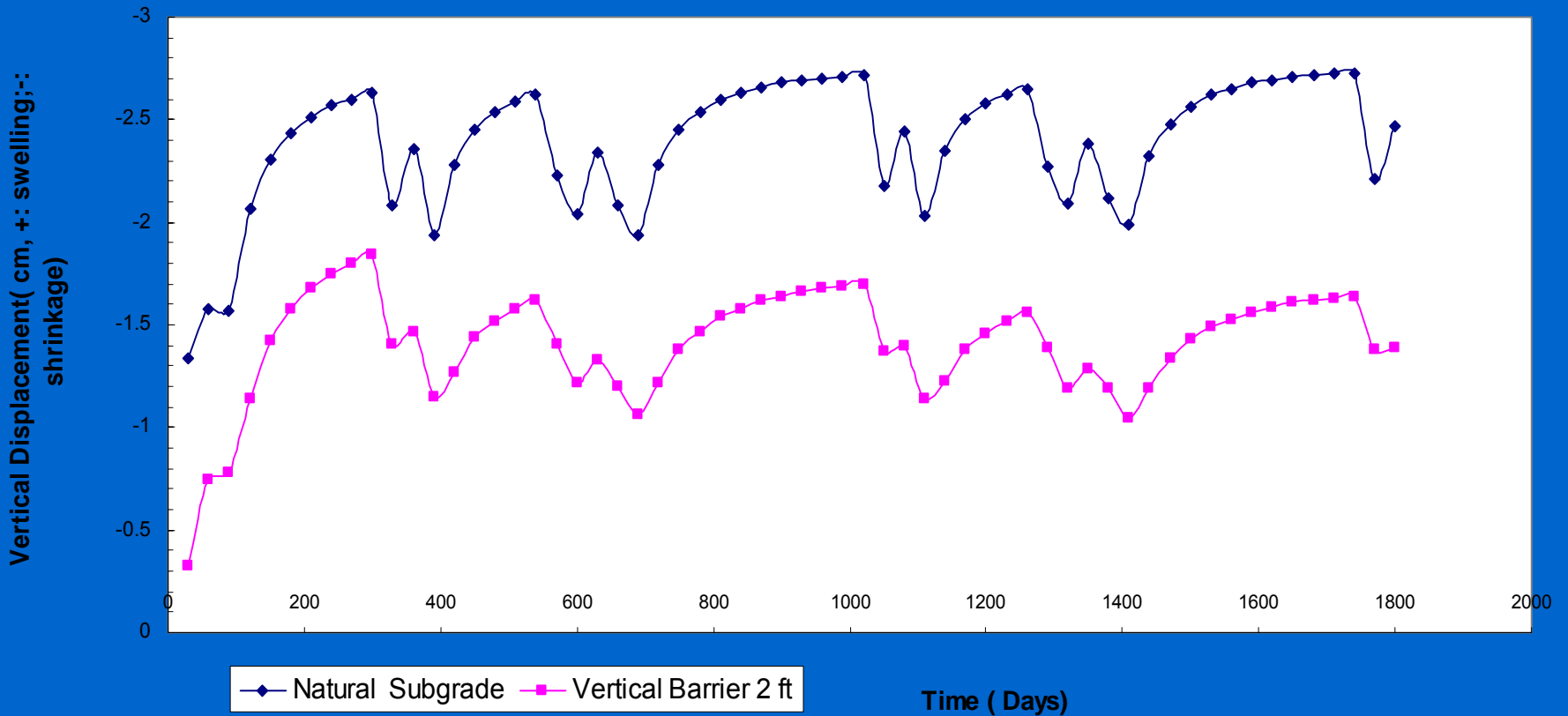


Analysis Program - Flodef



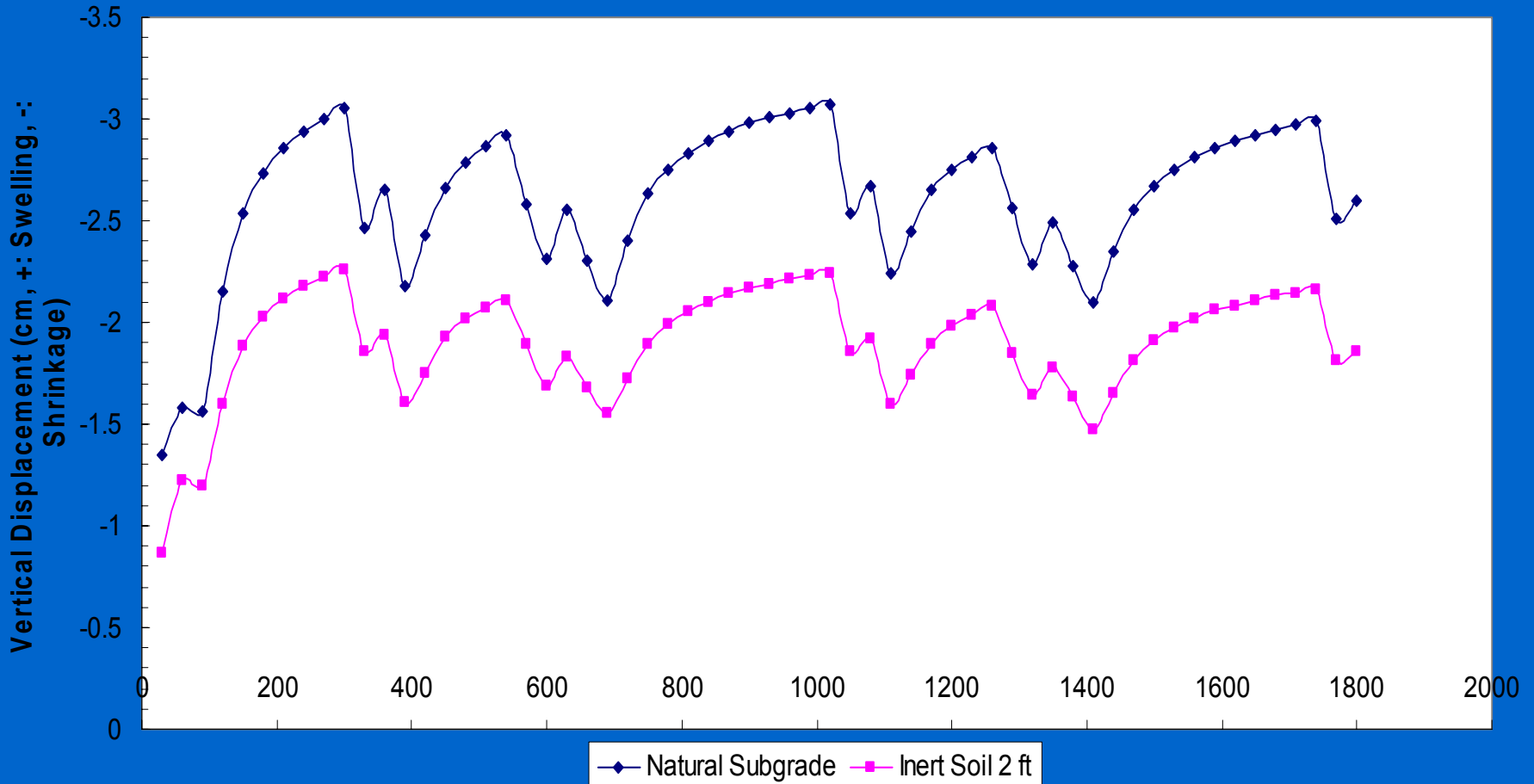
Analysis Program - Flodef

Vertical Displacement of Outer Wheel Path, Fort Worth Section C ,Initial Wet



Analysis Program - Flodef

Vertical Displacement of Outer Wheel Path, Fort Worth Section A/B, Initial Wet
Time (Days)



Design Program - Winpres





Design Program - Winpres

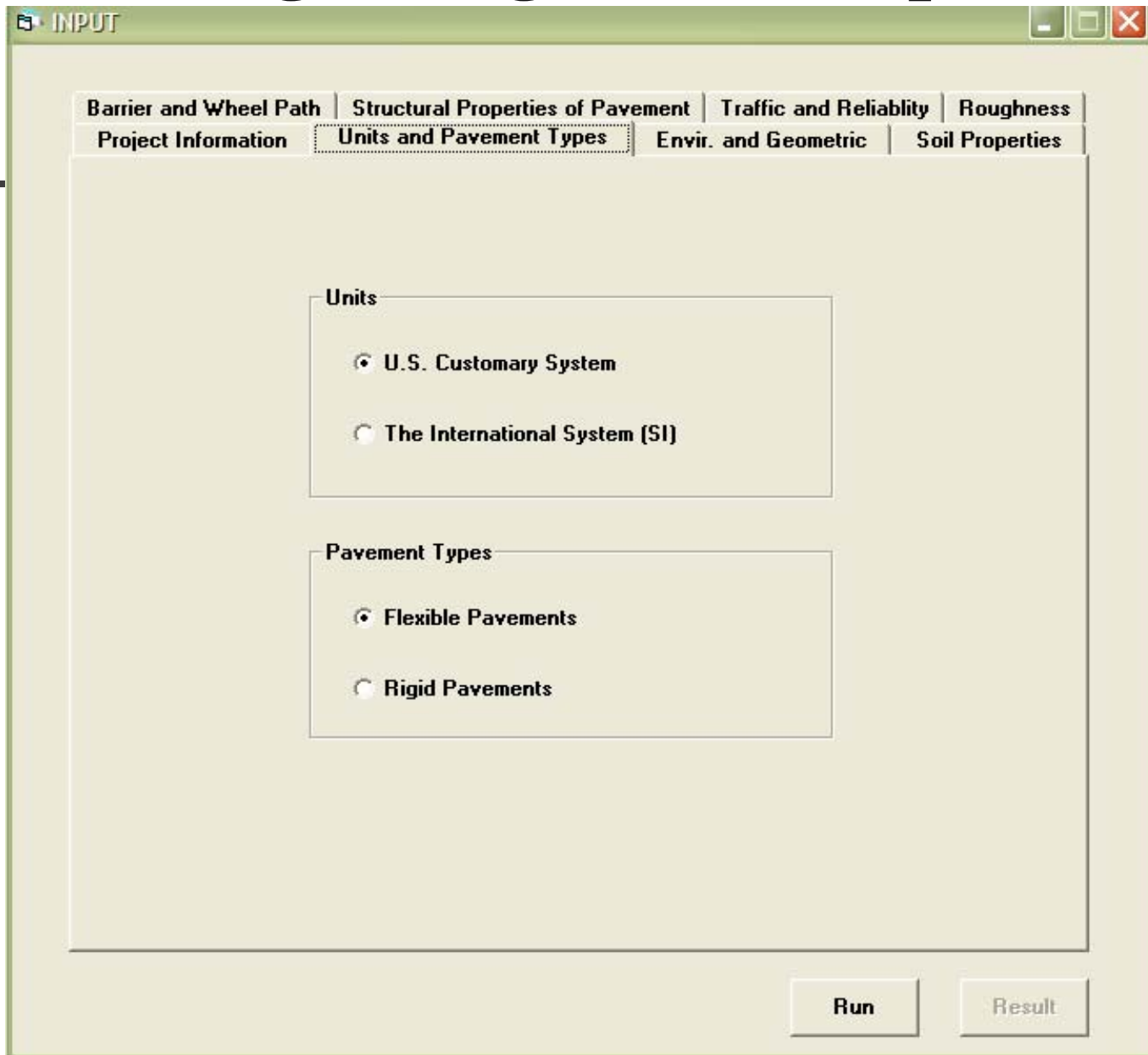
Input

- *Soil Index Properties*
- *Geographic Location*
- *Site Drainage and Vegetation*
- *Pavement Data*
- *Moisture Controls*
- *Traffic Data*
- *Reliability Level*

Output

- *Shrink-Swell versus Time*
- *PSI versus Time*
- *IRI versus Time*

Design Program - Winpres



INPUT

Barrier and Wheel Path | Structural Properties of Pavement | Traffic and Reliability | Roughness
Project Information | **Units and Pavement Types** | Envir. and Geometric | Soil Properties

Units

U.S. Customary System

The International System (SI)

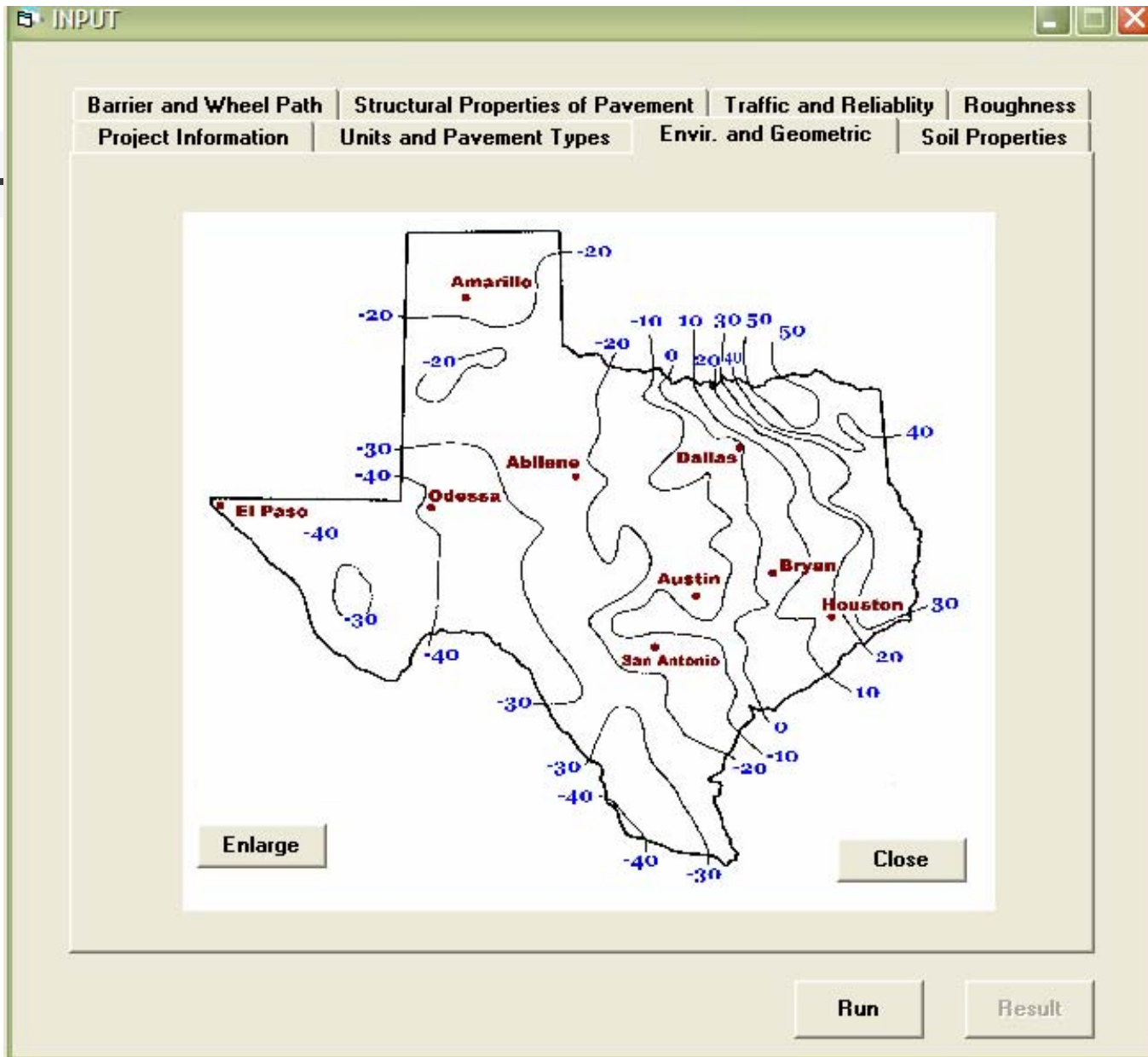
Pavement Types

Flexible Pavements

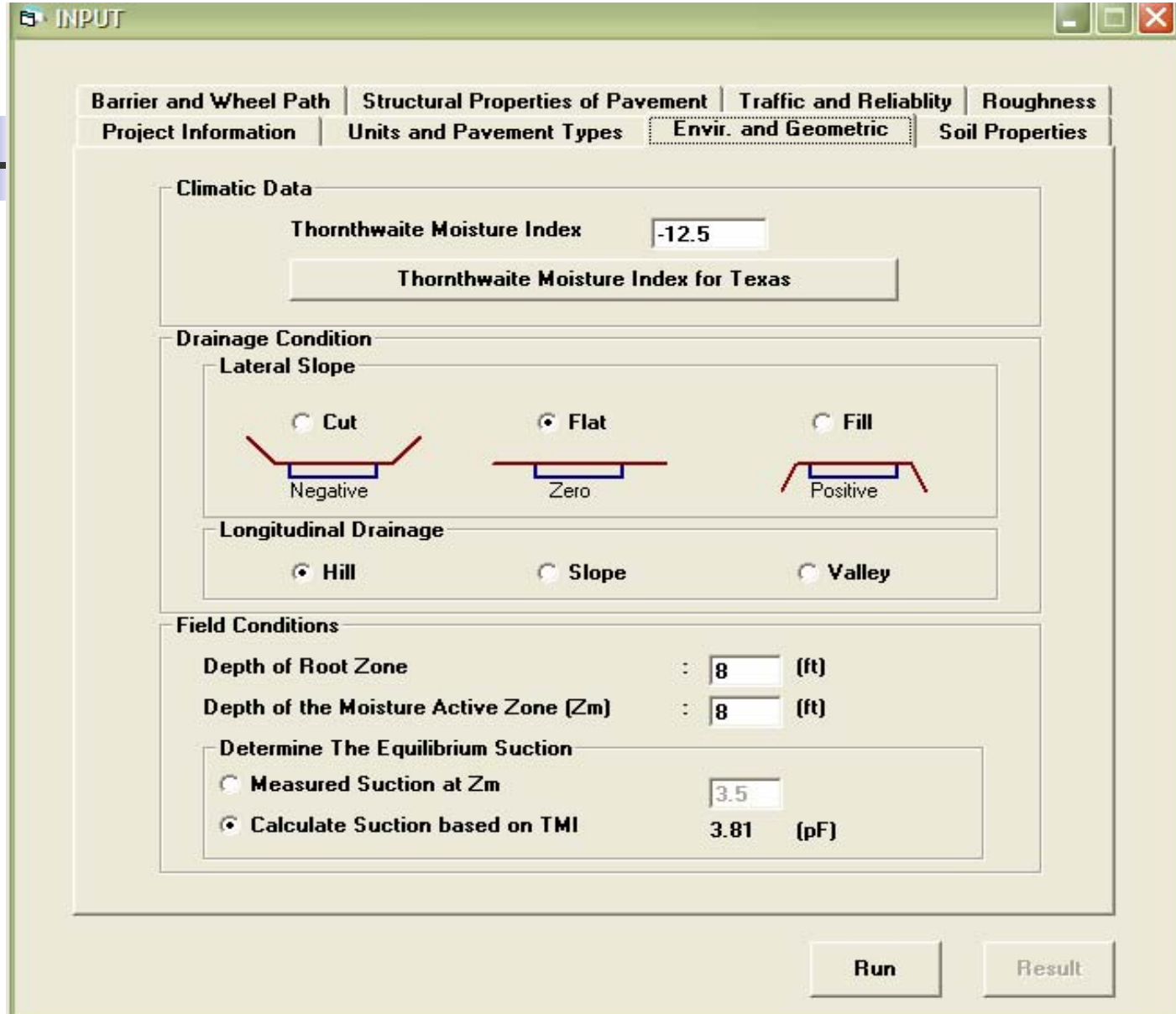
Rigid Pavements

Run Result

Design Program - Winpres



Design Program - Winpres



The image shows a screenshot of the Winpres software interface. The window title is 'INPUT'. The interface is divided into several tabs: 'Barrier and Wheel Path', 'Structural Properties of Pavement', 'Traffic and Reliability', 'Roughness', 'Project Information', 'Units and Pavement Types', 'Envir. and Geometric' (which is selected), and 'Soil Properties'. The 'Envir. and Geometric' tab contains the following sections:

- Climatic Data:** Thornthwaite Moisture Index is set to -12.5. There is a button labeled 'Thornthwaite Moisture Index for Texas'.
- Drainage Condition:**
 - Lateral Slope:** Three radio buttons are present: 'Cut' (unselected), 'Flat' (selected), and 'Fill' (unselected). Below each radio button is a diagram: 'Cut' shows a cross-section of a road with a negative slope, 'Flat' shows a horizontal road surface, and 'Fill' shows a cross-section of a road with a positive slope.
 - Longitudinal Drainage:** Three radio buttons are present: 'Hill' (selected), 'Slope' (unselected), and 'Valley' (unselected).
- Field Conditions:**
 - Depth of Root Zone: 8 (ft)
 - Depth of the Moisture Active Zone (Zm): 8 (ft)
 - Determine The Equilibrium Suction:** Two radio buttons are present: 'Measured Suction at Zm' (unselected) with a value of 3.5, and 'Calculate Suction based on TMI' (selected) with a value of 3.81 (pF).

At the bottom of the window, there are two buttons: 'Run' and 'Result'.

Design Program - Winpres

INPUT

Barrier and Wheel Path | Structural Properties of Pavement | Traffic and Reliability | Roughness
 Project Information | Units and Pavement Types | Envir. and Geometric | Soil Properties

Soil Profile

Layer 2 stabilized soil

Thickness of Soil Layer : 2 (ft) Dry Unit Weight : 120 (pcf)
 Liquid Limit : 40 (%) The Plasticity Index : 10 (%)
 % Passing #200 Sieve : 25 (%) % Less than 2 Microns : 10 (%)

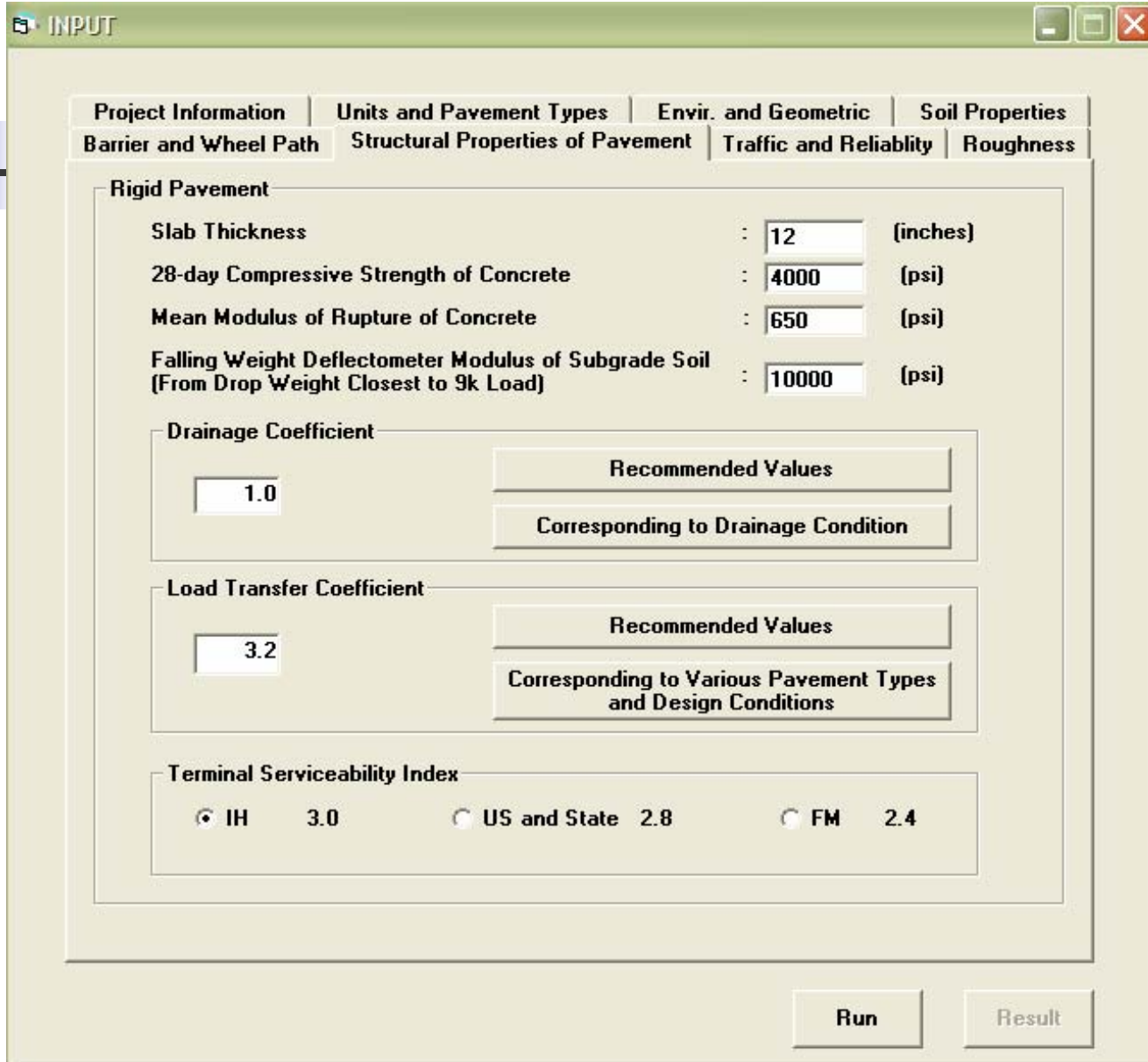
% Lime 6 (%) % Cement 6 (%)

Add Delete Previous Next

Layer	Soil Type	Thickness (ft)	Dry Unit Weight(pcf)	LL(%)	PI(%)	% Passing #200 Sieve	% Less than 2 Microns
1	inert	3	135	25	15	10	1
2	stabilized	2	120	40	10	25	10
3	natural	2	100	72.9	49.4	89.4	41.8
4	natural	1	100	80	51.3	90.3	47.2

Run Result

Design Program - Winpres



INPUT

Project Information | Units and Pavement Types | Envir. and Geometric | Soil Properties
Barrier and Wheel Path | Structural Properties of Pavement | Traffic and Reliability | Roughness

Rigid Pavement

Slab Thickness : (inches)
28-day Compressive Strength of Concrete : (psi)
Mean Modulus of Rupture of Concrete : (psi)
Falling Weight Deflectometer Modulus of Subgrade Soil (From Drop Weight Closest to 9k Load) : (psi)

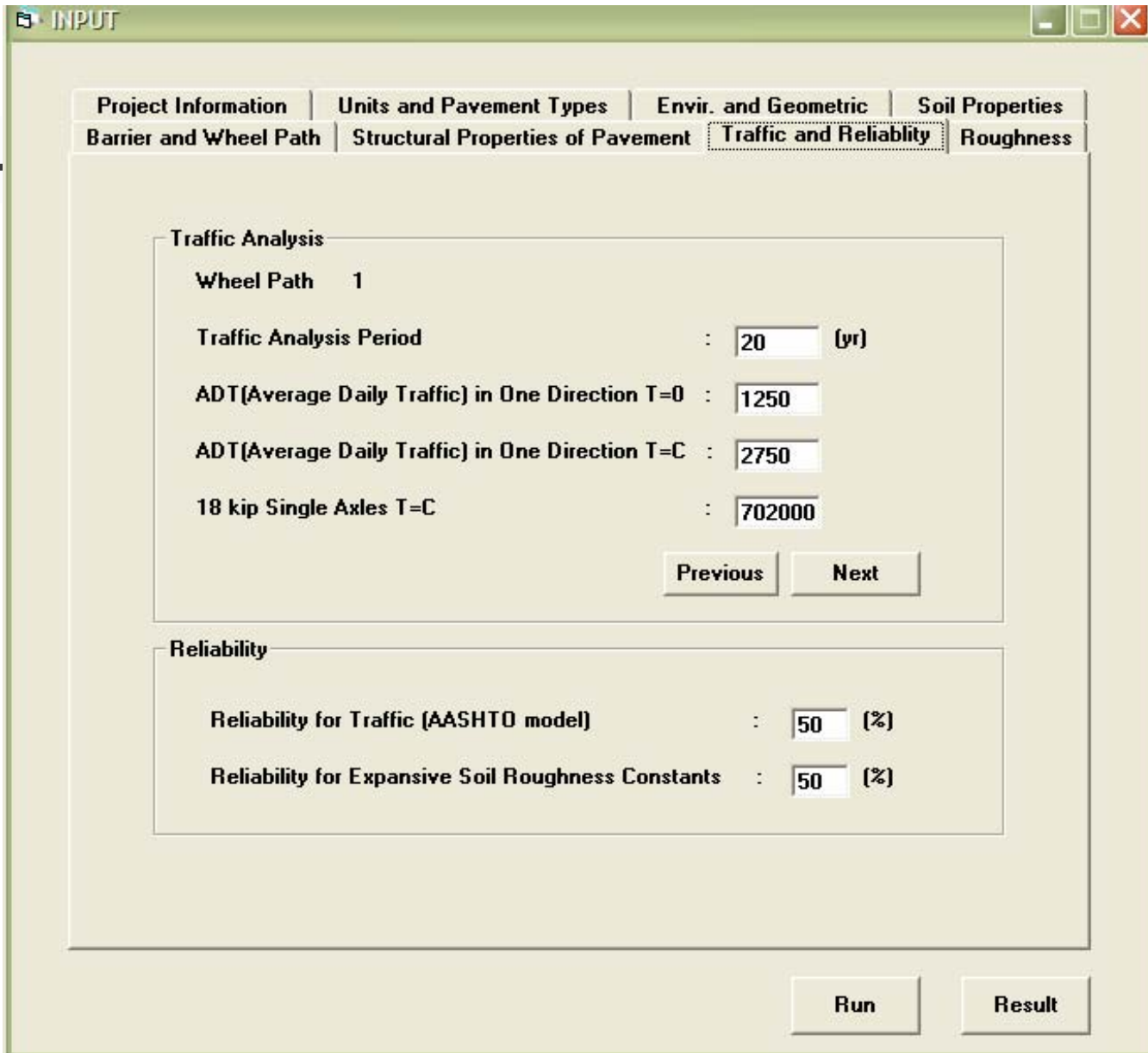
Drainage Coefficient

Load Transfer Coefficient

Terminal Serviceability Index

IH 3.0 US and State 2.8 FM 2.4

Design Program - Winpres



The image shows a screenshot of the Winpres software interface. The window title is 'INPUT'. The interface has a tabbed menu at the top with the following tabs: 'Project Information', 'Units and Pavement Types', 'Envir. and Geometric', 'Soil Properties', 'Barrier and Wheel Path', 'Structural Properties of Pavement', 'Traffic and Reliability' (which is the active tab), and 'Roughness'. The 'Traffic and Reliability' tab contains two sections: 'Traffic Analysis' and 'Reliability'. The 'Traffic Analysis' section includes a 'Wheel Path' dropdown set to '1', and three input fields: 'Traffic Analysis Period' (20 yr), 'ADT(Average Daily Traffic) in One Direction T=0' (1250), and 'ADT(Average Daily Traffic) in One Direction T=C' (2750). Below these is an input field for '18 kip Single Axles T=C' (702000). There are 'Previous' and 'Next' buttons. The 'Reliability' section includes two input fields: 'Reliability for Traffic (AASHTO model)' (50 %) and 'Reliability for Expansive Soil Roughness Constants' (50 %). At the bottom of the window are 'Run' and 'Result' buttons.

Project Information | **Units and Pavement Types** | **Envir. and Geometric** | **Soil Properties**
Barrier and Wheel Path | **Structural Properties of Pavement** | **Traffic and Reliability** | **Roughness**

Traffic Analysis

Wheel Path 1

Traffic Analysis Period : 20 (yr)

ADT(Average Daily Traffic) in One Direction T=0 : 1250

ADT(Average Daily Traffic) in One Direction T=C : 2750

18 kip Single Axles T=C : 702000

Previous Next

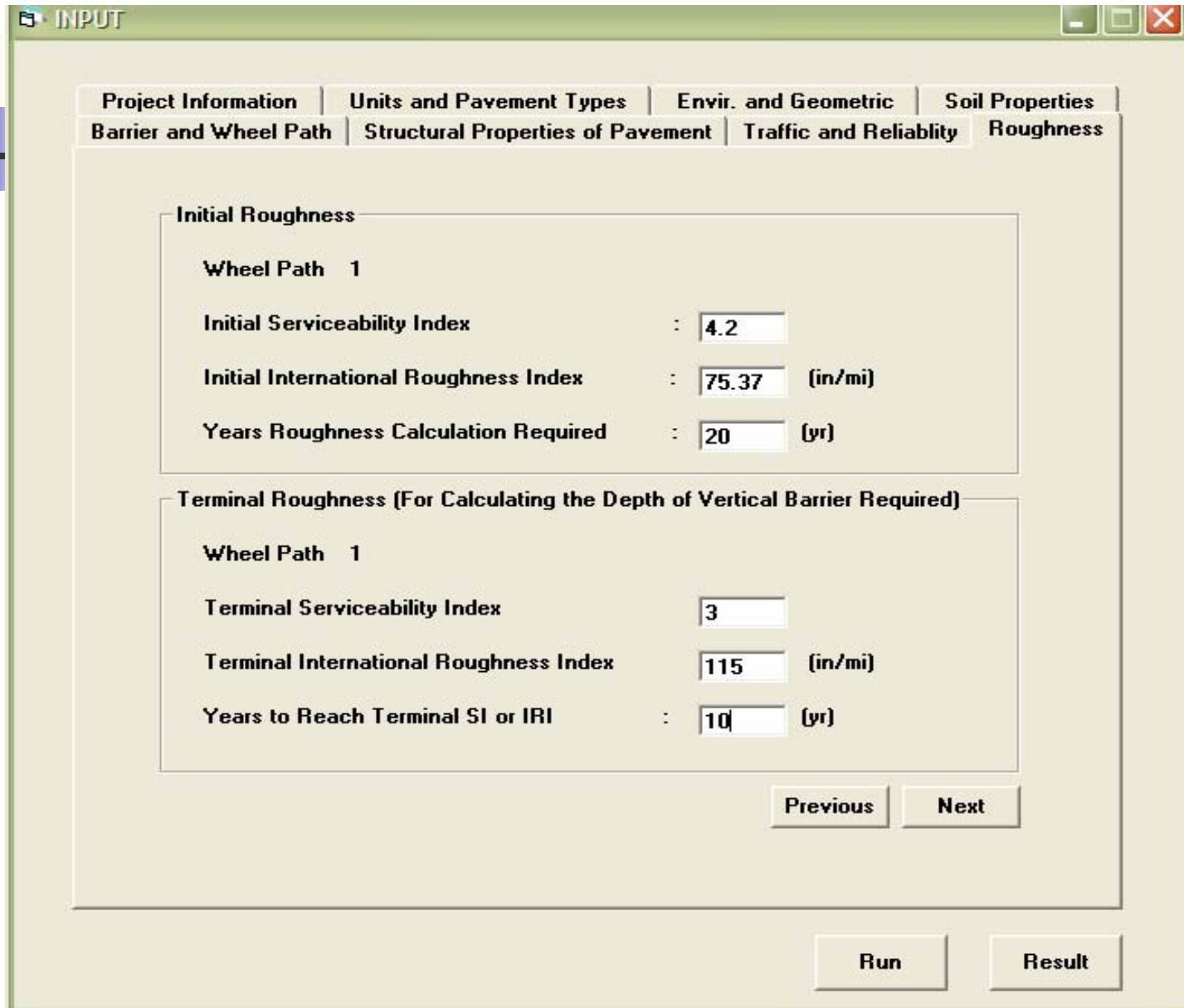
Reliability

Reliability for Traffic (AASHTO model) : 50 (%)

Reliability for Expansive Soil Roughness Constants : 50 (%)

Run Result

Design Program - Winpres



The image shows a screenshot of the Winpres software interface, specifically the 'INPUT' window. The window has a title bar with the text 'INPUT' and standard window control buttons (minimize, maximize, close). The main area is divided into several tabs: 'Project Information', 'Units and Pavement Types', 'Envir. and Geometric', 'Soil Properties', 'Barrier and Wheel Path', 'Structural Properties of Pavement', 'Traffic and Reliability', and 'Roughness'. The 'Roughness' tab is currently selected. The 'Initial Roughness' section contains three input fields: 'Initial Serviceability Index' (4.2), 'Initial International Roughness Index' (75.37 in/mi), and 'Years Roughness Calculation Required' (20 yr). The 'Terminal Roughness (For Calculating the Depth of Vertical Barrier Required)' section contains three input fields: 'Terminal Serviceability Index' (3), 'Terminal International Roughness Index' (115 in/mi), and 'Years to Reach Terminal SI or IRI' (10 yr). At the bottom of the window, there are four buttons: 'Previous', 'Next', 'Run', and 'Result'.

INPUT

Project Information | Units and Pavement Types | Envir. and Geometric | Soil Properties
Barrier and Wheel Path | Structural Properties of Pavement | Traffic and Reliability | **Roughness**

Initial Roughness

Wheel Path 1

Initial Serviceability Index : 4.2

Initial International Roughness Index : 75.37 (in/mi)

Years Roughness Calculation Required : 20 (yr)

Terminal Roughness (For Calculating the Depth of Vertical Barrier Required)

Wheel Path 1

Terminal Serviceability Index : 3

Terminal International Roughness Index : 115 (in/mi)

Years to Reach Terminal SI or IRI : 10 (yr)

Previous Next

Run Result

Design Program - Winpres

WinPRES

File Run Help

Calculated Vertical Movement

```

RIGID PAVEMENTS
INERT/STABILIZED/NATURAL
BARRIER DEPTH          = 0.00 ft

DEPTH OF ACTIVE ZONE   = 7.50 ft

VERTICAL SWELLING      = 0.220 ft
VERTICAL SHRINKAGE     = 0.071 ft
TOTAL 1-D MOVEMENT    = 0.291 ft

      2D VERTICAL MOVEMENT
DIST. FROM CENTER(ft)  MOVEMENT(inches)
      6.00              2.16
      9.00              2.26
      12.00             2.46
    
```

Output

```

COMPLETE OUTPUT FILE

PROJECT NAME           :Rigid-Natural-Inert-Sta. 1-3 (IH 635 Dallas)
PROJECT DATE           :December.20. 2003
PROJECT NUMBER         :00-0000-000
PROJECT ENGINEER       :Gyeong-Taek Hong

***** INPUT DATA *****

PAVEMENT TYPES         : RIGID PAVEMENTS

SOIL PROPERTIES
    
```

Suction Profile vs Depth

Serviceability Index vs time

International Roughness Index vs time

Input

Path 1 Path 2 Path 3

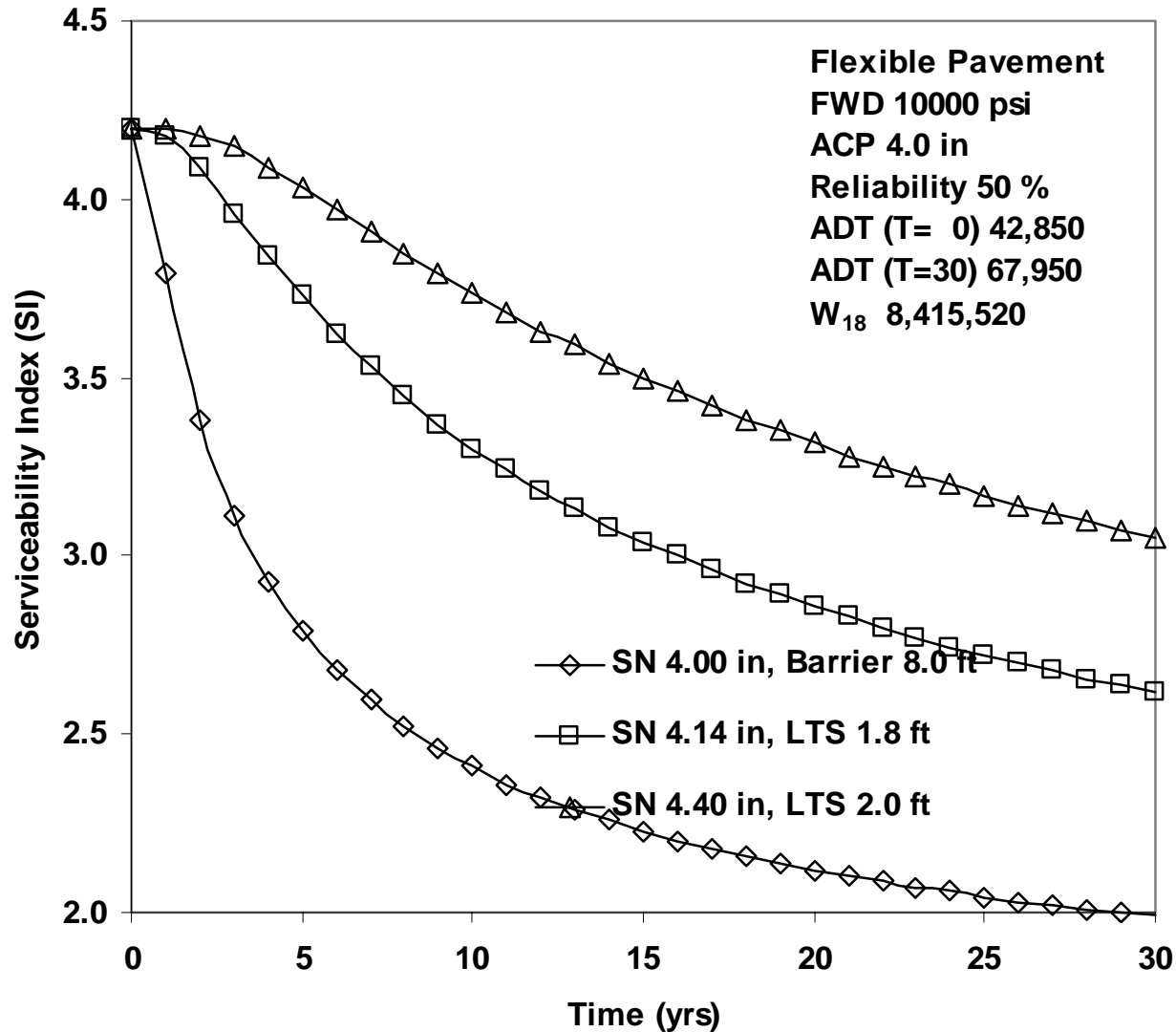
Status 2/5/2004 12:45 AM

start

애수 CD2 - 04 Ple... WinPRES - Micros... WinPRES User Manual - Micr... untitled - Paint 12:45 AM

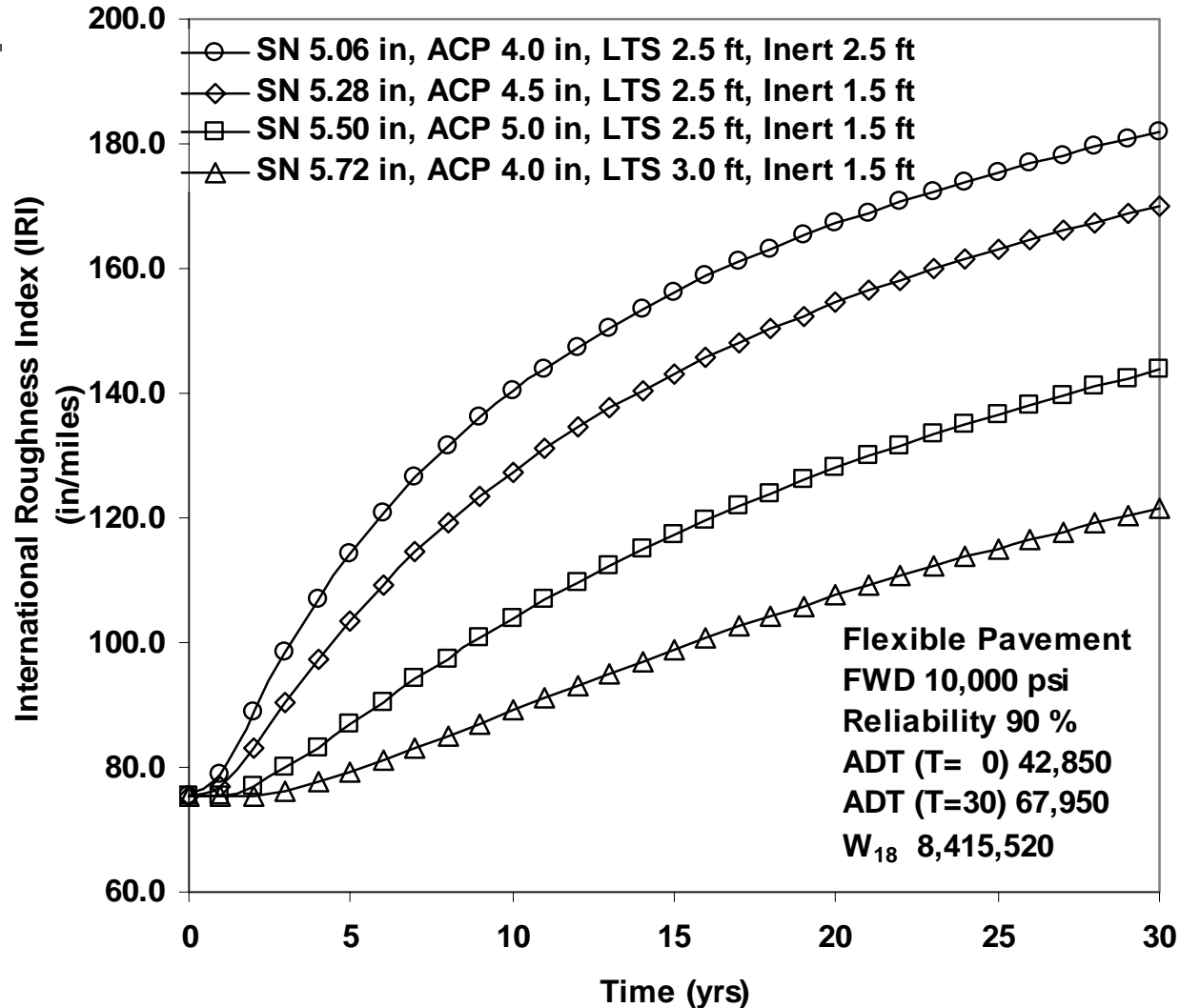
Design Program - Winpres

PSI versus Time



Design Program - Winpres

IRI versus Time



Laboratory Testing–Diffusion Coefficient



Apparatus

- *Thermocouple Psychrometers*
- *Sling Psychrometer*
- *Temperature Control Unit*
- *A drill-bit, knife, spatula, tape, sealing material (aluminum foil, plastic wrap, etc.)*

Laboratory Testing–Diffusion Coefficient

Laboratory Diffusion Test Setup



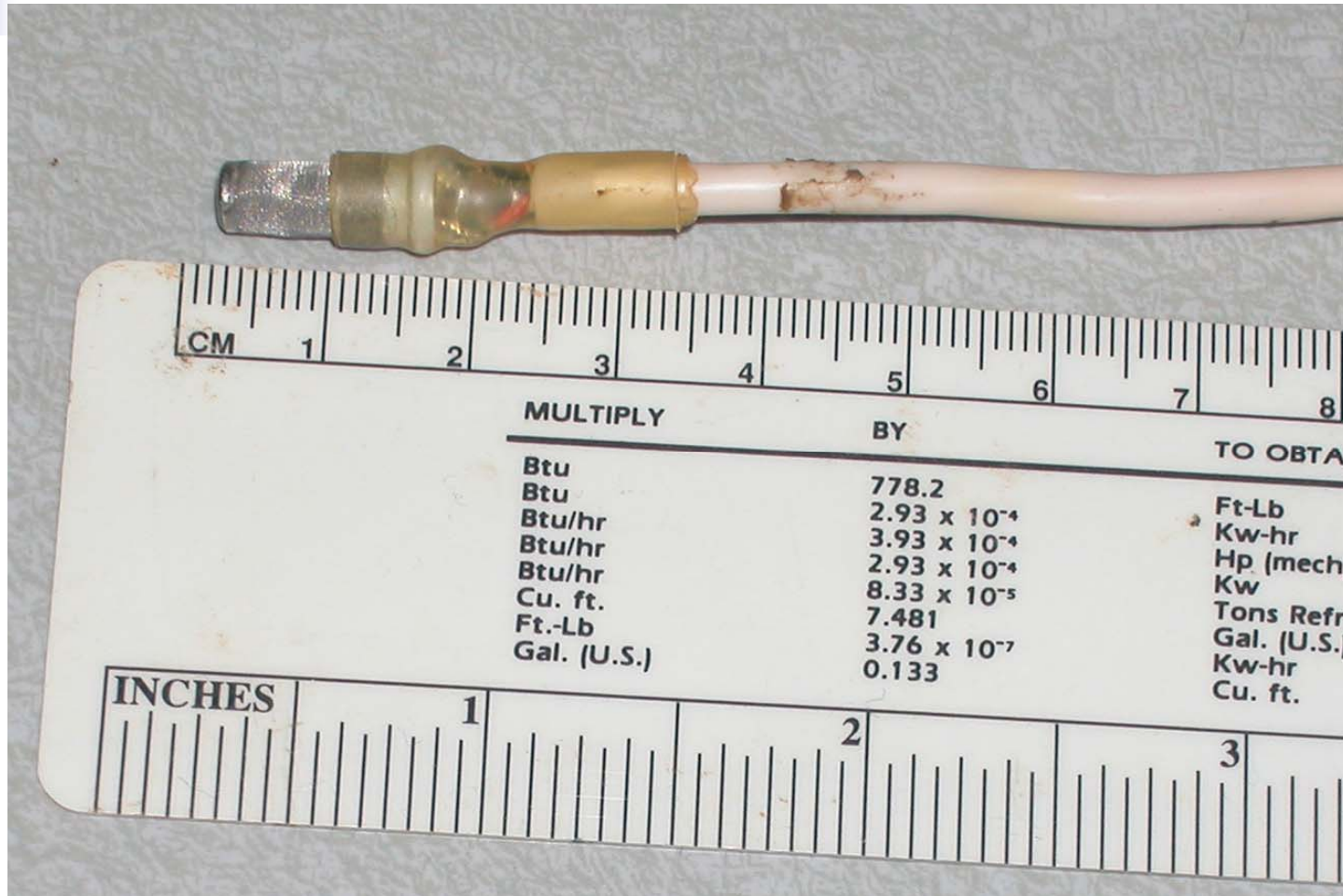
Laboratory Testing–Diffusion Coefficient

Temperature Control System



Laboratory Testing–Diffusion Coefficient

Thermocouple Psychrometer



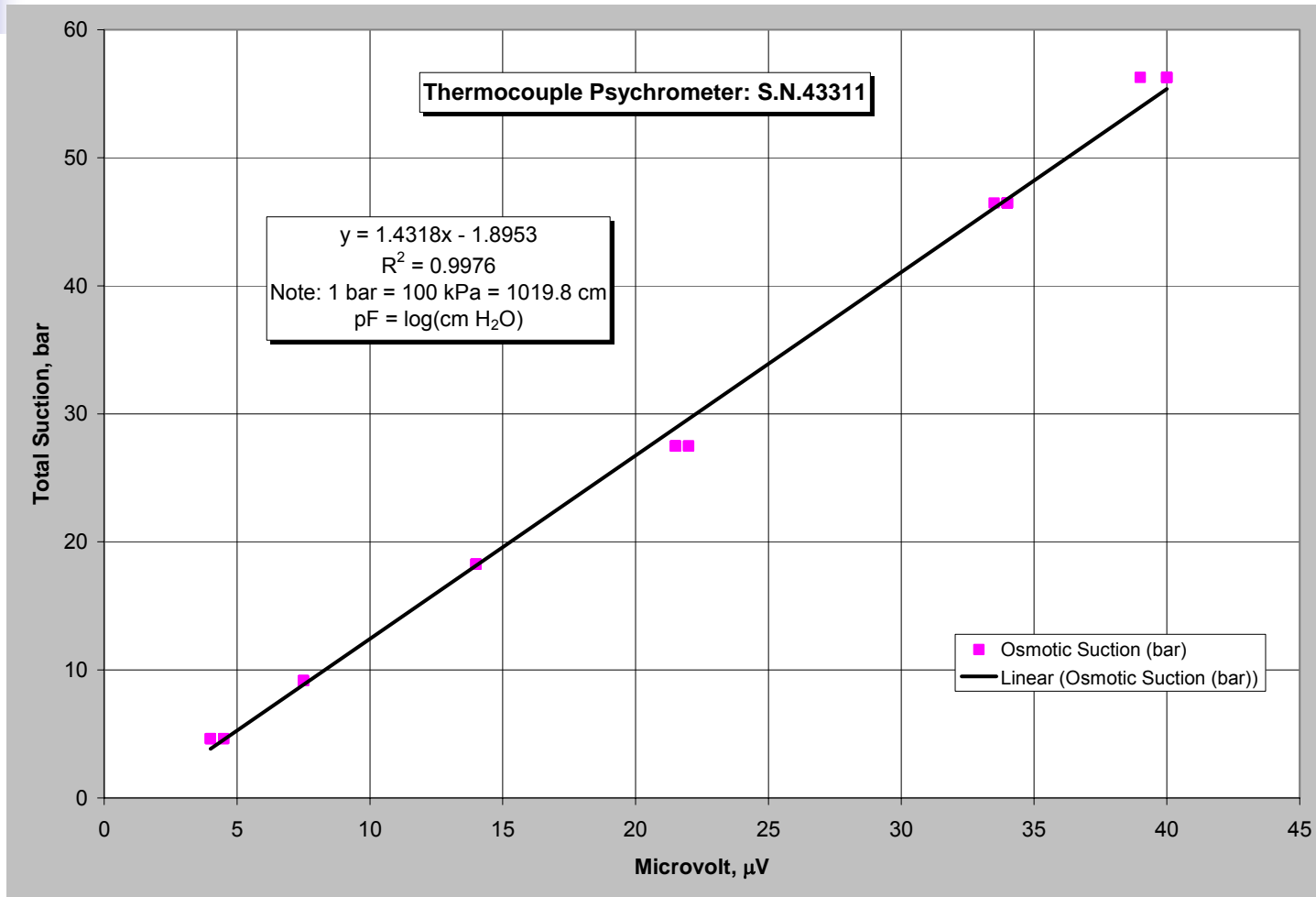
Laboratory Testing–Diffusion Coefficient

Psychrometer Calibration Solutions



Laboratory Testing–Diffusion Coefficient

Psychrometer Calibration Curve



Laboratory Testing–Diffusion Coefficient

Sling Psychrometer



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient

CR 7 Datalogger



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



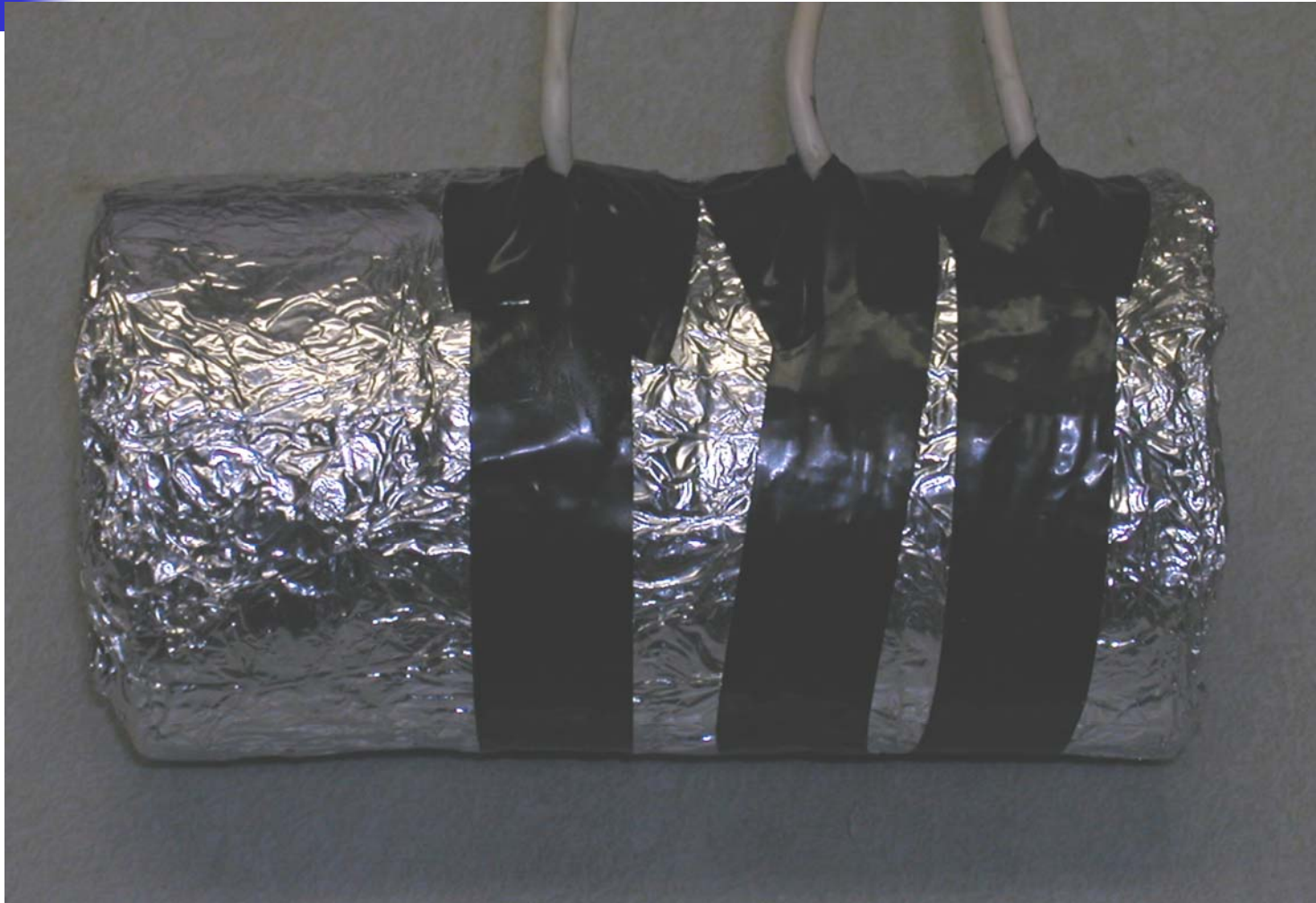
Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient

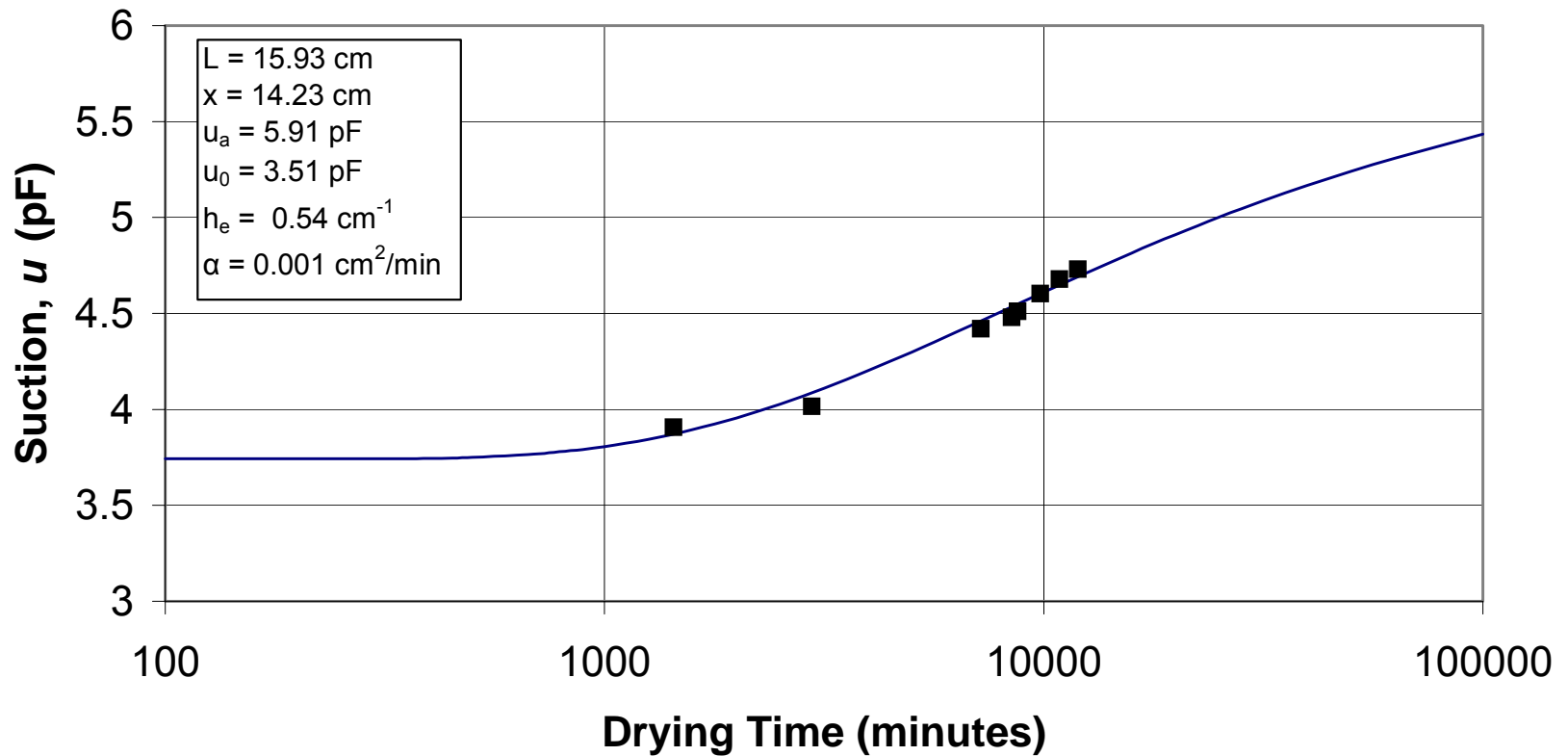


Laboratory Testing–Diffusion Coefficient



Laboratory Testing–Diffusion Coefficient

Diffusion Coefficient for BHC 2





Laboratory Testing–Summary

- Suction Measurements
 - Thermocouple Psychrometer
 - Filter Paper Method
- Diffusion Coefficient
- Atterberg Limits
- #200 Sieve
- -2 micron (Hydrometer Test)

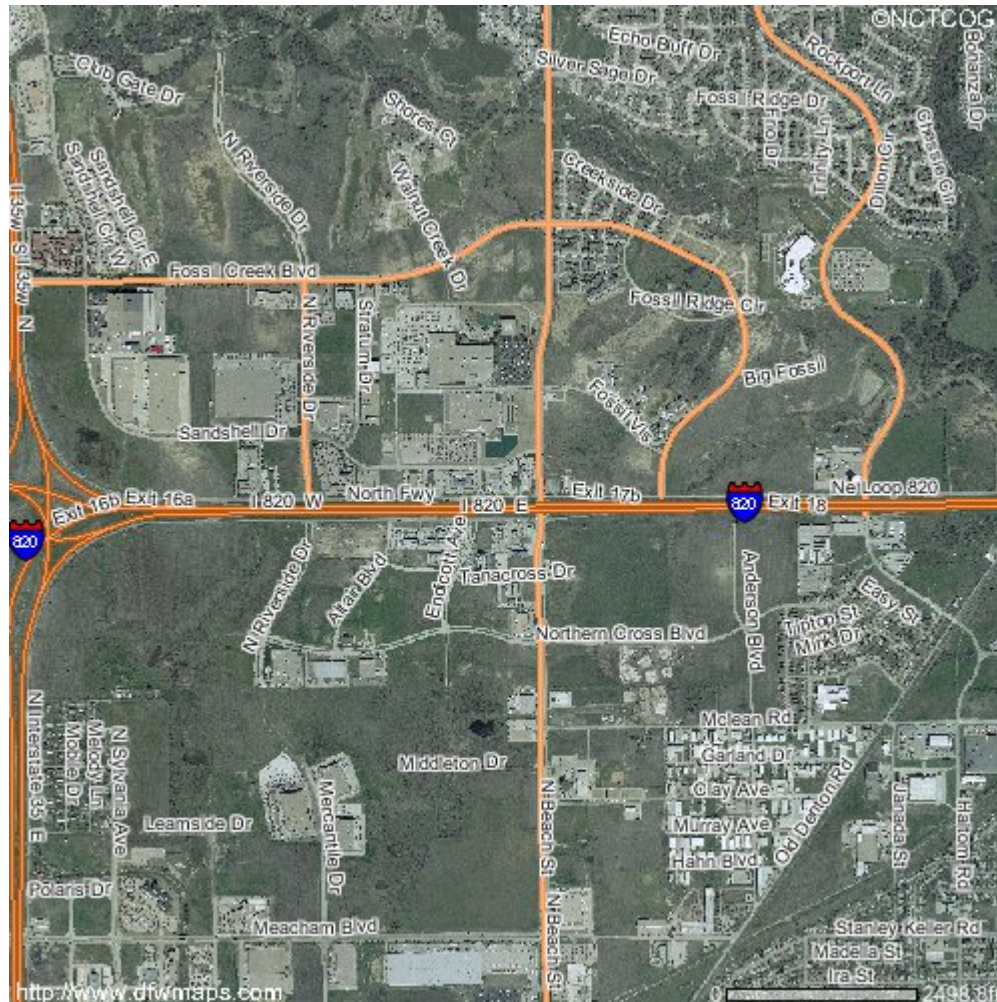


TxDOT Case Studies

- *Fort Worth District*
- *Atlanta District*
- *Austin District*

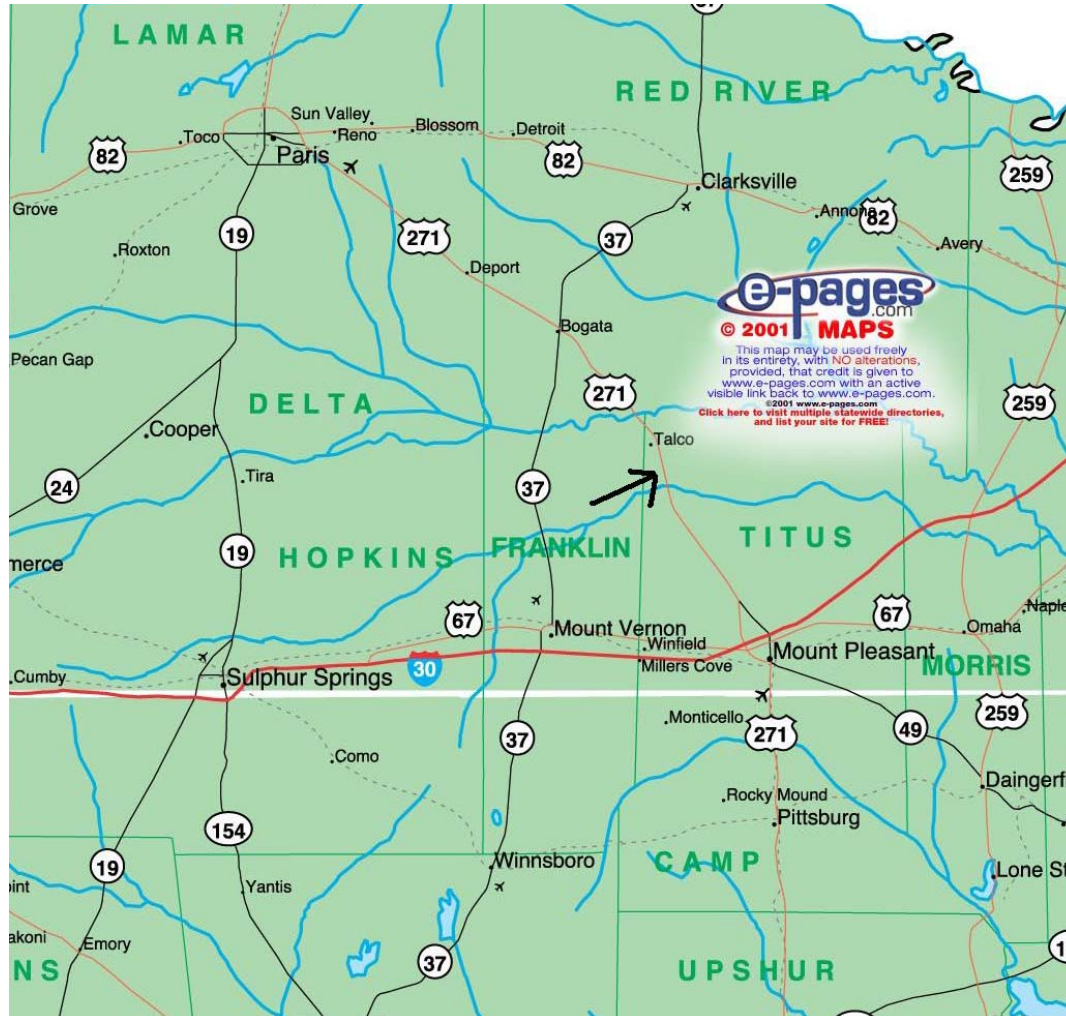
TxDOT Case Studies

Fort Worth District - North Loop 820



TxDOT Case Studies

Atlanta District - US 271



TxDOT Case Studies

Austin - Loop 360



TxDOT Case Studies



Index Properties

- Atterberg Limits
- Clay Fraction (Hydrometer analysis)
- Fines Fraction (Wet Sieve)

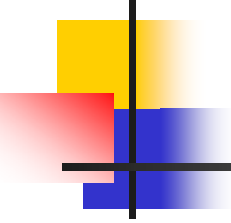
Suction

- Initial
- Matric } From filter paper test
- Water Content-Suction Curve
(From filter paper test and pressure plate apparatus)

Moisture Diffusion Coefficient

- Diffusion Test

TxDOT Case Studies

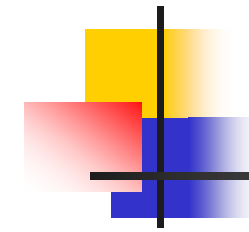


Sample No.	Sample Depth (m)	Liquid Limit (%)	Plasticity Index (%)	Percent Fines (%)	Initial Total Suction (log kPa)	Atmospheric Total Suction (log kPa)	Laboratory Measurements α_{intact} (cm ² /sec)
1(A1)	3.35-3.66	45	22	84.2	2.38	5.06	5.90E-05
2(A5)	0.91-1.22	49	30	-	2.02	5.21	7.86E-05
3(B2)	3.35-3.66	53	32	-	2.30	4.93	9.66E-05
4(A1)	1.52-1.68	37	17	83.5	1.84	5.06	4.83E-05
5(C2)	2.74-3.35	37	15	89.9	2.43	4.76	13.1E-05
6(B1)	0.61-1.07	33	19	76.5	2.45	4.84	10.6E-05
7(B3)	2.89-3.35	50	29	95.9	2.77	4.76	4.66E-05

TxDOT Case Studies

Sample No.	Sample Depth (m)	Liquid Limit (%)	Plasticity Index (%)	Percent Fines (%)	Initial Total Suction (log kPa)	Laboratory Measurements α_{intact} (cm ² /sec)	Field Estimates α_{field} (cm ² /sec)
1(A3)	2.74-3.04	63	43	93.6	2.25	5.05E-05	3.67E-03
2(B4)	3.96-4.26	45	21	99.4	2.56	1.08E-05	3.90E-03
3(C1)	0.61-0.91	62	36	99.7	2.28	3.73E-05	3.49E-03
4(C5)	2.13-2.43	42	19	98.2	2.81	1.73E-05	4.01E-03
5(B1)	1.07-1.52	47	29	75.3	2.53	5.65E-05	4.11E-03
6(B2)	1.98-2.43	68	48	91.8	2.39	6.30E-05	3.69E-03
7(B2)	2.89-3.26	68	48	90.6	2.21	1.07E-04	3.82E-03
8(B3)	1.07-1.52	49	29	84.9	2.46	3.21E-05	4.05E-03

Subgrade Movements for the Pavement Design with Minimum Acceptable Predicted Performance, Austin, Loop 1



Case Study Location	Type of Pavement	Acceptable Pavement Design*	Movements at the Edge of Pavement (in)			Movements in outer Wheel Path (in)	PVR (in)	
			Swell	Shrink	Tot	Total	Edge	Outer+
Main Lanes	Flexible	ACP 4.0 in LTS 2.8 ft	0.78	0.66	1.44	0.93	2.40	1.93
	Rigid	CRCP 12.0 in LTS 2.0 ft	1.03	0.76	1.79	1.19	2.54	2.10
Frontage Road	Flexible	ACP 4.0 in LTS 2.0 ft Inert 2.0 ft	0.71	0.54	1.25	0.93	2.08	1.76
	Rigid	CRCP 11.0 in	2.03	1.00	3.03	2.28	2.97	2.37



Summary

- *Total movement controls the rate of increase in roughness*
- *Shrink prediction alerts the designer to longitudinal cracking*



Summary of Comparisons

PVR:

- **Over-predicts swell**
- **Neglects shrink**
- **Overly conservative designs**



IMPLEMENTATION

Three TxDOT Laboratories:

- **Dallas-Fort Worth**
- **Austin**
- **Bryan**



IMPLEMENTATION

- ✓ **Laboratory Testing Equipment**
 - **Filter Paper Method**
 - **Thermocouple Psychrometer**
 - **Transistor Psychrometer**

- ✓ **Training Courses**
 - **Computer Programs**
 - **Analysis and Design**



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- *Mr. Anshuman Thakur*
and
- *TxDOT*



THANK YOU!

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