

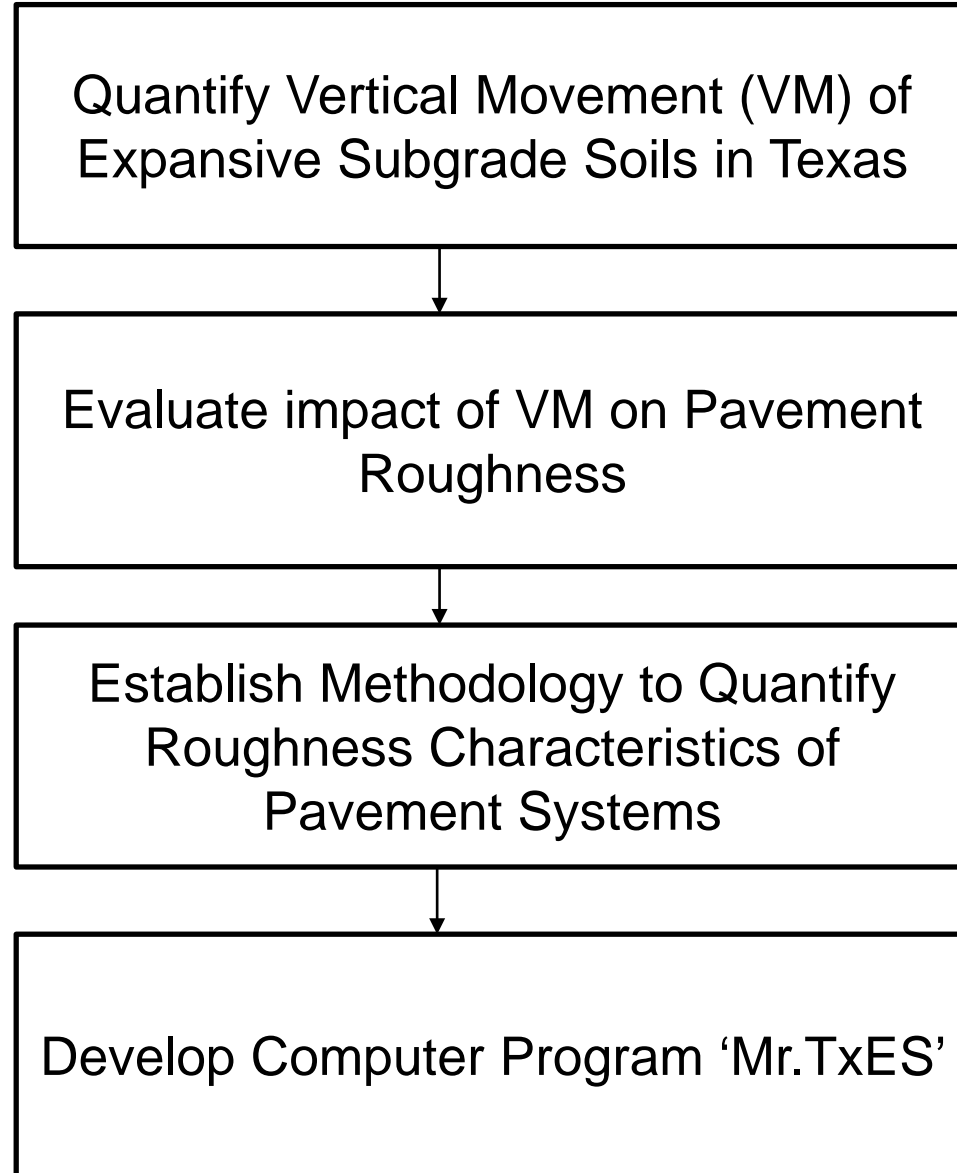


Methodology to Predict Roughness Characteristics of Flexible Pavement Systems in Texas

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STUDY OBJECTIVES





MOTIVATION

-Why Quantify Roughness?

- Impacts ride quality, vehicle costs etc.
- Helps monitor pavement networks.
- Prioritize future projects.

- How to Quantify Roughness?

- PSI (Pavement Serviceability Index)
 - 0 to 5 user subjective rating of the Pavement
- IRI (International Roughness Index)
 - Terminal IRI (Inches/Mile) = $533.45 \times \exp[-0.4664 \text{ PSI}_f]$

(Reference: Lytton et. al. 2004)



REVIEW OF AASHTO APPROACH

Loss of Serviceability due to Expansive Subgrade Soils ($\Delta\text{PSI}_{\text{swell}}$) is:

$$\Delta\text{PSI}_{\text{swell}} = 0.00335 \cdot V_r \cdot P_s \cdot (1 - e^{-\theta t})$$

' V_r ' is Potential Vertical Rise, ' P_s ' is Swell Probability, ' θt ' is Rate of Swell

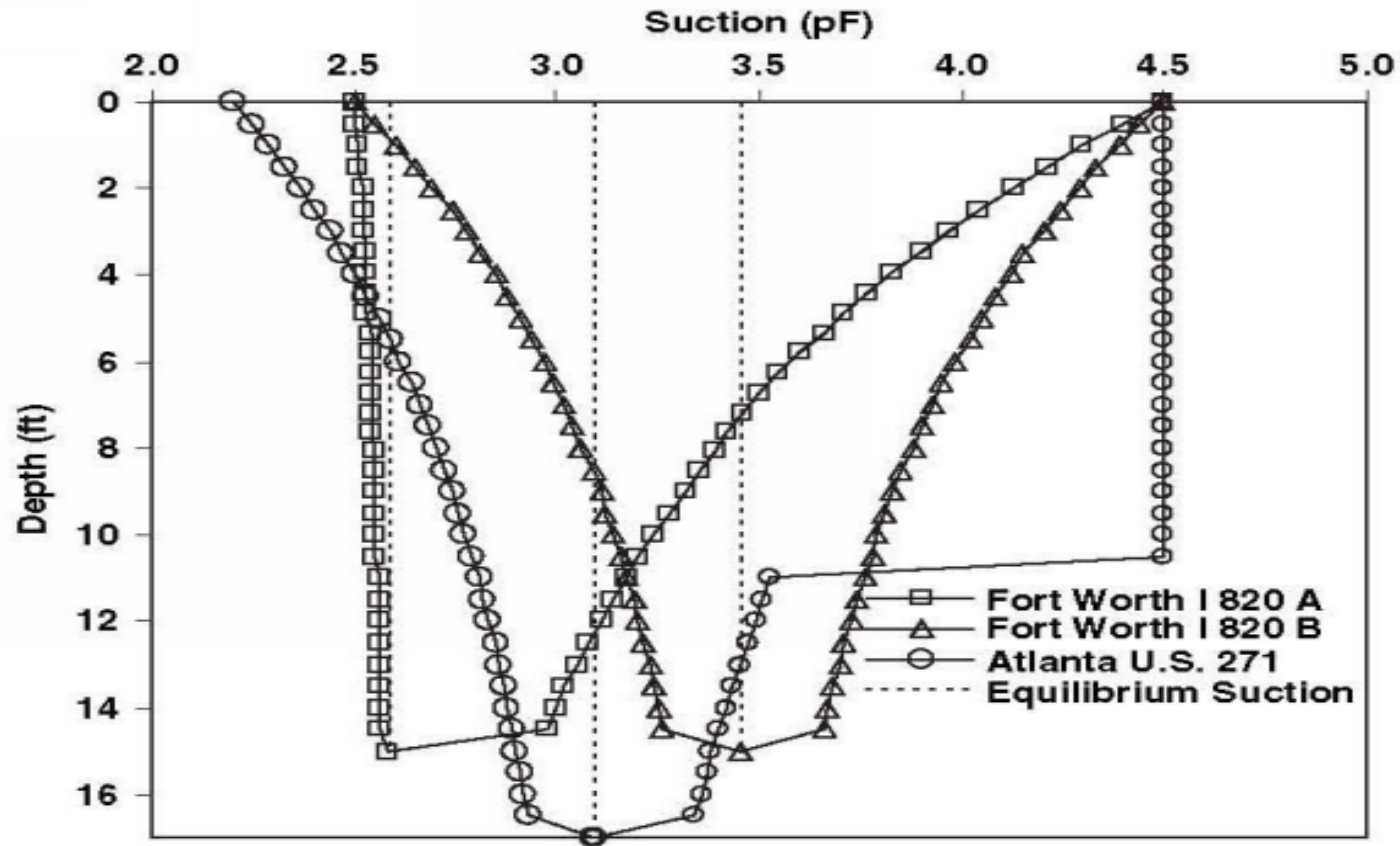
Limitations:

- 'Active Zone' not considered
- Effect of 'Shrinking' soils not considered
- Predictions are conservative

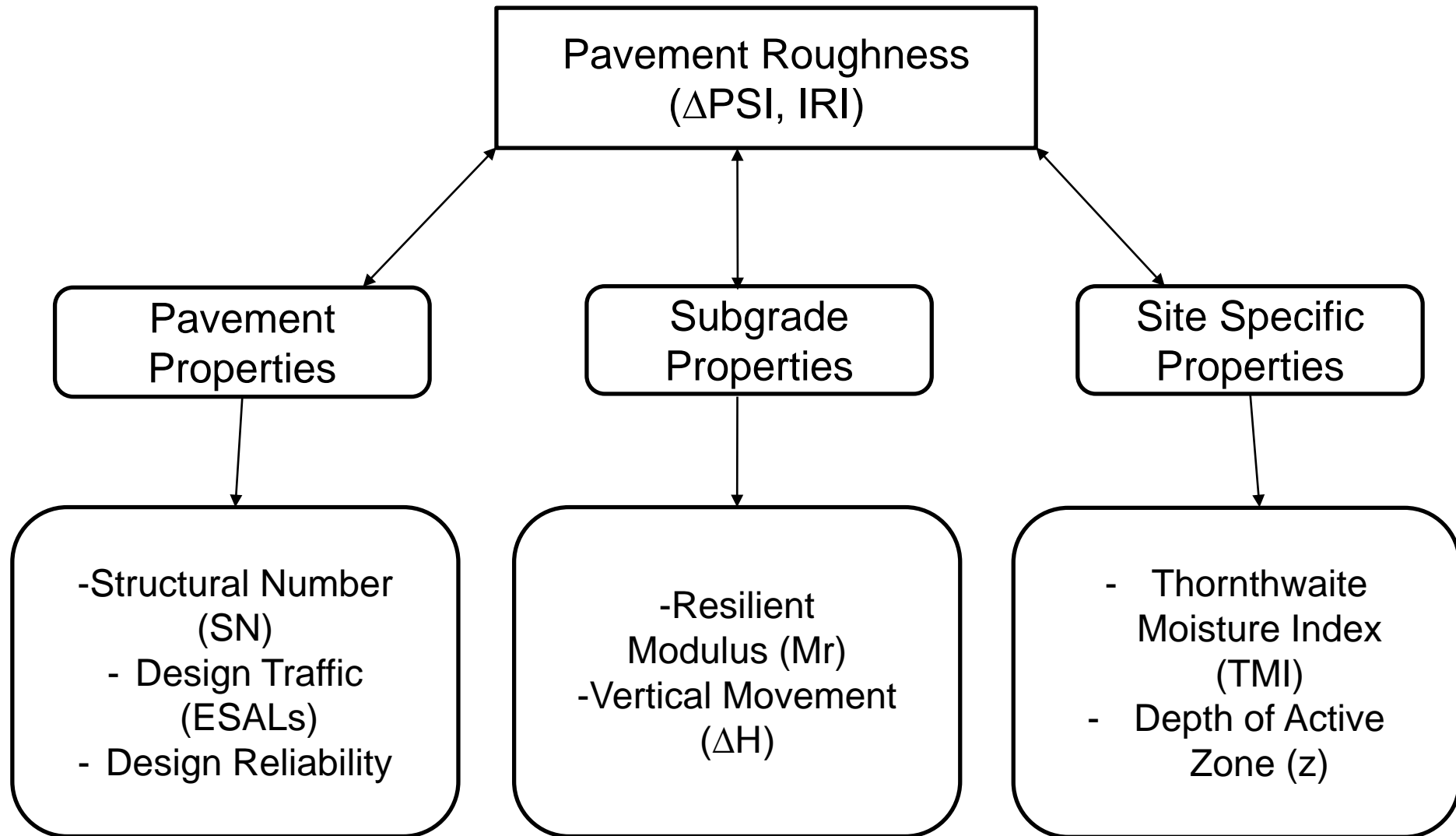
SIGNIFICANCE OF SUCTION

Suction < Equilibrium Suction → Drying Cycle (Soil Shrinks)

Suction > Equilibrium Suction → Wetting Cycle (Soil Swells)

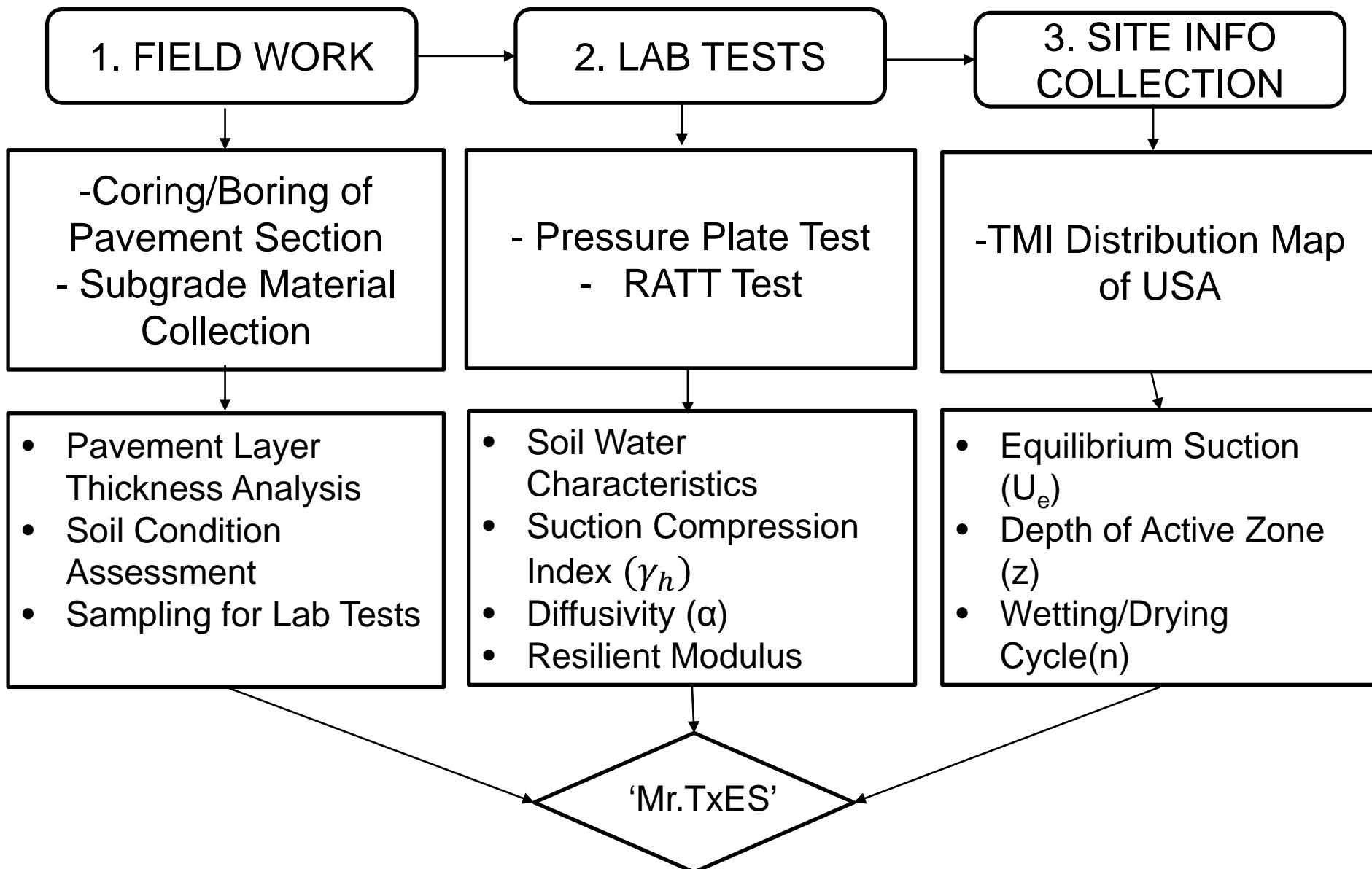


PROPOSED APPROACH

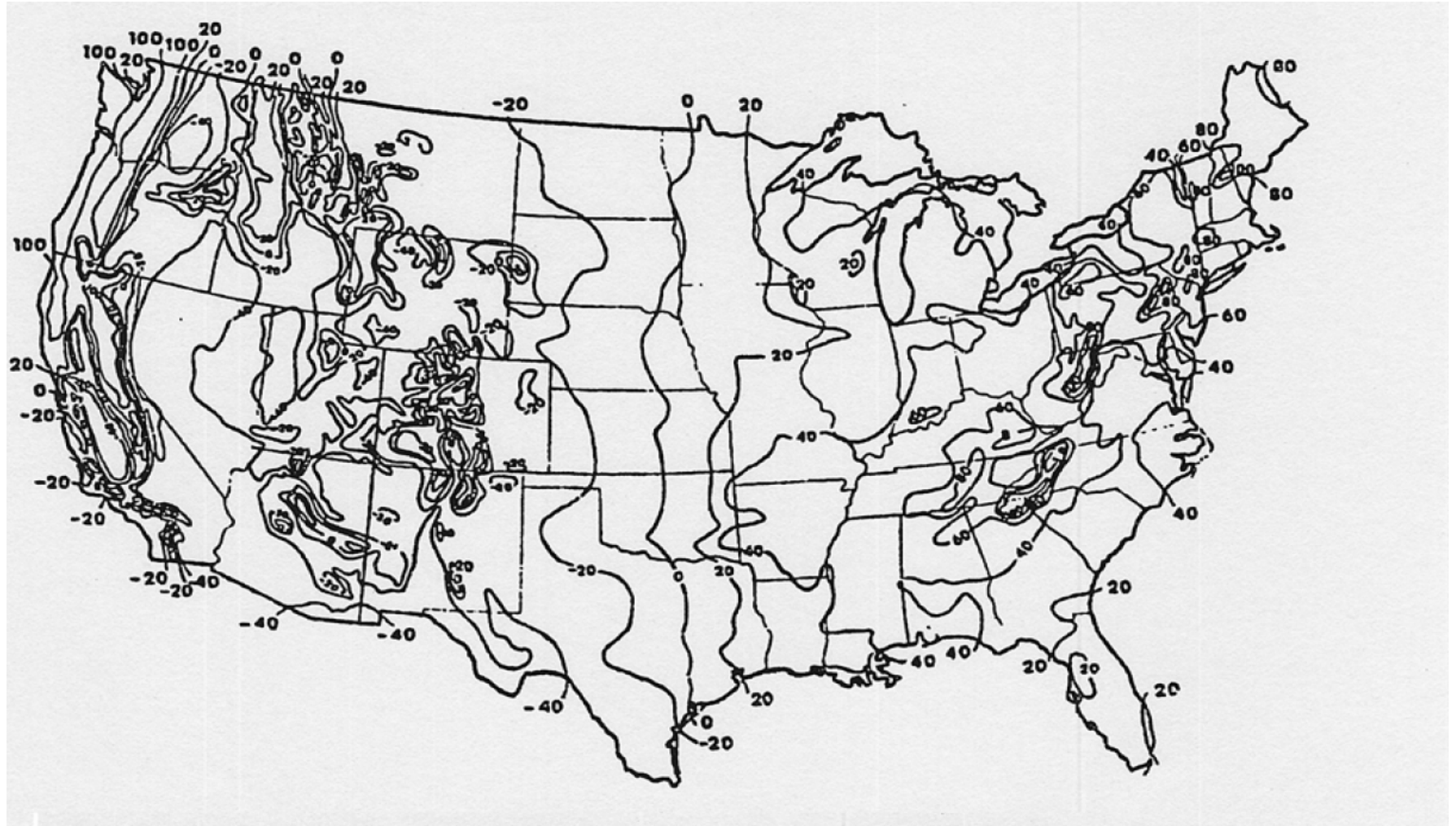




STEPS INVOLVED



TMI DISTRIBUTION IN USA



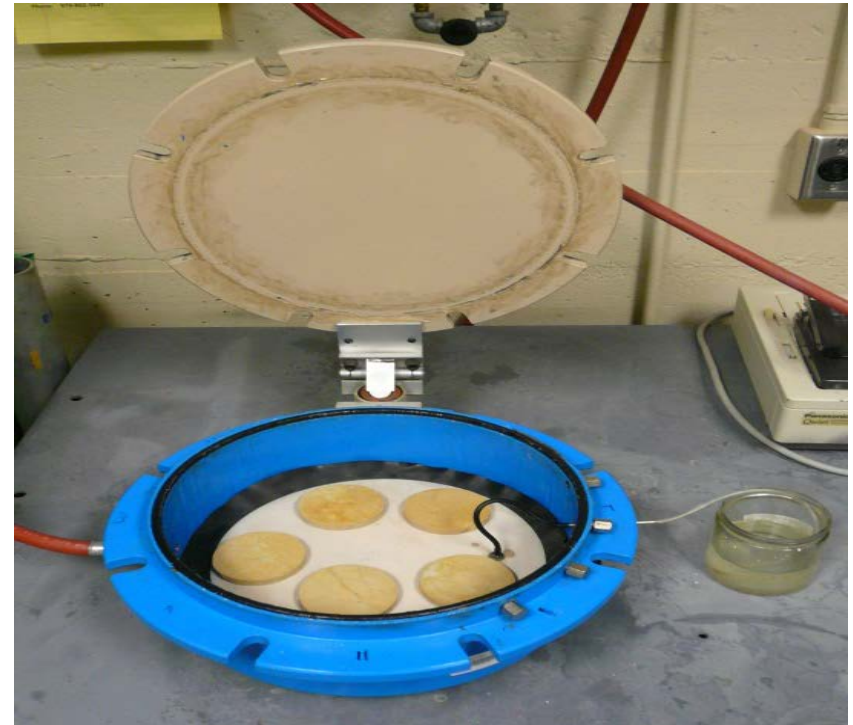
Thornthwaite moisture index distribution in the United States. (After Thornthwaite, 1948)



LABORATORY TESTS

Pressure Plate Test (ASTM D2325)

Suction Compression Index, $\gamma_h = \frac{\frac{\Delta V}{V}}{\Delta p F}$





LABORATORY TESTS

Rapid Accelerated Tri-Axial Test (AASHTO T 307)

$$\text{Resilient Modulus, } M_r = \frac{\text{Deviatoric Stress } (\sigma_d)}{\text{Recovered Elastic Strain } (\epsilon_r)}$$





BASIS FOR ESTIMATION VM

Step 1: Establish Suction vs. Depth profile as per Mitchell (1979)

$$U(z) = U_e \pm U_0 \exp \left[- \left(\frac{n\pi}{\alpha} \right)^{0.5} z \right]$$

'Ue', 'Uo', 'n', 'α' and 'z' are obtained through empirical relationships based on TMI and Climate data.

Step 2: Compute Volumetric Swelling and Shrinkage Strains within Depth increments

$$\left(\frac{\Delta V}{V} \right)_{i,swelling} = -\gamma_h \log_{10} \left(\frac{U_f}{U_i} \right) - \gamma_\sigma \log_{10} \left(\frac{\sigma_f}{\sigma_i} \right)$$

Step 3: Compute Vertical Swell and Shrinkage Strains and hence total VM

$$\Delta H_{total} = \sum_{i=1}^n f_i \left(\frac{\Delta V}{V} \right) \Delta z_i H$$

'f' is the crack fabric factor and assumes values of 0.5 for Shrinkage cycle and 0.8 for Swelling cycle.

BASIS FOR ESTIMATING ROUGHNESS



- Establish following Pavement Properties:
 - Initial Serviceability Rating (4.2 for Flexible Pavements)
 - Design life (t) in years
 - Design Traffic (W_{18}) ESALs
 - Design Reliability (Z_r)
 - Subgrade Resilient Modulus (M_r)
 - Total Vertical Movement (ΔH_{total})

$$\Delta PSI_t = (PSI_0 - 1.5) \exp \left[- \left(\frac{\rho_s}{t} \right) \right]^{0.66}$$

$$\rho_s = A_s - B_s \Delta H_{total}$$

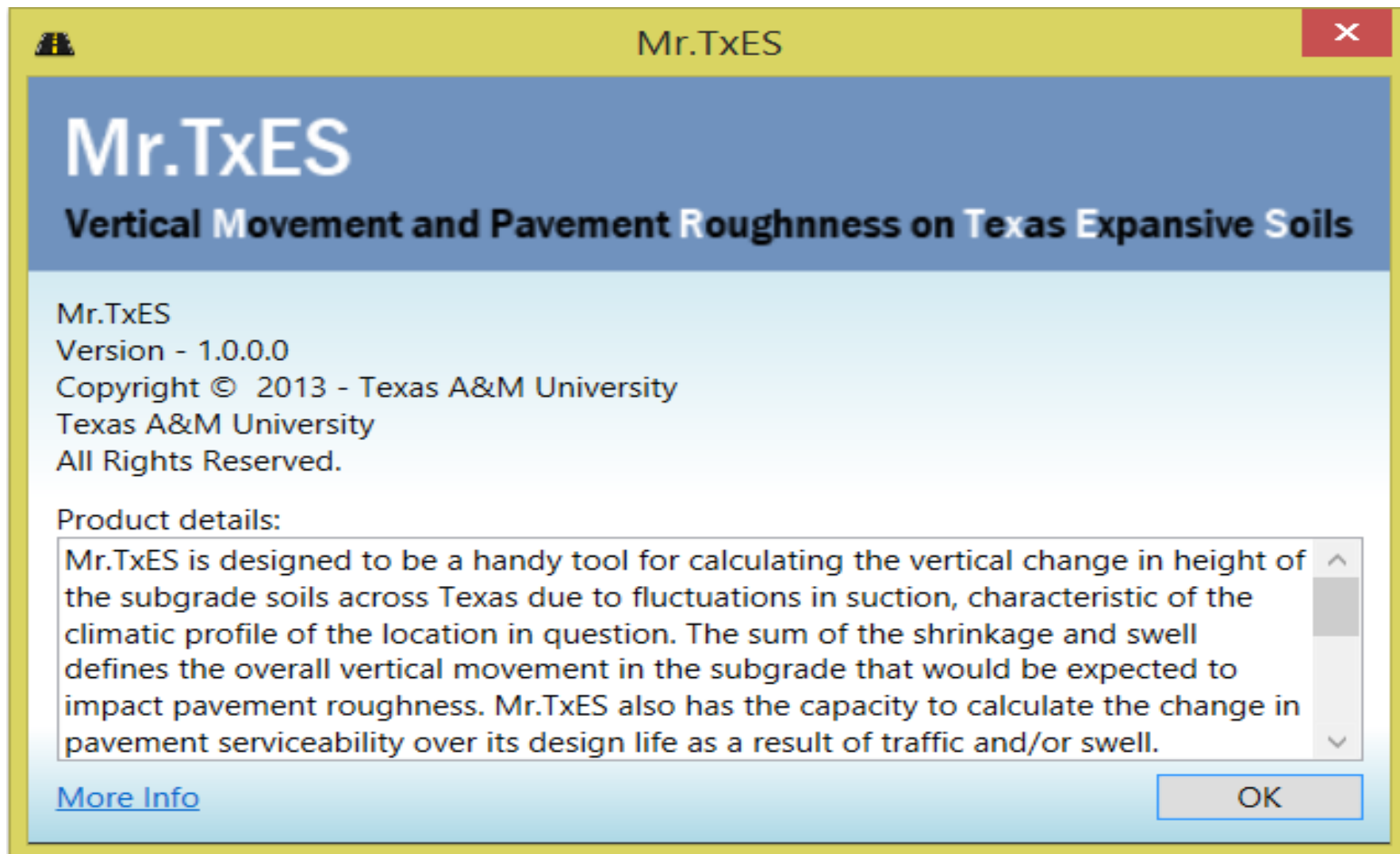
$$B_s = 17.96 + 4.195 Z_R$$

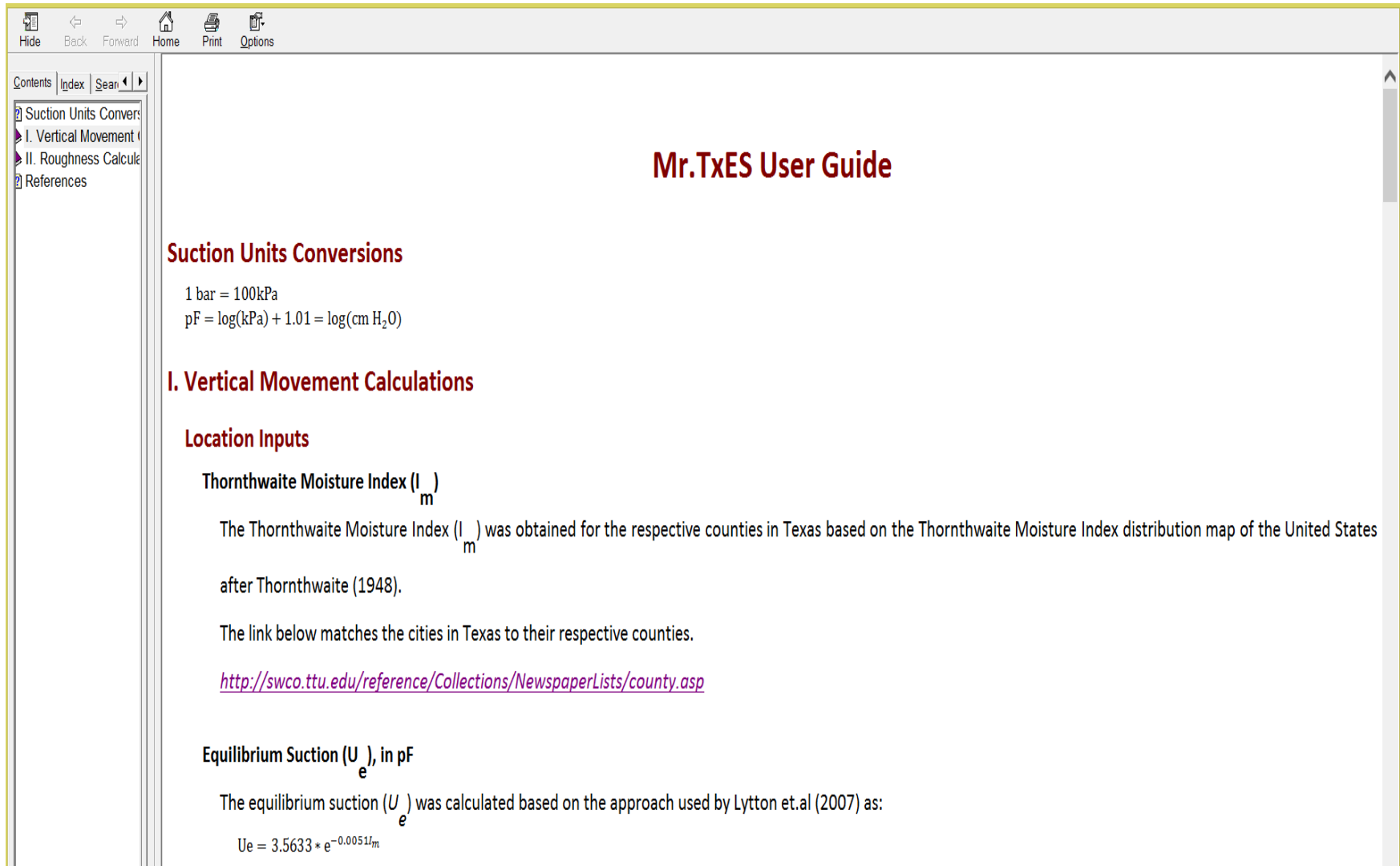
$$A_s = t \left[\ln(10^{-\lambda})^{1.52} \right]$$

$$\lambda = \left[0.4 + \frac{1,094}{(SN + 1)^{5.19}} \right] x \left[\log_{10} W_{18} - 9.36 \log_{10} (SN + 1) + 8.27 - 2.32 \log_{10} M_r + Z_R s_0 \right]$$



'Mr. TxES' COMPUTER PROGRAM





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- I. Vertical Movement Calculations
- II. Roughness Calculations
- References

Mr.TxES User Guide

Suction Units Conversions

1 bar = 100kPa
 $pF = \log(kPa) + 1.01 = \log(\text{cm H}_2\text{O})$

I. Vertical Movement Calculations

Location Inputs

Thornthwaite Moisture Index (I_m)

The Thornthwaite Moisture Index (I_m) was obtained for the respective counties in Texas based on the Thornthwaite Moisture Index distribution map of the United States after Thornthwaite (1948).

The link below matches the cities in Texas to their respective counties.

<http://swco.ttu.edu/reference/Collections/NewspaperLists/county.asp>

Equilibrium Suction (U_e), in pF

The equilibrium suction (U_e) was calculated based on the approach used by Lytton et.al (2007) as:

$$U_e = 3.5633 * e^{-0.0051I_m}$$



'Mr.TxES' PROJECT INPUTS

Mr.TxES

File Help About

General Information

Project Name:

Date:

User Name:

Soil Type:

Plasticity Index(PI):

Analysis Type

VERTICAL MOVEMENT ESTIMATION

Vertical Movement Calculation

County:

Based on Location

Thornthwaite Moisture Index (TMI or I_m):

Equilibrium Suction, U_e (pF): Manual Input

Depth of Active Zone, H_a (cm):

Wet/dry Excursions, n (cycles per year): Manual Input

Amplitude of Suction Variation, U_o (pF):

Input Data

Use Automatic f Use Automatic K_o

Crack Fabric Factor, f (swell) K_o (wet):

Crack Fabric Factor, f (shrinkage) K_o (dry):

Suction Measurement Input

Manual Input Manual Input (Single) Use SWCC Calculation

Suction Range (bar)	γ_h (Swell)	γ_h (Shrink)	Diffusivity α (Swell)	Diffusivity α (Shrink)
All	0.0245	0.0244	0.0028	0.0028

Result

ΔH Swell (in.):

ΔH Shrinkage (in.):

ΔH Total (in.):

VERTICAL MOVEMENT ESTIMATION

SWCC
_ □ ×

Sample Number:

Pressure Plate Test Data

Dry Weight of Sample,g:

W Saturated,g:

Water Content,w,%:

Pressure (bar)	Suction (log kPa)	Suction (pF)	Mass (g)	Water (%)	Mass of water (g)
0.50	1.70	2.71	125.1	12.86	14.25
1.00	2.00	3.01	124.7	12.49	13.85
5.00	2.70	3.71	124.4	12.22	13.55
10.00	3.00	4.01	124.1	11.95	13.25
15.00	3.18	4.19	123.9	11.77	13.05

Volume Measurement Data

Bar	Matric suction, pF	Trimmed Average weight (g)	Δ Mass (g)	Volume (cm ³)
1.00	3.01	1620	78.13	84.79
5.00	3.71	1620.4	77.43	84.38
10.00	4.01	1621.6	75.93	83.48
15.00	4.19	1622	75.33	83.12

SWCC Chart

Suction range (bar)	γ_b (swell)	γ_b (shrink)
0.00 - 1.00	0.00710	0.00706
1.01 - 5.00	0.00710	0.00706
5.01 - 10.00	0.03570	0.03532
10.00 - 15.00	0.02452	0.02441

Result

PAVEMENT ROUGHNESS ESTIMATION

Pavement Roughness Calculation

Pavement Properties Inputs

Structural Number (SN): Use Structural Number Table

AC Layer Thickness (in.)	4
Layer Coefficient For AC	0.44
Base Layer Thickness (in.)	10
Layer Coefficient For Base	0.2
Sub-Base Layer Thickness (in.)	0
Layer Coefficient for Sub-Base	0.12
Subgrade Layer Thickness (in.)	10
Layer Coefficient for Subgrade	0.1

Cumulative ESALs (W^{1.5}): Use ESAL Table

DesignLife	25
Projected Construction Year AADT	2500
Percent Heavy Trucks Class 4 or greater	70
Percent Trucks in Design Direction	50
Percent Trucks in Design Lane	100
Truck Equivalency Factor (avg. ESAL per truck)	1.537
Truck Volume Growth Rate	2

Resilient modulus (M_R) in psi: Use RaTT Test

Sample Diameter (in.)	6
Sample Height (in.)	6
Deviatoric Stress (psi)	4
Confining Pressure (psi)	6
Maximum Deformation (mm)	0.11
Minimum Deformation (mm)	0.05

Design Reliability (%):

Initial Serviceability, PSI_i:

ΔH Total (mm.):

Result

Initial Serviceability, PSI_i:

ΔPSI:

Terminal Serviceability, PSI_f:

Terminal IRI(in/mile):

PAVEMENT ROUGHNESS ESTIMATION

Pavement Roughness Calculation

Pavement Properties Inputs

Structural Number (SN): Use Structural Number Table

Cumulative ESALs (W^{1.5}): Use ESAL Table

Resilient modulus (M_R) in psi: Use RaTT Test

Design Reliability (%):

Initial Serviceability, PSI:

ΔH Total (mm.):

Result

Initial Serviceability, PSI:

ΔPSI:

Terminal Serviceability, PSI:

Terminal IRI(in/mile):

Charts

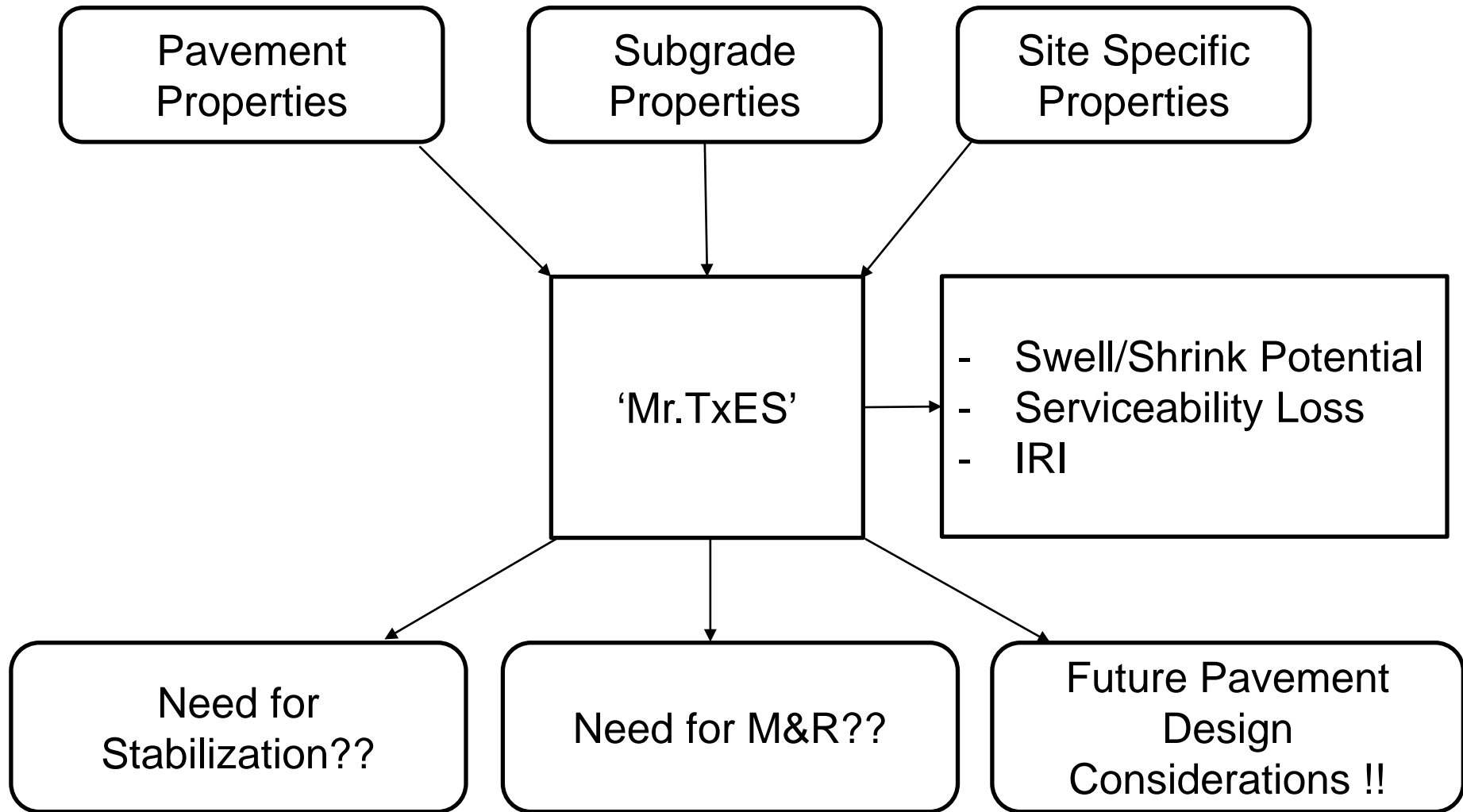
The graph plots ΔPSI on the y-axis (0.00 to 2.00) against Time in Months on the x-axis (0.00 to 500.00). Two data series are shown: 'Traffic+Swell' (blue line with diamond markers) and 'Traffic Only' (red line with diamond markers). Both series show an upward trend over time, with 'Traffic+Swell' reaching a higher ΔPSI value of approximately 1.93 at 500 months, while 'Traffic Only' reaches approximately 0.75 at the same time.

Time (Months)	ΔPSI (Traffic+Swell)	ΔPSI (Traffic Only)
0	0.00	0.00
50	0.75	0.10
100	1.10	0.15
200	1.45	0.30
300	1.70	0.45
400	1.85	0.60
500	1.93	0.75

< Prev Done



SUMMARY





FUTURE WORK/ IDEAS

- 'Mr.TxES' → 'Mr.USES'
- Sensitivity Analysis
- Cost Analysis
- Automate SWCC generation
- Incorporate use of LTPP traffic data



QUESTIONS??

THANK YOU

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