Methodology to Predict Roughness Characteristics of Flexible Pavement Systems in Texas

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STUDY OBJECTIVES

Quantify Vertical Movement (VM) of Expansive Subgrade Soils in Texas

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Evaluate impact of VM on Pavement Roughness

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Establish Methodology to Quantify Roughness Characteristics of Pavement Systems

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Develop Computer Program ‘Mr.TxES’

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 x exp[-0.4664 PSI_f]

(Reference: Lytton et. al. 2004)

REVIEW OF AASHTO APPROACH

Loss of Serviceability due to Expansive Subgrade Soils (ΔPSI_{swell}) is:

$$\Delta PSI_{swell} = 0.00335 .\ V_r\ .P_s\ .(1- e^{-\theta t})$$

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

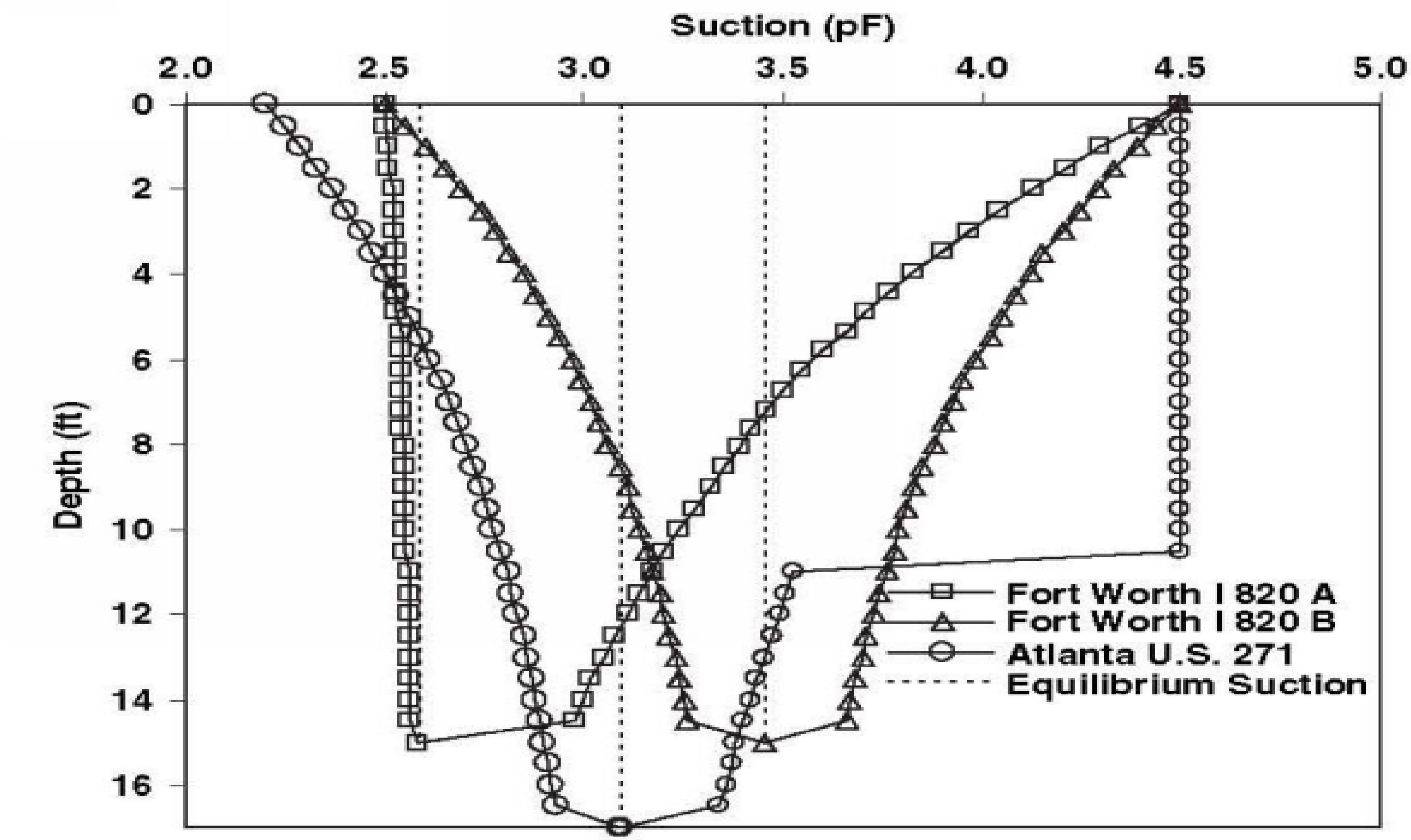
Limitations:

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

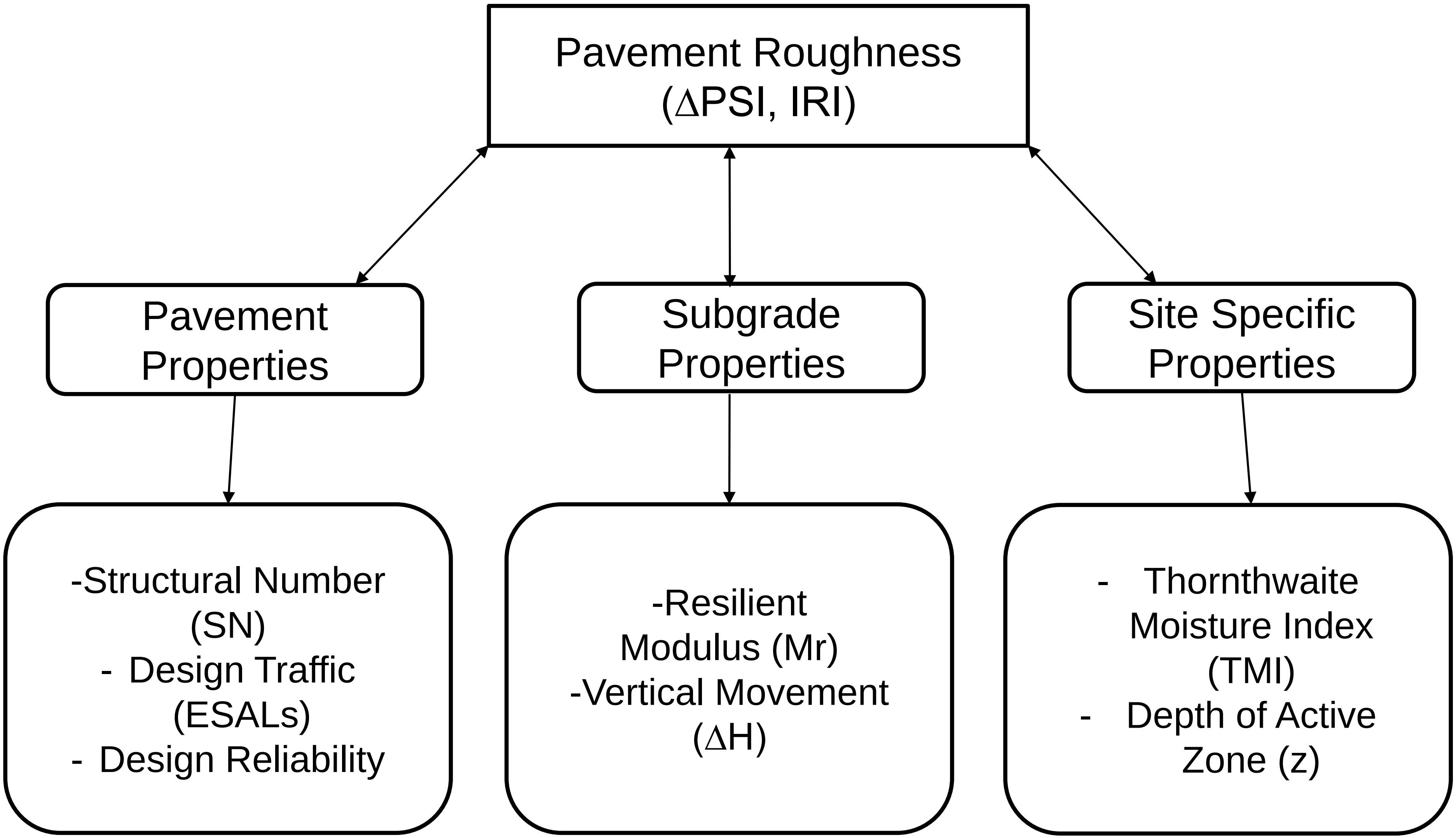
SIGNIFICANCE OF SUCTION

Suction < Equilibrium Suction ⟶ Drying Cycle (Soil Shrinks)

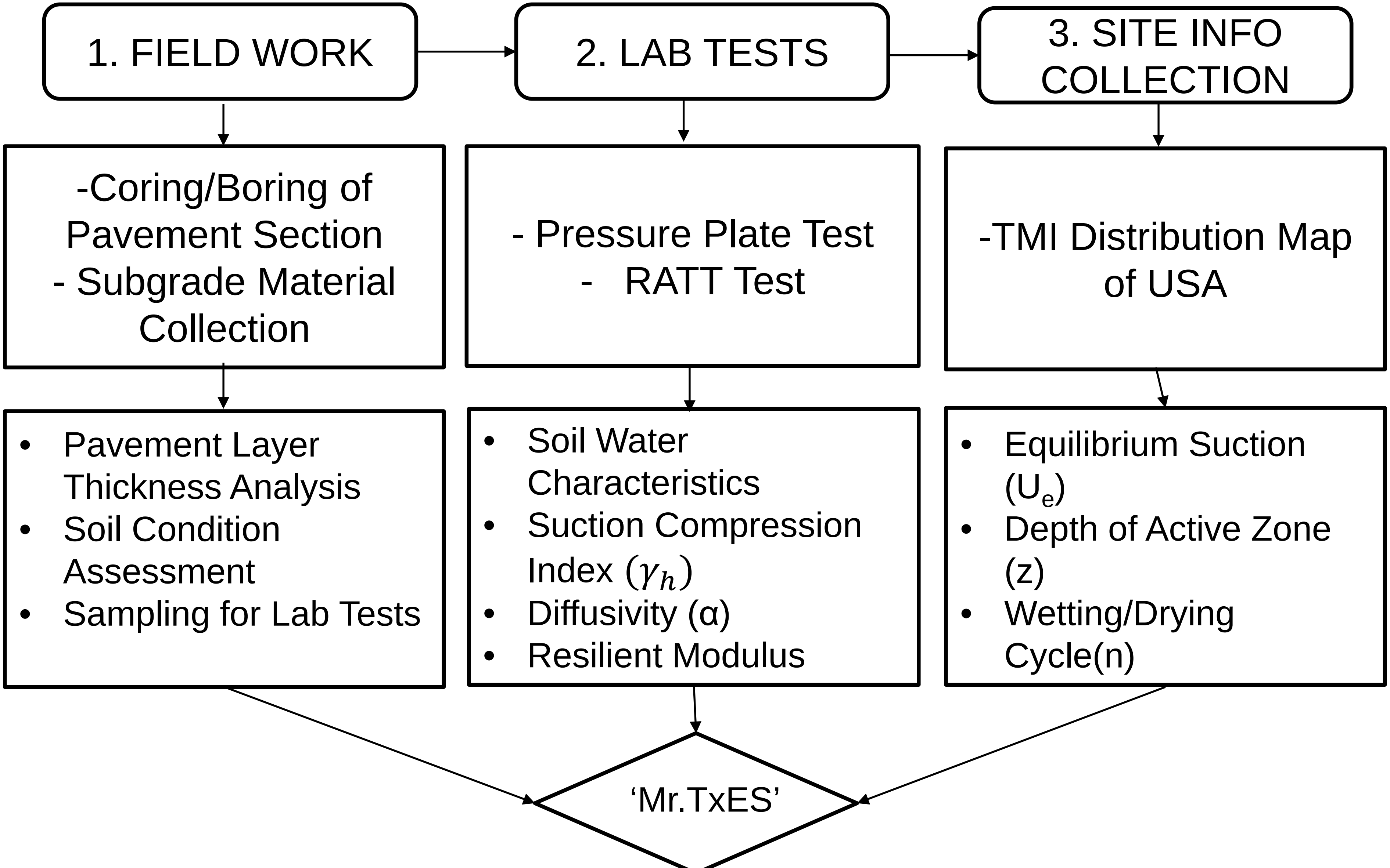
Suction > Equilibrium Suction ⟶ Wetting Cycle (Soil Swells)



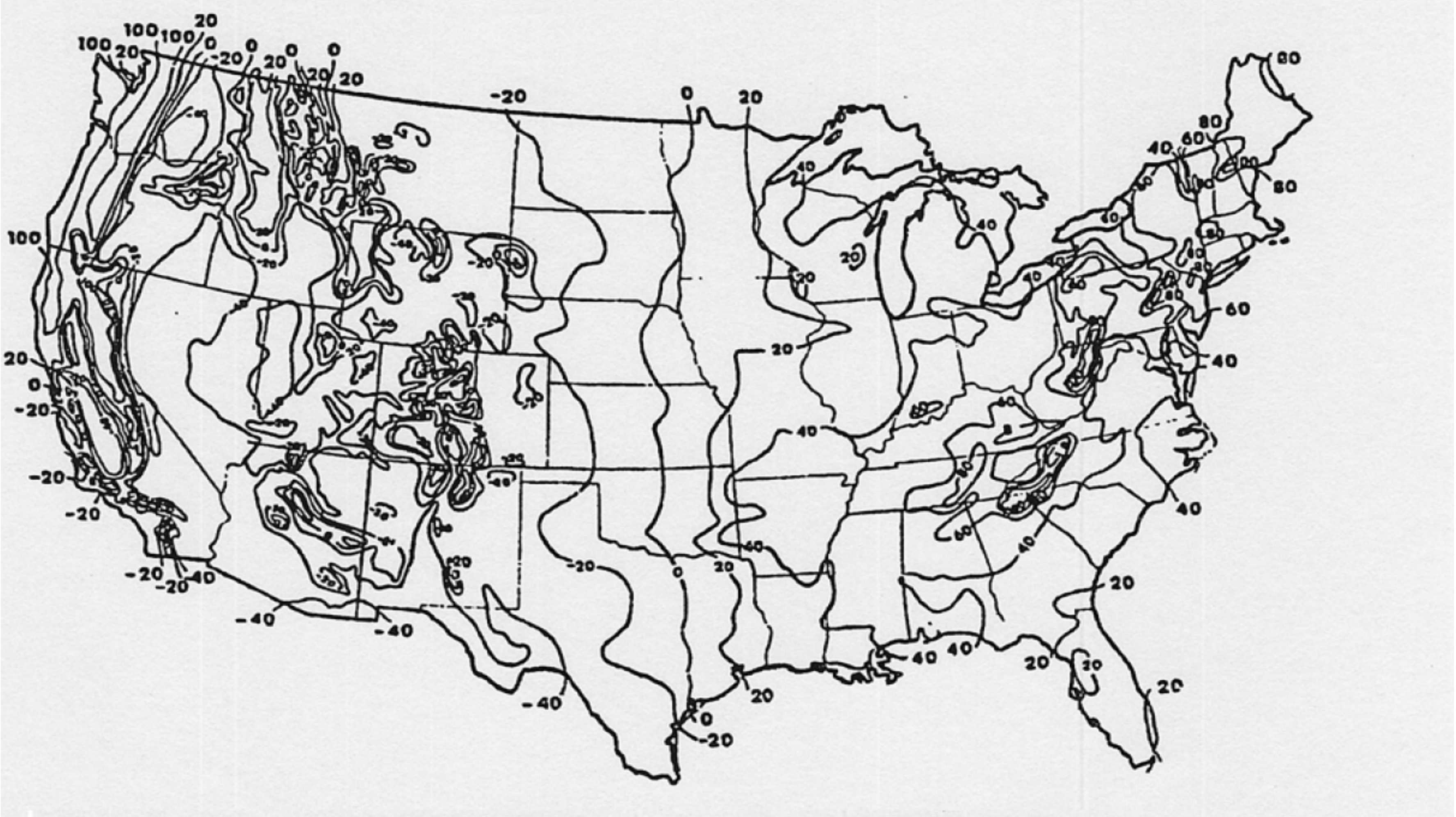
PROPOSED APPROACH



STEPS INVOLVED



TMI DISTRIBUTION IN USA

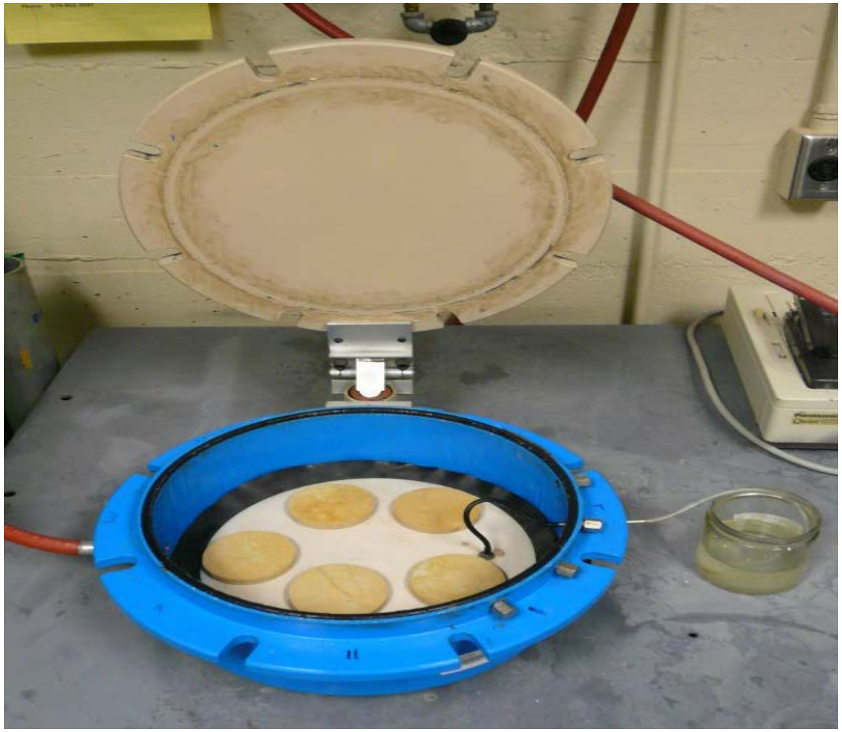


Thornthwaite moisture index distribution in the United States. (After Thornthwaite, 1948)

LABORATORY TESTS

Pressure Plate Test (ASTM D2325)

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



LABORATORY TESTS

Rapid Accelerated Tri-Axial Test (AASHTO T 307)

Resilient Modulus, $M_r = \dfrac{Deviatoric\ Stress\ (\sigma_d)}{Recovered\ Elastic\ Strain\ (\varepsilon_r)}$

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 ROUGNESS

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

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

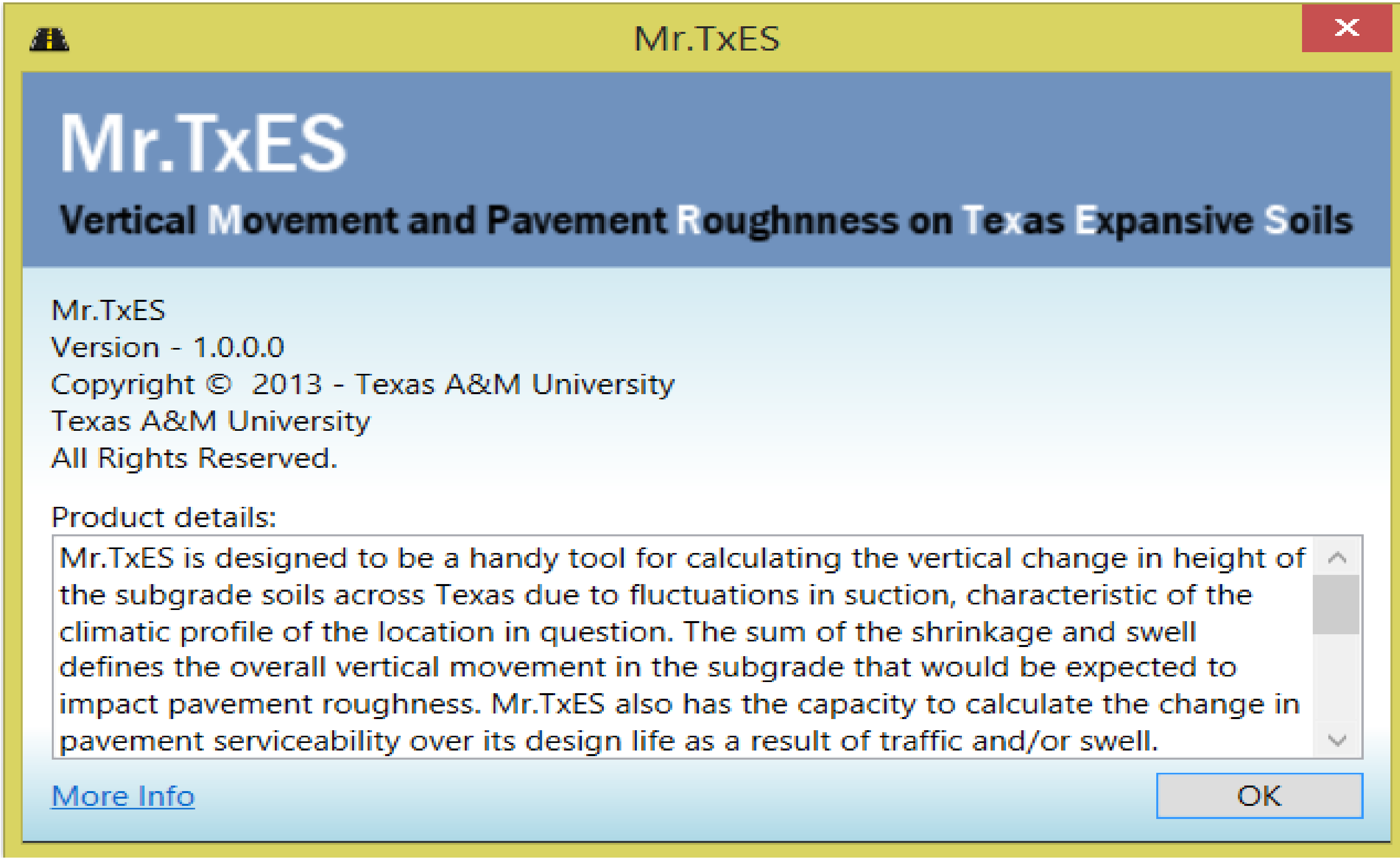
$$\rho_s = A_s - B_s \Delta H_{total}$$

$$B_s = 17.96 + 4.195 Z_R$$

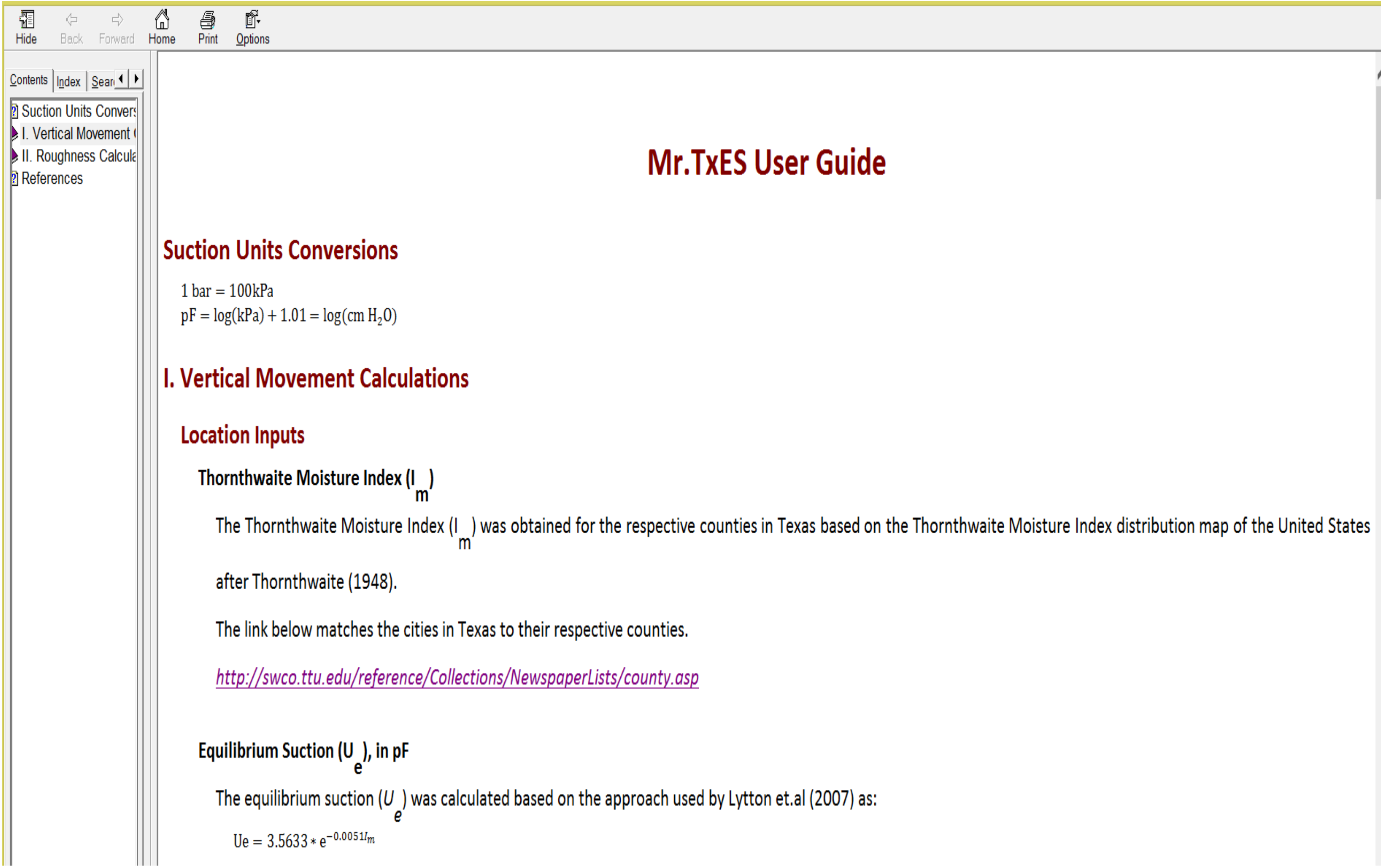
$$A_s = t\left[\ln\left(10^{-\lambda}\right)^{1.52}\right]$$

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

‘Mr. TxES’ COMPUTER PROGRAM



‘Mr.TxES’ USER GUIDE SNAPSHOT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I. Vertical Movement
II. Roughness Calcul
References

Mr.TxES User Guide

Suction Units Conversions

1 bar = 100kPa

pF = log(kPa) + 1.01 = log(cm H_2O)

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.

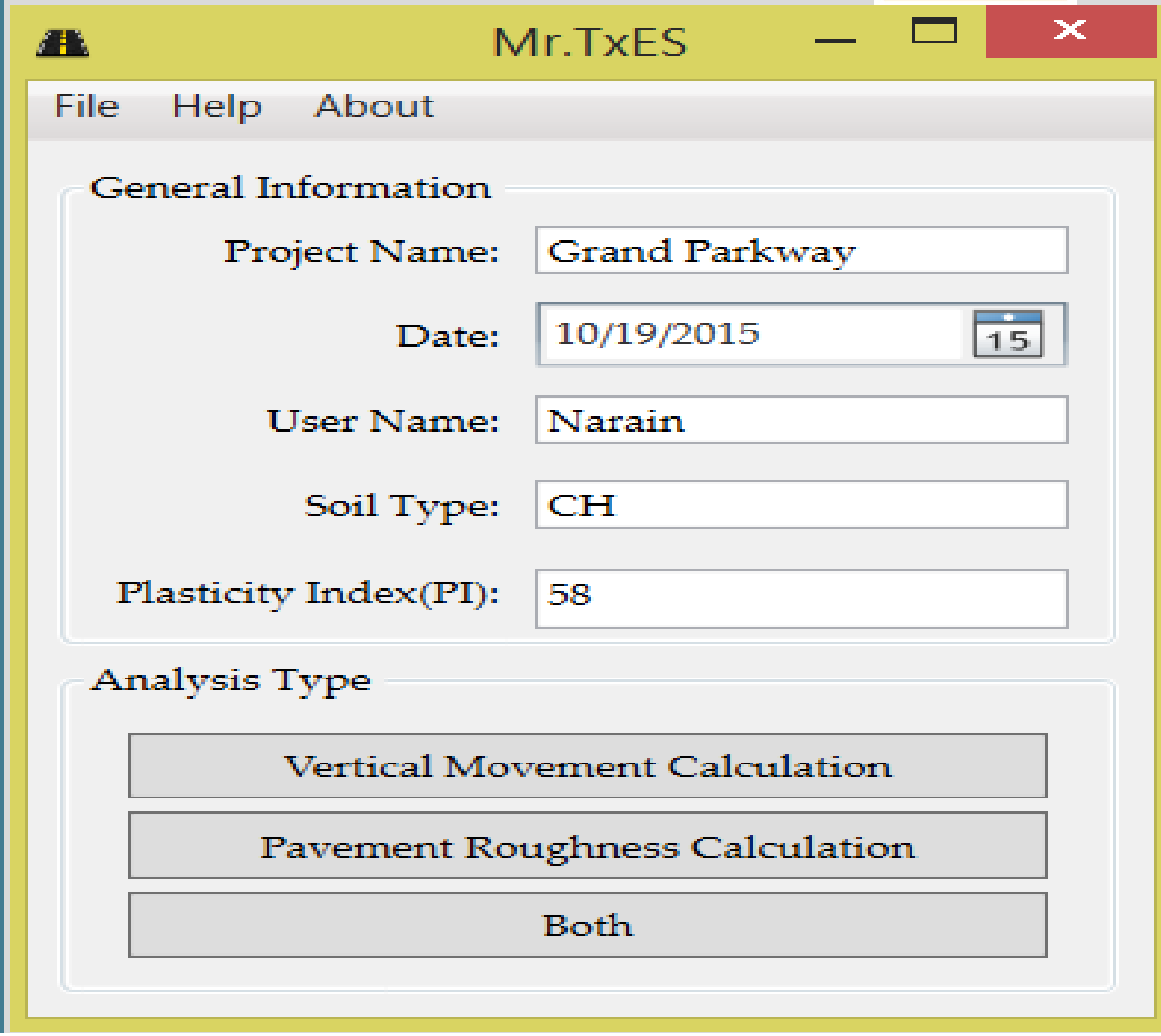
http://swco.ttu.edu/reference/Collections/NewspaperLists/county.asp

Equilibrium Suction (U_e), in pF

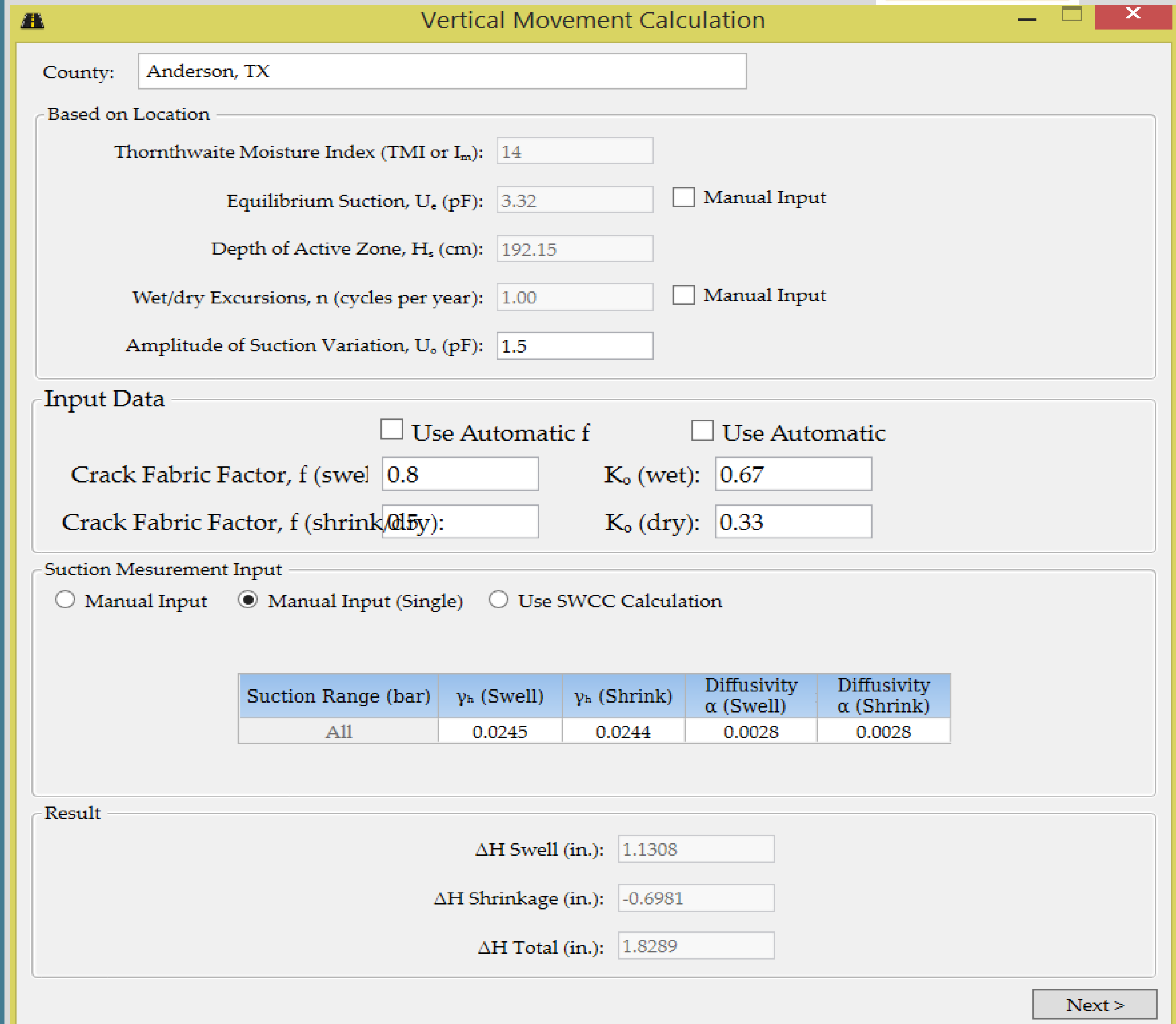
The equilibrium suction (U_e) was calculated based on the approach used by Lytton et.al (2007) as:

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

‘Mr.TxES’ PROJECT IINPUTS



VERTICAL MOVEMENT ESTIMATION



VERTICAL MOVEMENT ESTIMATION

SWCC

Sample Number: 1

Pressure Plate Test Data

Dry Weight of Sample,g: 110.85

W Saturated,g: 127.43

Water Content,w,%: 14.96

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

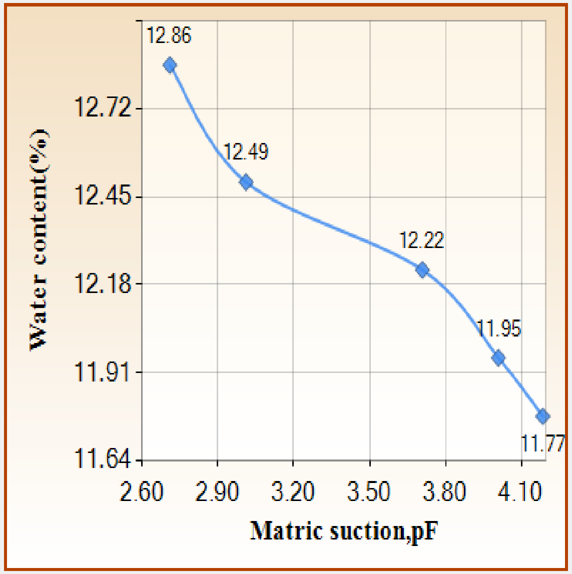
Volume Measurement Data

Bar	Matric suction, pF	Trimmed Average weight (g)	Δ Mass (g)	Volume (cm³)
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

Result

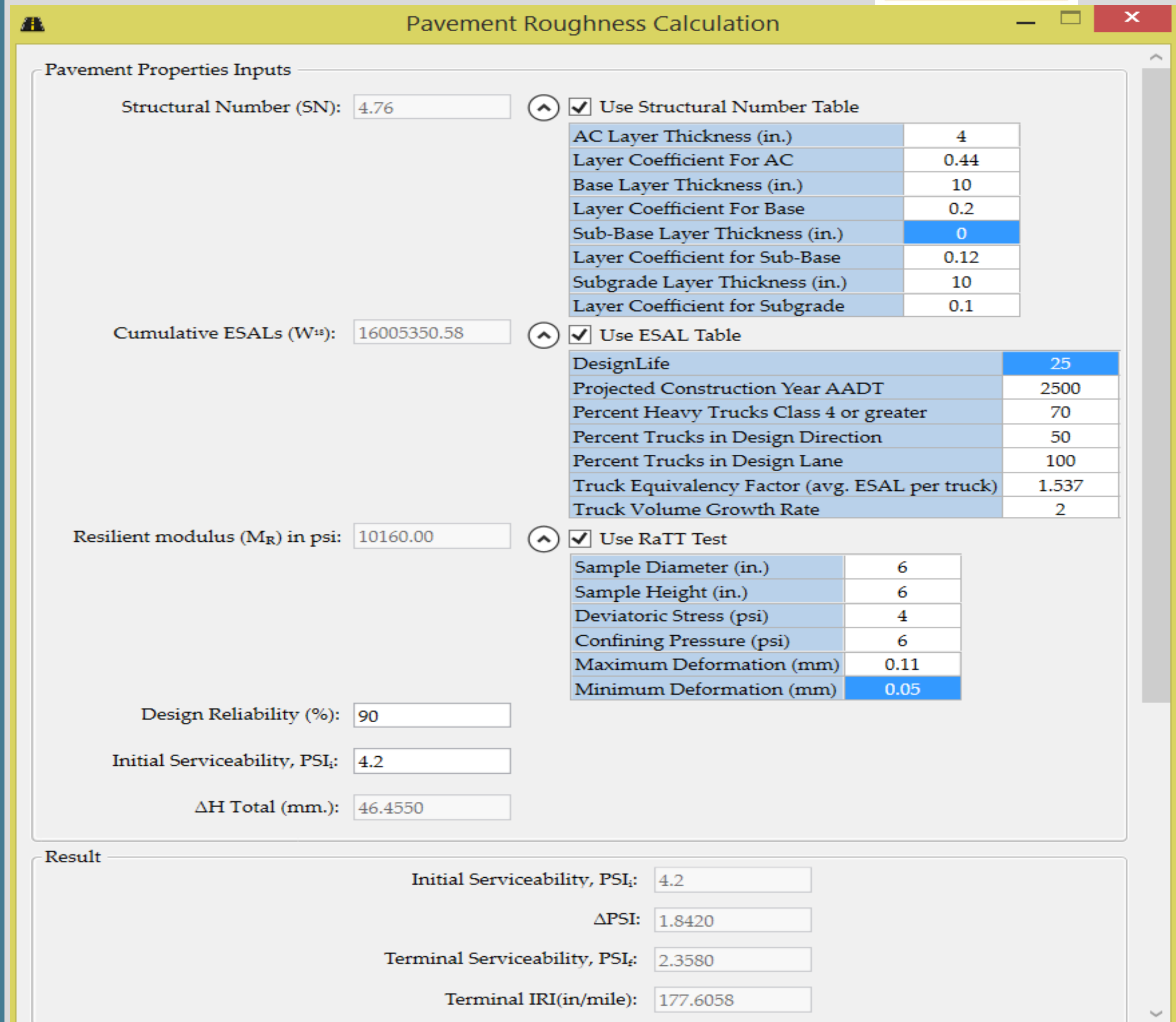
Suction range (bar)	γ_h (swell)	γ_h (shrink)
0.00 - 1.00	0.00710	0.00706
1.01 - 5.00	0.00710	0.00706
5.01 - 10.00	0.03570	0.03532
10.00 - 15.00	0.02452	0.02441

SWCC Chart

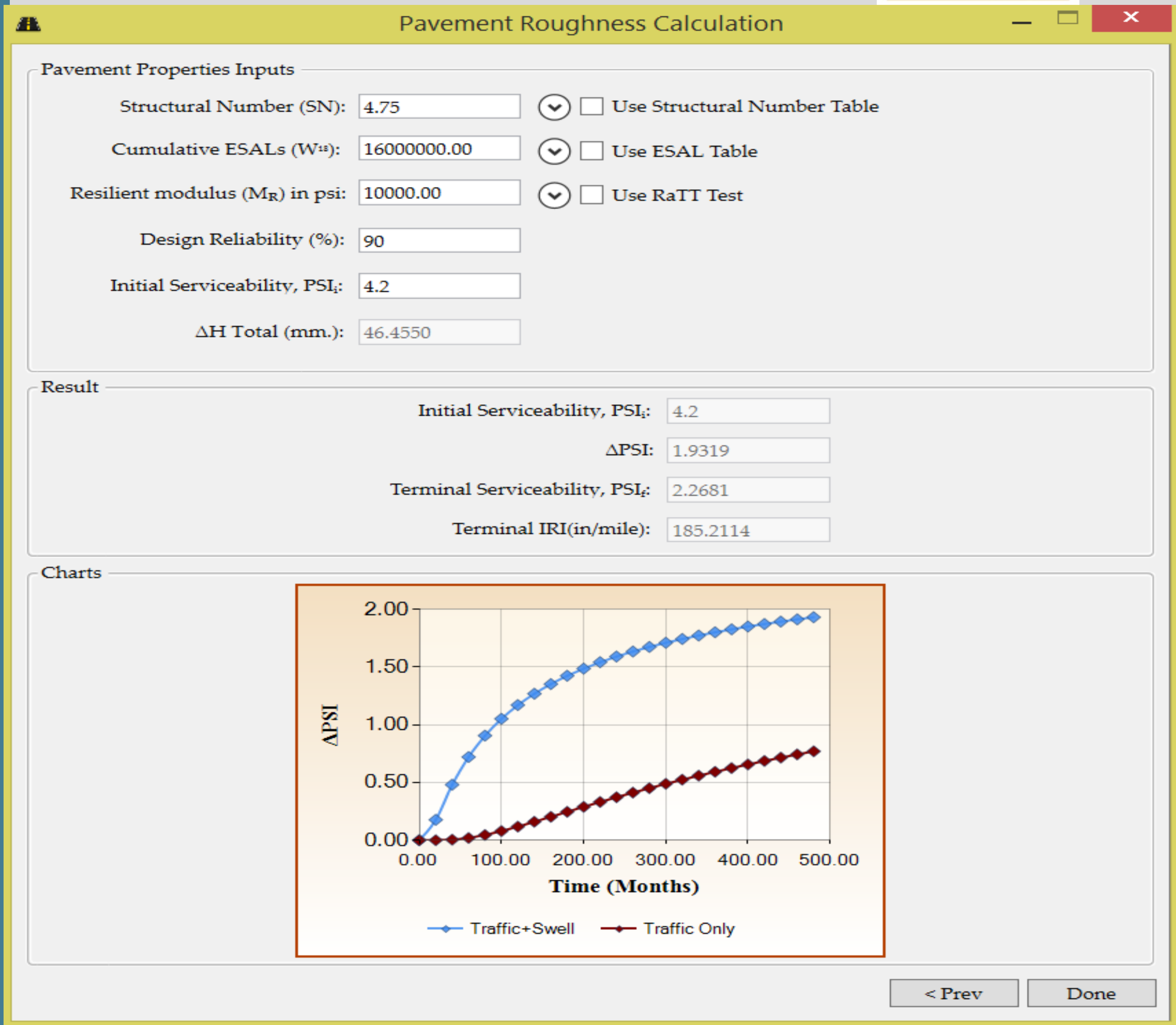


Done

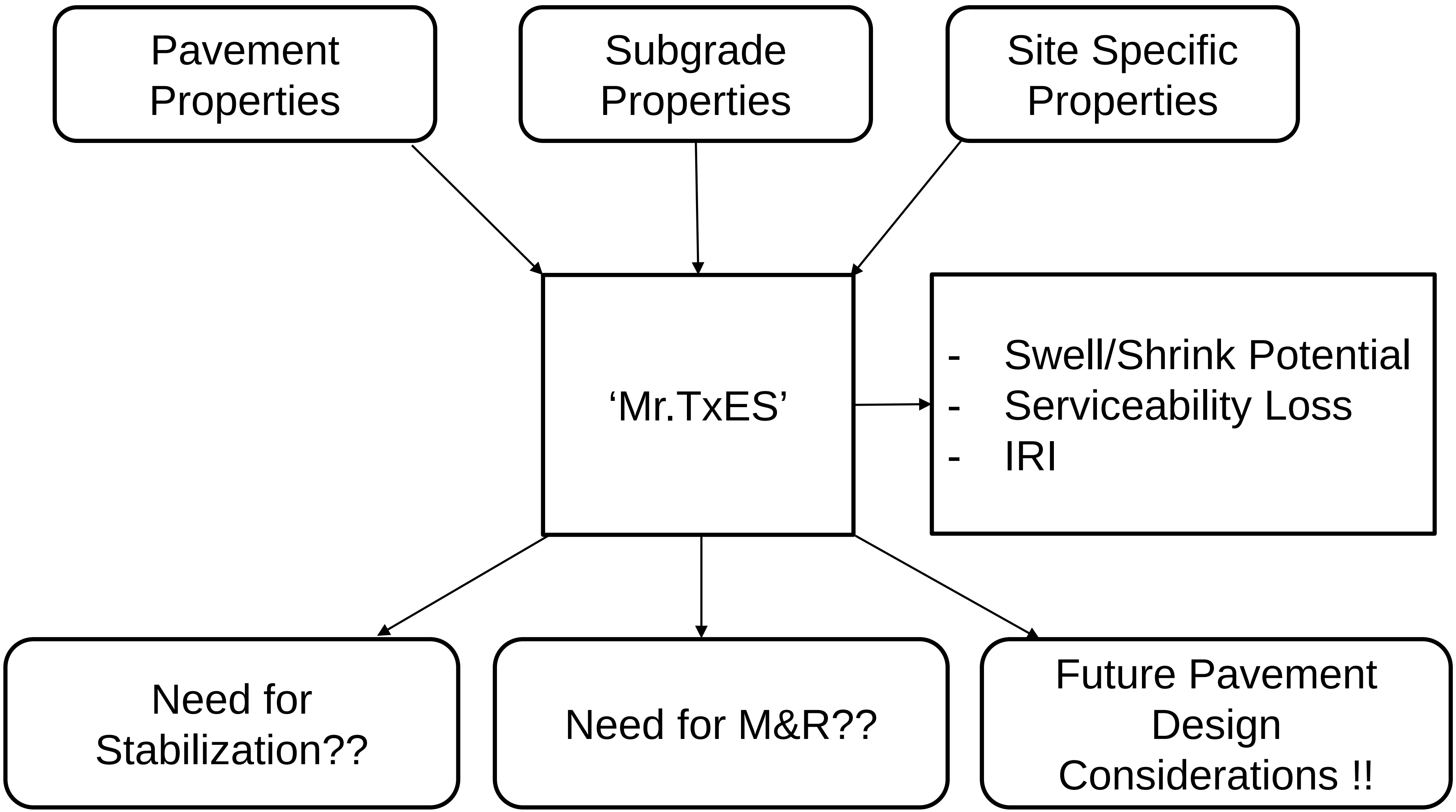
PAVEMENT ROUGHNESS ESTIMATION



PAVEMENT ROUGHNESS ESTIMATION



SUMMARY


Pavement Properties
Subgrade Properties
Site Specific Properties
'Mr.TxES'
- Swell/Shrink Potential
- Serviceability Loss
- IRI
Need for Stabilization??
Need for M&R??
Future Pavement Design Considerations !!

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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