Incorporation of Environmental Factors in Flexible Pavement Design

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  - Len Oliver
  - Mike Presley

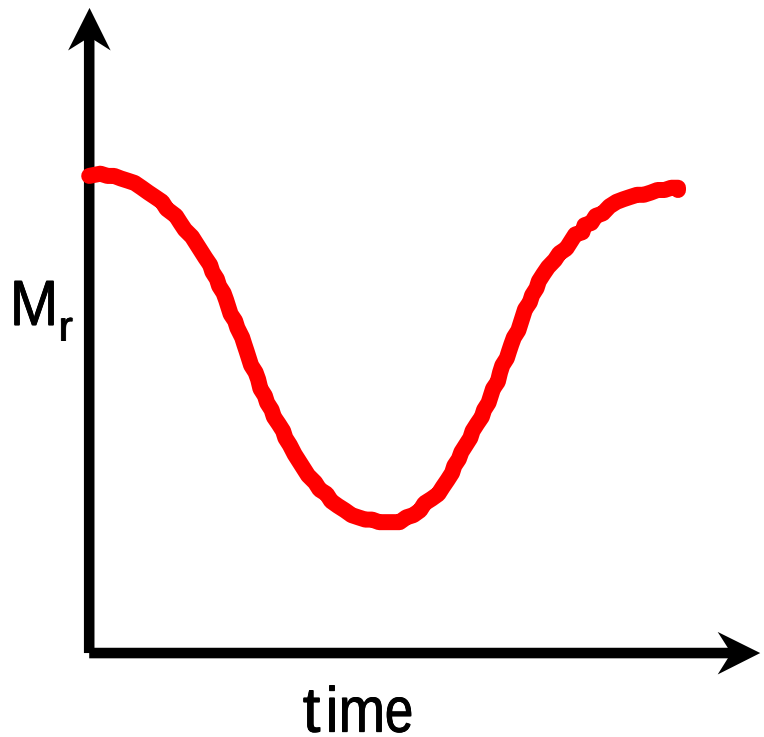
Introduction

- **Mechanics-based approach to flexible pavement design**
  - **resilient modulus (M_r) used to define behavior of each layer in pavement system**
  - **M_r is a function of stress level, loading history, temperature, etc..**
- **M_r of subgrade soil dependent upon environmental factors**
  - **changes in moisture conditions**
  - **freeze/thaw state**

Introduction

What value(s) of M_r to use for design?

- **High or maximum value**
  - **the "best case" properties may not be safe or reliable**
- **Low or minimum value**
  - **the "worst case" properties may not be economical**
- **Mean value**
  - **"average" properties may not reflect the relative duration of the seasons during which the "best case" and "worst case" properties occur**



Introduction

- **Laboratory studies investigated variation of subgrade resilient modulus due to changes in**
  - **water content**
  - **degree of saturation**
  - **matric potential**
- **But, there is a little data on the seasonal variations of the moisture conditions**

Introduction

AASHTO Guide (1993)

- **Suggests a procedure to incorporate the seasonal variation of subgrade M_r in the design process to determine M_R**
  - **(M_R = *effective roadbed resilient modulus)***
- **M_R is the single value of subgrade resilient modulus which reflects the cumulative damage from the entire year**
- **unfortunately, knowledge of the seasonal variation of modulus is required**

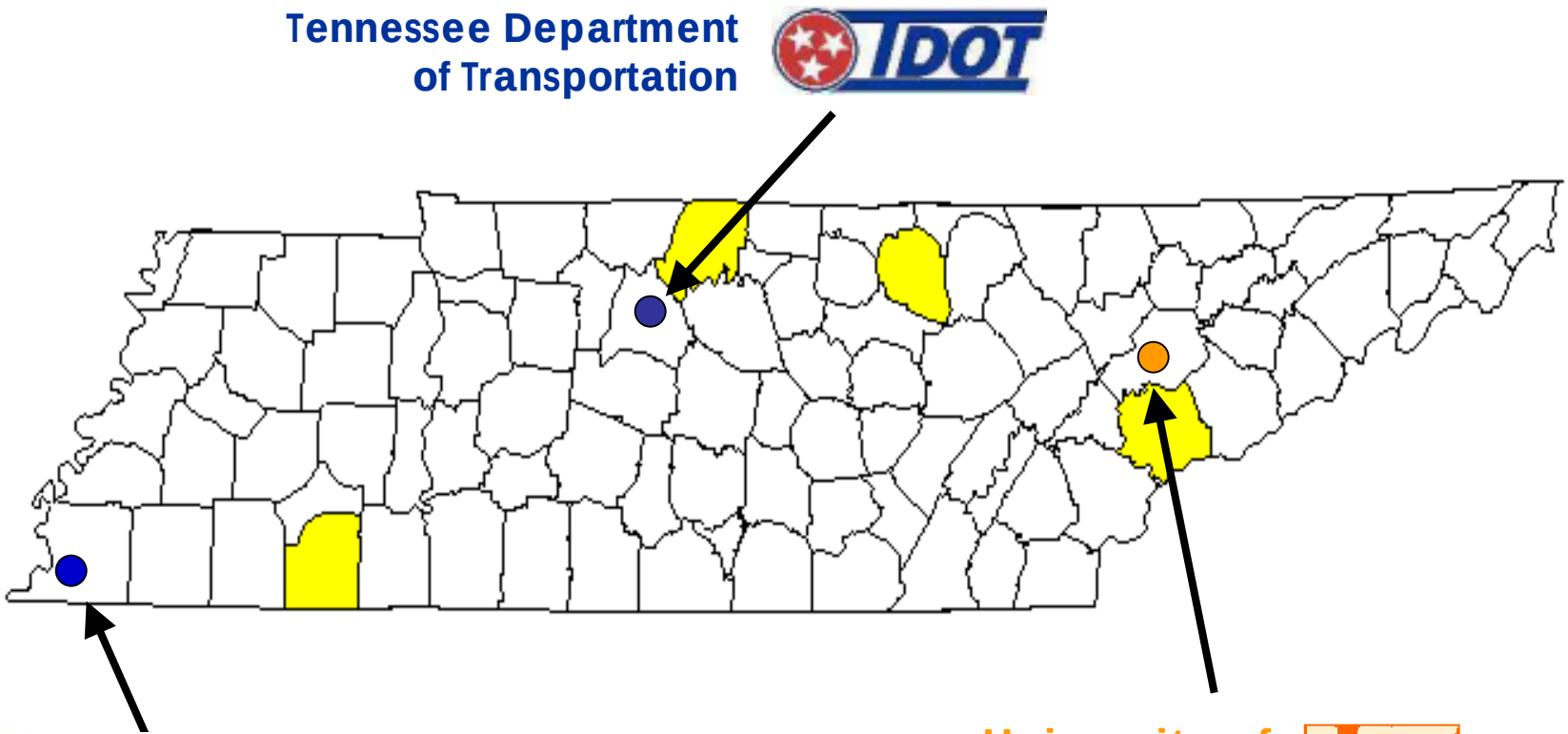
Objectives of Research

- Measure seasonal variations of water content and temperature in pavement systems
- Measure the effects of those variations on pavement structural capacity
- Develop methods to incorporate those effects into existing pavement design procedures used by TDOT

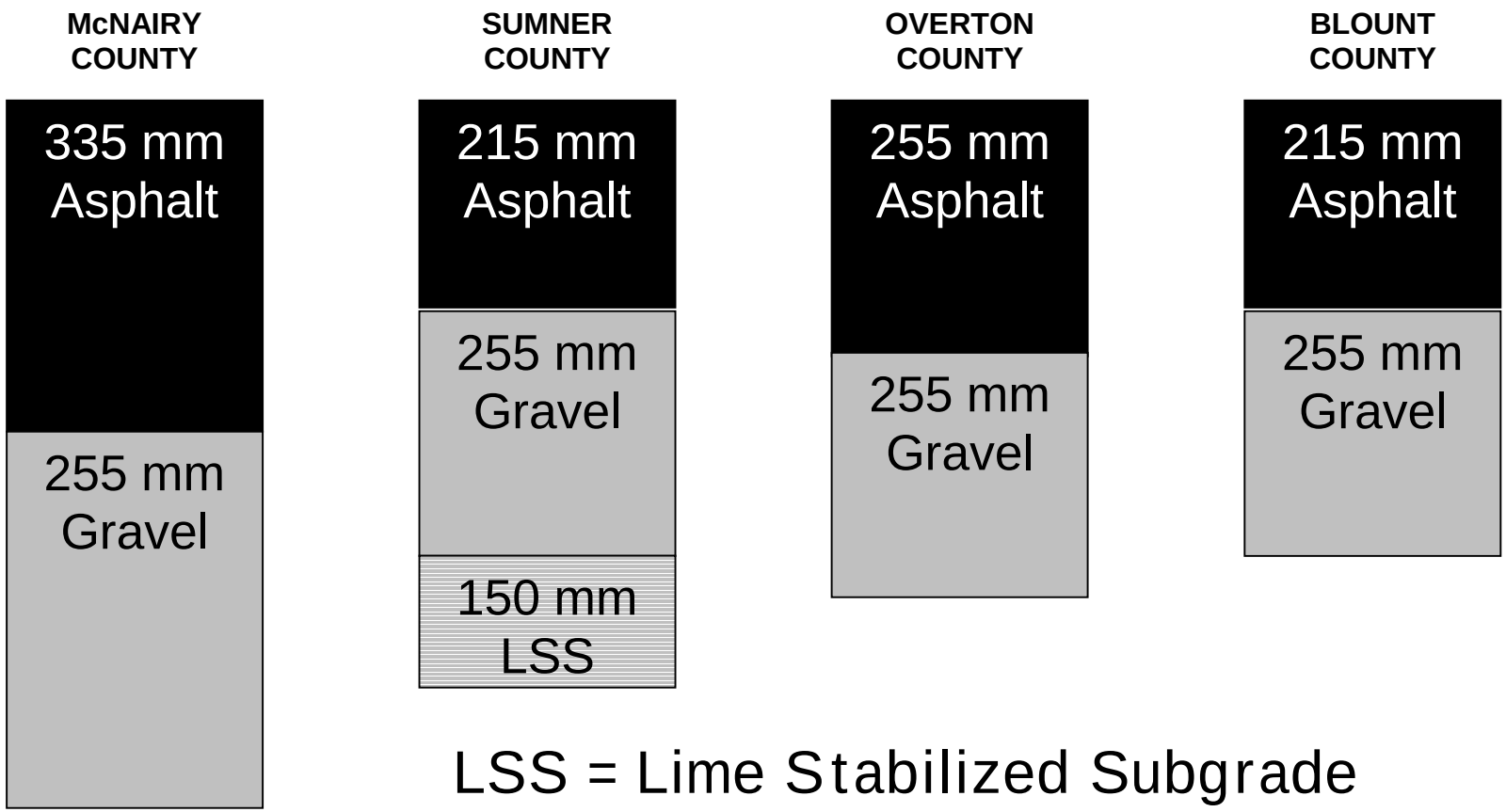
Objective 1

Measure seasonal variations of water content and temperature inside pavement systems

Instrumented Pavement Sites



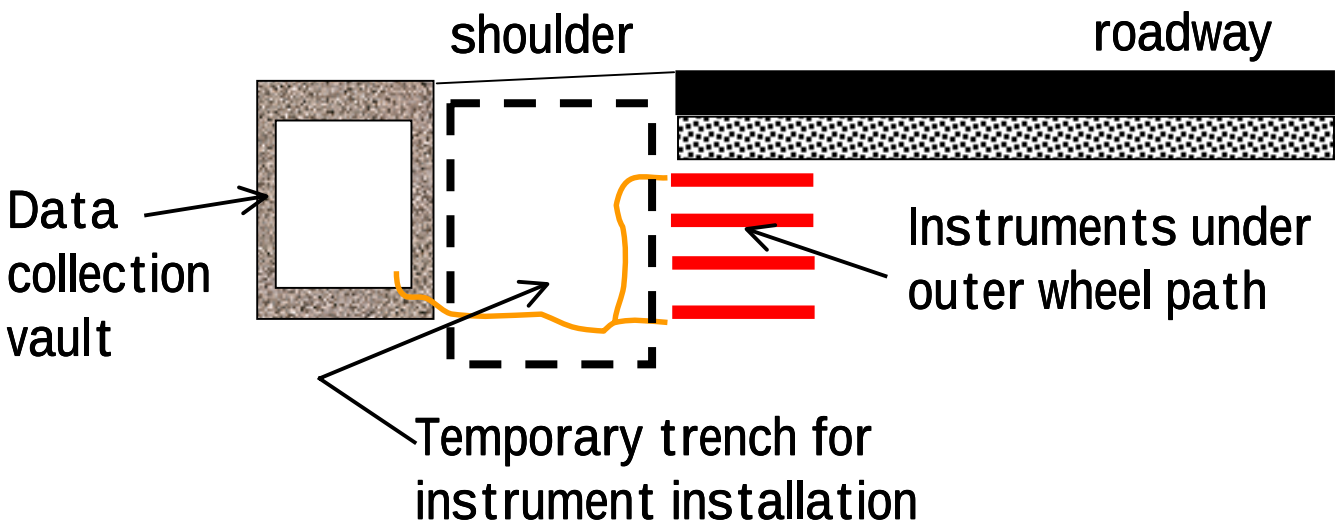
Pavement Sections



LSS = Lime Stabilized Subgrade

Pavement Instrumentation

Instrumentation installed under outer wheel path from trench in shoulder



Schematic of instrumentation system (section)

Pavement Instrumentation

- Time Domain Reflectometry (TDR)
  - Used to measure water content
  - Probes have 5 segments
  - Probes are 5 feet long

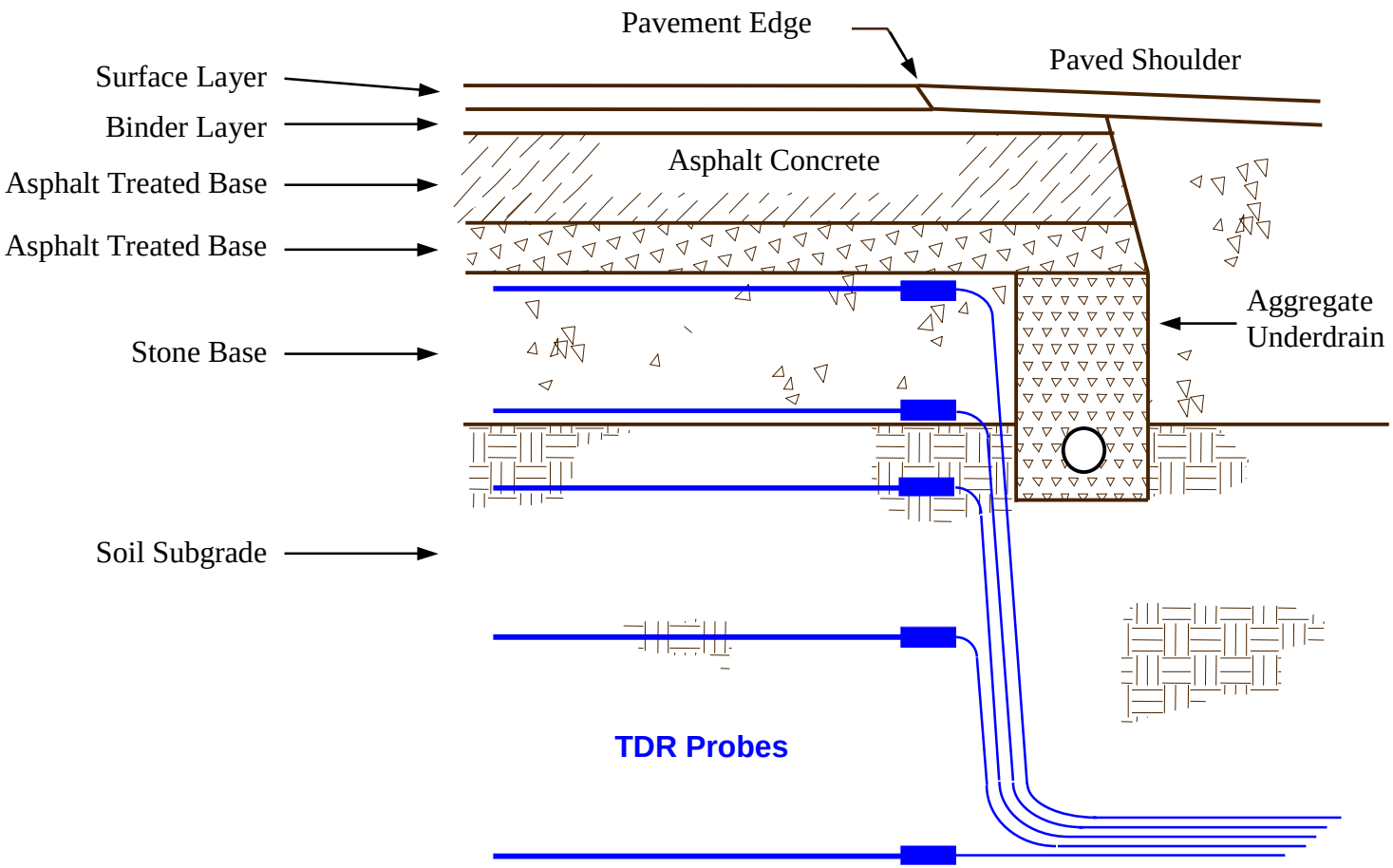
Buried TDR Probes

Pavement Instrumentation

Installing TDR Probes

Pavement Instrumentation

TDR Probes

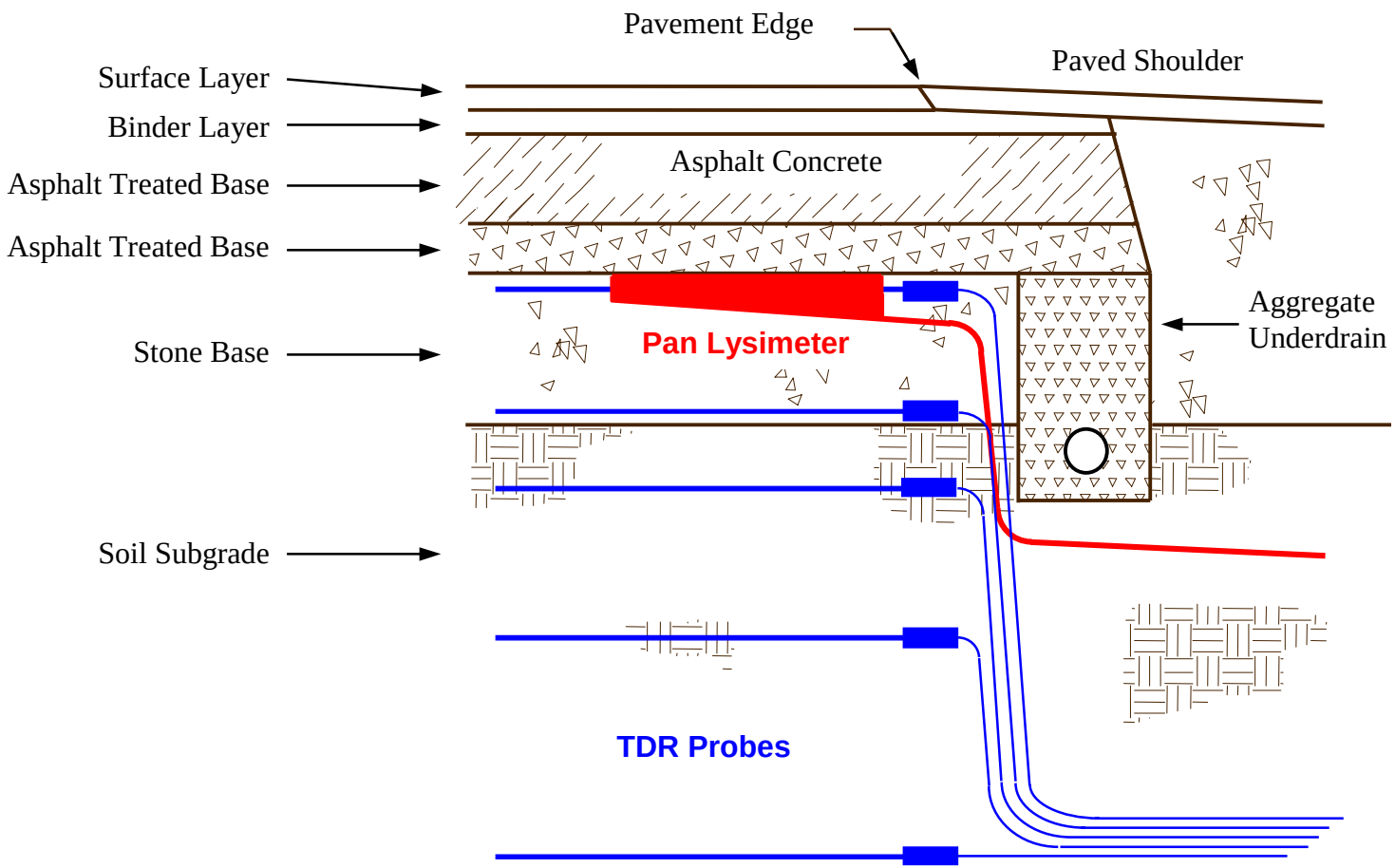


Pavement Instrumentation

- Pan Lysimeters
  - Measure infiltration through AC layers

  - Some located in the wheel path
  - Others located under a pavement joint

Pavement Instrumentation



Pavement Instrumentation

- Thermistors
  - Measure pavement temperature
  - 1” below surface
  - 1” above stone base
  - AC mid-height
  - In soil subgrade

Installing Thermistors

Pavement Instrumentation

- Weather Station
  - Air temperature
  - Solar radiation
  - Rainfall
  - Relative humidity
  - Wind speed

Pavement Instrumentation

Cable Trench

Pavement Instrumentation

Underground Vault

Pavement Instrumentation

- Data collected once each minute
- Hourly averages are stored on data logger
- Data sent to UT by cell phone once a day

Underground Instrumentation Panel

Pavement Instrumentation

Field Verification Tests

Drilling & sampling pavement and subgrade

Field Verification Tests

Pan lysimeter flush test

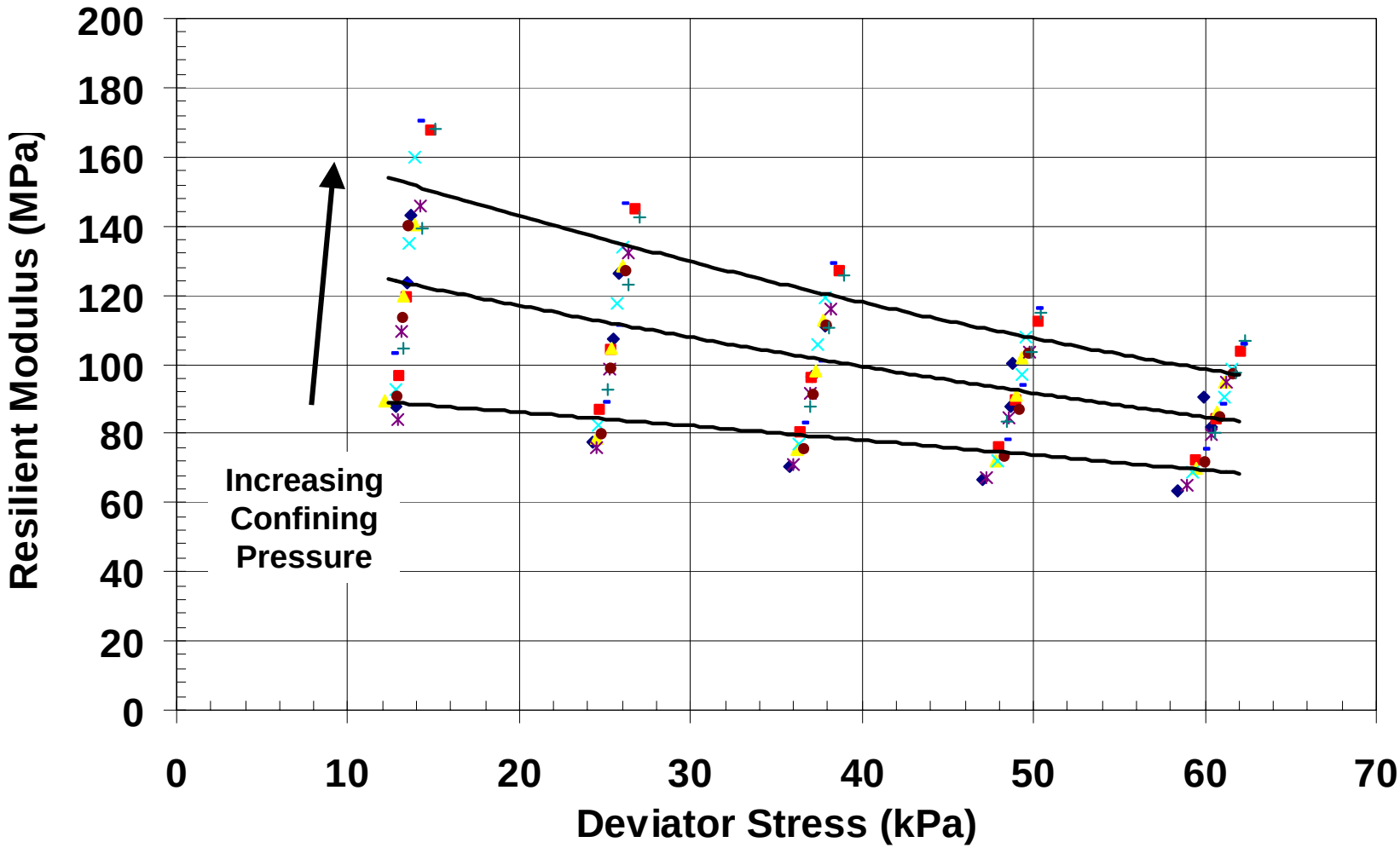
Material Characterization

- Index tests
  - Atterberg limits, Proctor tests, etc.
- Resilient modulus tests
  - AASHTO Standard Test Method

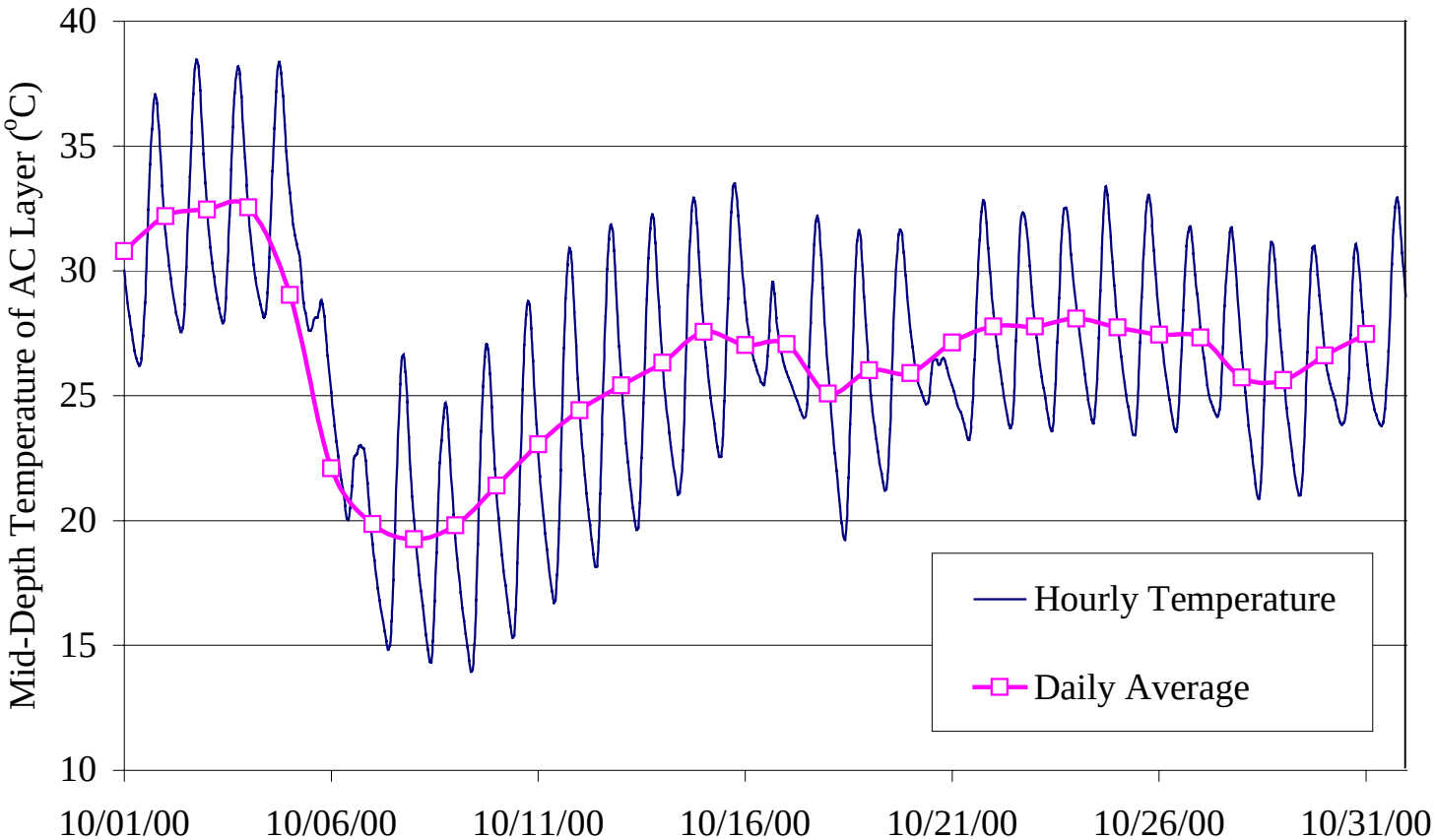
Material Characterization

- Resilient modulus
  - AASHTO T 307-99 Determining the Resilient Modulus of Soils and Aggregate Materials

Material Characterization



Observations: Pavement Temperature



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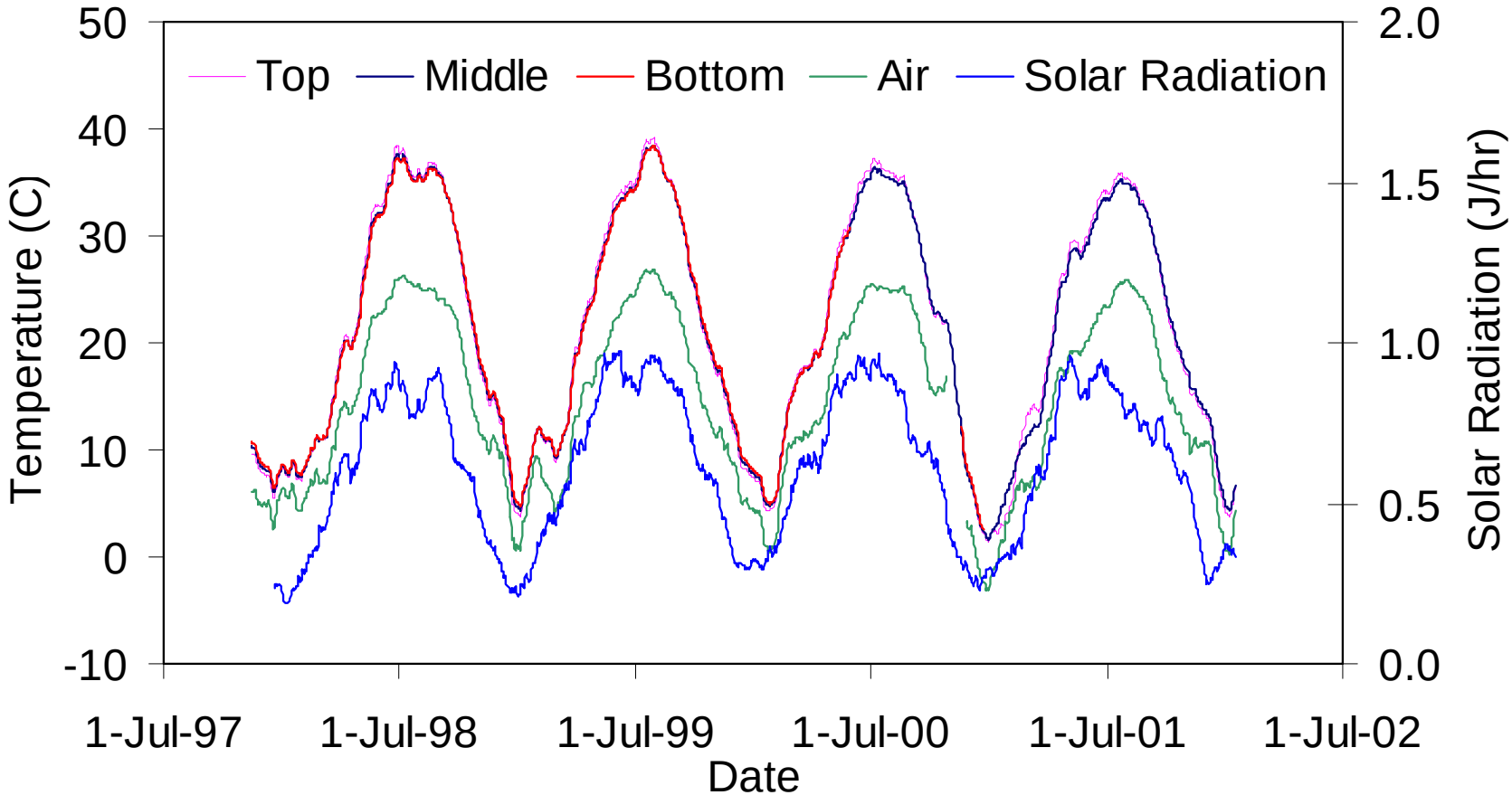
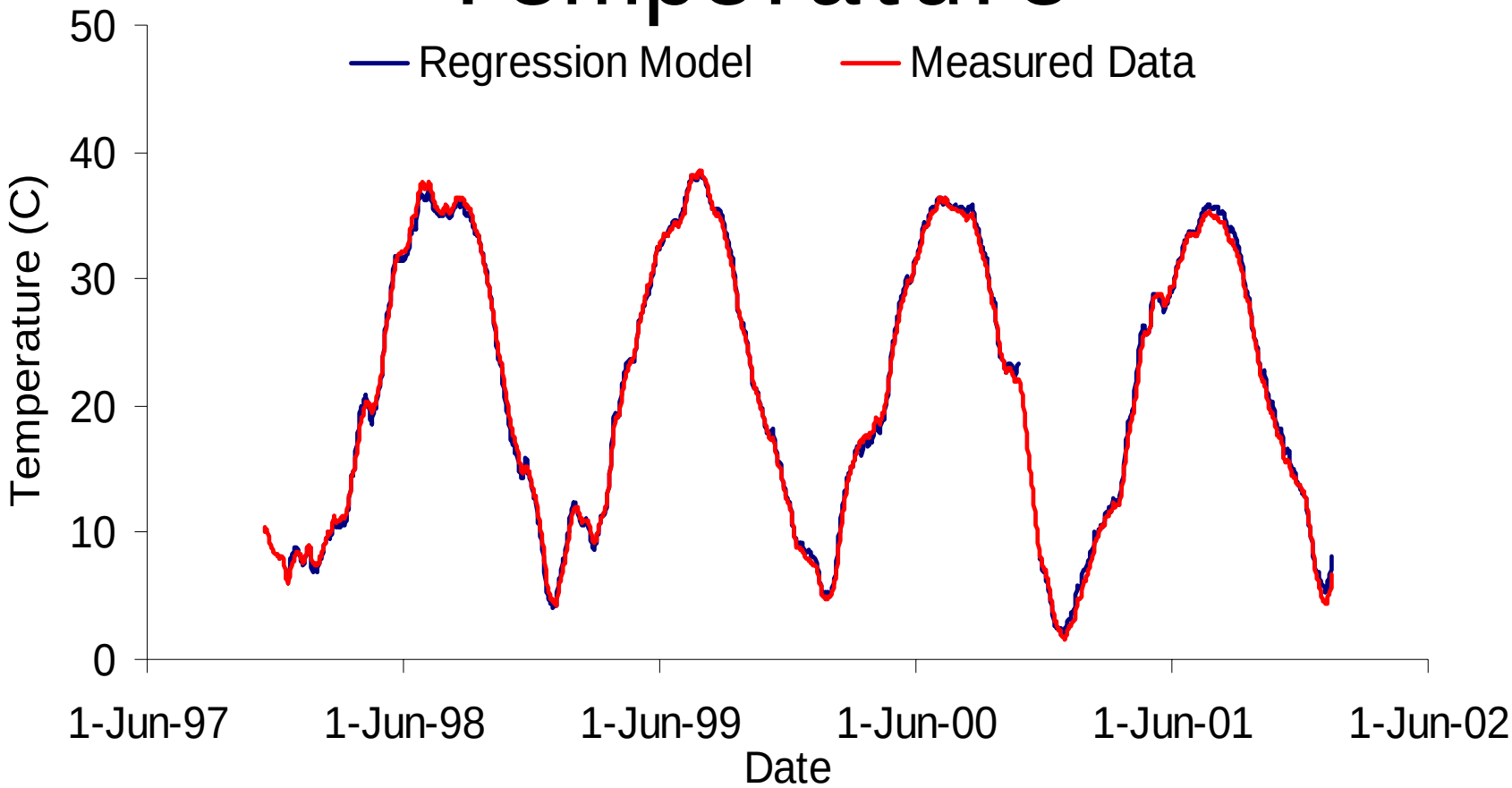
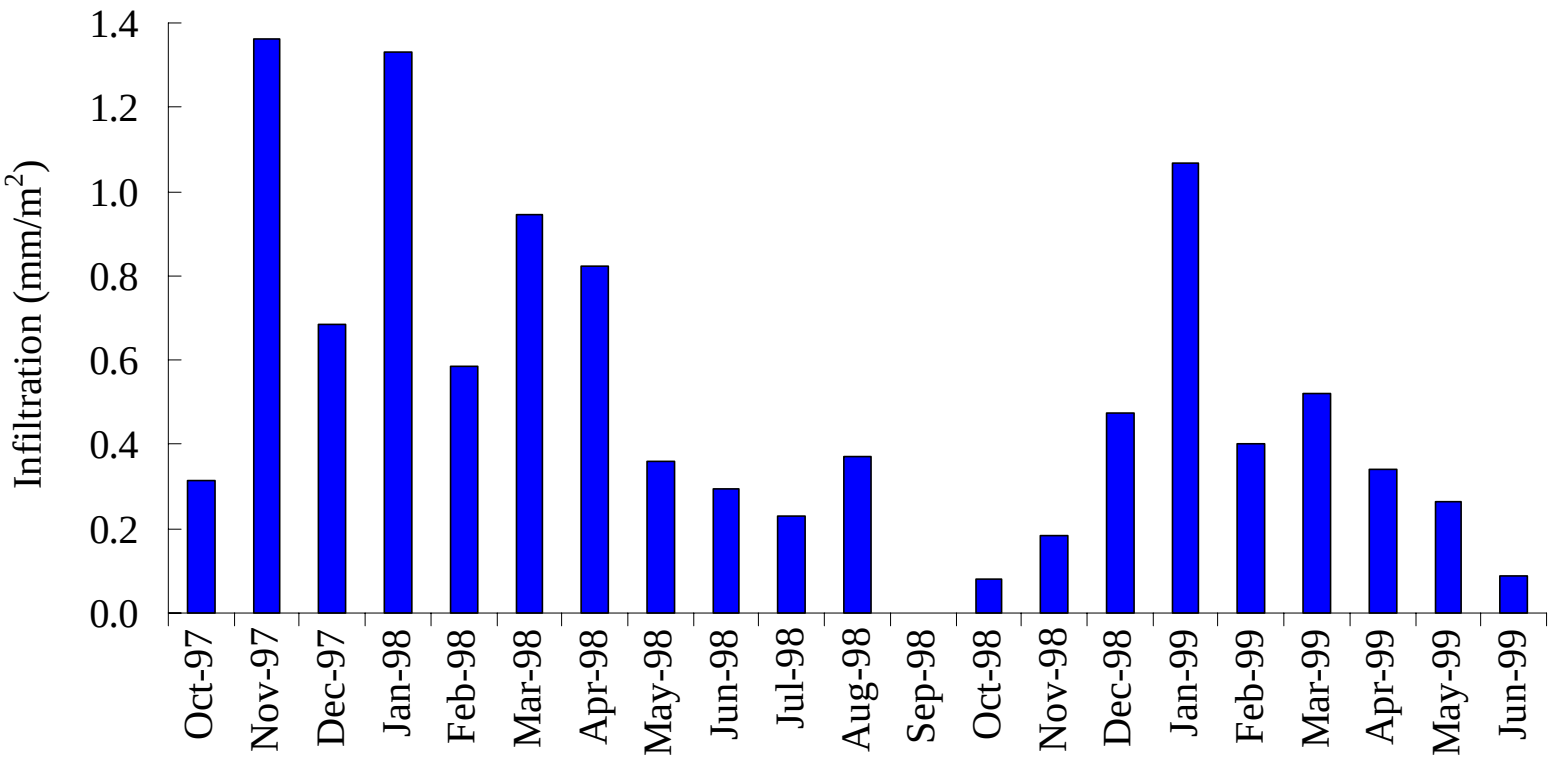


Observations: Pavement Temperature



Observations: Infiltration

McNairy County before binder and surface courses added



Observations: Infiltration

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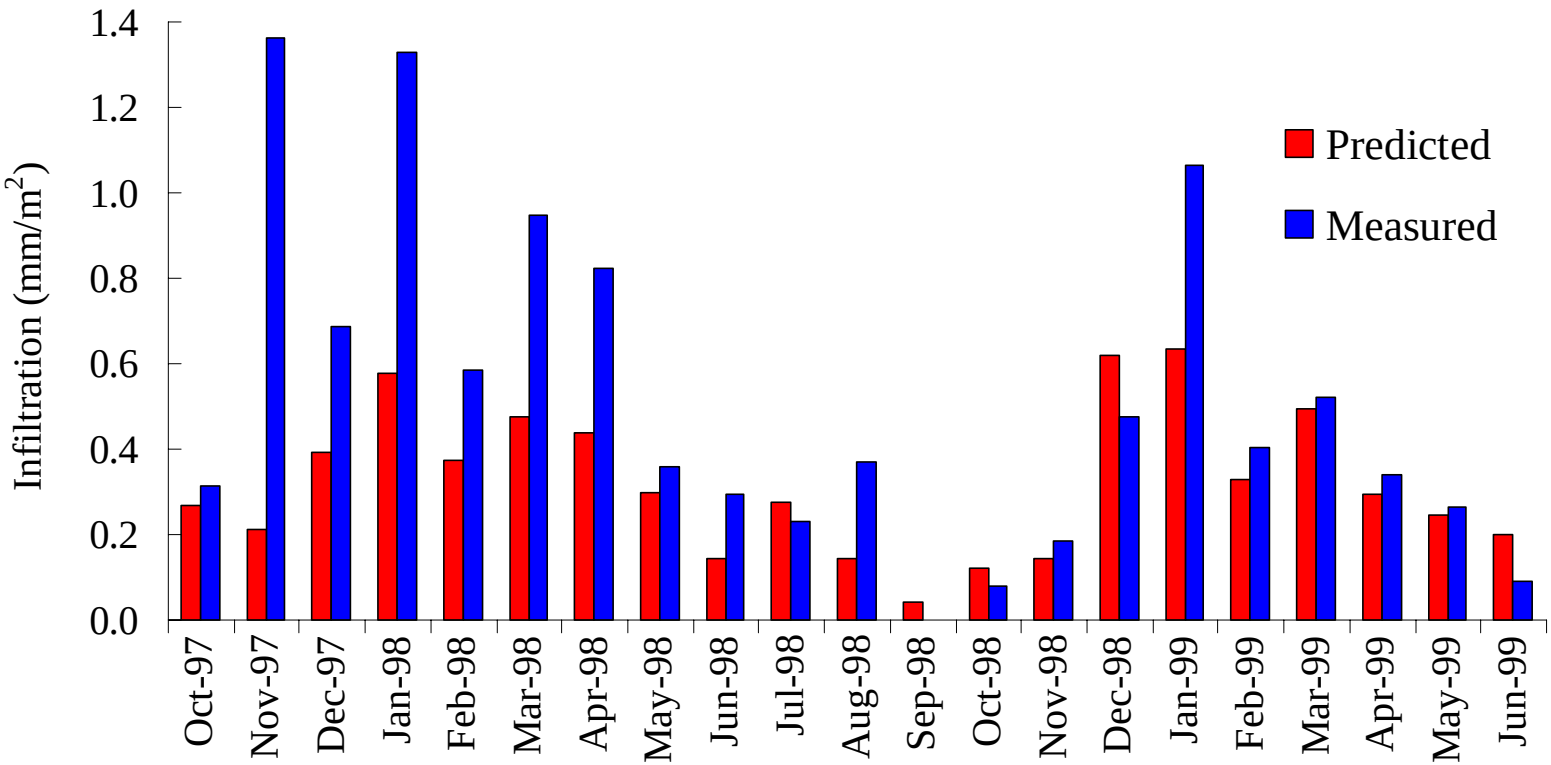
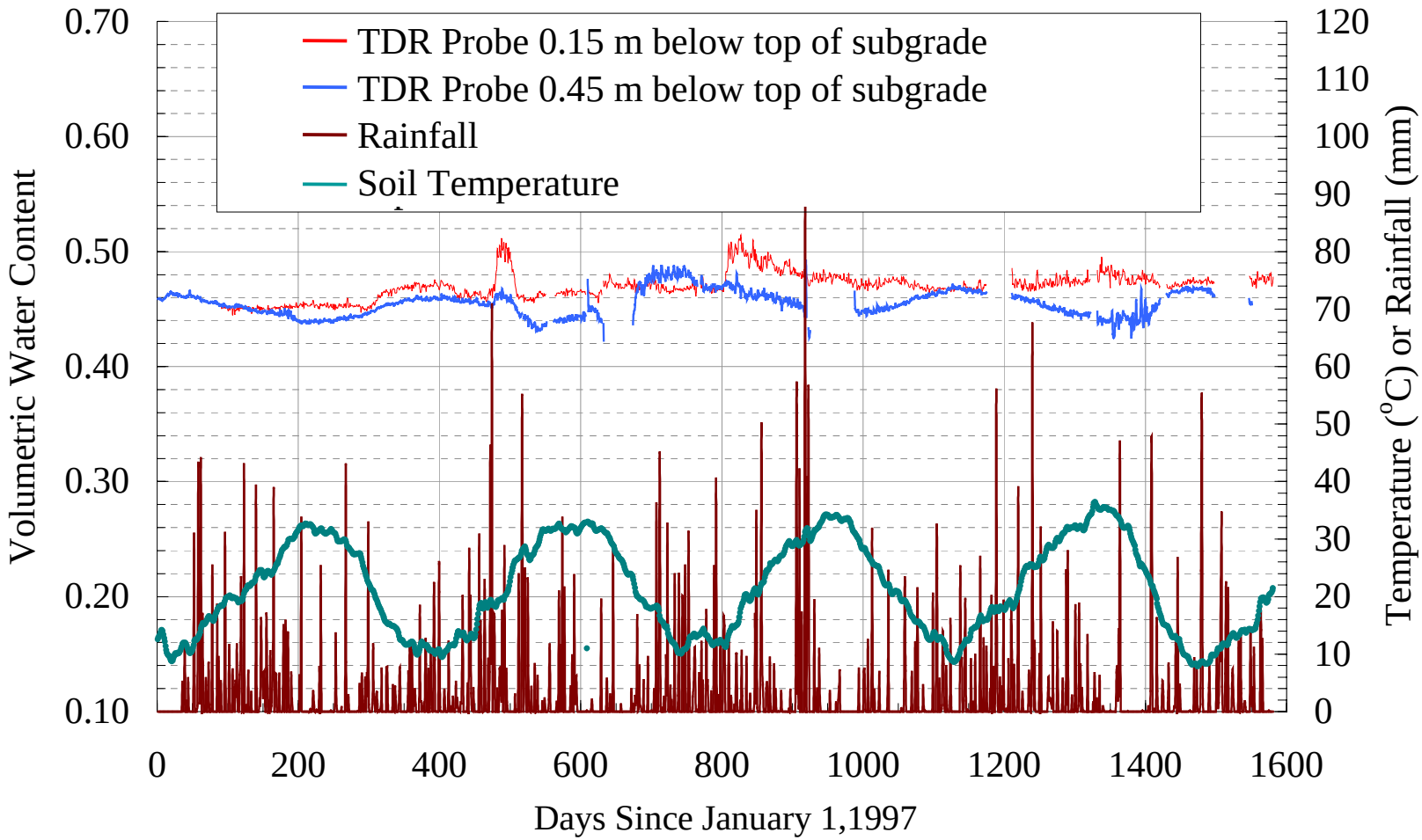


Observations: Infiltration

- Since binder and surface course was placed, infiltration of water has essentially ceased (only small measurable amounts of infiltration).
- Function of lysimeters verified by field flush tests
- Will infiltration increase as pavement ages?

Observations: Subgrade Water Content



Objective 2

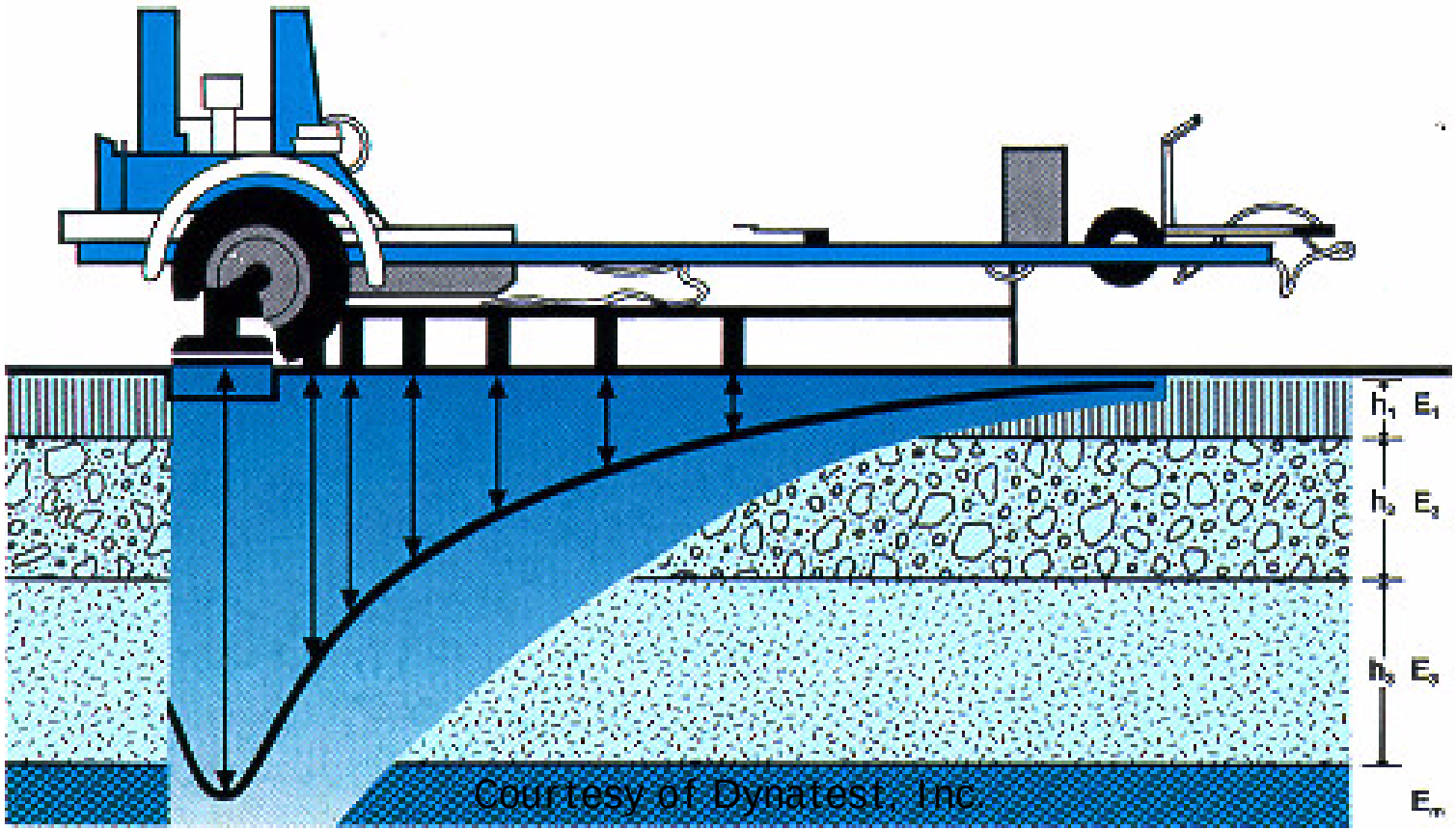
Measure the effects of moisture and temperature variations on pavement structural capacity

Pavement Response

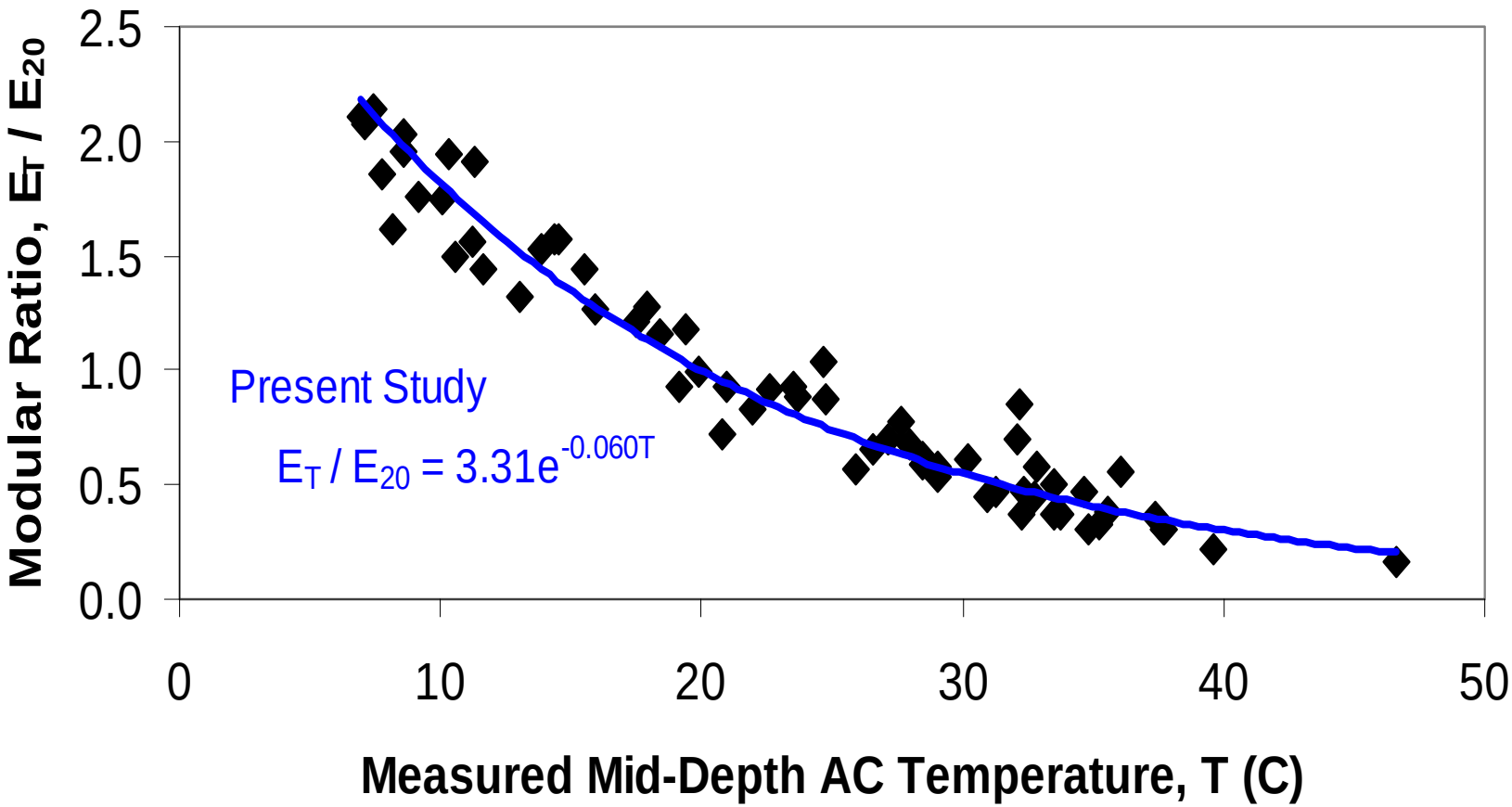
- Measured with Falling Weight Deflectometer

FWD

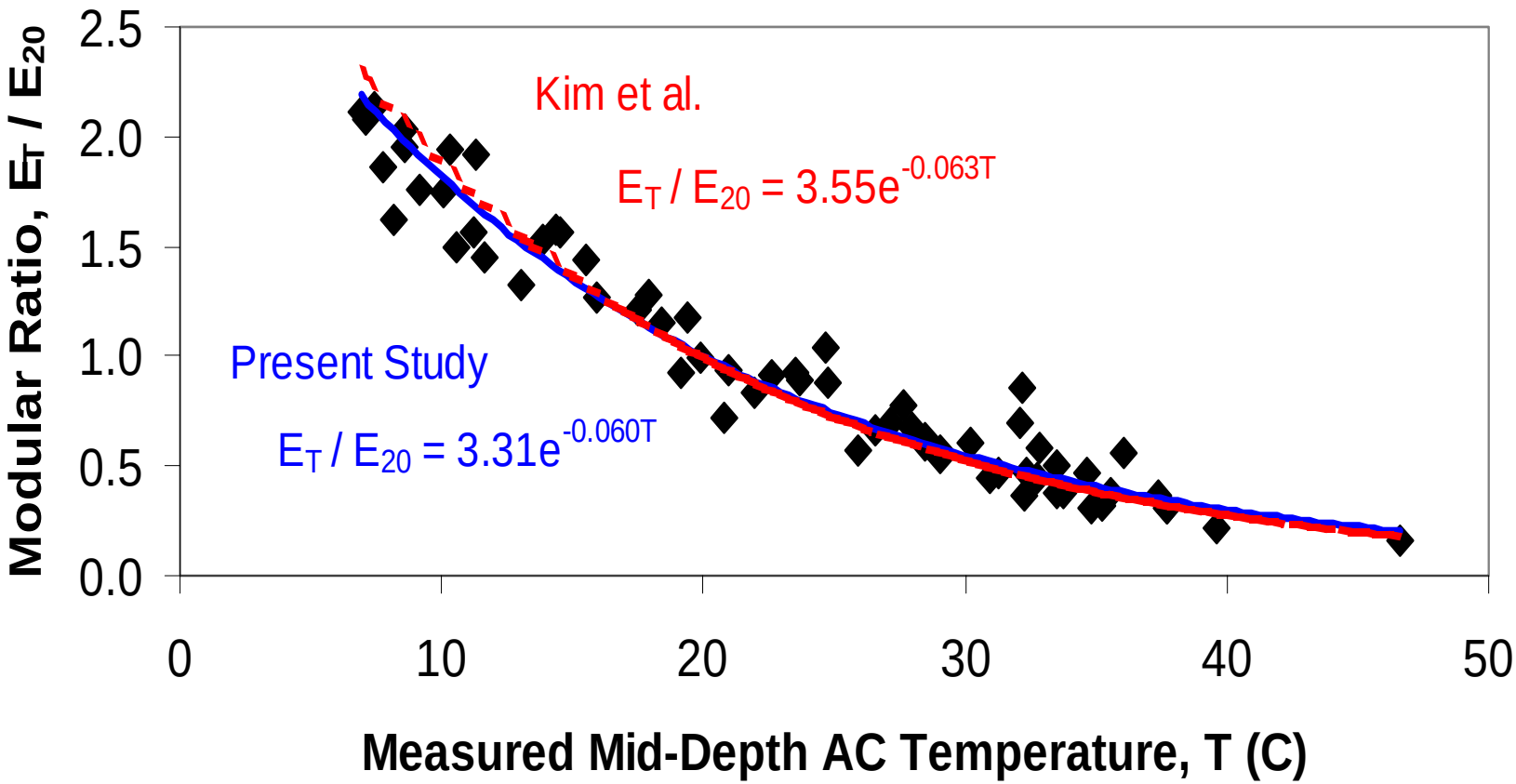
Pavement Response



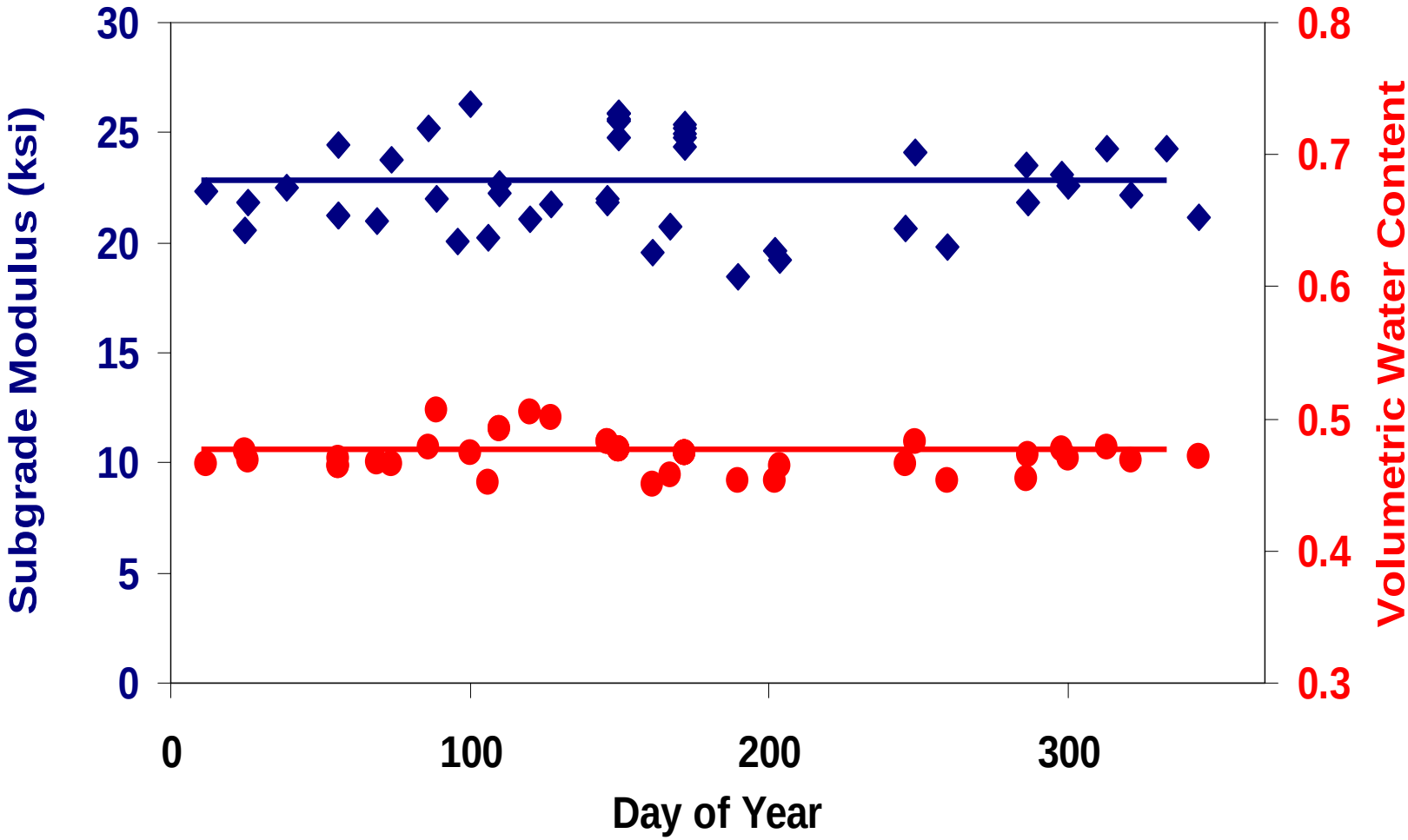
Pavement Response



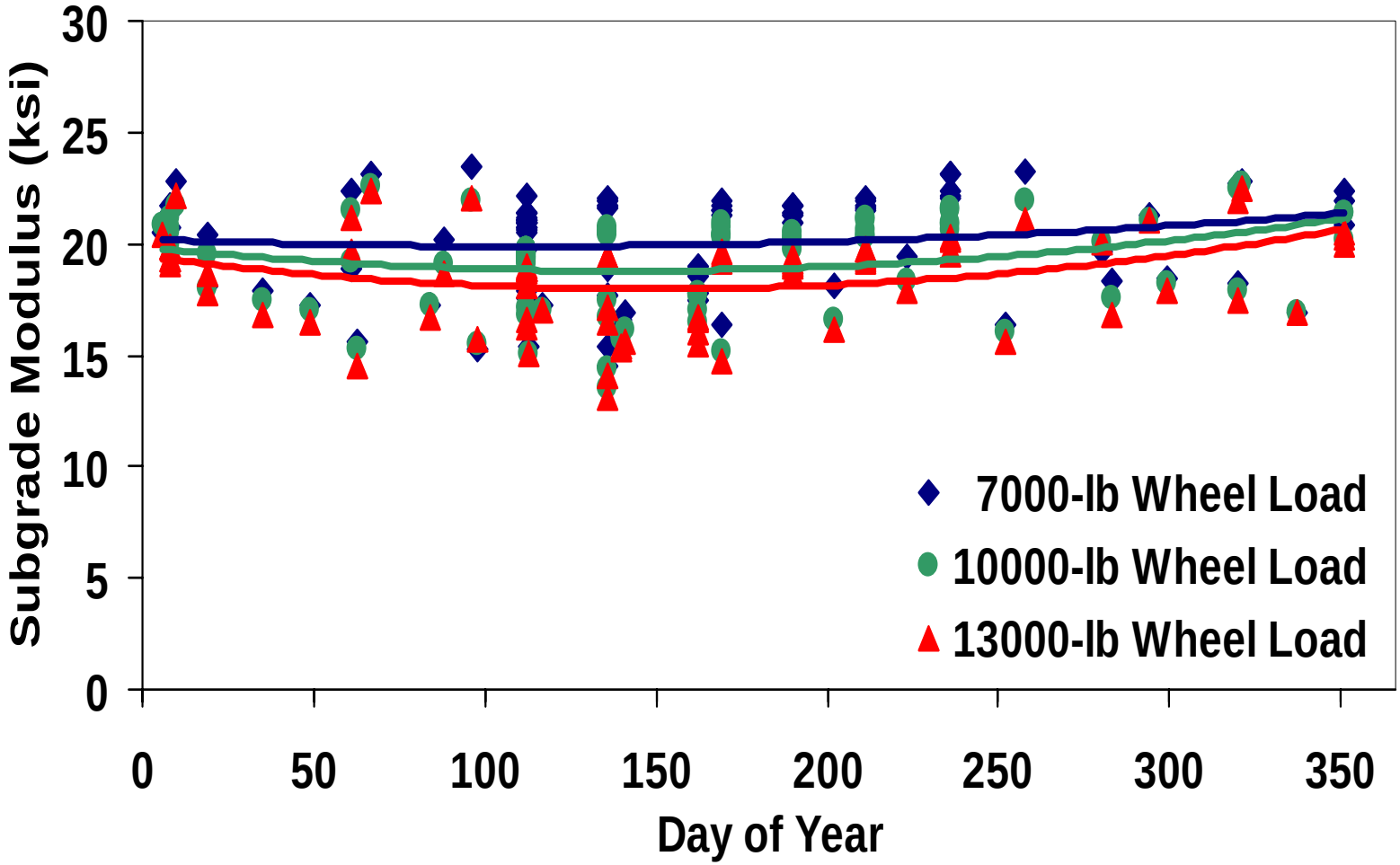
Pavement Response



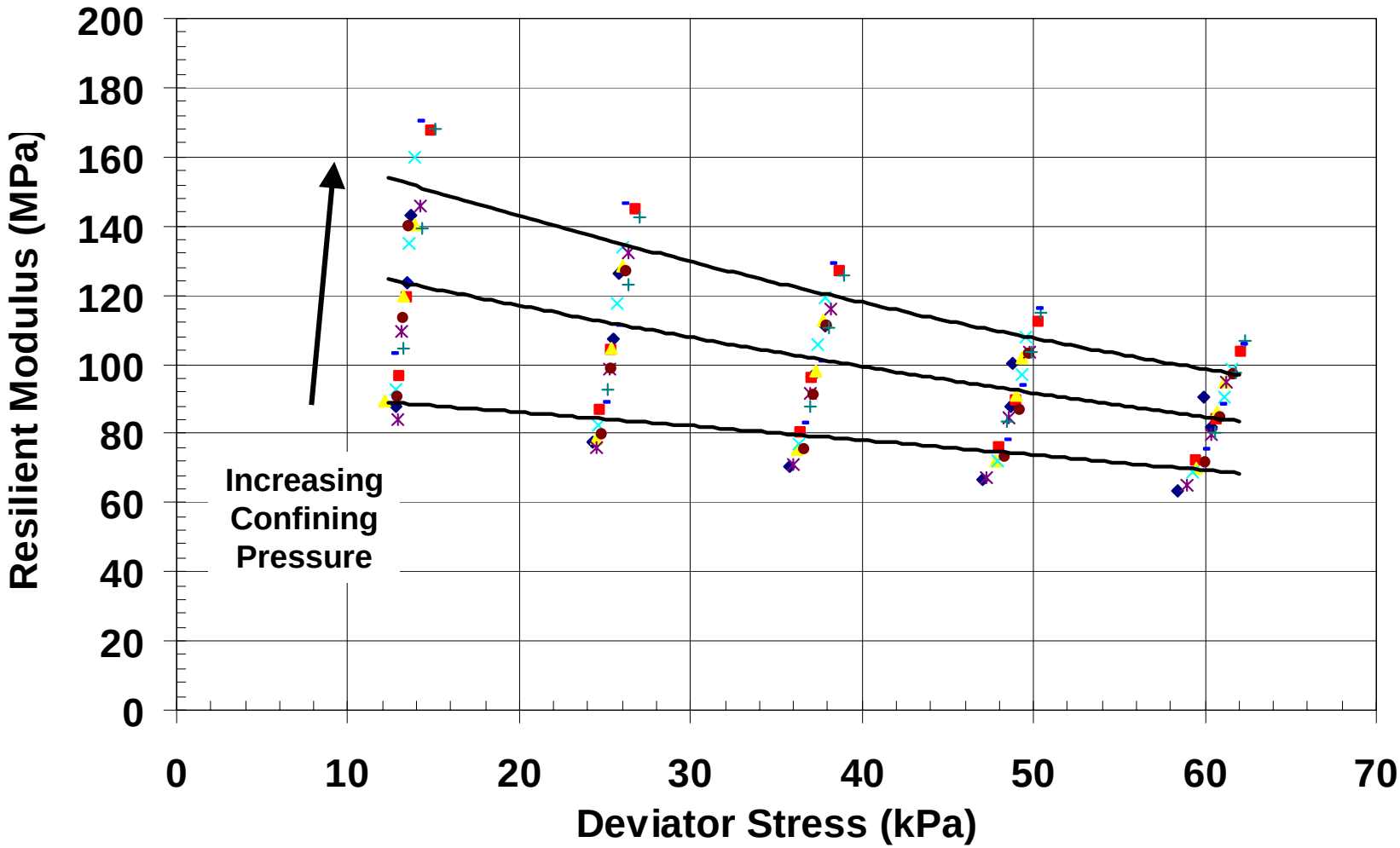
Pavement Response



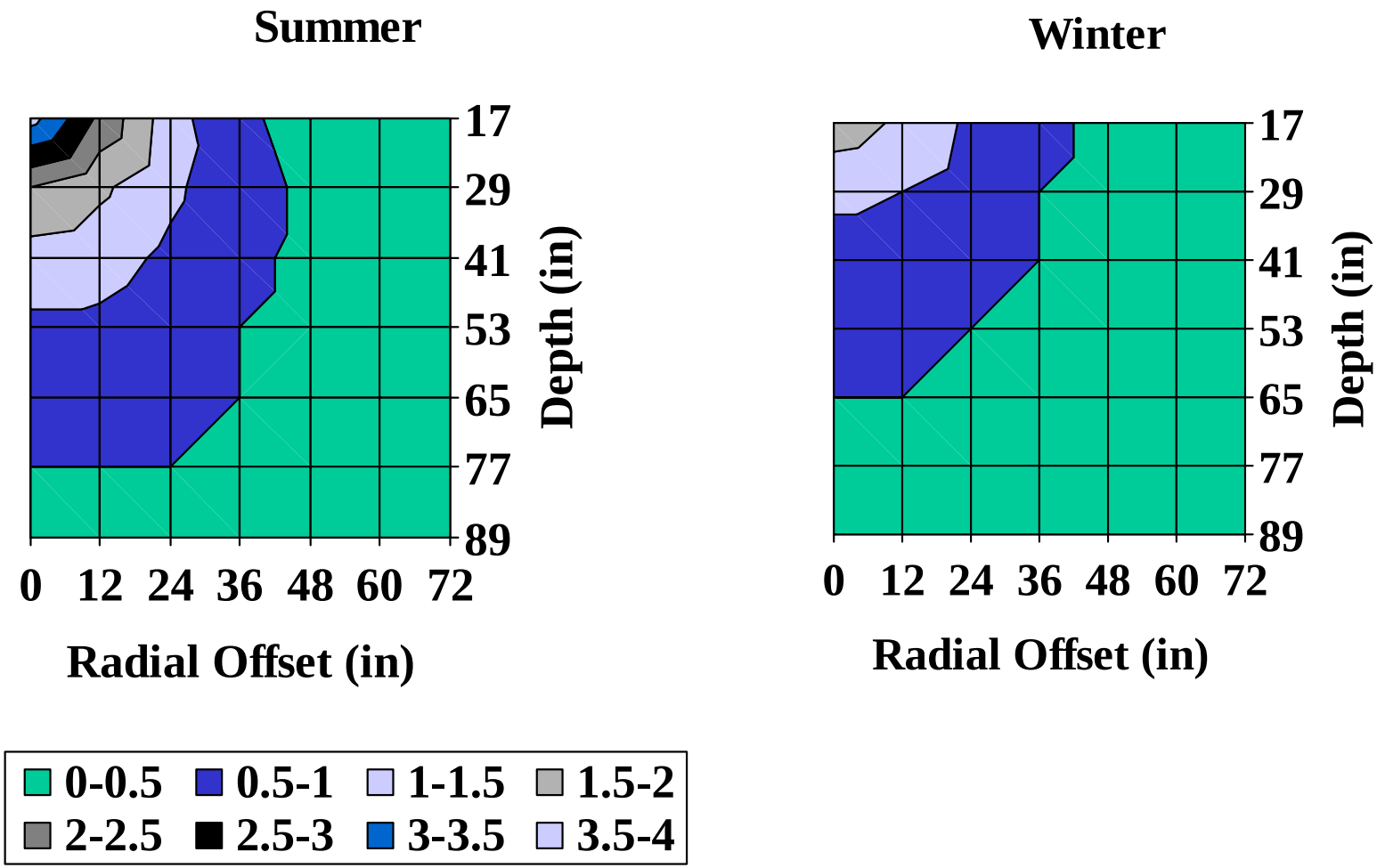
Pavement Response



Material Characterization



Pavement Response



Objective 3

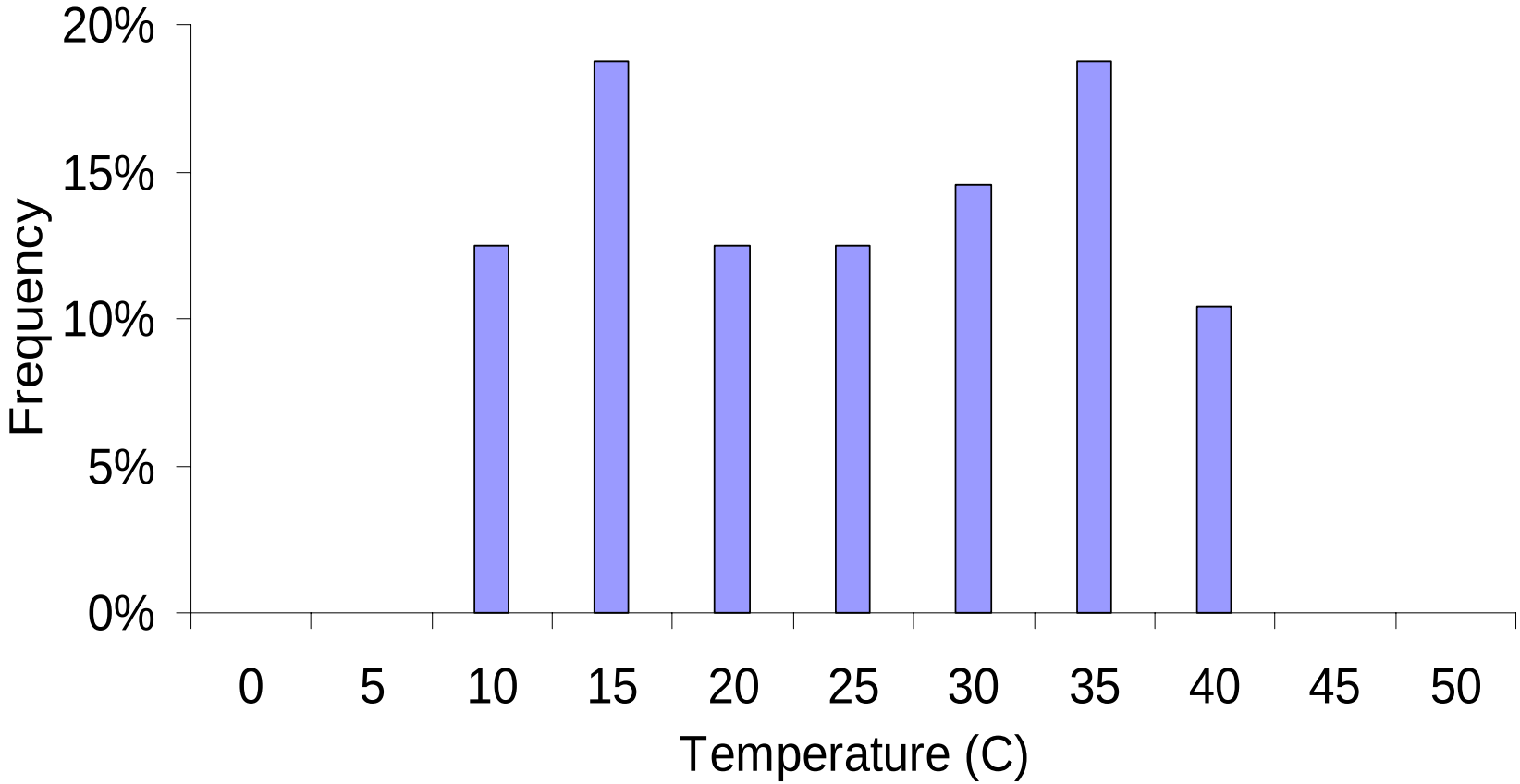
Develop methods to incorporate environmental effects into TDOT pavement design procedures

Temperature Averaging

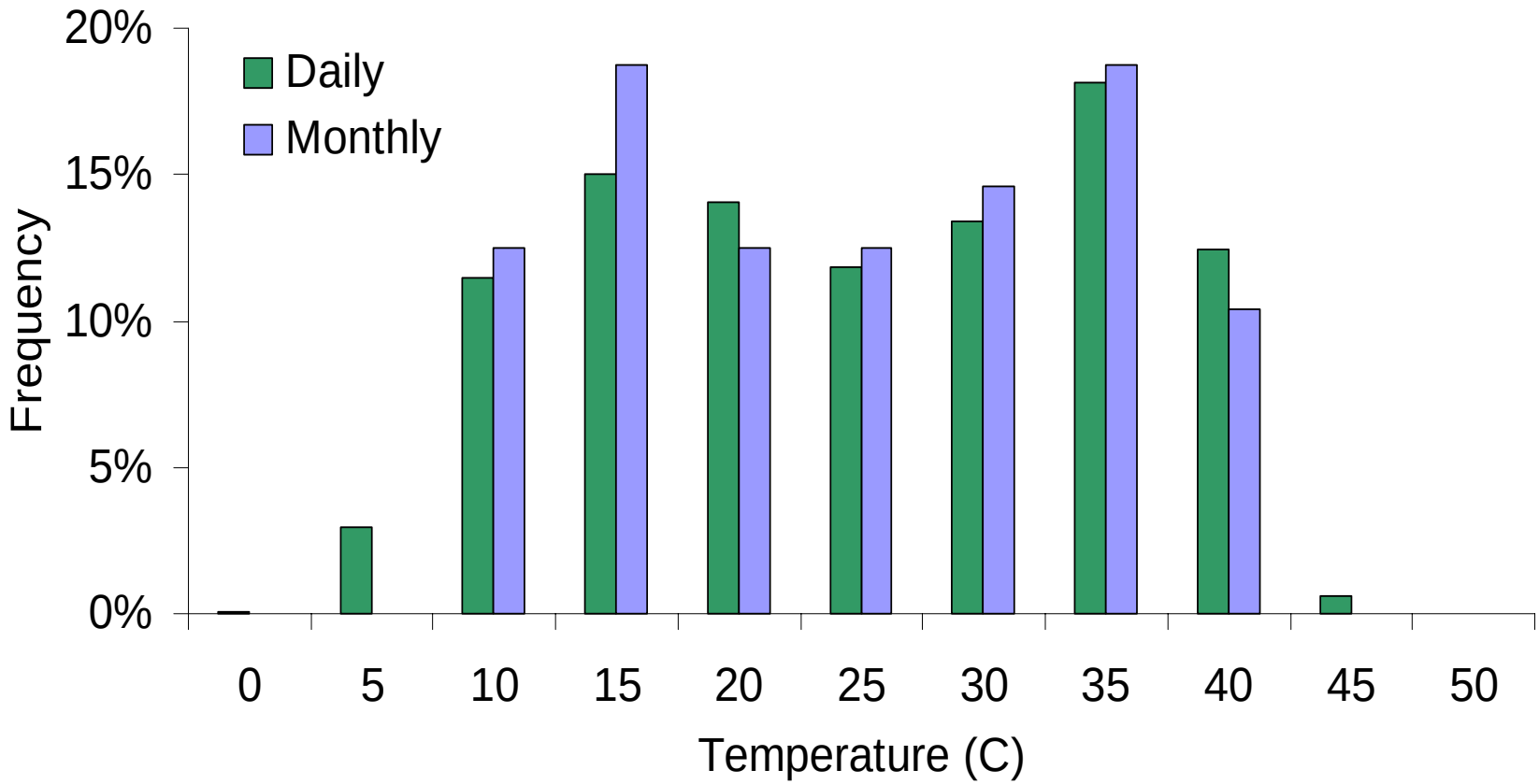
- AC stiffness varies with temperature
- AC stiffness affects the stiffness of underlying stress-dependent materials
- Pavement life estimates are based on the pavement stiffness and so can vary widely depending on AC temperature used in the analysis

Temperature Averaging:

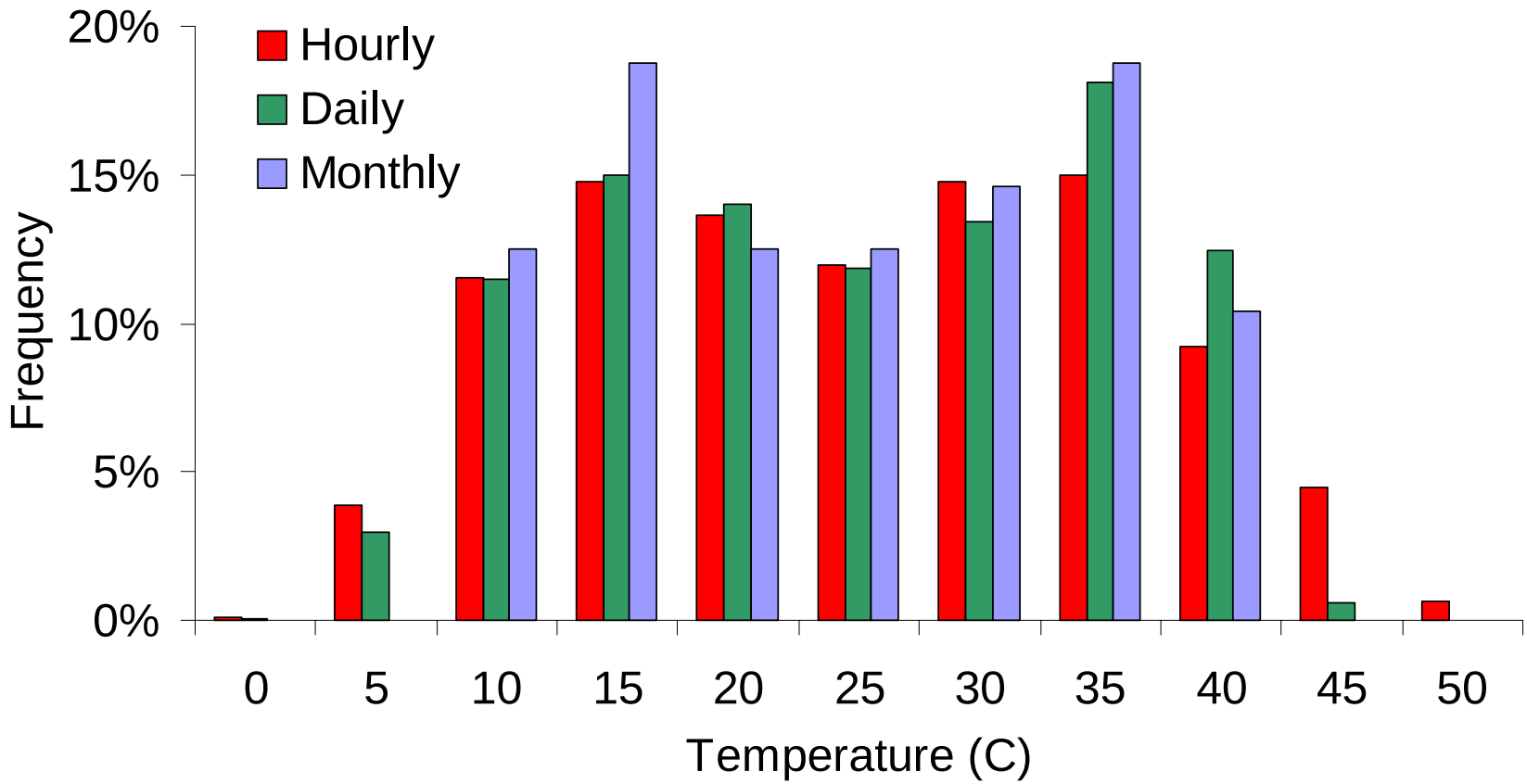
Monthly Data



Temperature Averaging:
Monthly and Daily Data



Temperature Averaging:
Monthly, Daily, & Hourly Data

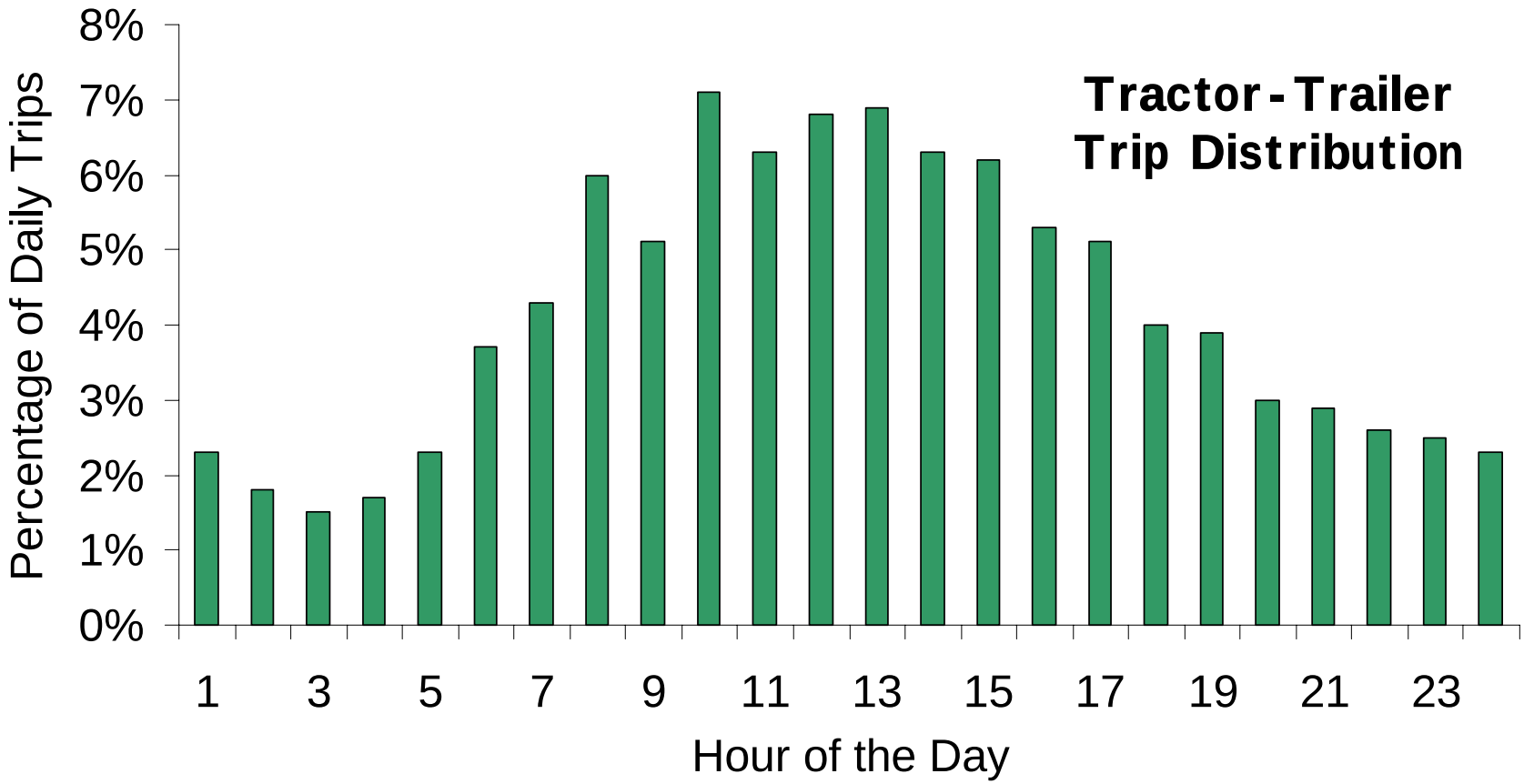


Temperature Averaging

- What is the effect of the temperature averaging interval on computed design life?
- What is the effect of assuming a uniform distribution of traffic throughout the day?

Temperature Averaging

Effect of Traffic Distribution



Temperature Averaging

Subgrade Stiffness	Pavement Life Overestimation Using Uniform Traffic and ...		
	Hourly Average Temps	Daily Average Temps	Monthly Average Temps
Very soft	**11%**		
Soft	**10%**		
Medium	**10%**		
Stiff	**9%**		

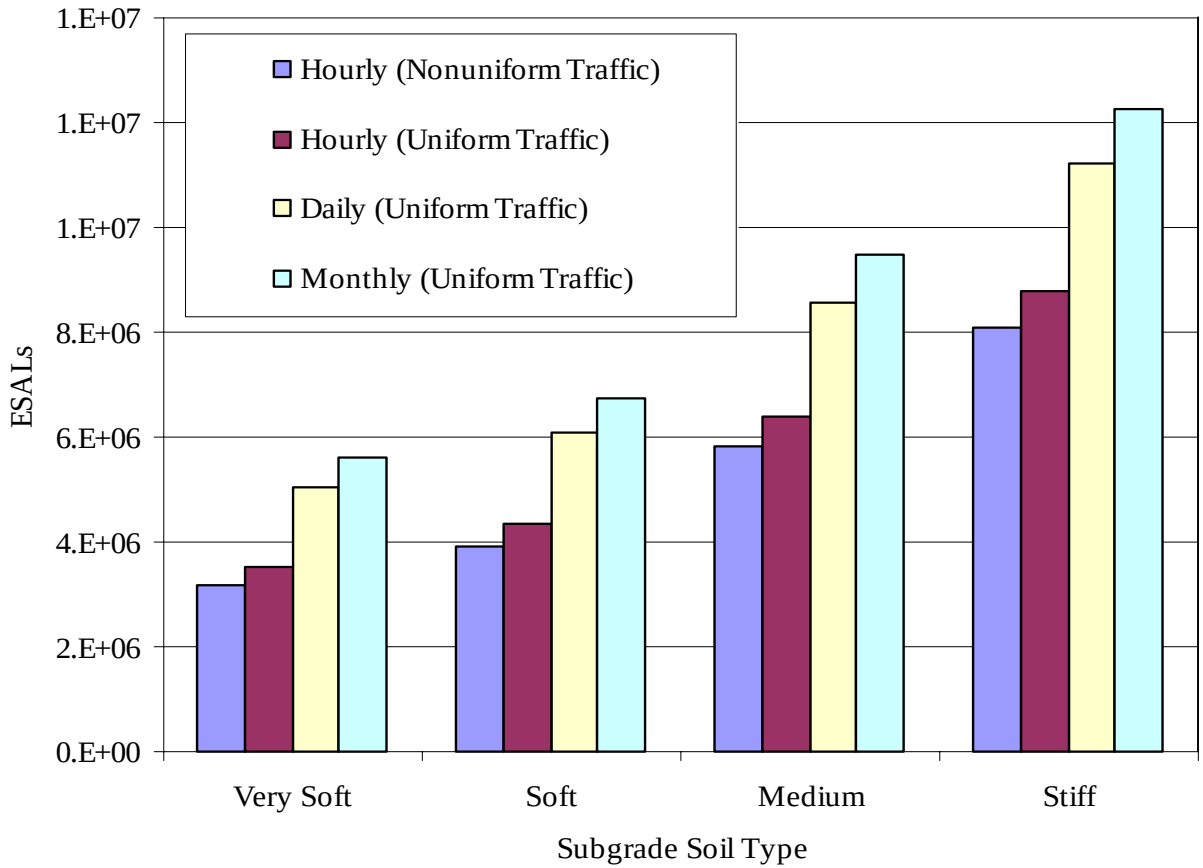
Temperature Averaging

Subgrade Stiffness	Pavement Life Overestimation Using Uniform Traffic and ...		
	Hourly Average Temps	Daily Average Temps	Monthly Average Temps
Very soft	**11%**	**58%**	
Soft	**10%**	**54%**	
Medium	**10%**	**47%**	
Stiff	**9%**	**39%**	

Temperature Averaging

Subgrade Stiffness	Pavement Life Overestimation Using Uniform Traffic and ...		
	Hourly Average Temps	Daily Average Temps	Monthly Average Temps
Very soft	**11%**	**58%**	**76%**
Soft	**10%**	**54%**	**71%**
Medium	**10%**	**47%**	**62%**
Stiff	**9%**	**39%**	**52%**

Temperature Averaging



Temperature Averaging

- To obtain the most reliable estimates of design life, use hourly temperature data whenever possible.
- If hourly truck traffic distribution is known, reliability can be increased even more.

Summary and Conclusions

Summary

- Four years of data at 4 sites in TN
  - Climatic data
  - Pavement temperature
  - Base and subgrade moisture
  - Infiltration
  - Layer moduli
- This is a rare and valuable dataset

Conclusions

- TDOT surface courses are relatively impermeable (at least early on)
- TDOT designs limit the stresses in subgrade
- Water content of subgrade may not change much seasonally (at least in fill sections)

Conclusions

- FWD is sensitive enough to pick up stress-dependence of subgrade soils
- Using monthly average temperatures to estimate asphalt modulus can lead to under-designed pavements

Issues to Address

Issues to Address

- As instrumented pavements age, how will they respond to wheel loads?
  - AC properties will certainly change
  - Infiltration will probably increase
  - Drainage layers may stop working
  - Water content may change long-term

Issues to Address

- Do “cut” sections respond the same as “fill” sections now and over time
  - Measure FWD response in cut areas at the same time as in fill areas
  - Measure water content (by sampling) and compare to TDR data in fill sections

Questions?