



# Pavement Foundation Quality Assurance Opportunities

Arizona Pavements and Materials Conference  
Phoenix, Arizona

November 15-16, 2017

John Siekmeier P.E. M.ASCE

*Your Destination...Our Priority*



# Acknowledgements

- ▶ Minnesota DOT Districts and Local Agencies
- ▶ Other State DOTs, FHWA and NCHRP
- ▶ Contractors and Manufacturers
- ▶ Universities and Consulting Engineers
- ▶ U.S. Congress “MAP-21” and “FAST”



# Presentation Outline

- ▶ Pavement Foundations are Important
- ▶ Pavement Design Framework
- ▶ Performance Based Specifications
- ▶ Quantifying Moisture and Geogrid
- ▶ Lessons Learned and Next Steps



# Pavement Foundations are Important

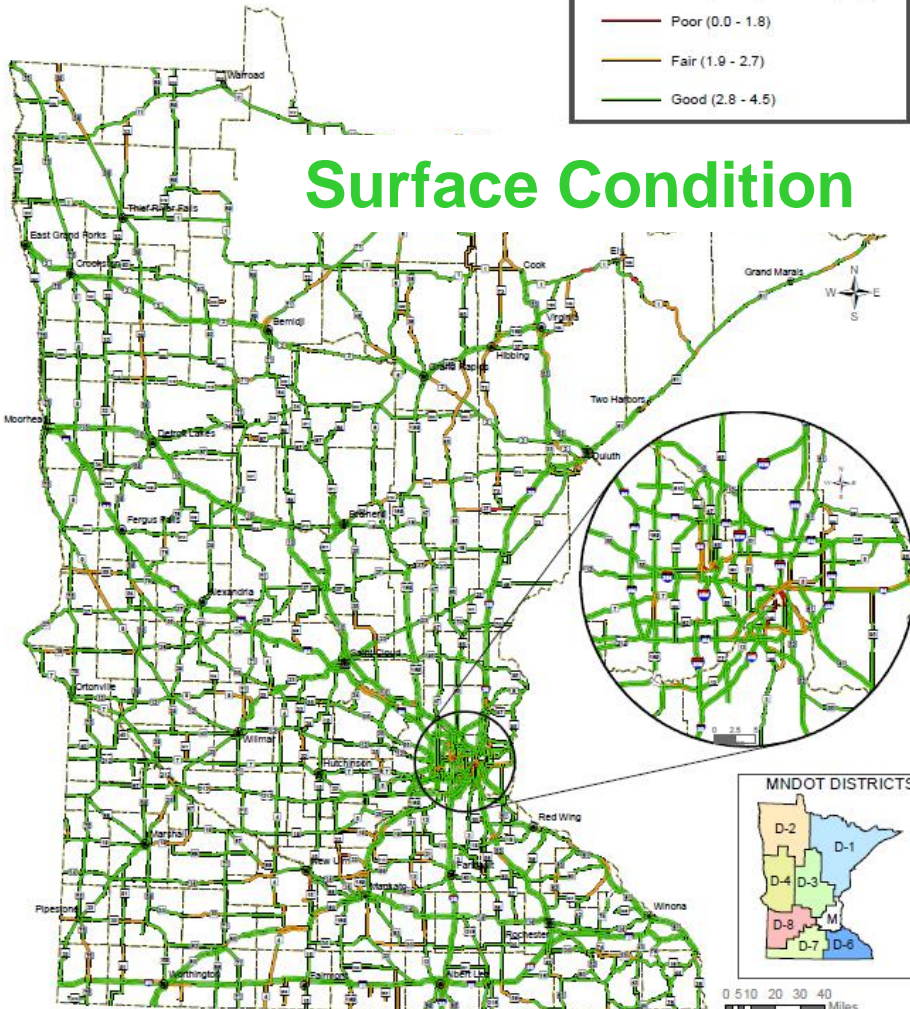
**mn** DEPARTMENT OF  
TRANSPORTATION

STATEWIDE  
2016 PAVEMENT CONDITION

Pavement Quality Index (PQI)

- Poor (0.0 - 1.8)
- Fair (1.9 - 2.7)
- Good (2.8 - 4.5)

Surface Condition



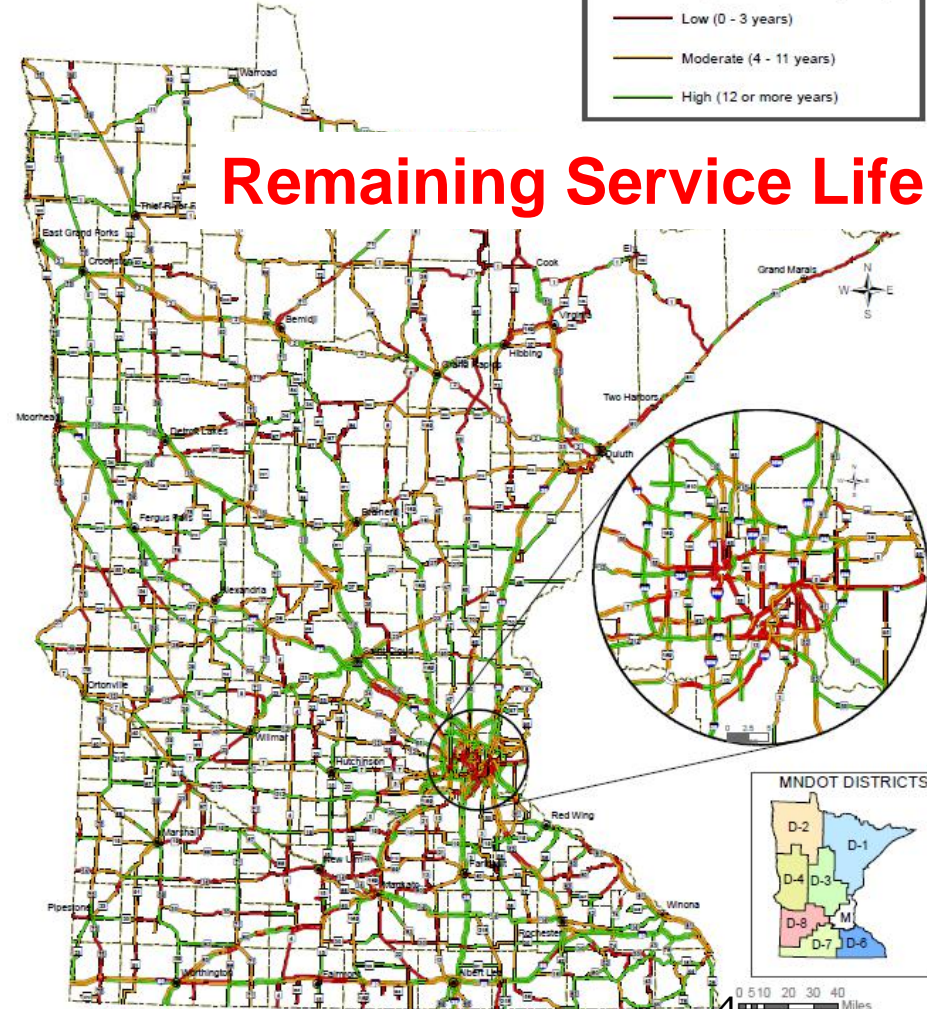
**mn** DEPARTMENT OF  
TRANSPORTATION

STATEWIDE  
2016 PAVEMENT CONDITION

Remaining Service Life (RSL)

- Low (0 - 3 years)
- Moderate (4 - 11 years)
- High (12 or more years)

Remaining Service Life

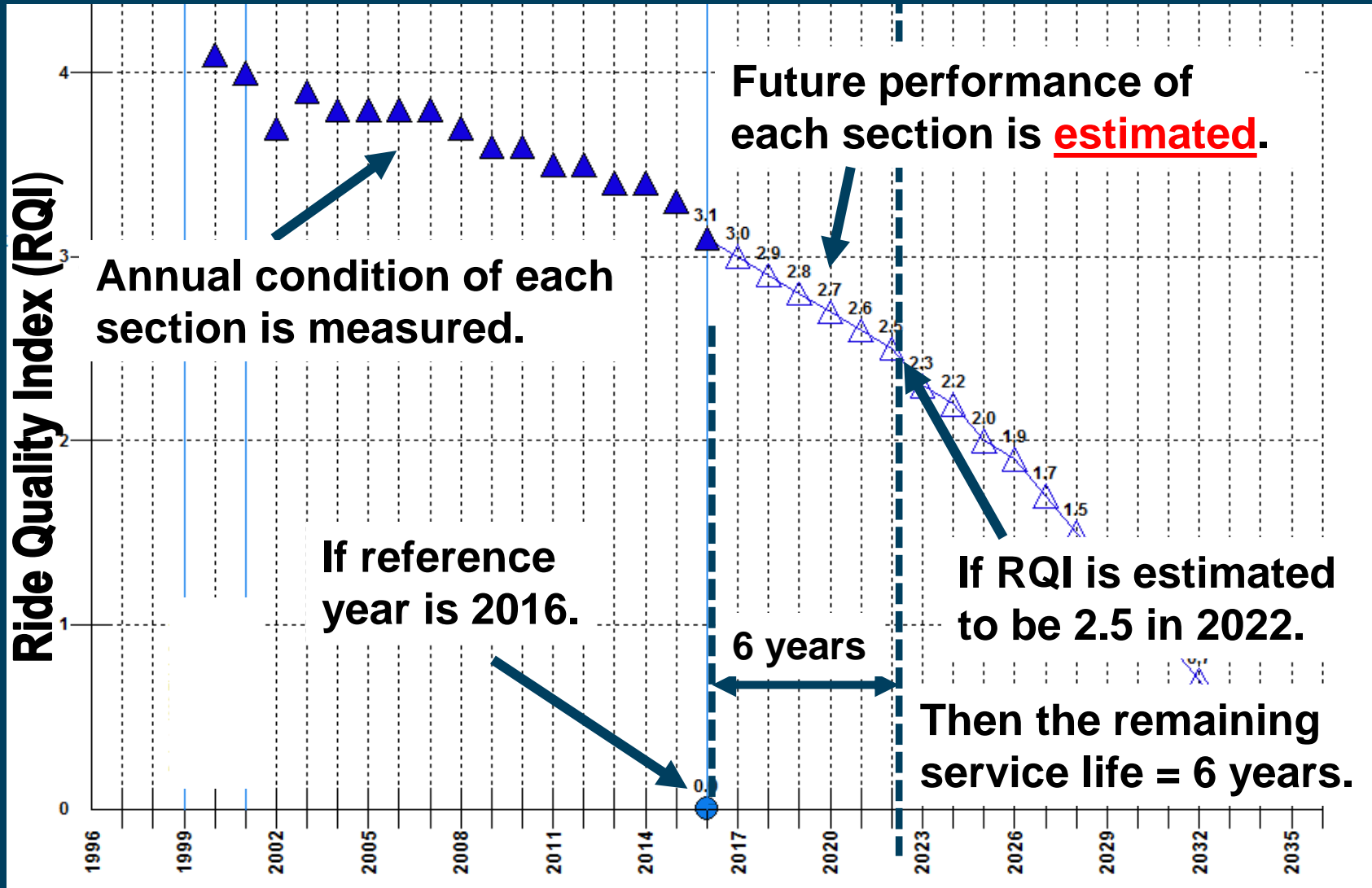




# Pavement Management Van



# What is Remaining Service Life?



# Mechanistic Pavement Design is Part 1 of the Solution

- ▶ Provides the framework for using performance based material properties
- ▶ Free pavement design software available [www.dot.state.mn.us/app/mnpave/index.html](http://www.dot.state.mn.us/app/mnpave/index.html)
- ▶ Just Google “MnPAVE”



# Minnesota Department of Transportation

Office of Materials & Road Research

1400 Gervais Avenue, MS 645

Maplewood, MN 55109

## Memo

TO: PCMG, CMG, MnDOT Districts, Materials Engineers, Soils Engineers, State Aid

FROM: Glenn M. Engstrom, Director  
Office of Materials & Road Research

DATE: October 31, 2014

SUBJECT: Pavement Design Manual Publication

I am pleased to announce the publication of the MnDOT Pavement Design Manual.

This publication represents a significant effort to update pavement design procedures and codify existing documents into a single point of reference. As of November 1, 2014, all MnDOT pavement designs shall follow the pavement design, pavement-type selection, LCCA, and alternate bidding as laid out in the Pavement Design Manual. To view the manual, please follow <http://www.dot.state.mn.us/materials/pvmtdesign/newmanual.html>





# Design Requires Performance Inputs

Structure

Confidence Level  
(50 to 99%)

85

Default

View

☒ Thickness Values

☐ Coefficient of Variation

☐ Adjusted Thickness

☐ Mill and Overlay

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4
<input type="radio"/> 2	Old HMA	4
<input type="radio"/> 3	AggBase	12
<input type="radio"/> 4	EngSoil	24
<input checked="" type="radio"/> 5	UndSoil	

BasicIntermediateAdvanced

View

☒ Test Results

☐ Resistance Factors

☐ Coefficient of Variation

Check box to enter test data.  
Uncheck to use Basic defaults.

Old HMA Modulus

☒ Default Values

☐ FWD Deflections

FWD Data

Agg. Test Type

☐ Lab Mr, ksi

☒ R-Value

☐ DCP,mm/blow

Soil Test Type

☐ Lab Mr, ksi

☒ R-Value

☐ DCP,mm/blow

☐ Silt % Clay %

Other

☒ Design Modulus, ksi

☐ Poisson's Ratio

PG 58-34

PG 58-28

CL5

CL

CL

MINNESOTA

DEPARTMENT OF TRANSPORTATION

# Performance Based Construction Testing is Part 2 of the Solution

- ▶ Draft specifications produced by NCHRP 10-84 and Transportation Pooled Fund TPF 5(285)
- ▶ Modified version is available at NRRA Pooled Fund website (Geotechnical Team)  
<http://www.dot.state.mn.us/mnroad/nrra/index.html>
- ▶ Just Google “NRRA”



# Change is Underway

- ▶ From Traditional Construction Testing
  - Specify Relative Density
  - Specify Gravimetric Moisture
  - Observation and Test Rolling
- ▶ To Performance Based Construction Testing
  - Specify Modulus and/or Strength
  - Specify Volumetric and/or Gravimetric Moisture
  - Observation, Test Rolling, and/or Intelligent Compaction



# DCPs and LWDs in Indiana

	DCPs	LWDs
Indiana DOT	130+	60+
Private Sector	30+	10+

DCP Indiana DOT Test Method No. 509-15P

LWD Indiana DOT Test Method No. 508-12T





# Back to the Future: Ralph Proctor reminds us.

- Strength is not achieved by density alone.
- Optimum moisture is for compaction.
- Need to avoid rutting during construction.

photo courtesy of Dr. J. David Rogers  
University of Missouri-Rolla



# Ralph Proctor, 1945, Trans 110, ASCE

- ▶ “Methods for hand compaction, such as dropping various weight tampers from different heights and mechanical tampers, were tried and discarded.”
- ▶ “No use is made of the actual peak dry weight.”
- ▶ “The measure of soil compaction used is the indicated saturation penetration resistance.”



# Proctor Penetrometer



Photo courtesy of Humboldt



# Dynamic Cone Penetrometer

ASTM D 6951-03





# Light Weight Deflectometer

**ASTM E 2583 07**

(includes load measurement)

**ASTM E 2835 11**

(no load measurement)

**AASHTO TP 123-01 draft**

(determining lab target values)

**AASHTO TP 456-01 draft**

(field quality assurance)

[http://roads.maryland.gov/OPR\\_Research/MD-17-TPF-5-285-LWD\\_REPORT.pdf](http://roads.maryland.gov/OPR_Research/MD-17-TPF-5-285-LWD_REPORT.pdf)



# Benefits of Performance Tests

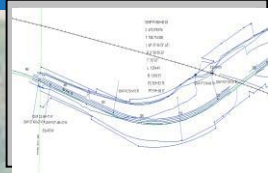
- ▶ Empowers inspector with useful measures
- ▶ Verifies pavement design inputs
- ▶ Creates as-built record of construction
- ▶ Optimizes future pavement designs





# Design, Construction and Performance

## Pavement Design



## Construction Quality Control



12INP PI 508+60.83  
X 473,379.574  
Y 189,714.409  
40° 37' 06.72" (LT)  
D 2° 59' 56.33"  
T 707.07'  
L 1,354.41'  
R 1,910.51'  
PC 501+53.76  
PT 515+08.17

EQUATION:

NP PC

## Performance Measurement



## Construction Quality Assurance



# Construction Testing Summary

- ▶ LWDs and DCPs are being used to measure properties that significantly affect performance (this includes moisture measurement).
- ▶ Minnesota DOT policy encourages compaction equipment be used to fully map the as-built pavement layers.
- ▶ AASHTO draft specifications are available for performance based construction management.





# Quantifying the Importance of Moisture



# MnROAD Case Studies



Ruth Roberson Thesis, 2007



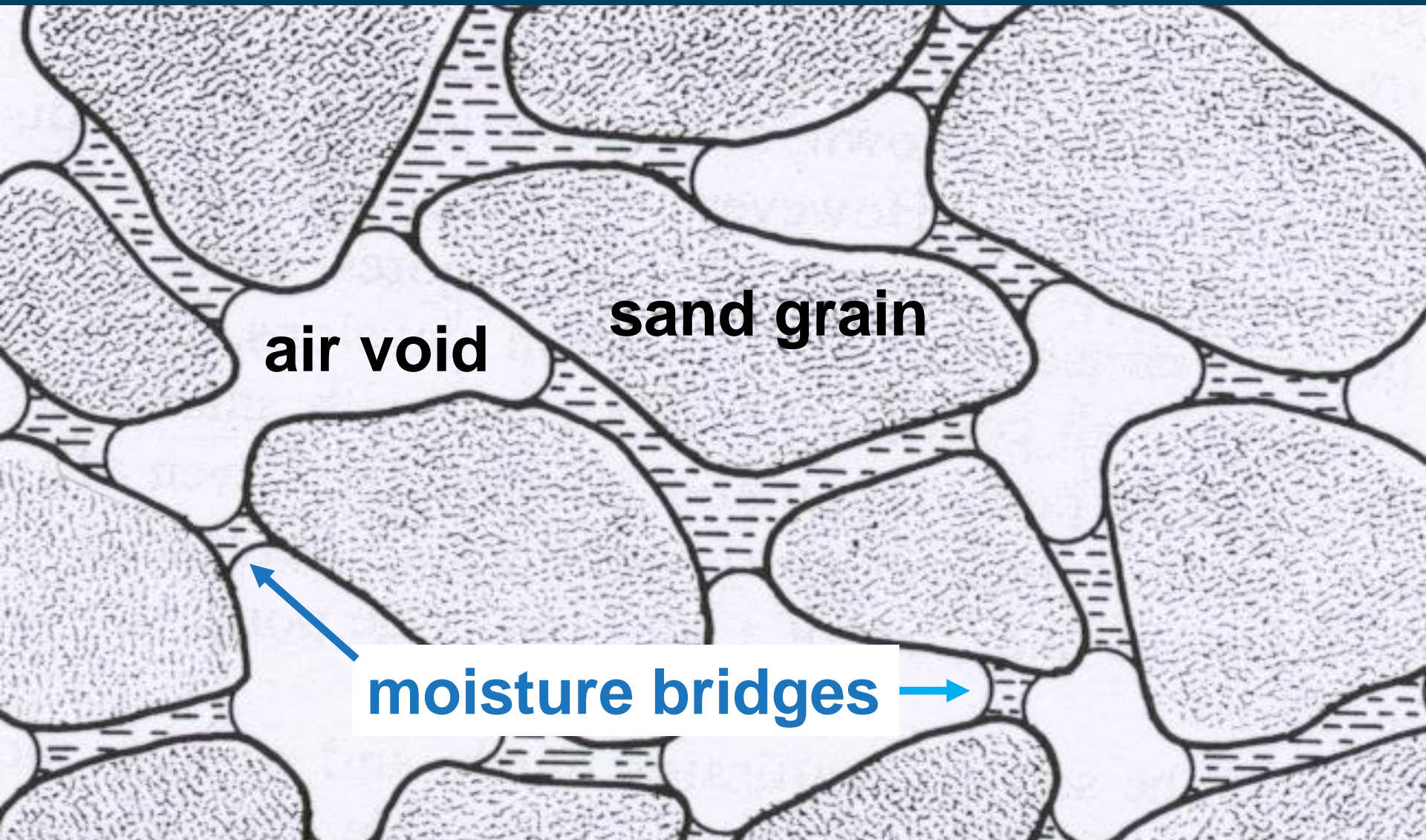
# Lessons Learned from Case Studies

- ▶ Modulus and strength are greatly affected by the moisture between the particles, which causes a suction or tensile stress between the particles.
- ▶ Tensile stress between particles depends on:
  - Quantity of sand, silt, and clay particles (gradation)
  - Particle shape (roughness)
  - Porosity (total void space “openness”)
  - Moisture content (how much water is in the voids)






# Fundamentals of Soil Physics, Hillel



# Need Moisture Content Inputs



## Structure

Confidence Level (50-99)  ☐ Use Mean Values

Overburden Calculation

View

- ☒ Thickness Values
- ☐ Coefficient of Variation
- ☐ Adjusted Thickness

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	5
<input type="radio"/> 2	AggBase	9
<input type="radio"/> 3	Subbase	12
<input type="radio"/> 4	EngSoil	36
<input checked="" type="radio"/> 5	UndSoil	

Design Mode:

Units

- ☒ English
- ☐ SI

Finished Structure  
Go to Control Panel

Basic | Intermediate | Advanced

Design Mode

- ☒ Use values from Basic Design Level
- ☐ Use values from Intermediate Design Level
- ☐ Advanced mode (enter values now)

Parameter Shown Below

- ☐ Design Modulus, ksi
- ☐ Poisson's Ratio
- ☒ Seasonal Modulus Multipliers
- ☐ Modulus Coefficient of Variation, %

Structural Number = 3.7

moisture included here

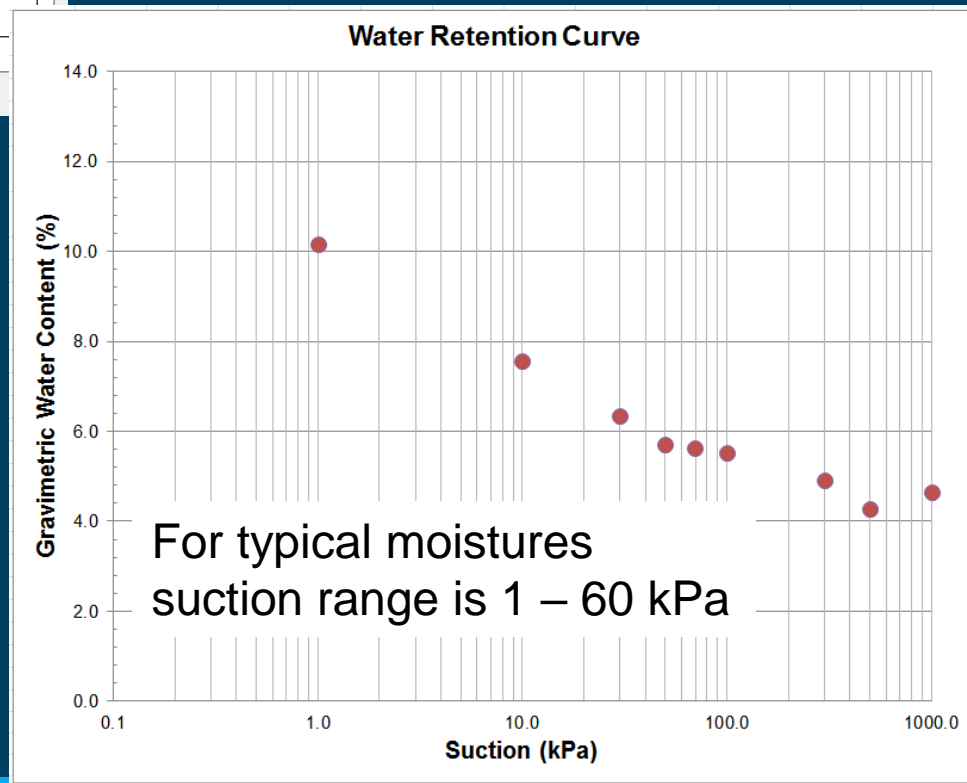
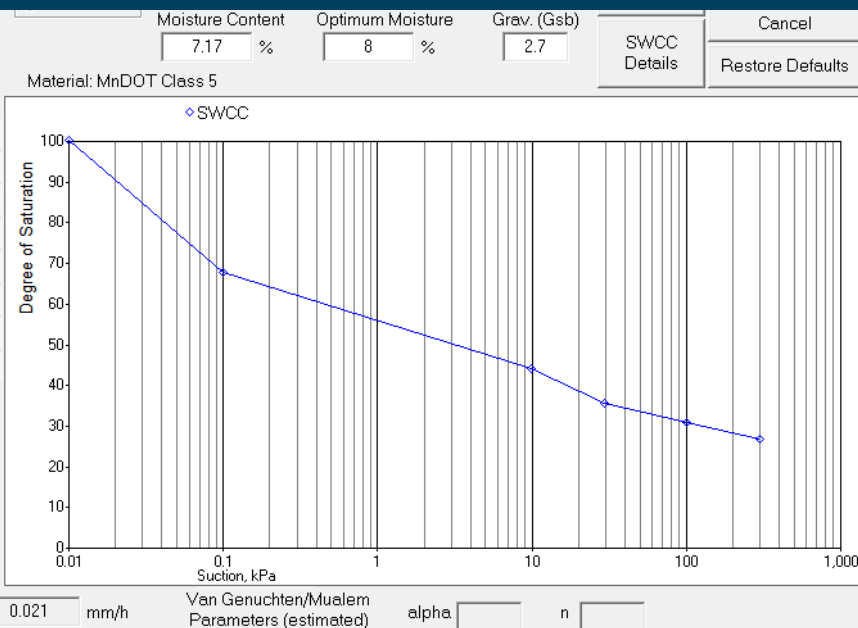
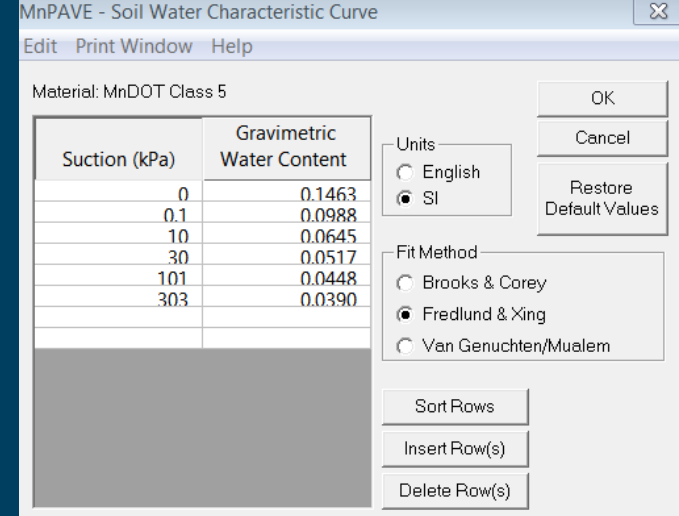
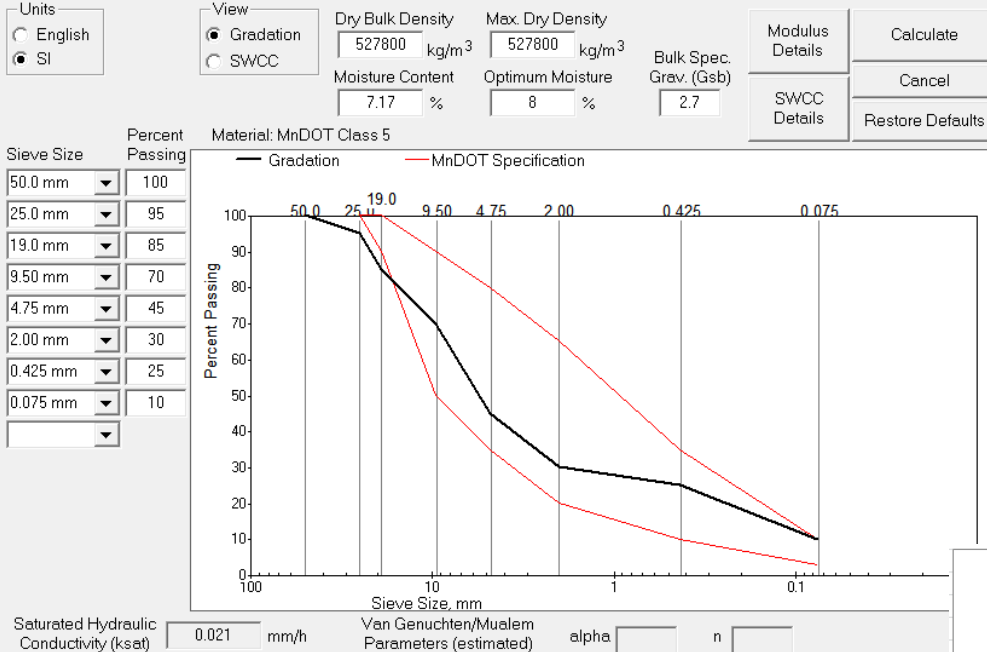
Fall	Winter	Early Spring	Late Spring	Summer
1	1	1	1	1
1	10	0.36	0.84	1.02
1	10	0.3	0.7	0.85
1	10	10	0.7	0.85
1	10	10	0.7	0.85

Simulate FWD | Simulate LWD | View Damage Equations

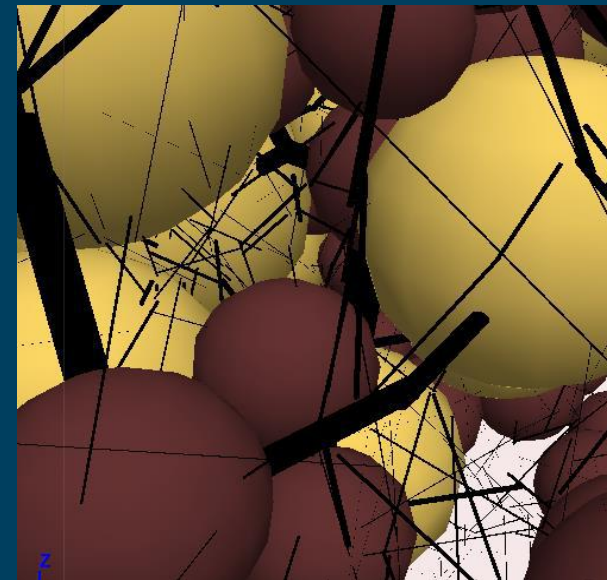
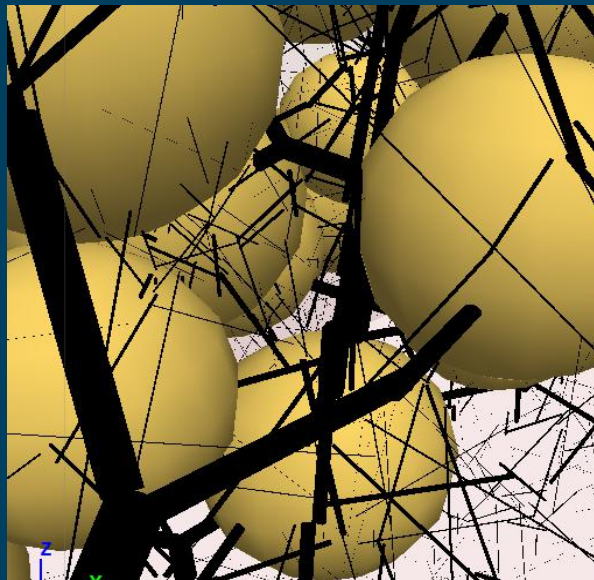
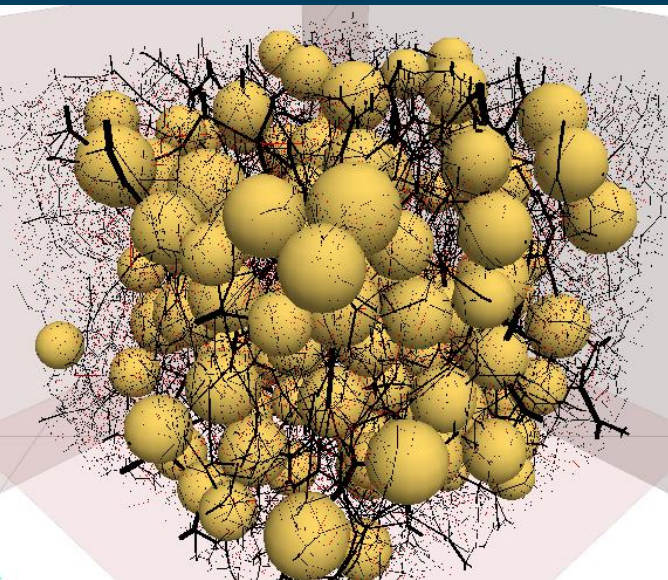
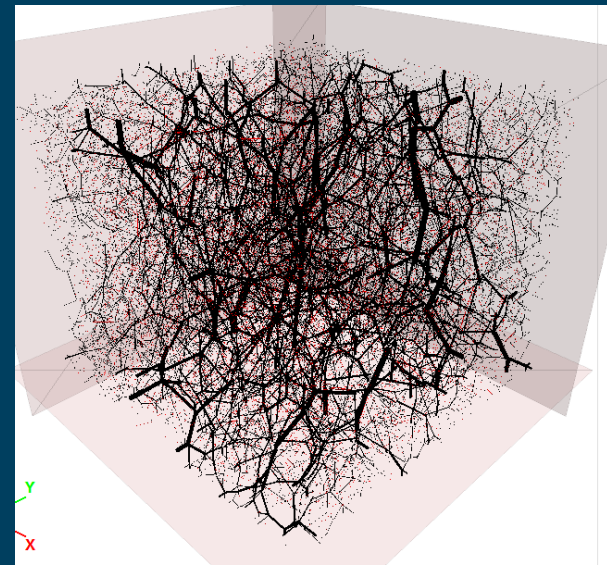
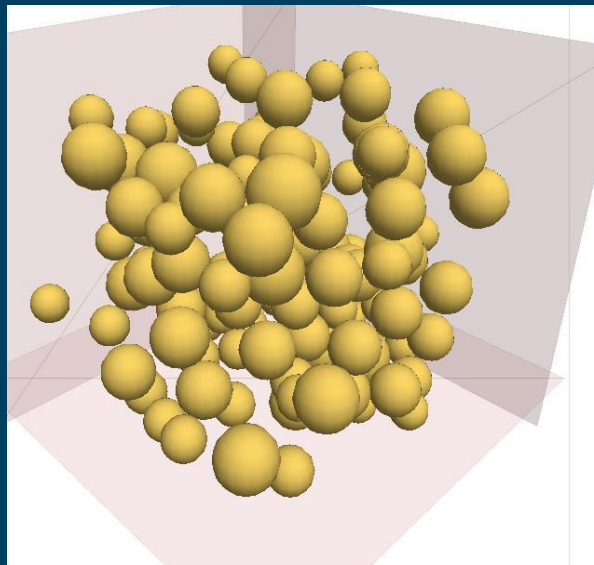
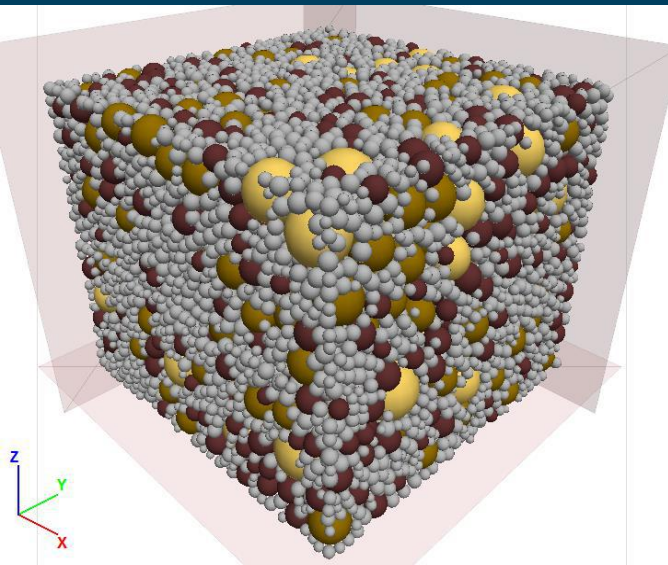
View Pavement Temperature Equation | Input Moisture Characteristics





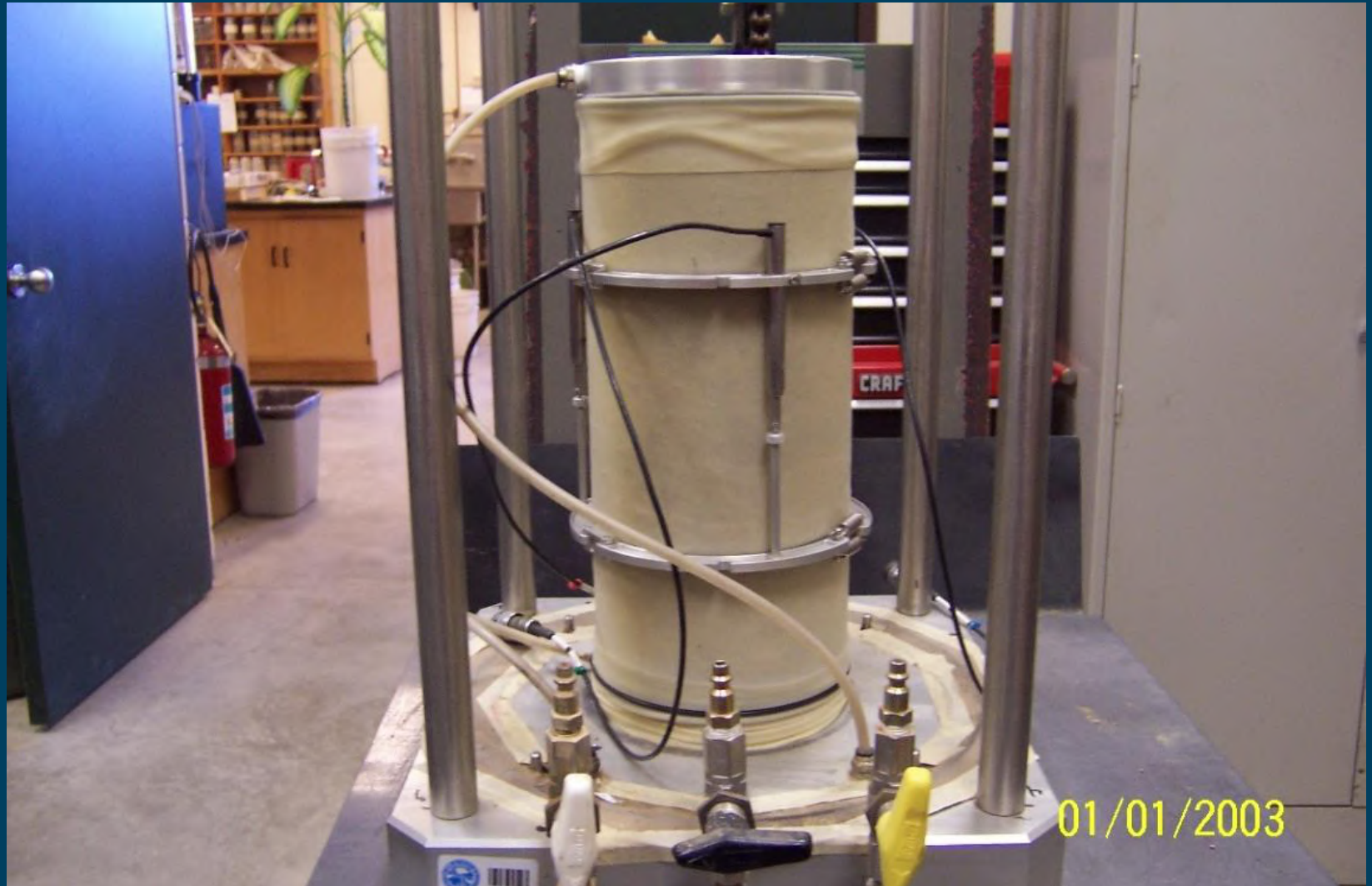


# Distinct Element Model with Suction

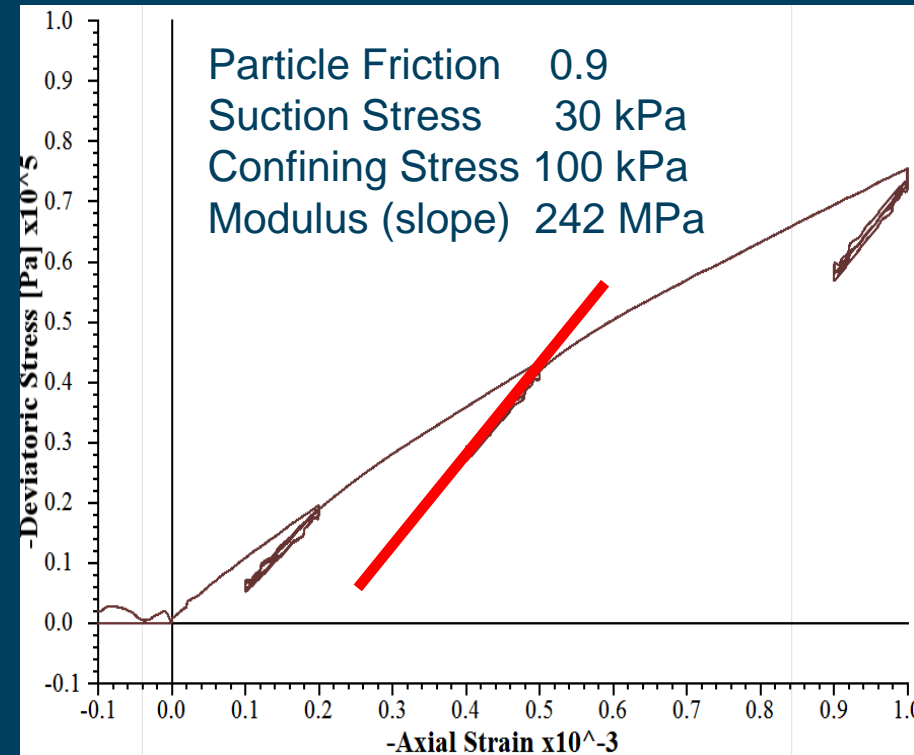
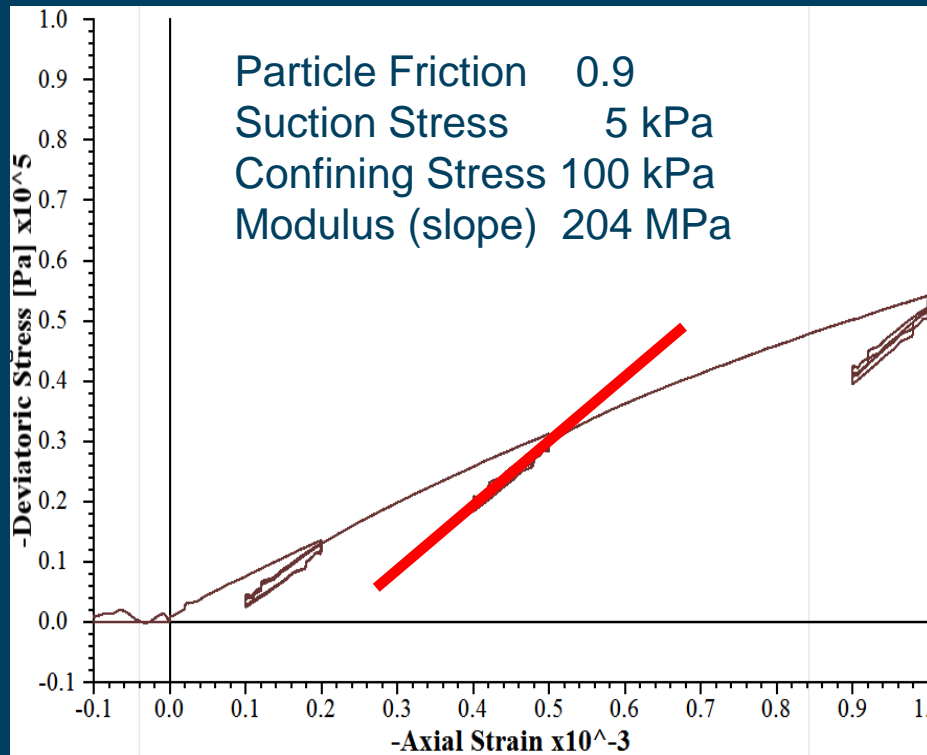




# Laboratory Resilient Modulus



# Numerical Modeling Results




Increasing suction increases resilient modulus.





# Seasonal Factors Compared



## Structure

Confidence Level (50-99)  ☐ Use Mean Values

Overburden Calculation

View

☒ Thickness Values

☐ Coefficient of Variation

☐ Adjusted Thickness

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	5
<input type="radio"/> 2	AggBase	9
<input type="radio"/> 3		
<input type="radio"/> 4		
<input checked="" type="radio"/> 5	UndSoil	

Design Mode:

Units

☒ English

☐ SI

Finished Structure

Go to Control Panel

Basic | Intermediate | Advanced

Design Mode

☒ Use values from Basic Design Level

☐ Use values from Intermediate Design Level

☐ Advanced mode (enter values now)

Parameter Shown Below

☐ Design Modulus, ksi ☐ Adjusted

☐ Poisson's Ratio

☒ Seasonal Modulus Multipliers

☐ Modulus Coefficient of Variation, %

Structural Number = 3.7

Fall	Winter	Early Spring	Late Spring	Summer
1	1	1	1	1
1	10	0.36	0.84	1.02
1	10	10	0.7	0.85

View Pavement Temperature Equation

Input Moisture Characteristics

original factors

1

0.5

0.7

1.2

DEM results from PFC



# Quantifying the Benefit of Geogrid



# Geogrid History and Widening



Photo courtesy of Jim Bittmann





# TH 72 Geogrid Installation 2011



Photo courtesy of Jim Bittmann



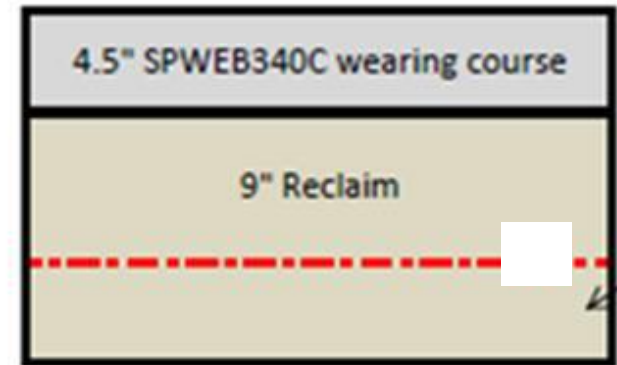




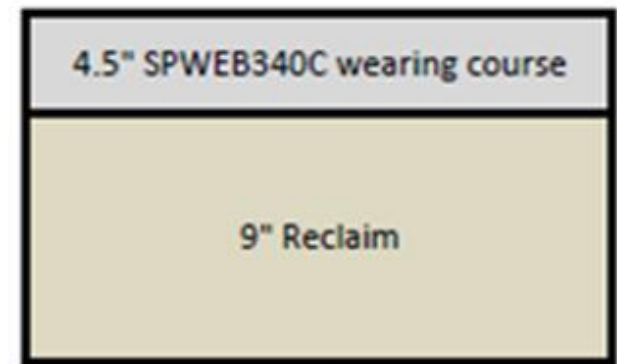
# Geogrid in Aggregate Base Layer

- Ideally geogrid would be the only difference between test sections.
- Reality is that other variables include soil, water, and temperature.

TEST SECTION Q



TEST SECTION R





# Field Testing and Numerical Modeling of In Situ Resilient Modulus



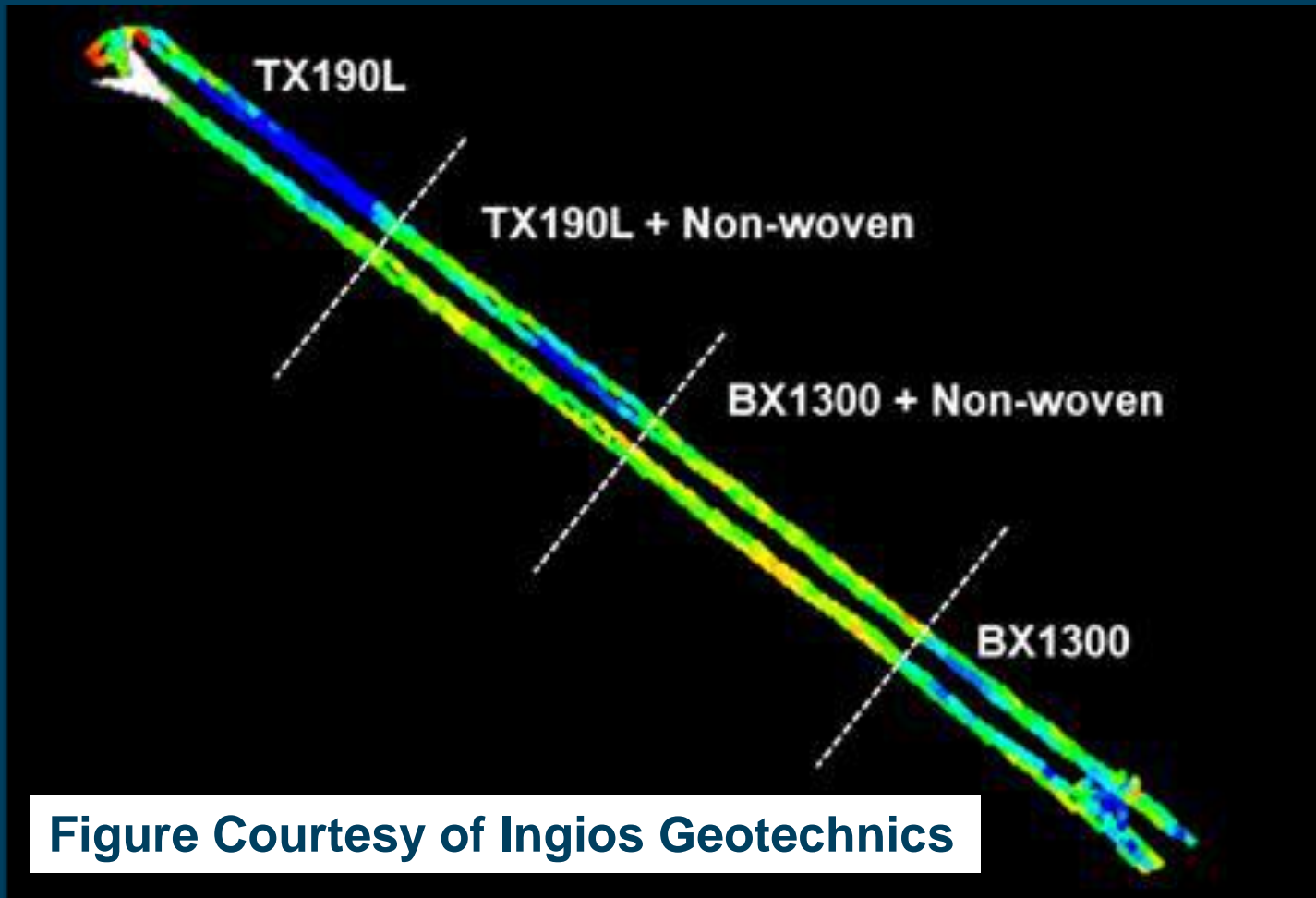


# Automated Plate Load Test (Ingios) Trunk Highway 72 September 2016 MnROAD July August 2017





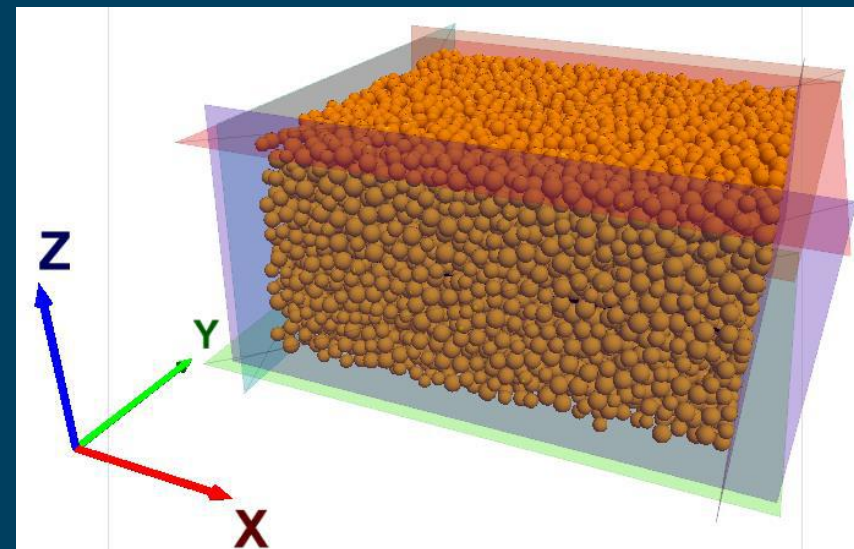
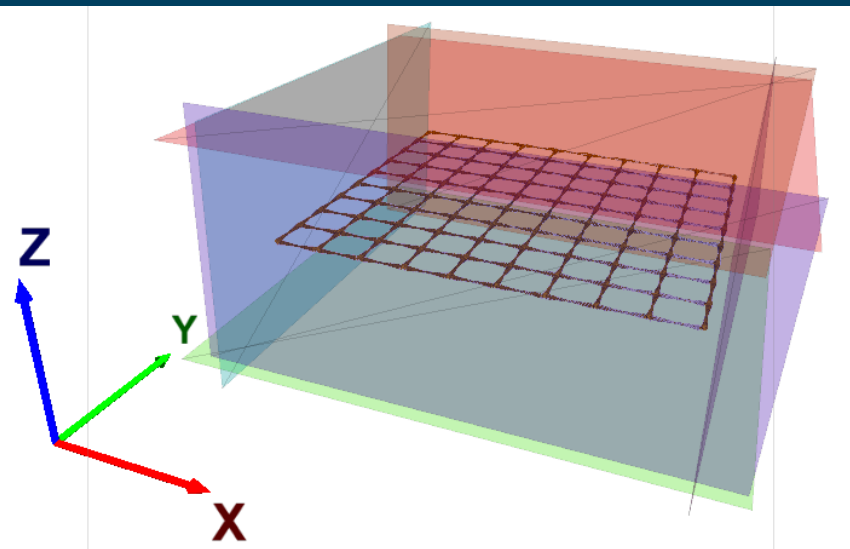
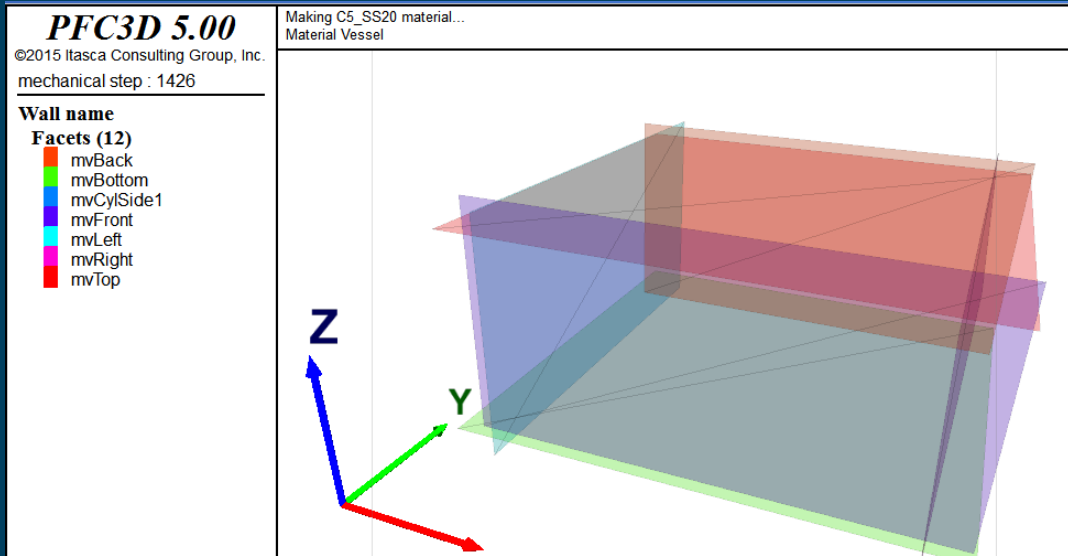
# IC Map of Geogrid MnROAD 2017



Link to Research Pays Off Seminar, David White, October 2017  
<http://www.dot.state.mn.us/mnroad/researchpayoff/index.html>



# Numerical Modeling of Geogrid



# Parameters Studied

Aggregate gradation

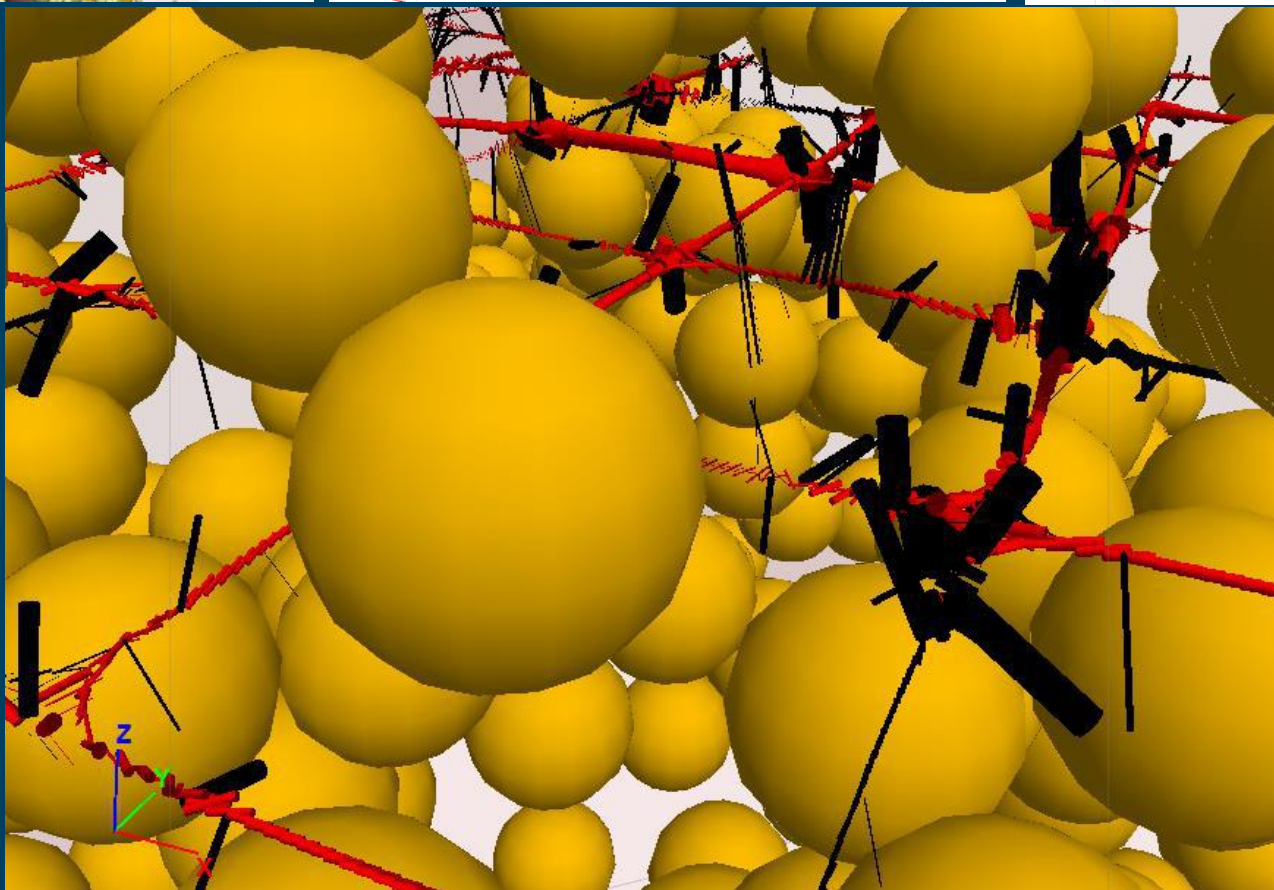
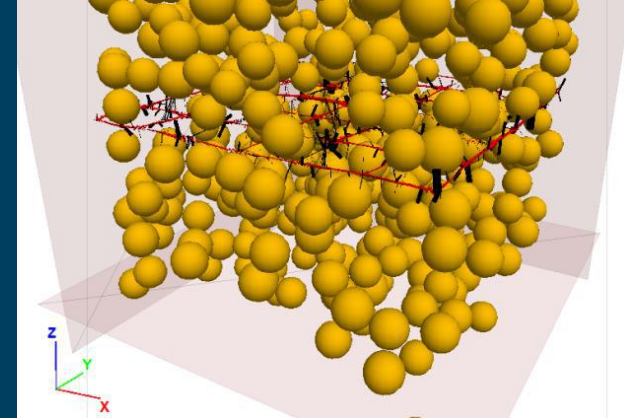
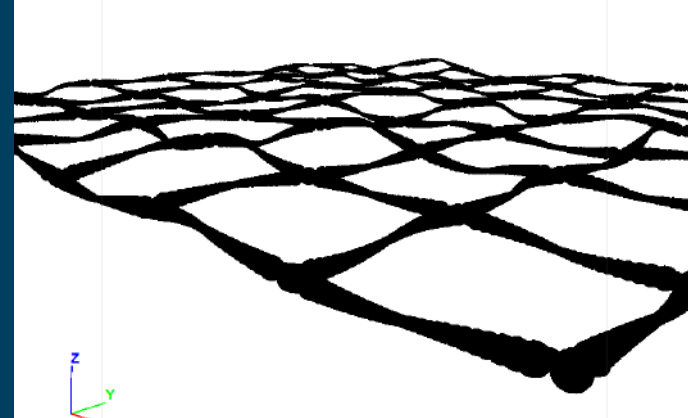
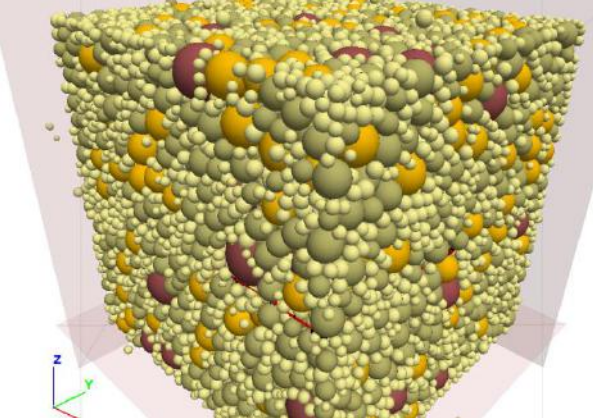
Friction between particles (roughness)

Moisture content (suction/tensile stress)

Confining stress

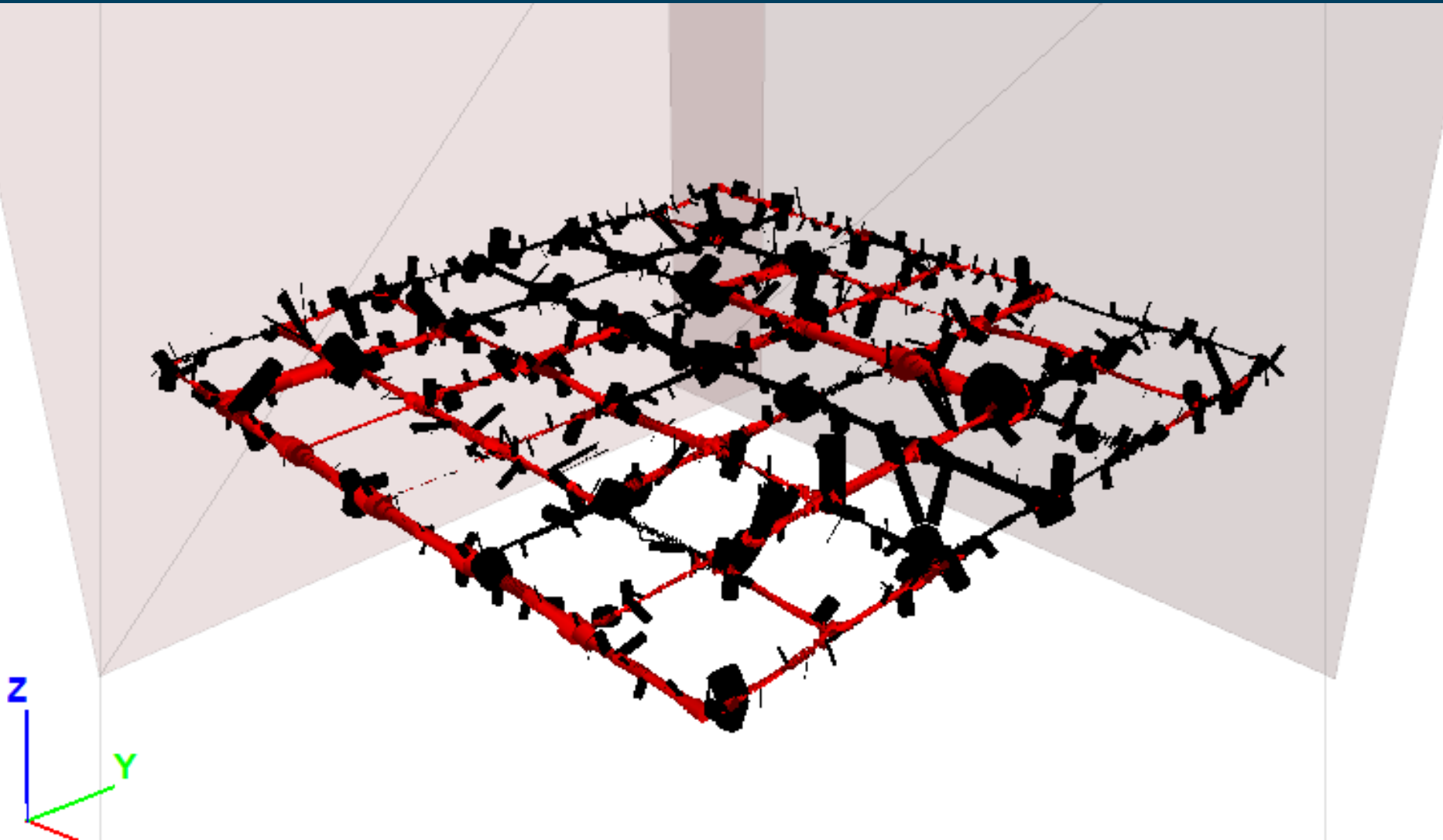
Geogrid depth within aggregate base layer



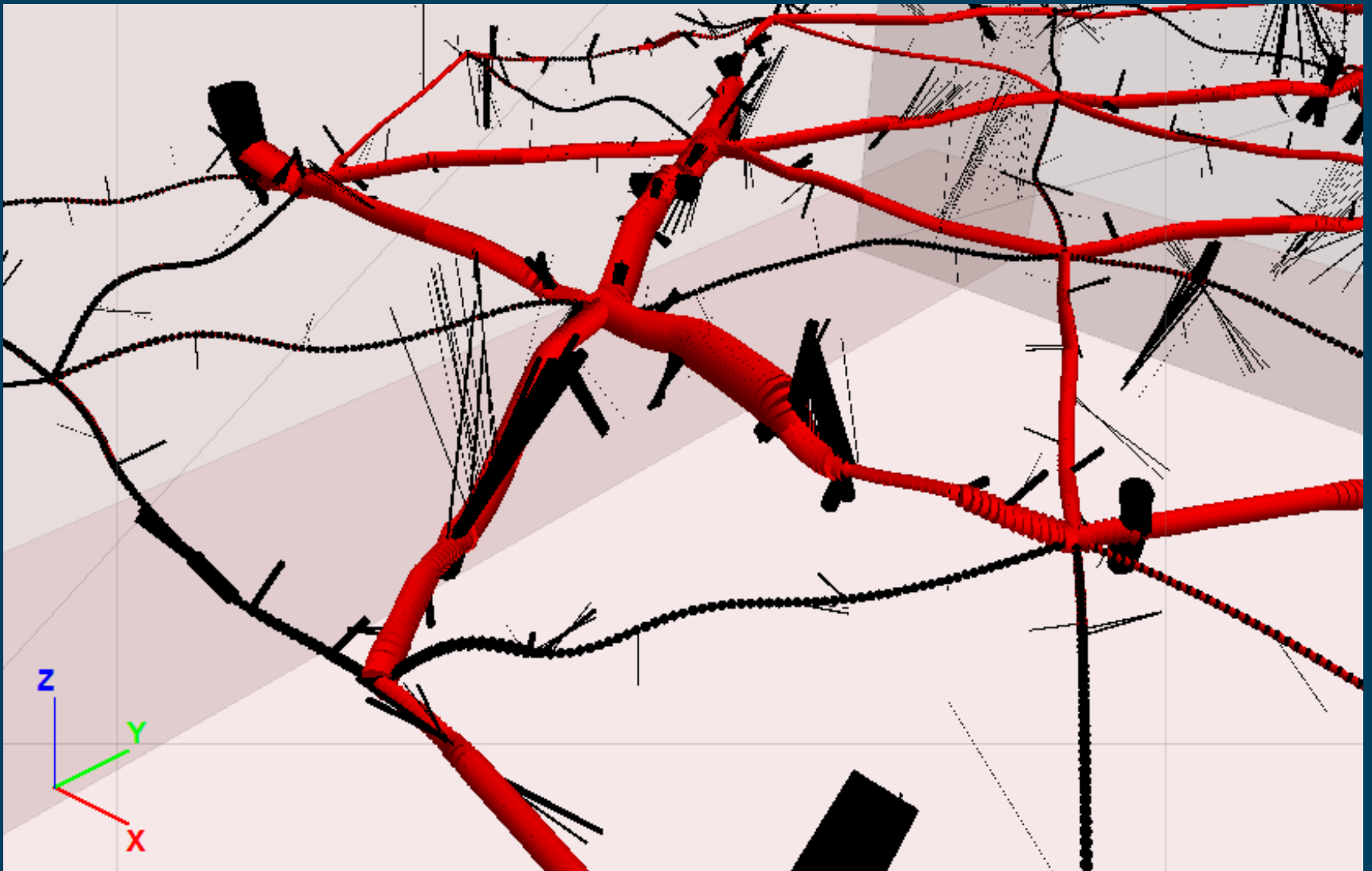




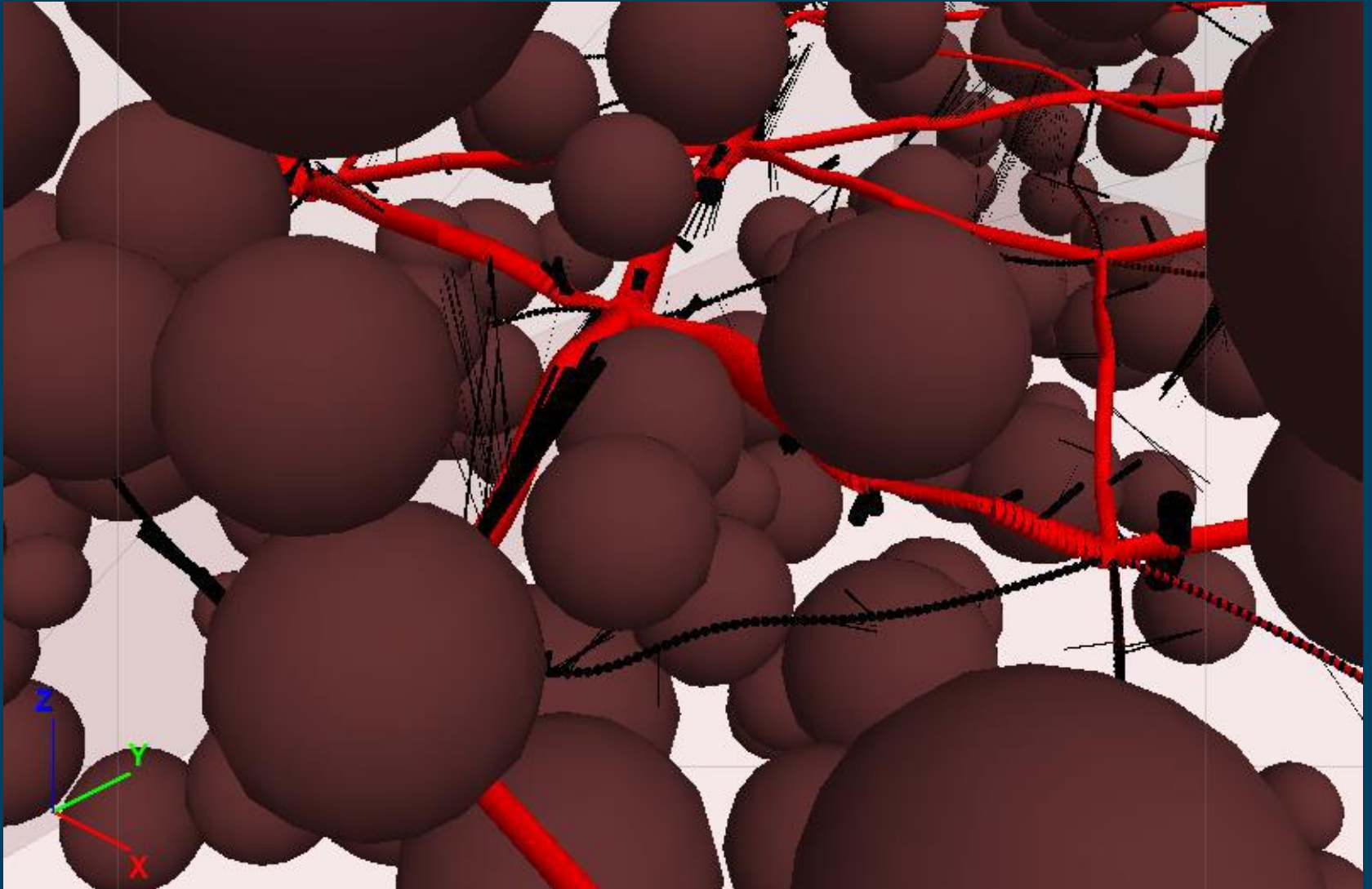
# Geogrid with Red Showing Tension



# Triaxial Grid Deformed by Aggregate



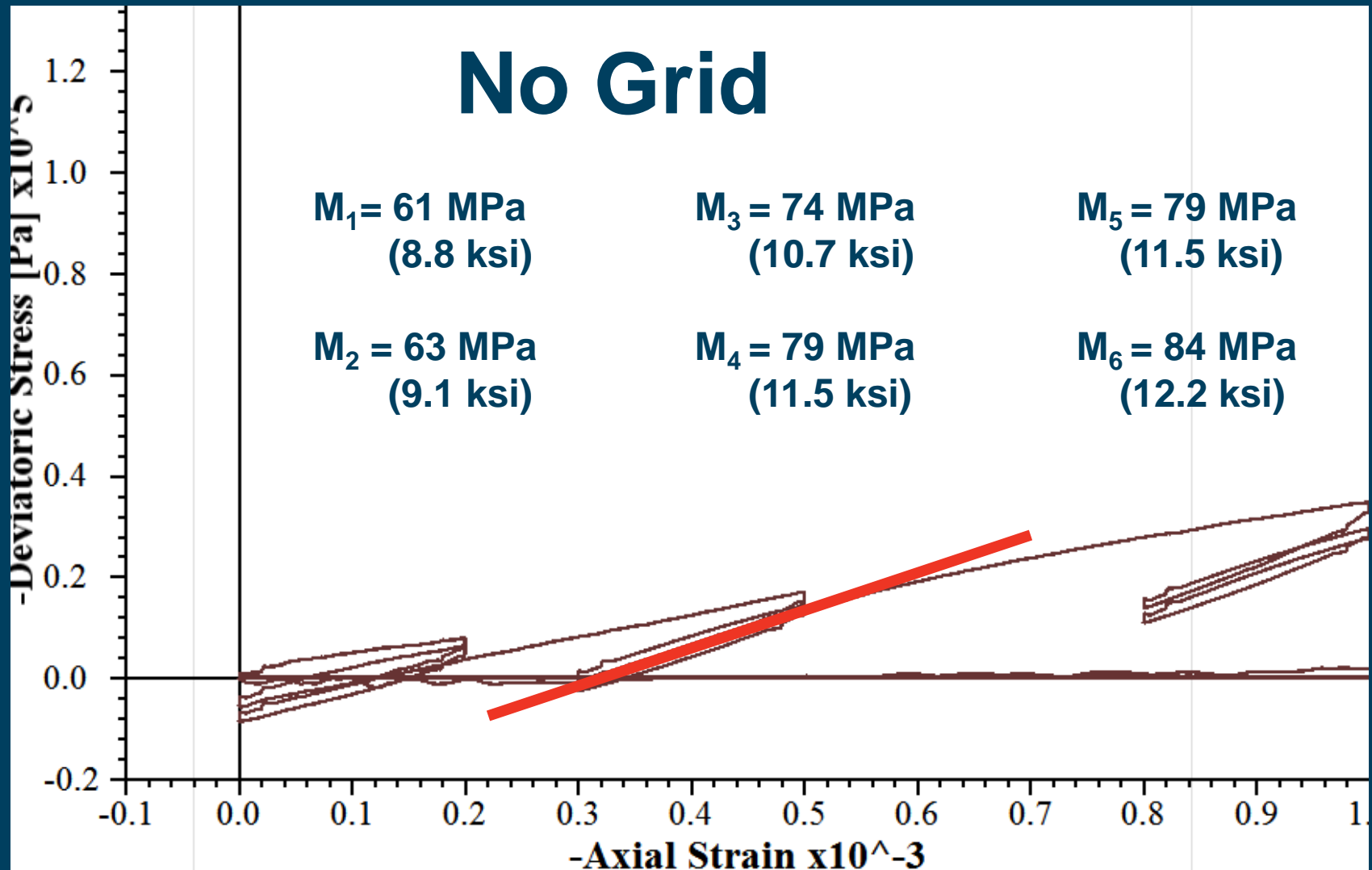
# Triaxial Grid Deformed by Aggregate





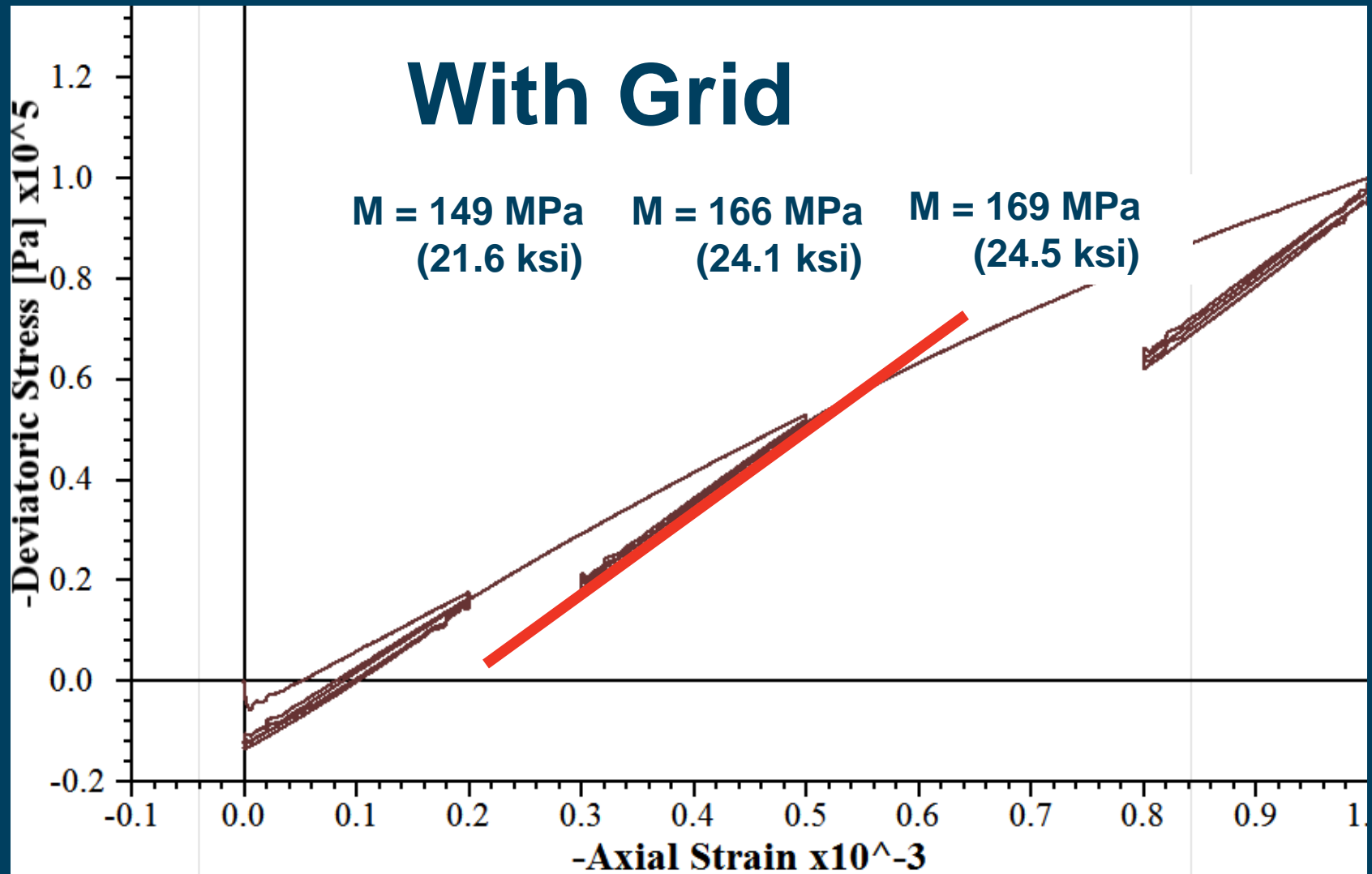
# Modulus of 8 Inch Aggregate Base Layer

Confinement = 150 kPa Particle Friction = .8 Moisture Tension = 1 kPa (gap 3 mm)



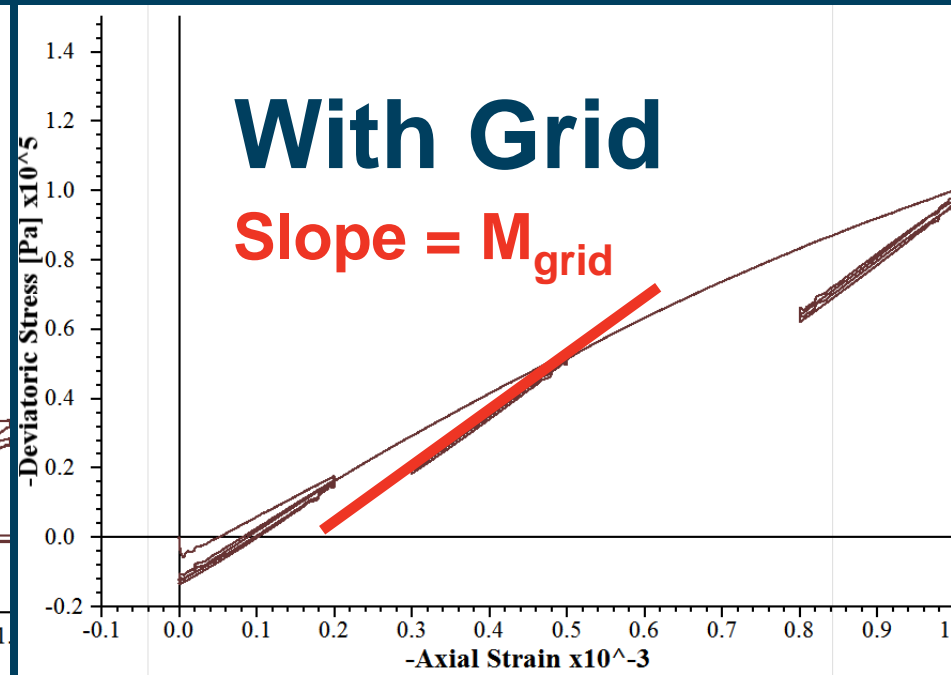
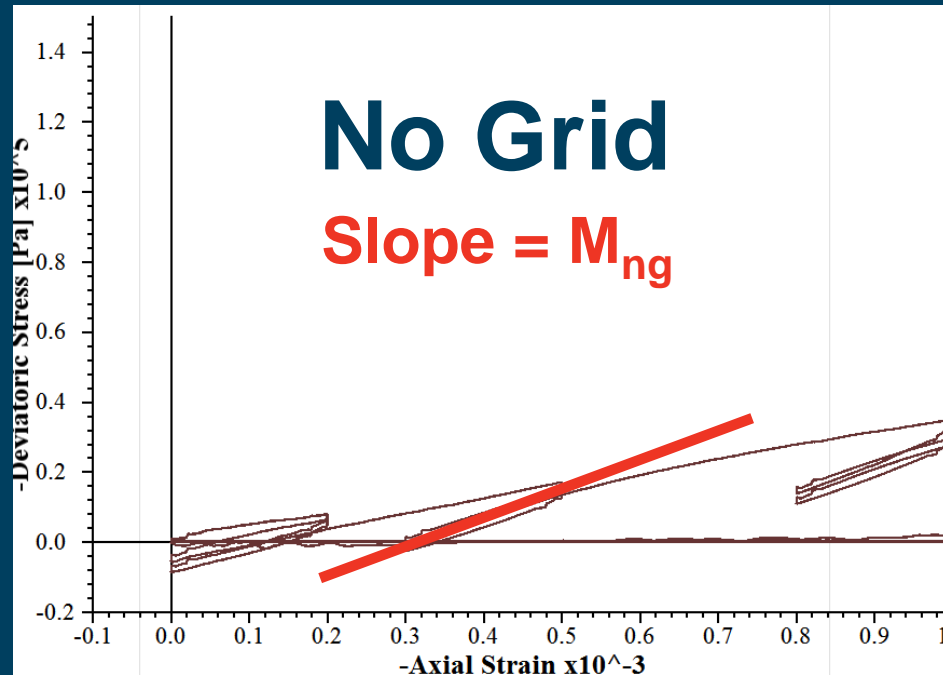
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# Modulus of 8 Inch Aggregate Base Layer

Confinement = 150 kPa Particle Friction = .8 Moisture Tension = 1 kPa (gap 3 mm)



## Geogrid Gain Factors

( $M_2/M_1$  at axial strain)

(0.02%)

**2.4**

**2.4**

(0.05%)

**2.2**

**2.1**

(0.1%)

**2.1**

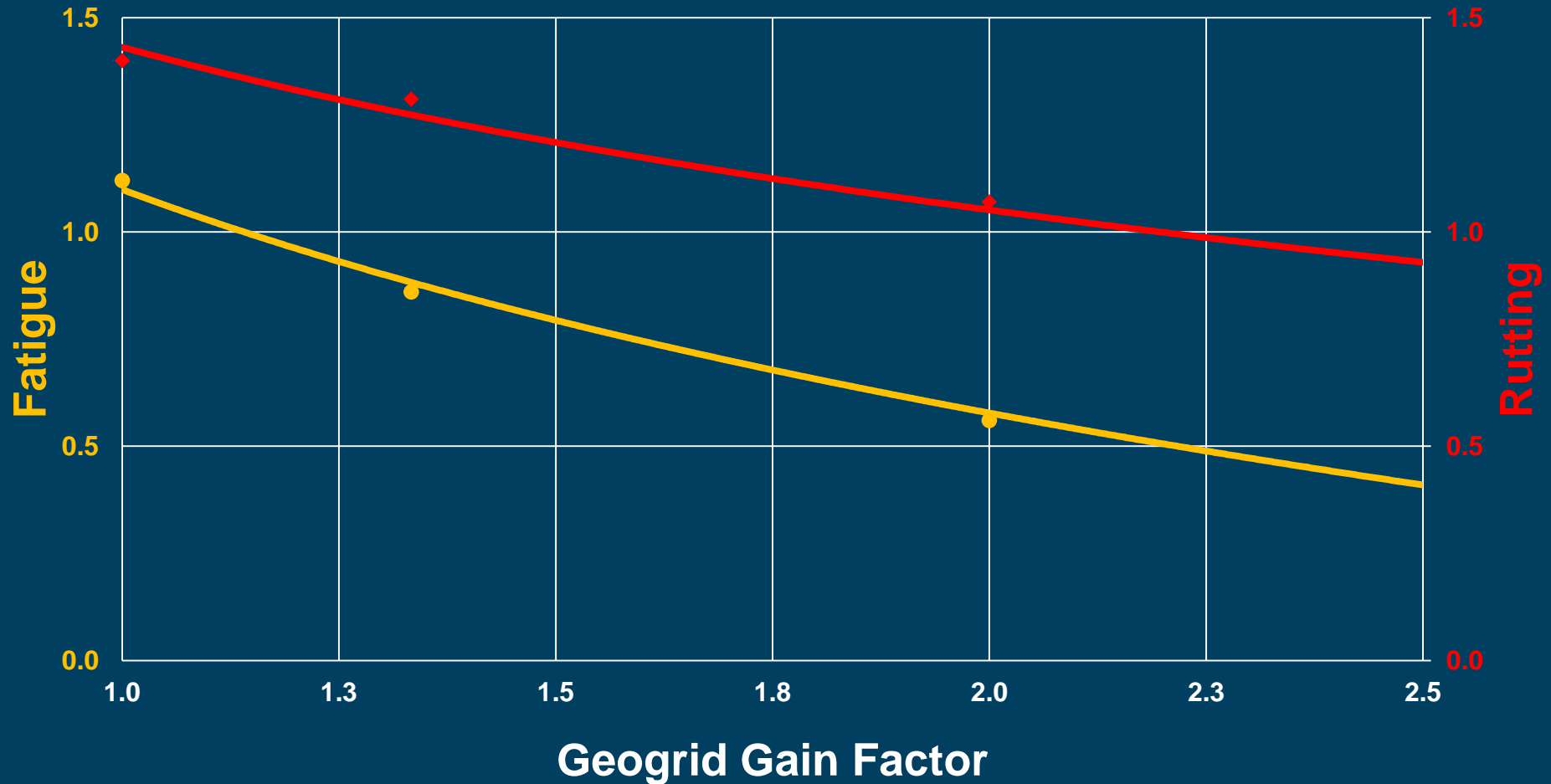
**2.0**





# Rutting vs Geogrid Gain Factor

Damage must be less than of 1.0 to achieve 20 year design life.



# Lessons Learned and Next Steps

- Modulus increases as moisture suction increases.
- Geogrid provides a quantifiable benefit that enhances pavement performance.
- Implementation continues so that the people's investments are used more effectively.



# Thanks for Listening.

Please ask questions and keep pulling together.

