

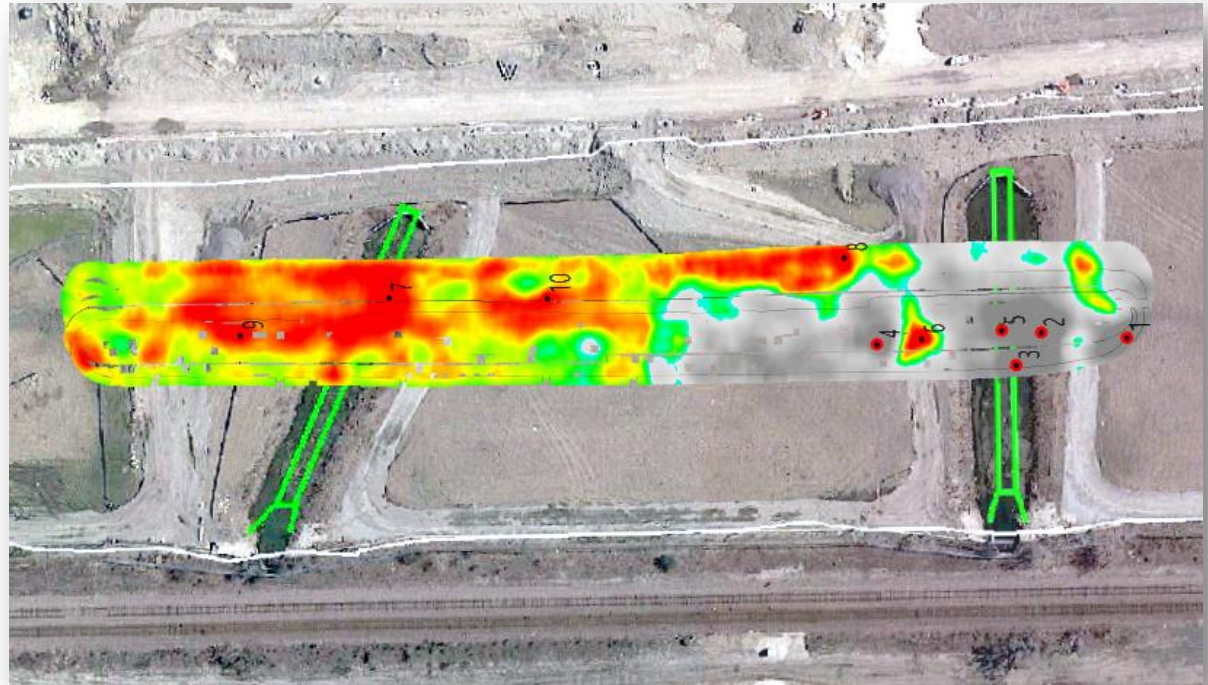
Geotechnical Risks for Pavement Foundations!

Presenter:

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President and Chief Engineer
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November 21, 2019

Does this pavement foundation meet the design requirement?



We believe...

- Long(er) life pavement systems are needed to provide sustainable solutions.
- Increased pavement layer thickness does not compensate for foundation deficiencies.
- Uniform pavement support is critical to performance but requires special controls.
- New technologies are needed to improve mechanistic pavement foundation construction.

Thick pavements can't cover up bad foundations!

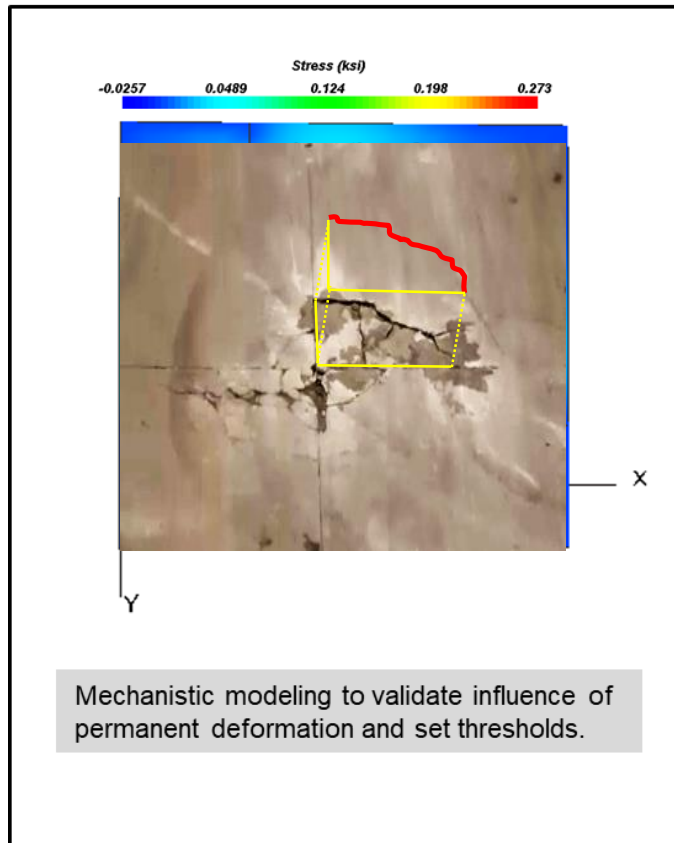


Heavy loads accelerate foundation problems!

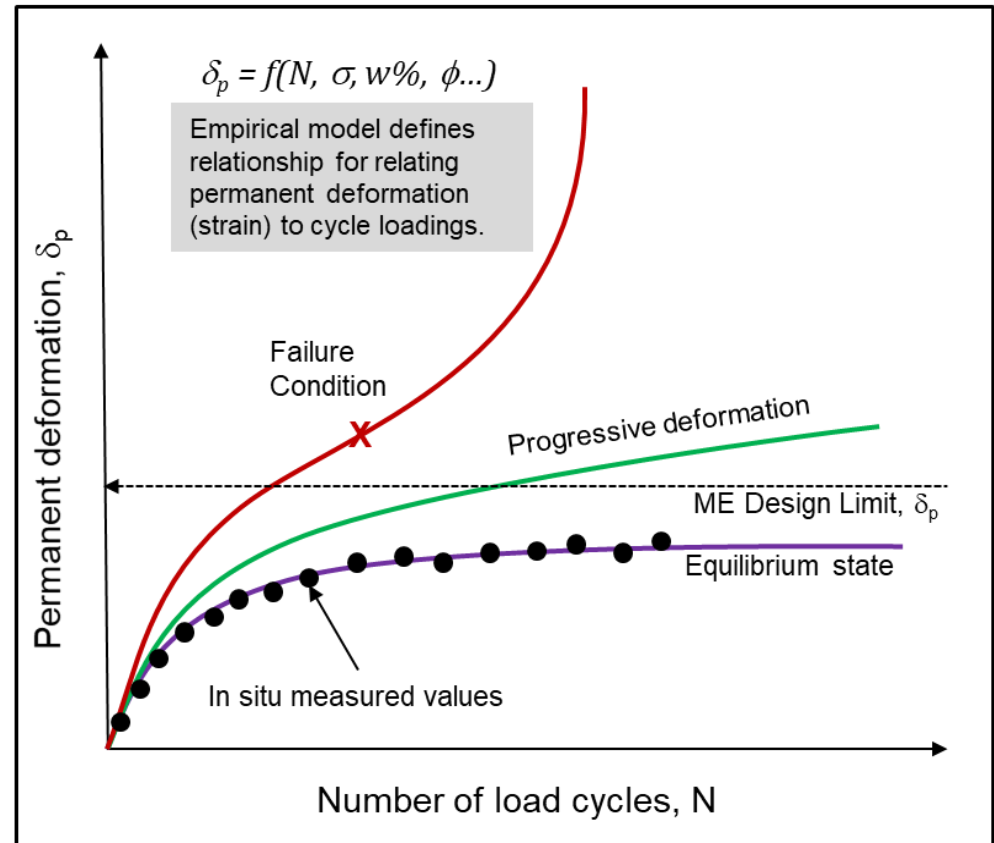


Research efforts with empirical modeling for predictions and mechanistic modeling to establish threshold limits are needed.

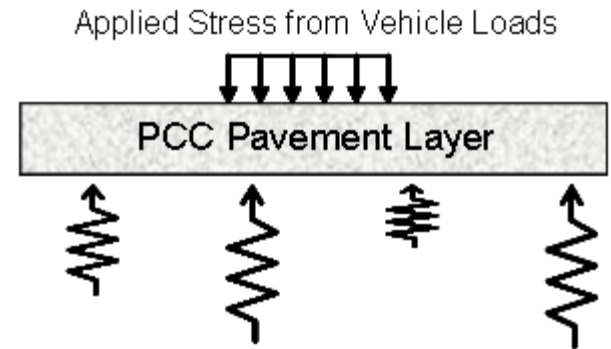
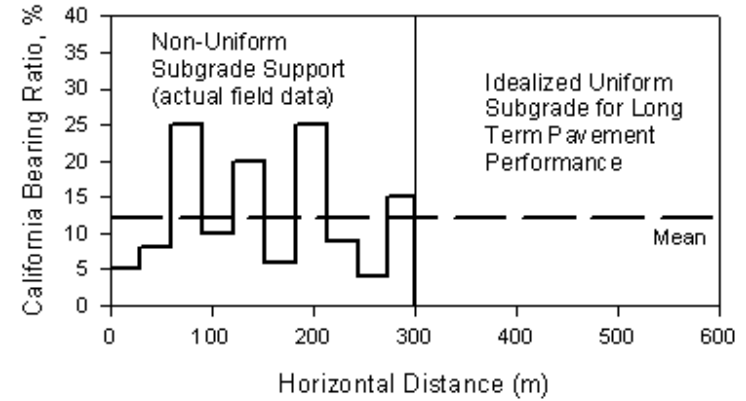
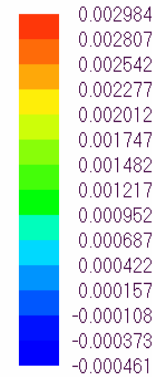
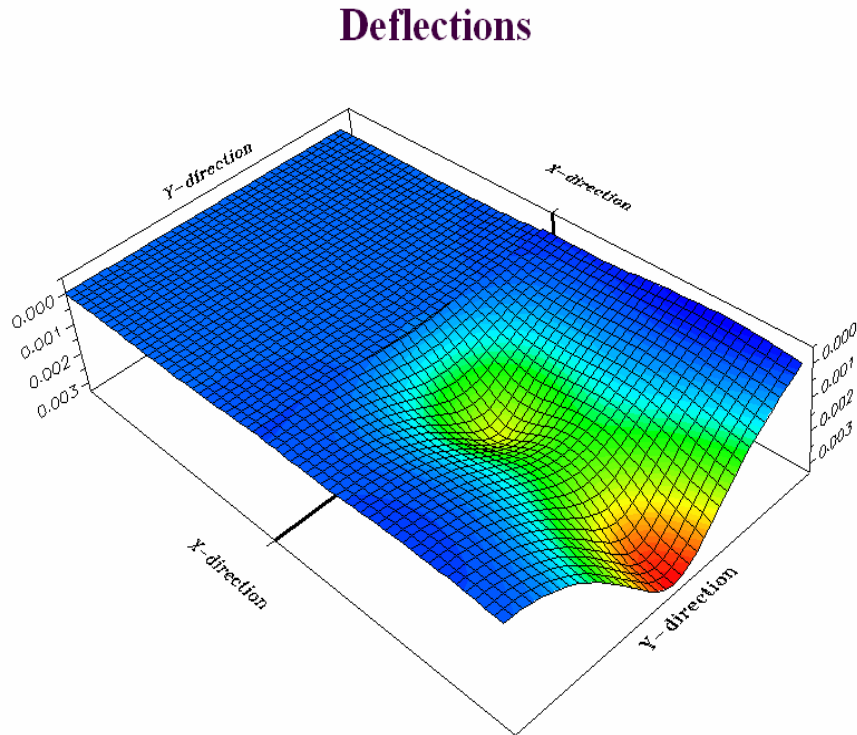
Mechanistic Modeling



Empirical Modeling



Non-uniform support results in localized stress concentrations under rigid pavements

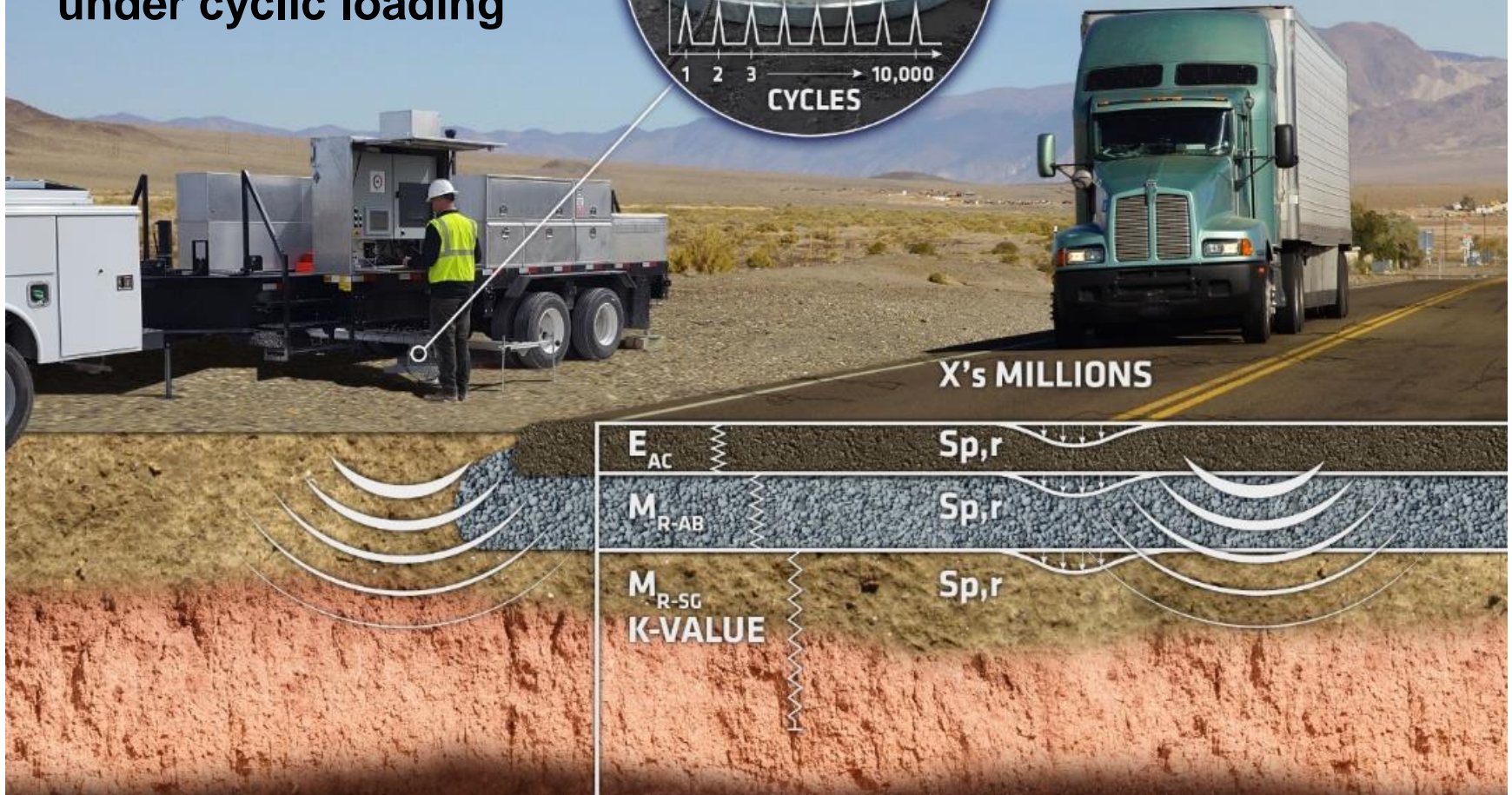


Non-uniform stiffness modeled using "springs" with modulus of subgrade reaction values estimated from in-situ tests

Fatigue life increases 1.7 times on average with uniform support

(White et al. 2004)

Automated Plate Load Testing (APLT) measures stress-dependent modulus under cyclic loading



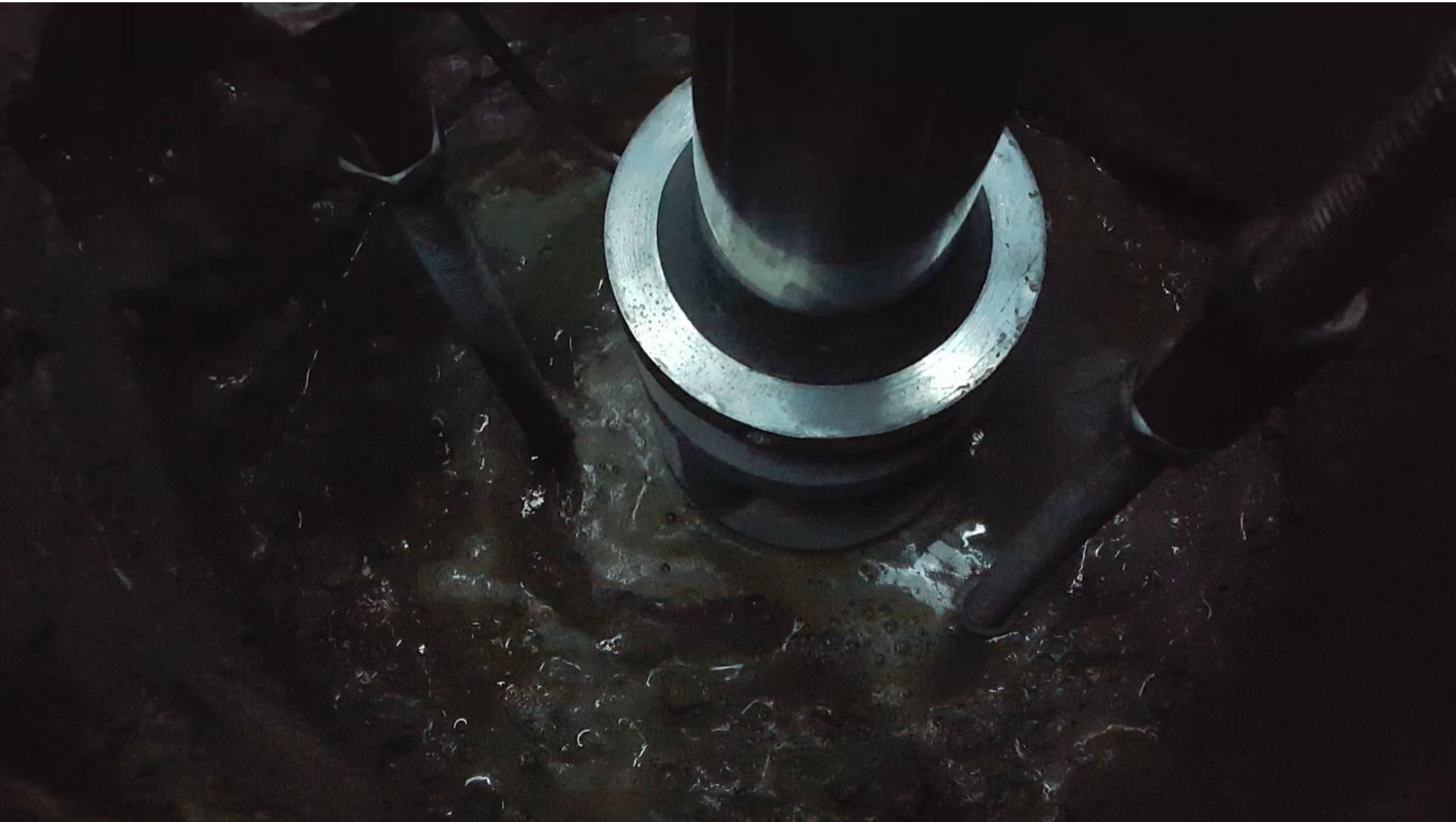
Subgrade Composite
 $M_r = 3,293$ psi



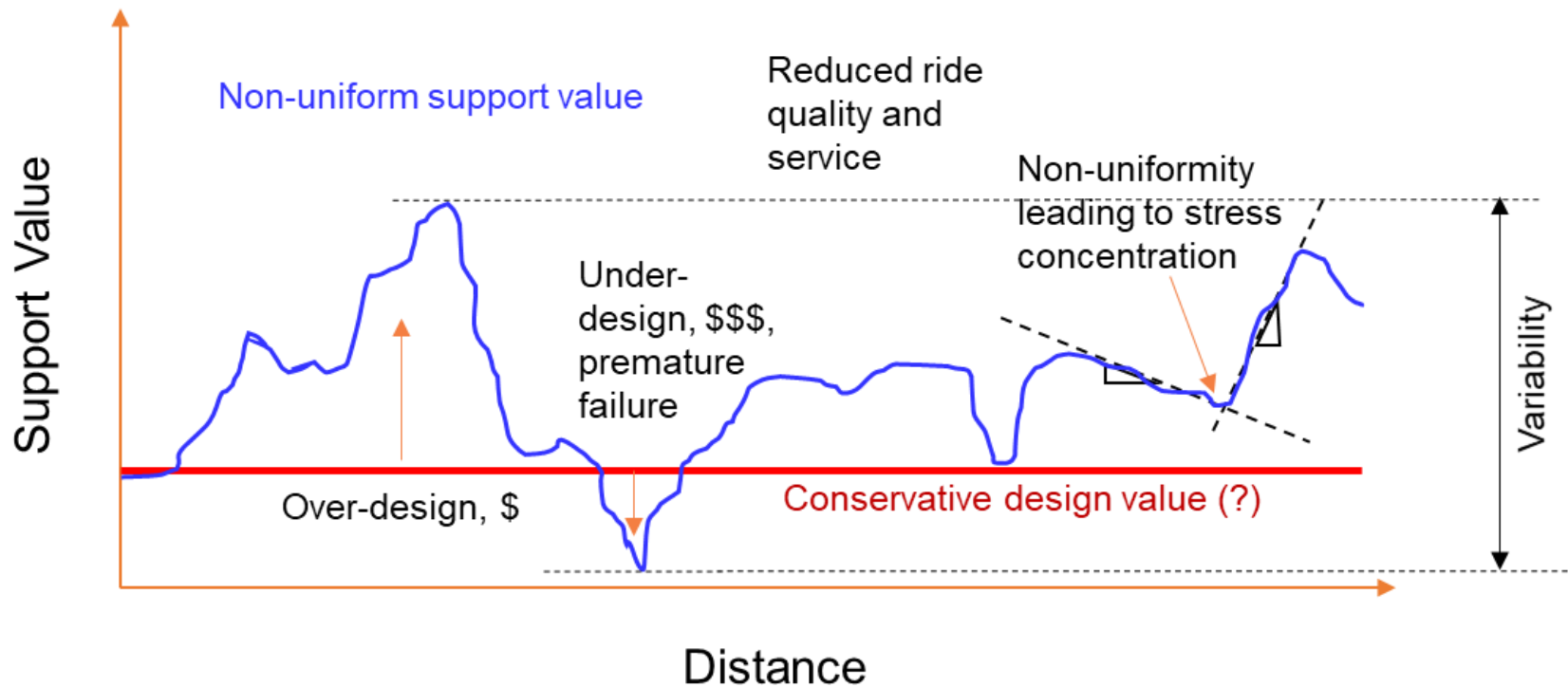
Subbase/Subgrade Composite
 $M_r = 25,162$ psi



Maintaining stability with proper draining is critical.

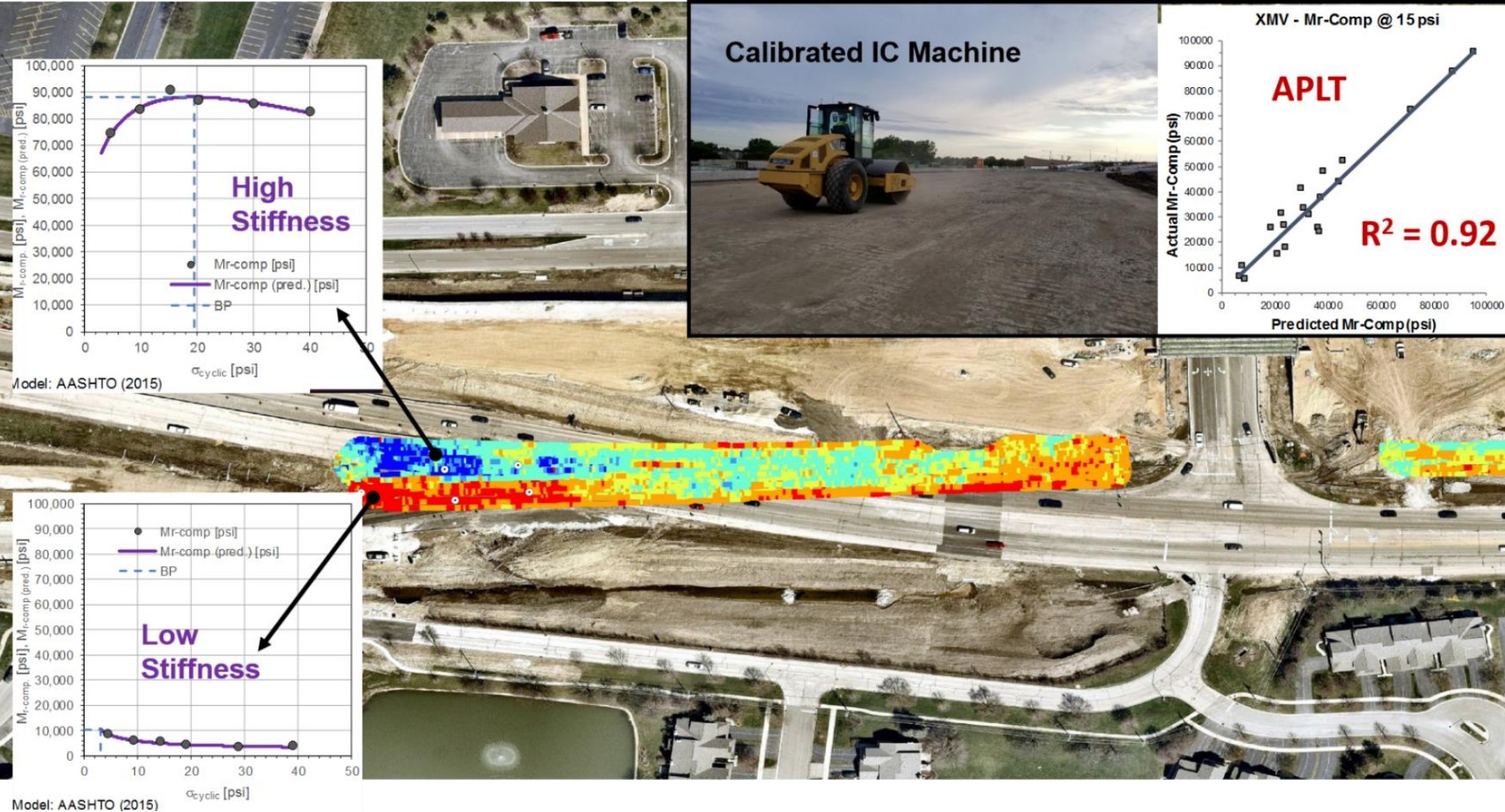


Spatially variable increases risks of reduced pavement life.



Subgrade: Spatial Map of Resilient Modulus

COMP-Score *Connect*

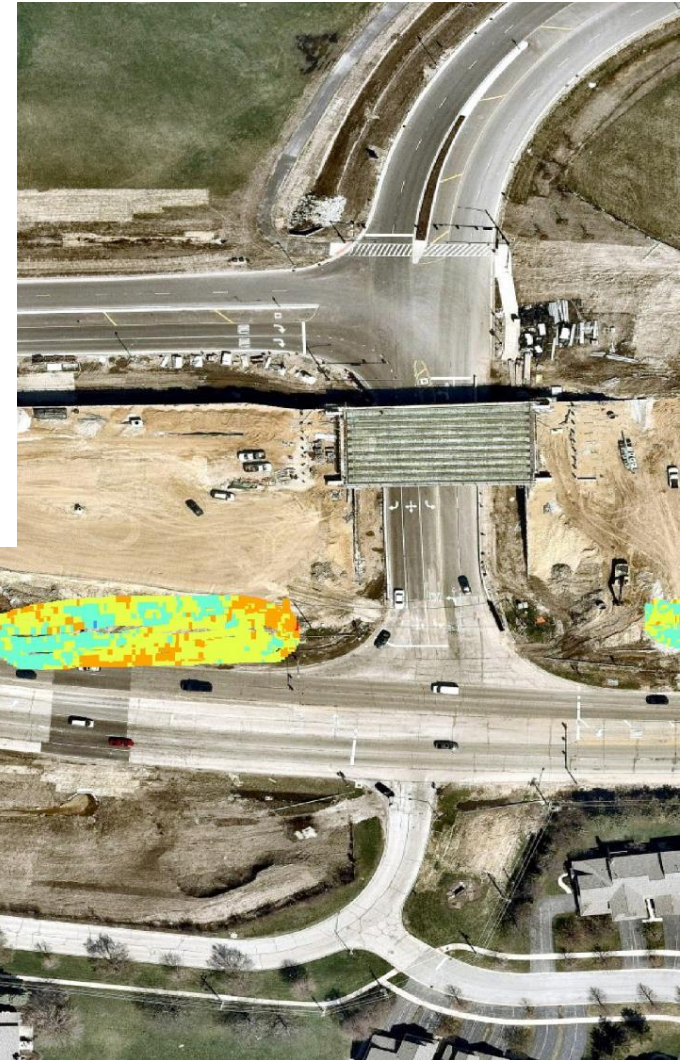
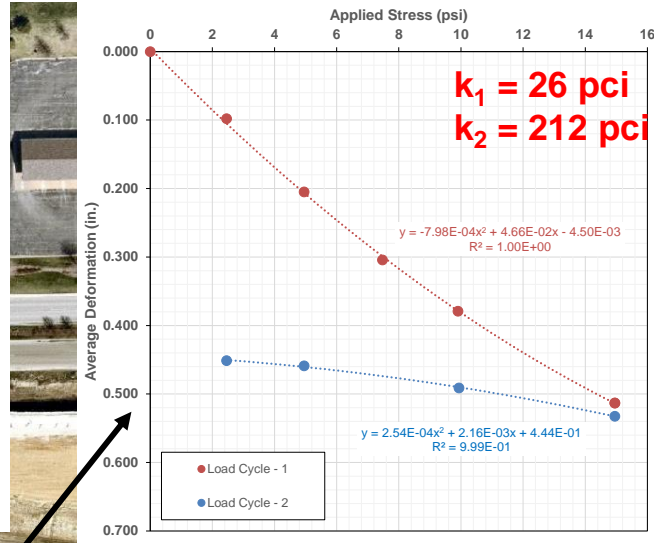
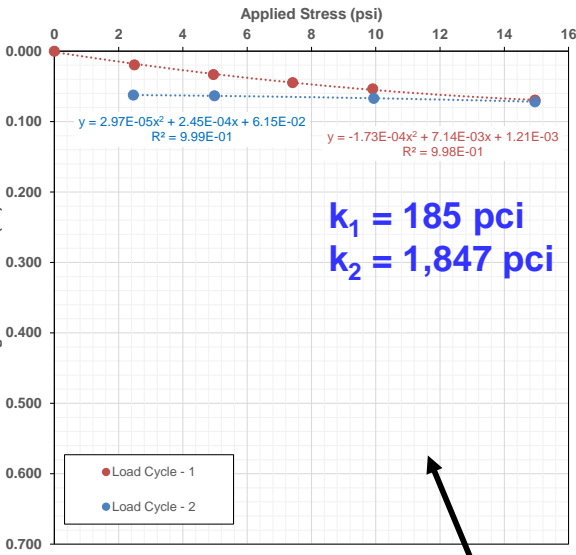


Passed QC/QA process?



Aggregate Base: Spatial Map of Resilient Modulus

COMP-Score **Connect**

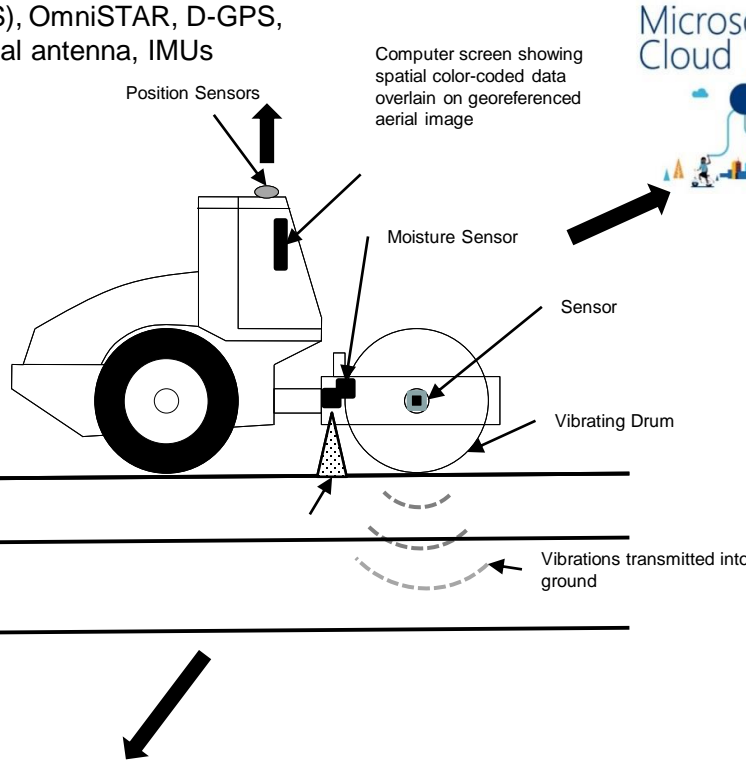


COMP-Score *Connect*



Options for GNSS:

SBAS (WAAS), OmniSTAR, D-GPS, RTK-GPS, dual antenna, IMUs

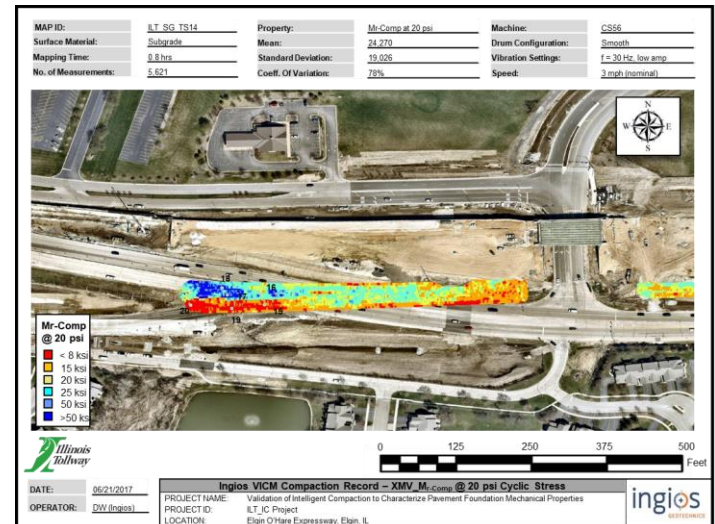


Outputs:

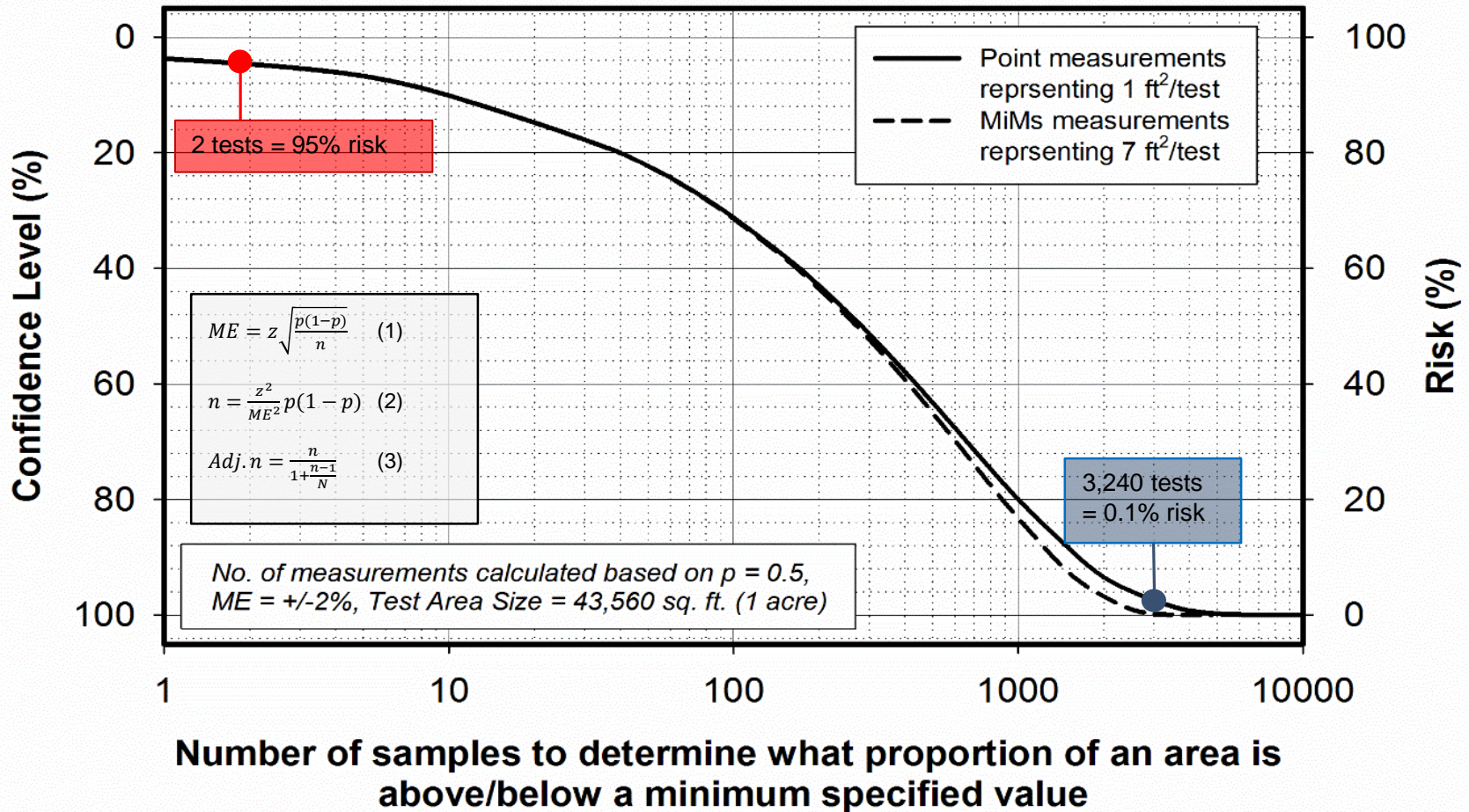
- Real-Time Monitoring
- Engineering Reports
- Email Alert Messages
- Control charts
- Calibration Verification
- WebCam and Pictures
- QC/QA Records
- Asset Mapping
- QC/QA Test Locations

Options for Engineering Outputs:

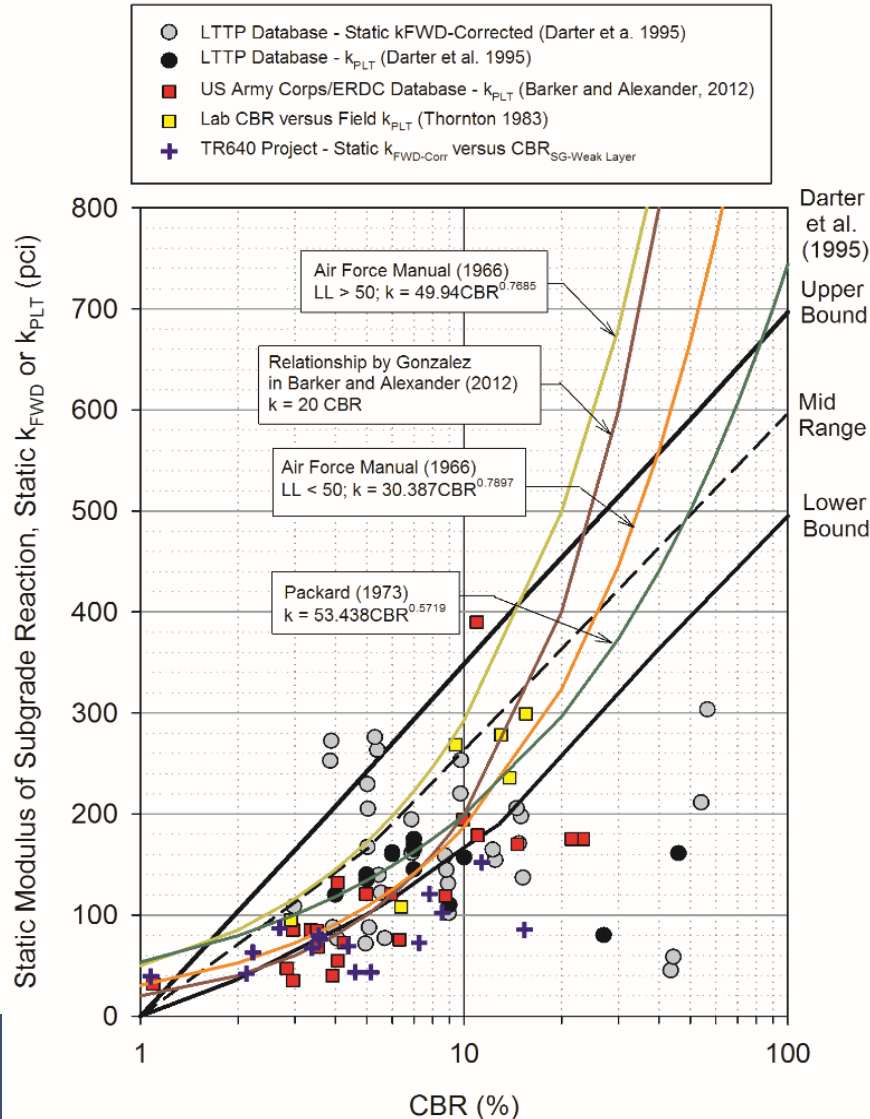
M_r , E_s , k-value, CBR, γ_d^* , $w\%^*$, Material type



Decreasing Risk With Full Coverage Testing



Indirect methods and *empiricism* are convenient and cost less up front but introduce substantial risks



Example of empirical relationships to estimate k -value from CBR

Terzaghi (1955) noted when describing coefficients of subgrade reaction, “widespread among engineers” is the “erroneous conception” that the “numerical value of coefficient of subgrade reaction depends exclusively on the nature of the subgrade”, and without proper consideration of the test methods, “such values can be very misleading”.



One QC/QA test to document, where?





LWD tests performed every 2.5 to 3 ft at 25 locations (1 to 25) across the pavement width

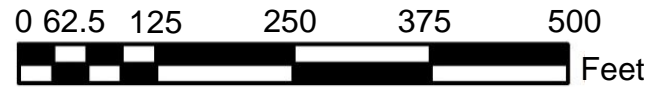
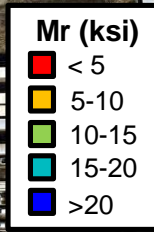
PRODUCTION MAP 2A - PGE

PRODUCTION MAP 1A - PGE

CALIBRATION TS1 - PGE

CALIBRATION TS3 - PGE

- LWD
- ⊙ LWD & DCP



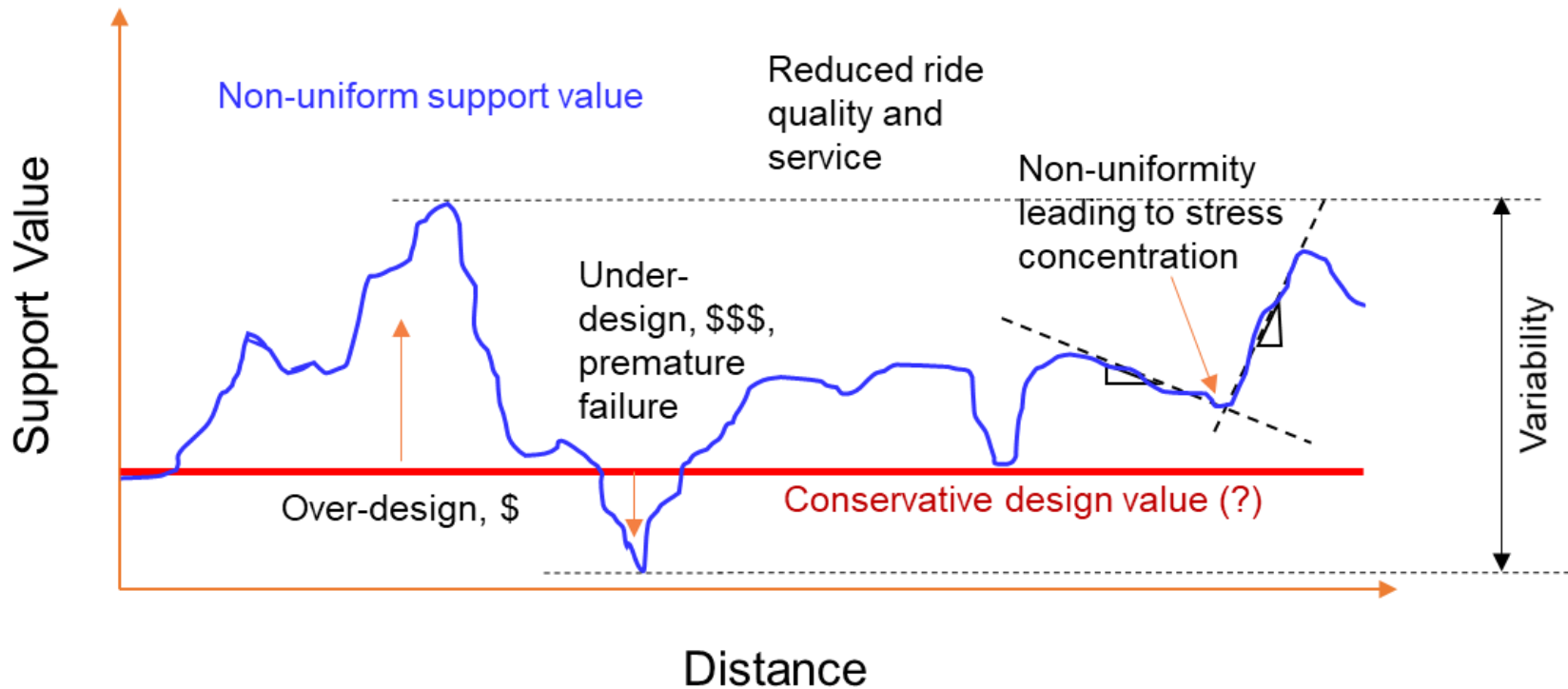
COMP-Score *Connect*

DATE: 10/12/16 TO 10/17/16
 OPERATOR: INGIOS / PLOTE

HAMM H11 Smooth Drum Roller – HMV Report
 PROJECT NAME: Validation of Intelligent Compaction to Characterize Pavement Foundation Mechanical Properties
 PROJECT ID: ILT_IC Project
 LOCATION: Elgin O'Hare Expressway, Elgin, IL



What value do you select to represent pavement foundation modulus...?



Pavement design excludes

Pavements

non-uniformity.

- Design and Analysis
- Materials and Construction Technology
- Management and Preservation
- Surface Characteristics
- Construction and Materials Quality Assurance
- Environmental Stewardship

Pavements Design

Status of Pavement Design in the US (2003)

FHWA considers implementation of mechanistic-empirical pavement design a critical element in improving the National Highway System. To help move the implementation forward, FHWA intends to provide significant support for these efforts. To kick start this endeavor, the [Design Guide Implementation Team \(DGIT\)](#) worked with the FHWA division office materials and pavement engineers to complete a questionnaire for State highway agencies on the current status of pavement design. The questionnaire consisted of seven short questions pertaining to planned or current activities related to implementation of mechanistic-empirical design. [Forty-eight State division offices and the District of Columbia](#) responded to the questionnaire.

Materials

- [Pavement Materials](#)
- [Resilient Modulus](#)

Traffic

- [Obtaining Traffic Data to Support M-E Design](#)
- [Traffic Data for Pavement Design Workshops](#)

Climate

- [LTPP](#)
- [DGIT One-day workshop on Climatic inputs to M-E Pavement Design](#)

Asphalt

- [SuperPave Models and Software](#)

Concrete

- [CPTP Products](#)
- [CPTP Update, July 2005](#)
- [Mobile Concrete Laboratory](#)

Design Guide Implementation Team

- [Traffic Inputs for M-E PDG](#)
- [Design Guide Implementation Team Events](#)
- [Workshop Registration](#)
- [Workshop Webcasts](#)
- [Software Download: NCHRP 1-37A Pavement Design Guide](#)
- [Workshops: Materials Inputs for Design](#)
- [Interactive Website: NCHRP 1-40 User Comments](#)
- [Mechanistic - Empirical Pavement Design \(pdf version, 0.1 mb\)](#)

General

- [Construction of a Pavement Subsurface Drainage System](#)
- [Life-Cycle Cost Analysis in Pavement Design \(pdf version, 0.1 mb\)](#)

Recycling

- [Fly Ash Facts for Highway Engineers](#)

Publications

More Information

- [Design Guide Implementation Team](#)
- [Pavement Publications](#)

Contacts

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[E-mail Eric](#)

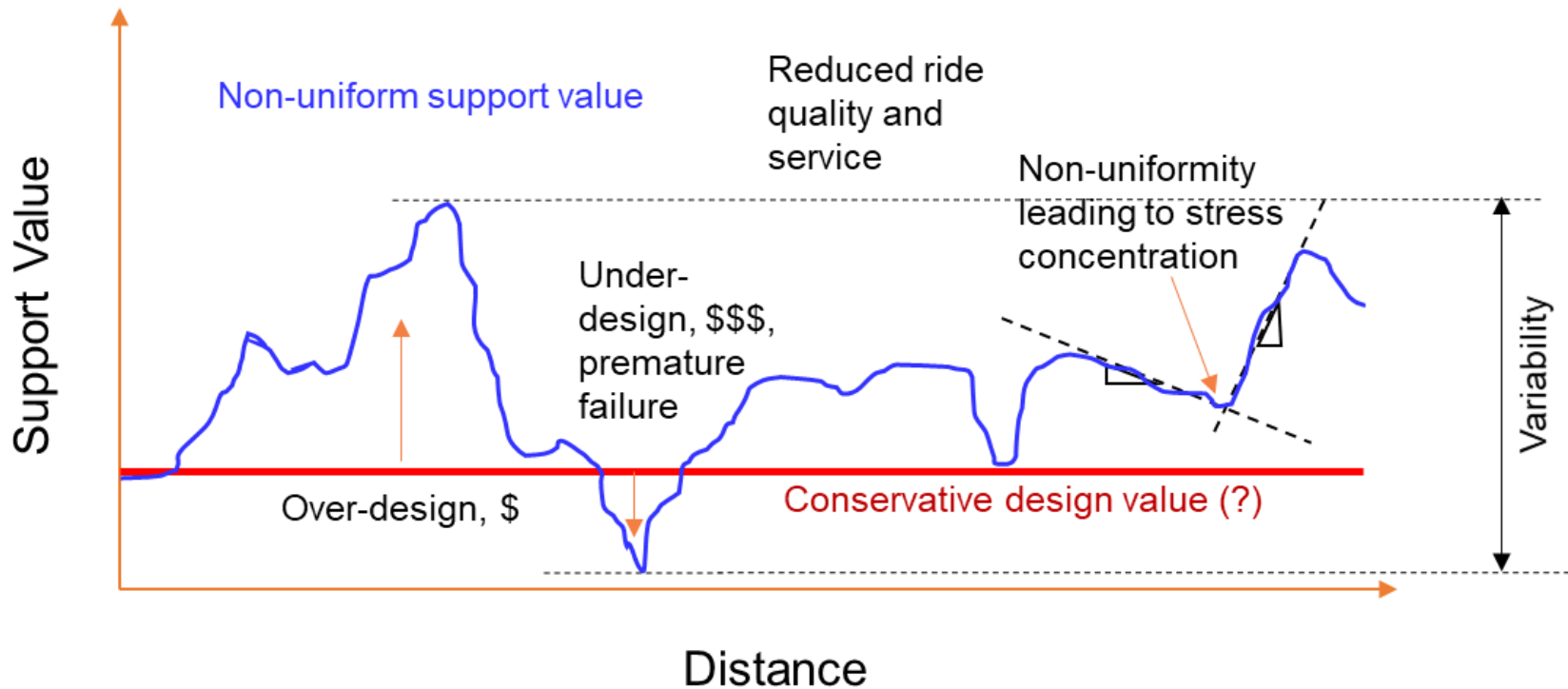
Jim Sherwood
Office of Research, Development and Technology
202-493-3150
[E-mail Jim](#)

— The AASHTO design methodology requires the mean k-value, **not the lowest value** measured or some other conservative value —

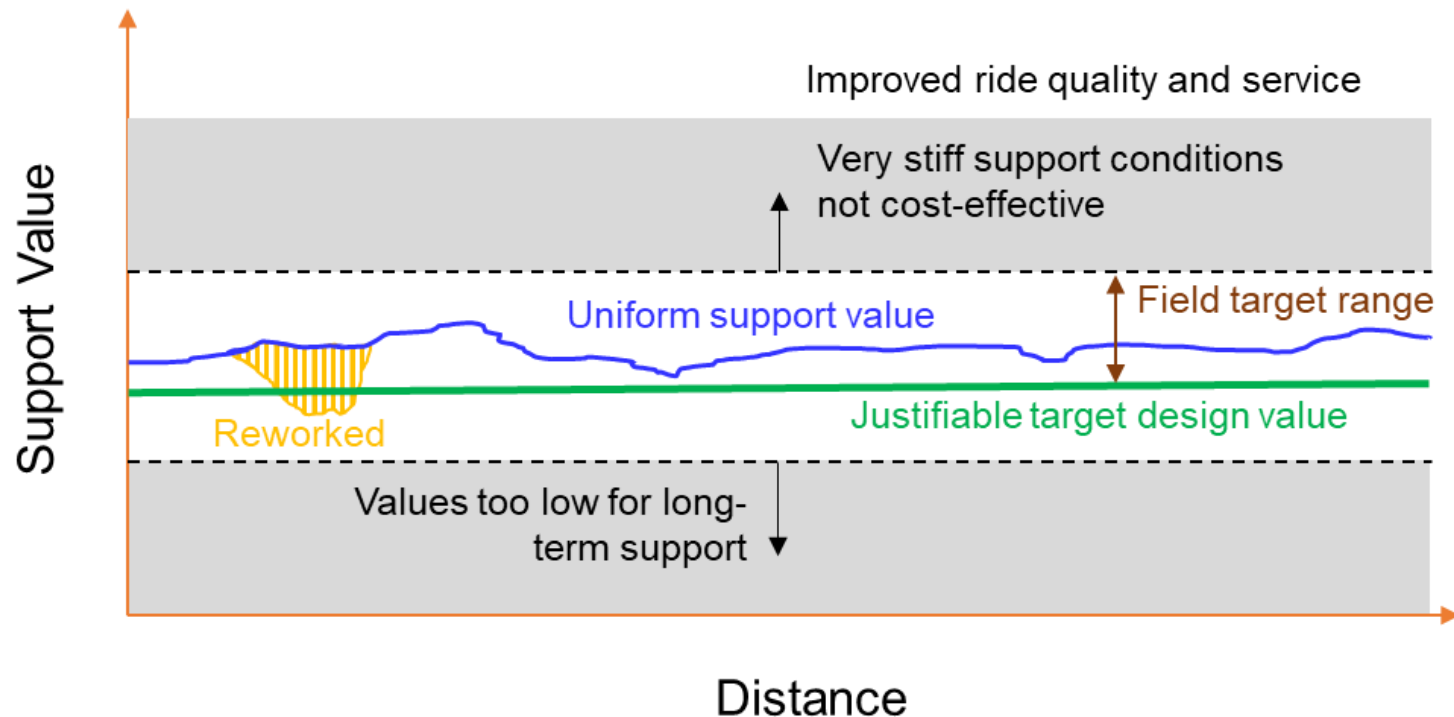
— **Exclude** from the calculation of the mean k-value...values that appear to be significantly out of line with the rest of the values —

(MEPDG Design Guide from NCHRP 1-37A Part III, March 2004)

What value do you select to represent pavement foundation modulus...?



Reduce risks with improved field control to ensure design assumptions are verified!



Reduce risks using mechanistic QC/QA parameters.

1. Achieve the minimum critical engineering parameter values over the entire site;
2. Limit variability of critical engineering parameter values over the entire site;
3. Restrict spatial areas of non-compliances; and
4. Control moisture contents to ensure post placement volumetric stability.

Production Use of VIC on I-25 Project

- Onsite VIC Training provided to roller operators.
- Contractor enabled to verify constructed M_r and meet project design requirements.



Aggregate base layer stabilized with geogrid.



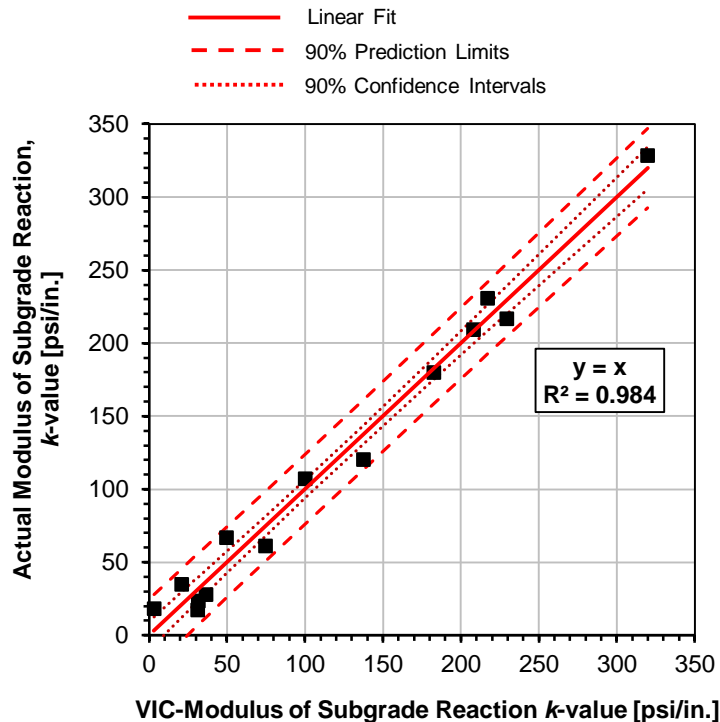
APLTs used to calibrate VIC machine to resilient modulus.



VIC Roller becomes an extension of the APLT



Validated Intelligent Compaction (VIC) M5 Calibration Record



Actual k -value Statistics

Min.	17.5 psi/in.
Max.	328.3 psi/in.
Mean	117.3 psi/in.
Median	86.9 psi/in.
Std. Dev.	99.5 psi/in.
Coeff. of Var.	85%

VIC k -value Statistics

Min.	3.1 psi/in.
Max.	319.8 psi/in.
Mean	117.3 psi/in.
Median	87.4 psi/in.
Std. Dev.	98.8 psi/in.
Coeff. of Var.	84%

Regression Equation

$$k\text{-value} = 1.000 \times \text{VIC } k\text{-value} + 0$$

Regression Statistics

N	14
R^2	0.984
$R^2(\text{adj.})$	0.966
RMSE	18.2 psi/in.
%SE*	15.56%
F-value	54.39
p-value	<0.0001

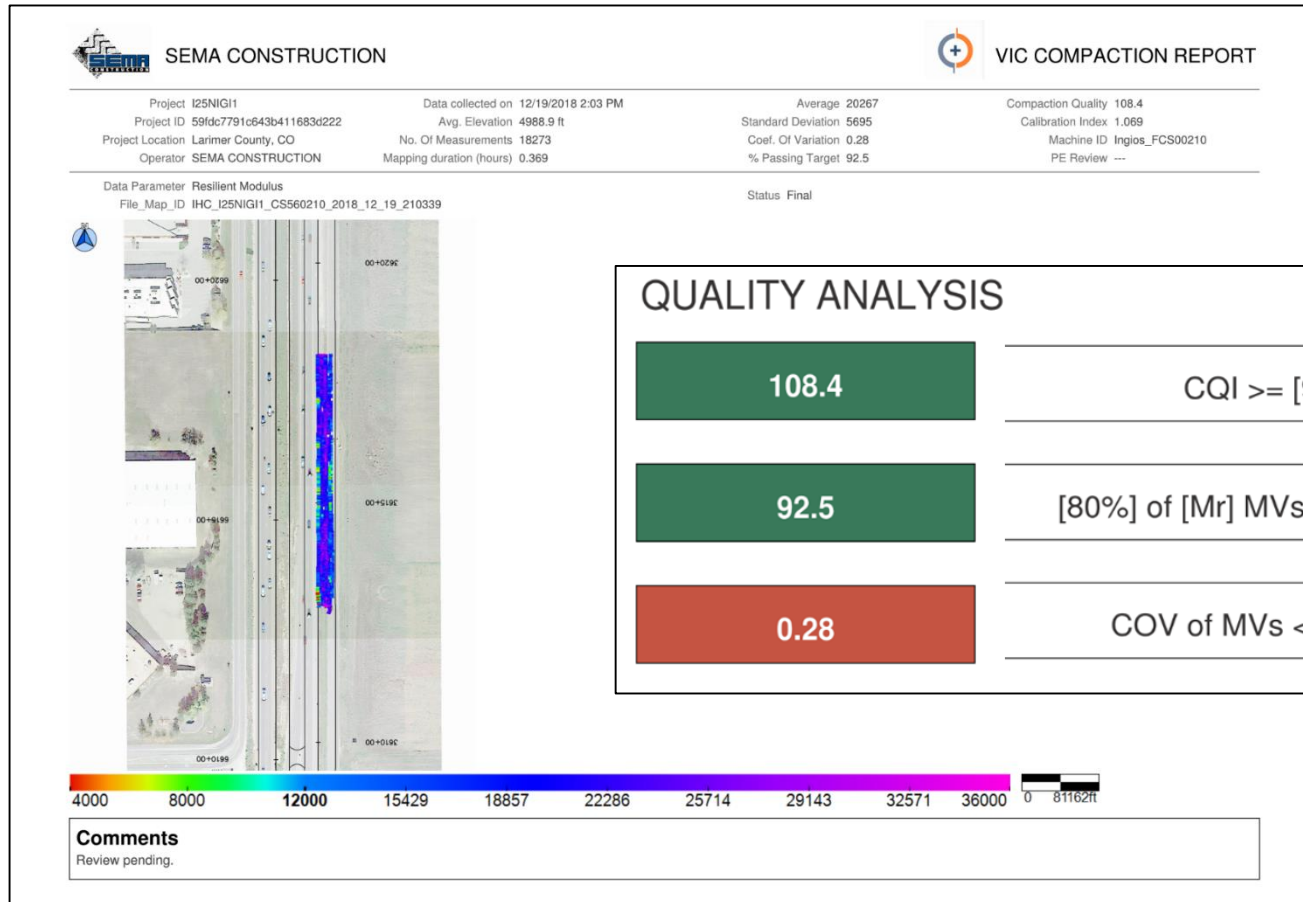
*Percent error in prediction relative to mean

Does the calibration meet the IL
Tollway I-7-4688 specification
requirement of minimum $R^2 \geq 0.85$?

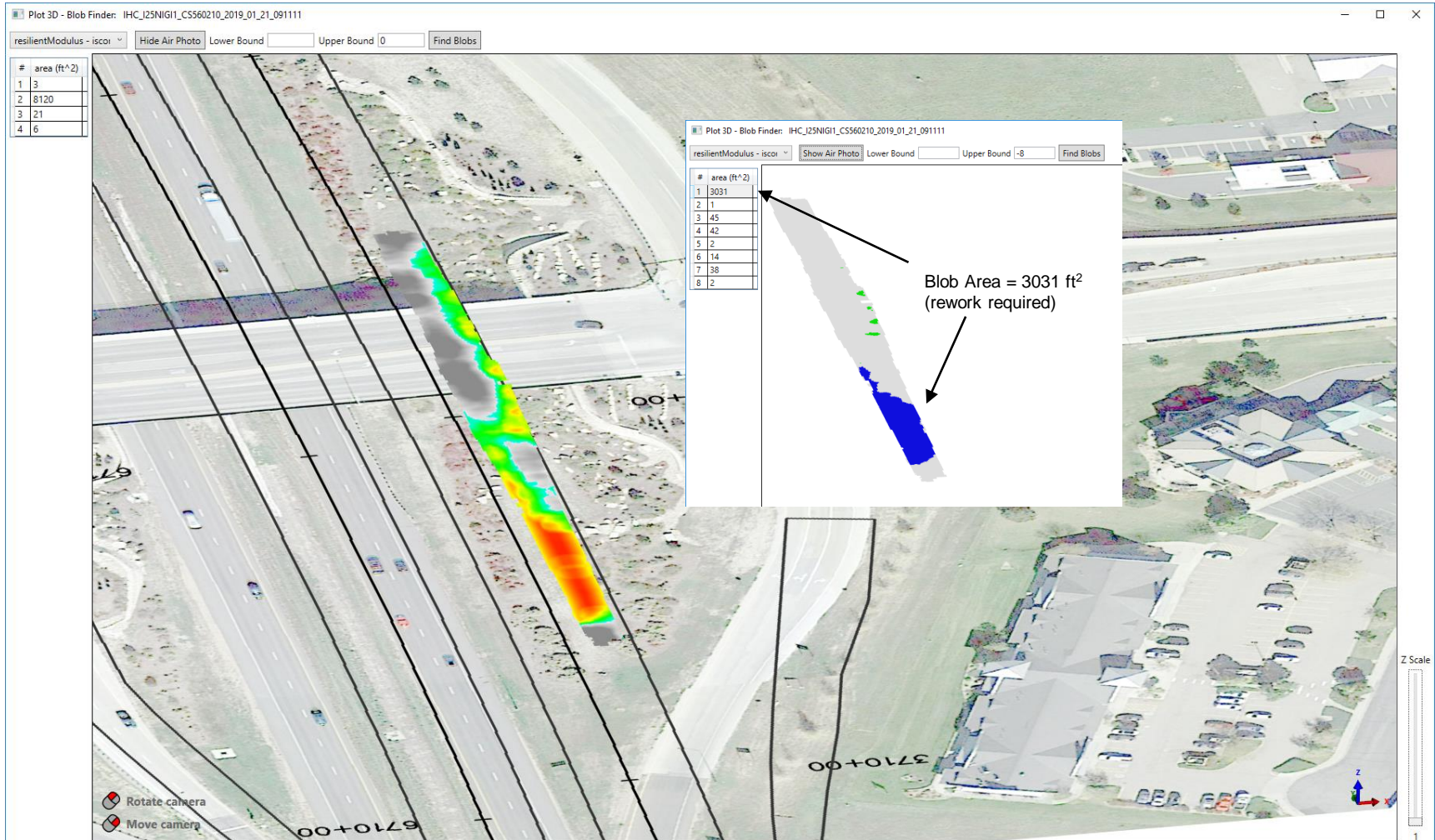
YES

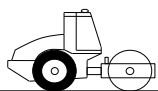


Auto-Generated VIC Compaction Reports from COMP-Score *Connect*



COMP-Score R^2 (rework areas) Blob Identifier for Rework Areas

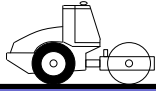




Cells 124-424

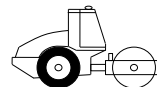
6 in. Class 5Q Aggregate Base

Sand Subgrade

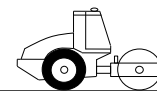


Cells 138-238

Existing Material
Mixture of existing subgrade and base material



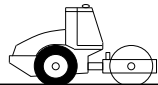
Cells 139-239



Cells 139-239

6 in. Class 5Q Aggregate Base

4 in. Common Borrow

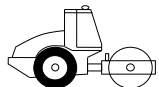


Cells 185-186

12 in. Coarse (Cell 185) or Fine (Cell 186) Recycled Concrete Aggregate Base

3.5 in. Common Borrow

Sand Subgrade

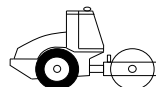


Cells 188-189

12 in. Recycled Aggregate Base (Cell 189) or Crushed Limestone Base (Cell 188), Class 6

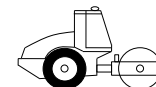
3.5 in. Common Borrow

Clay Subgrade



Cells 133-235

Existing Base Material

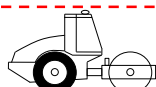


Cells 133-235

Cold Central Plant Rec. AC

Existing Base Material

Sections reworked to include geosynthetic/geogrid at subbase/subgrade interface



Cells 128-228

6 in. Class 6 Aggregate Base

9 in. Large Aggregate Subbase

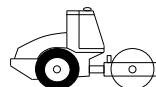
Clay Subgrade



Cells 128-228

9 in. Large Aggregate Subbase

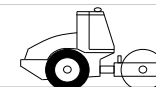
Clay Subgrade



Cells 127-227

18 in. Large Aggregate Subbase
Cell 227 – subbase placed in 2 lifts (9 in. each), Cell 127 – subbase placed in 1 lift

Clay Subgrade



Cells 127-227

6 in. Class 6 Aggregate Base

18 in. Large Aggregate Subbase
Cell 227 – subbase placed in 2 lifts (9 in. each), Cell 127 – subbase placed in 1 lift

Clay Subgrade

SUMMARY OF DIFFERENT CROSS-SECTIONS W/ VIC MAPPING

PROJECT NAME: 2017 MnROAD Unbound Layer Evaluation Using Intelligent Compaction
PROJECT ID: MnROAD_IC
LOCATION: MnROAD, Albertville, Wright County, MN





INGIOS APLT TEST EQUIPMENT

PROJECT NAME: 2017 MnROAD Unbound Layer Evaluation Using Intelligent Compaction

PROJECT ID: MnROAD_IC

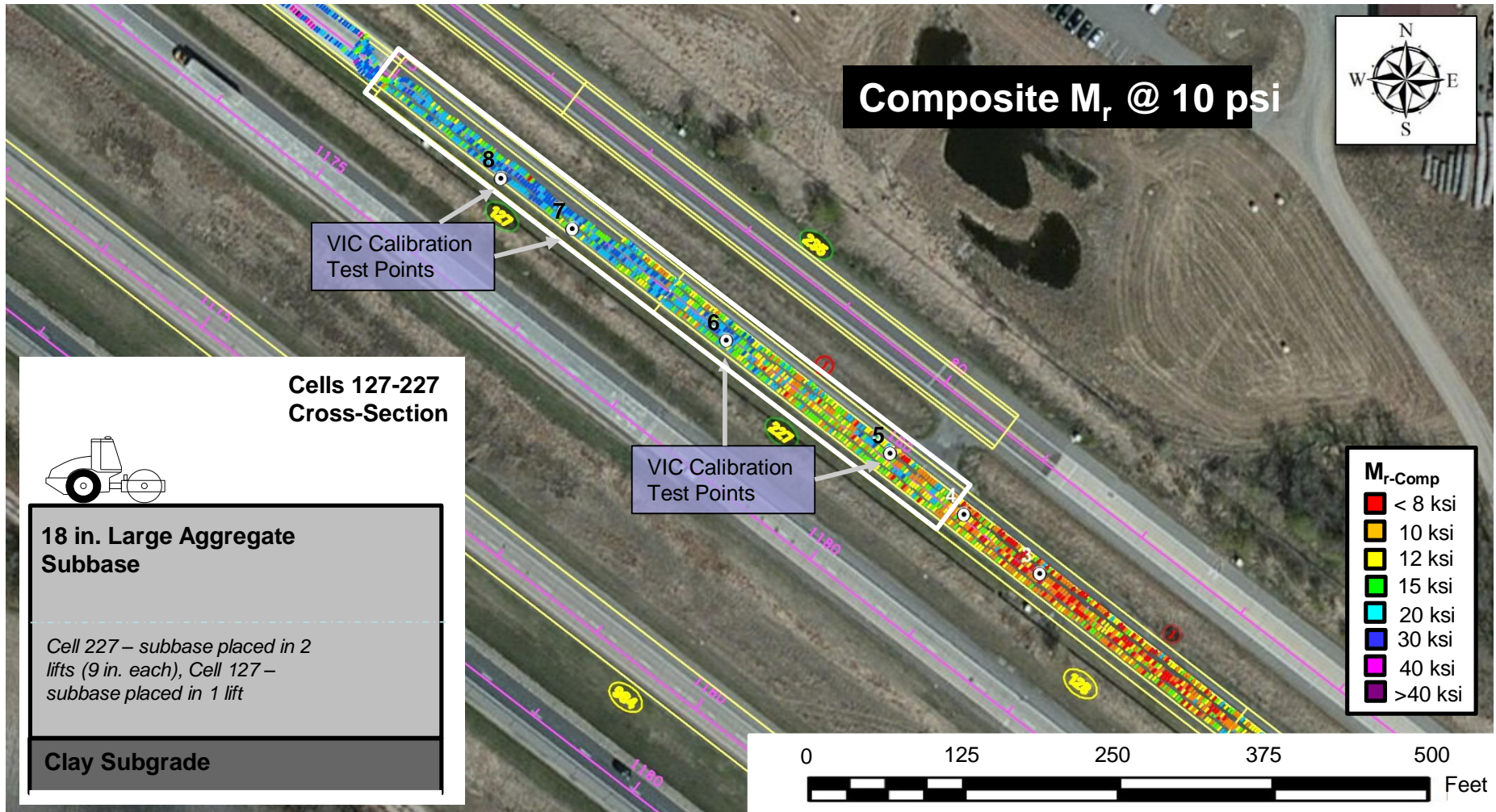
LOCATION: MnROAD, Albertville, Wright County, MN



MAP ID:	Cells 127/227_Subbase	
Surface Material:	Subbase	
Mapping Time:	5 min	4 min
No. of Measurements:	332	412

Meas. Property:	M _{r-Comp} @ 10 psi plate contact stress	
Mean:	17.5 ksi	13.1 ksi
Standard Deviation:	4.4 ksi	3.7 ksi
Coeff. Of Variation:	25%	28%

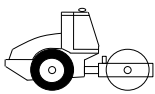
Machine:	CS56
Drum Configuration:	Smooth
Vibration Settings:	f = 30 Hz, low amp
Speed:	3 mph (nominal)



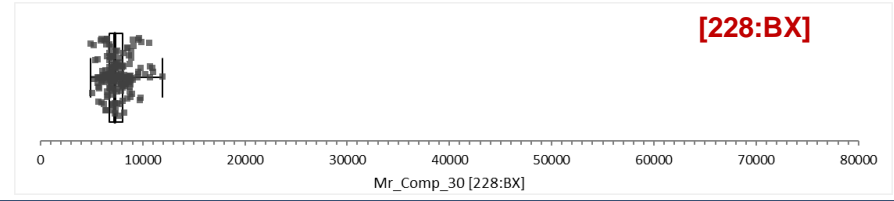
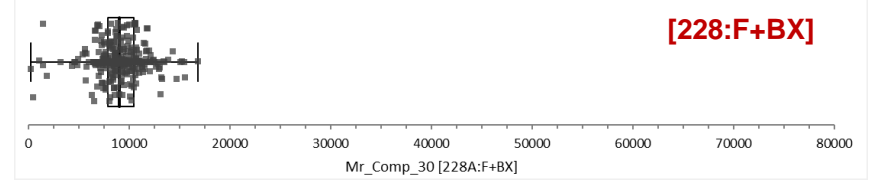
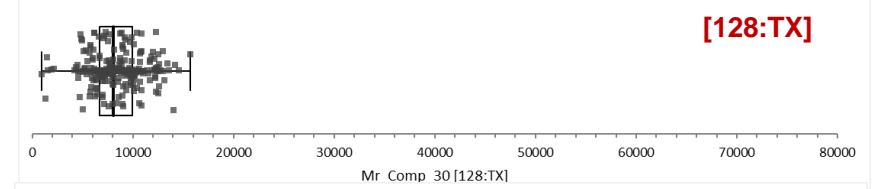
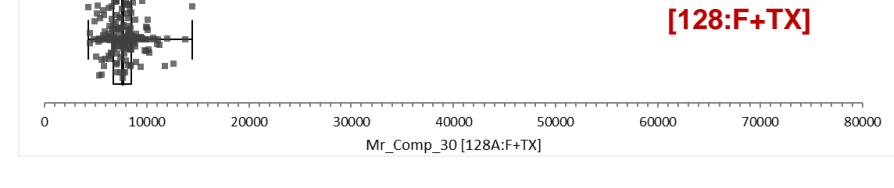
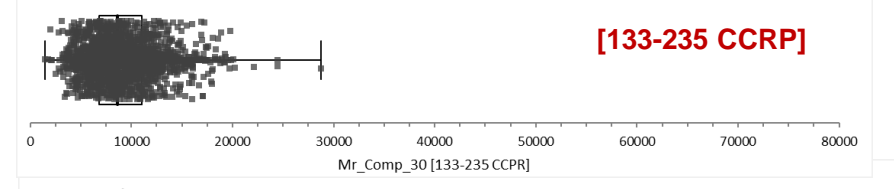
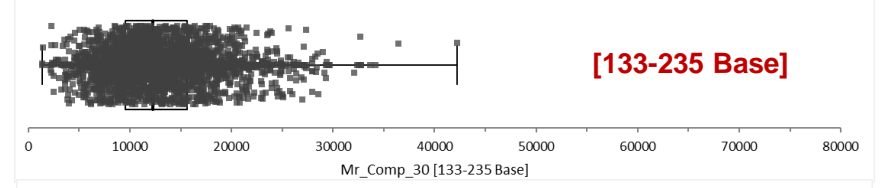
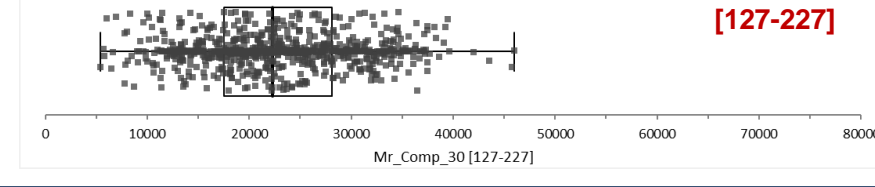
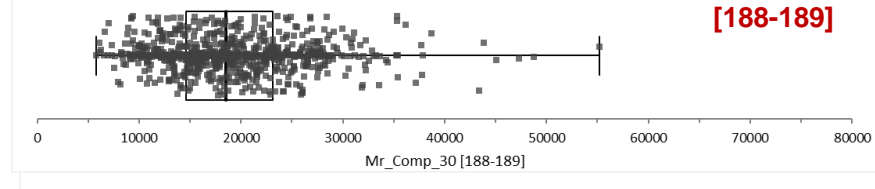
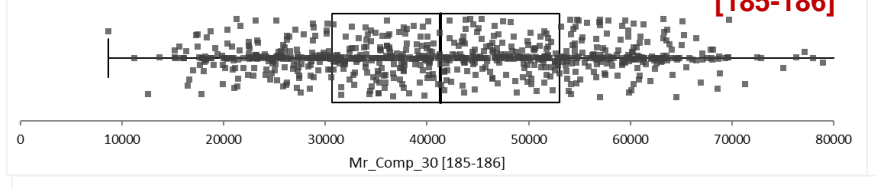
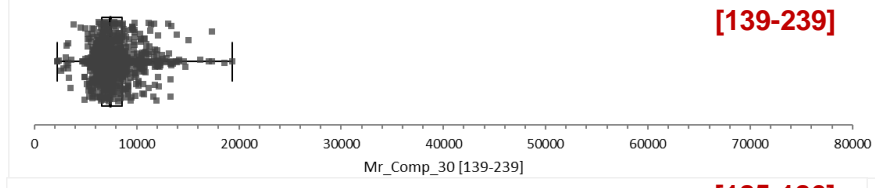
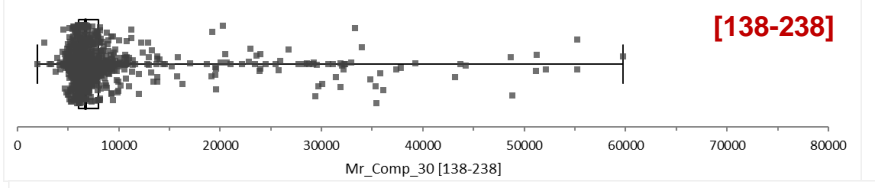
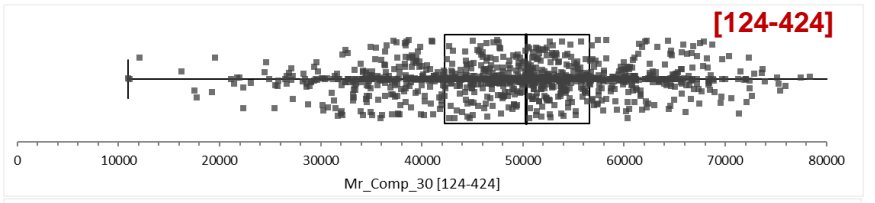
DATE:	08/17/2017
OPERATOR:	PV (Ingios)

Ingios VIC Record – VIC M _{r-Comp} @ 10 psi Plate Contact Stress	
PROJECT NAME:	2017 MnROAD Unbound Layer Evaluation Using Intelligent Compaction
PROJECT ID:	MnROAD_IC
LOCATION:	MnROAD, Albertville, Wright County, MN





Box Plots – M_{r-Comp}–30 psi



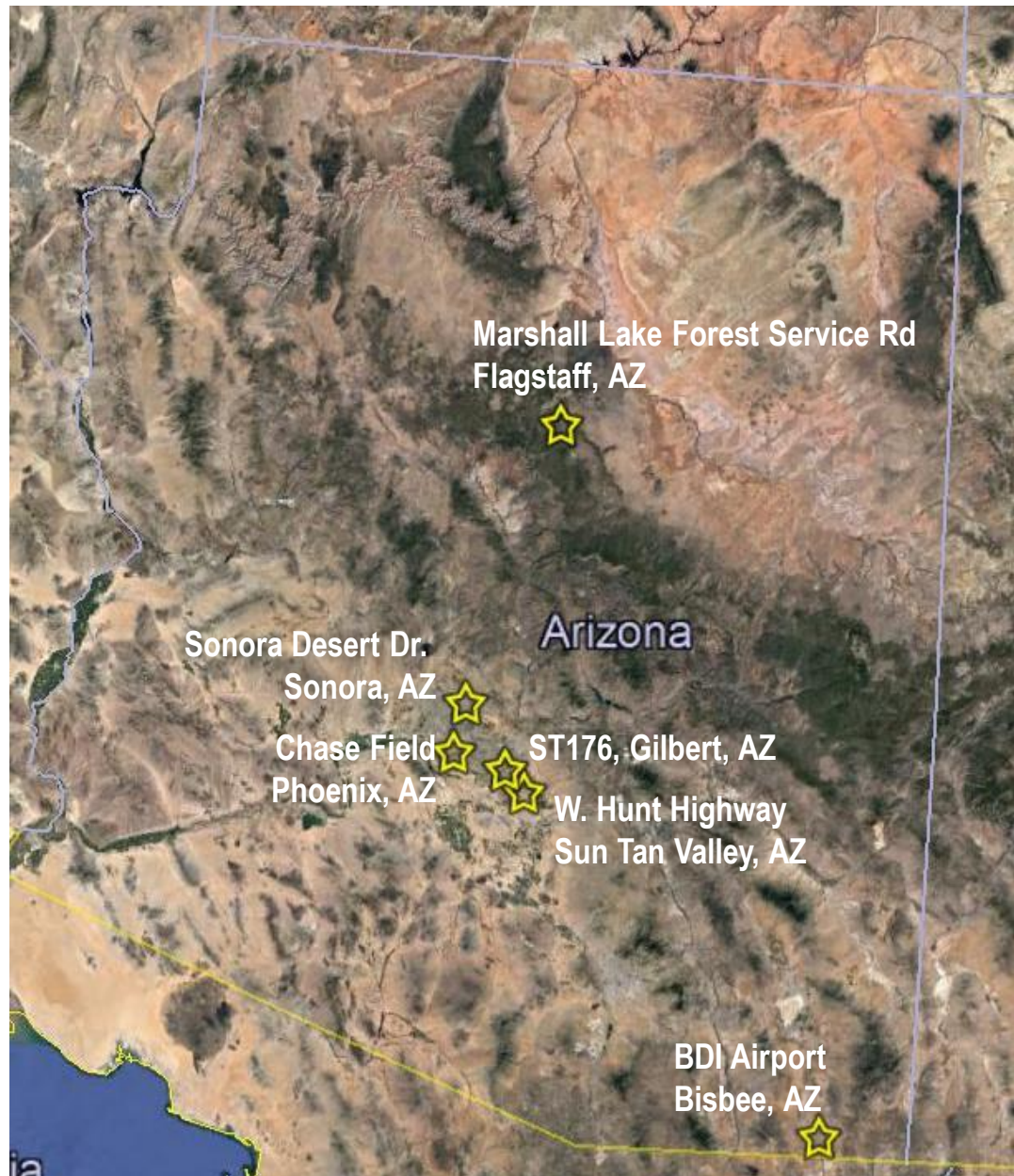
Box and Jitter plots of M_{r-Comp} @ 30 psi plate contact stress

PROJECT NAME: 2017 MnROAD Unbound Layer Evaluation Using Intelligent Compaction
 PROJECT ID: MnROAD_IC
 LOCATION: MnROAD, Albertville, Wright County, MN



APLTs were performed at multiple project sites in AZ since 2015 to assess in-situ performance of geogrid stabilized pavement foundations.

Tensar[®]



San Tan Valley, AZ – TX5 Geogrid



Aggregate base over TX5 geogrid compacted using pneumatic roller

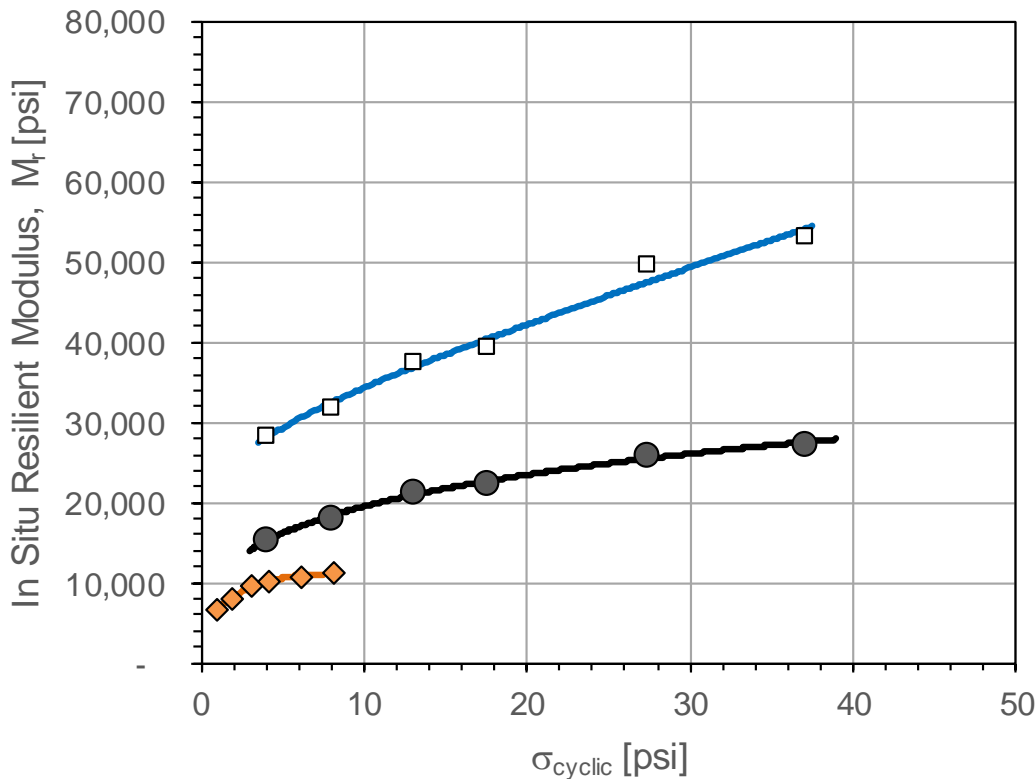


APLT on S. Higley Rd in Gilbert AZ to evaluate performance of geogrid reinforced base layer.



APLT results allowed determining *in-situ* “universal” model parameters for base and subgrade layers.

- Mr-Base[psi] — Mr-Base (pred.) [psi]
- ◇ Mr-Subgrade [psi] — Mr-Subgrade (pred.) [psi]
- Mr-comp [psi] — Mr-comp (pred.) [psi]



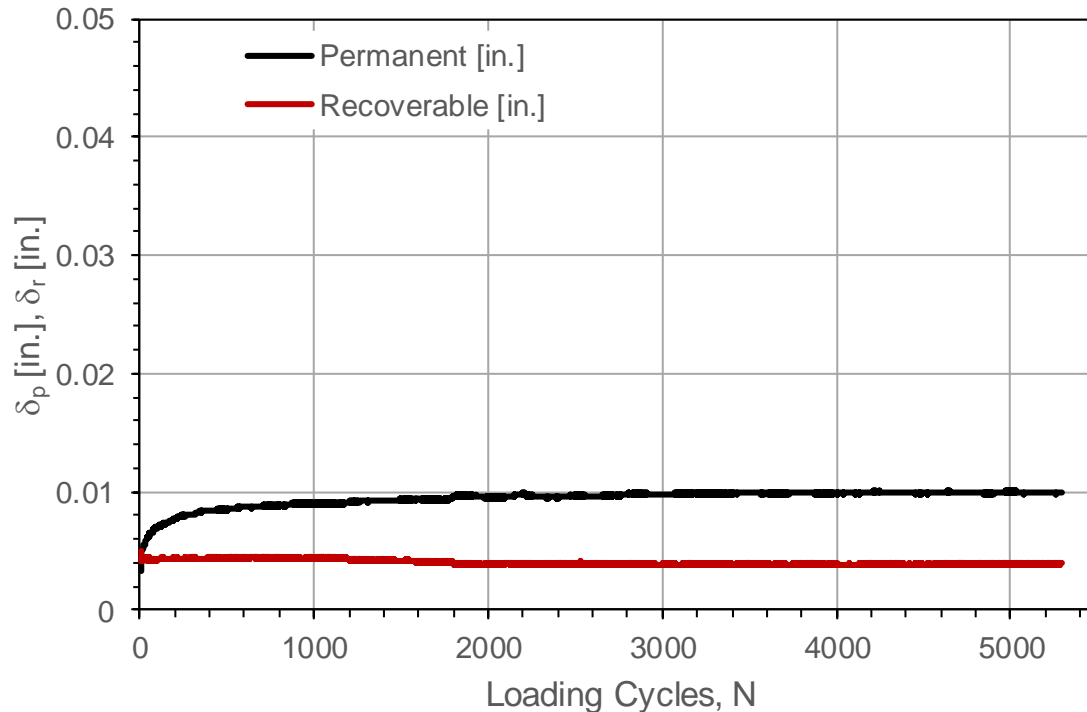
Model: AASHTO (2015)

$$M_{r-comp} = k_1^* P_a \left(\frac{\theta}{P_a} \right)^{k_2^*} \left(1 + \frac{\tau_{oct}}{P_a} \right)^{k_3^*}$$

Parameter	Value	P-Value
k_1^*	1,178.5	1.08E-07
k_2^*	0.275	8.89E-03
k_3^*	-0.067	8.54E-01
Adj. R^2	0.992	
Std. Error [psi]	413	

Parameter	Value	P-Value
k_1^* (Base)	1945.0	3.07E-07
k_2^* (Base)	0.144	1.26E-01
k_3^* (Base)	1.151	1.08E-01
Adj. R^2	0.981	
Std. Error [psi]	1328	
k_1^* (Subgrade)	1379.8	5.42E-06
k_2^* (Subgrade)	0.714	1.34E-03
k_3^* (Subgrade)	-6.191	7.69E-03
Adj. R^2	0.993	
Std. Error [psi]	141	

APLT extended cycle testing (5k cycles) allowed permanent deformation/rutting forecasting.



Permanent Deformation Prediction Parameters

$$C = 0.0048$$
$$d = 0.0876$$
$$R^2 = 0.9299$$

$$N^* = 756 \text{ Cycles}$$
$$\delta_p \text{ at } N^* = 0.0086 \text{ in.}$$
$$\text{Adj. } \delta_p \text{ at } N^* = 0.0038 \text{ in.}$$

$$N_{0.05} = >>10,000,000 \text{ Cycles}$$

$$\delta_p = CN^d$$

What we've learned...

- Non-uniformity can be measured and specified. It affects performance!
- Pavement foundation systems should be designed, stabilized, and optimized!
- Field process control can be driven by mechanistic design values.
- APLT and VIC identify areas of non-compliance and bring great value to the pavement system.

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Thank you!

