Geotechnical Risks for Pavement Foundations!

Presenter:
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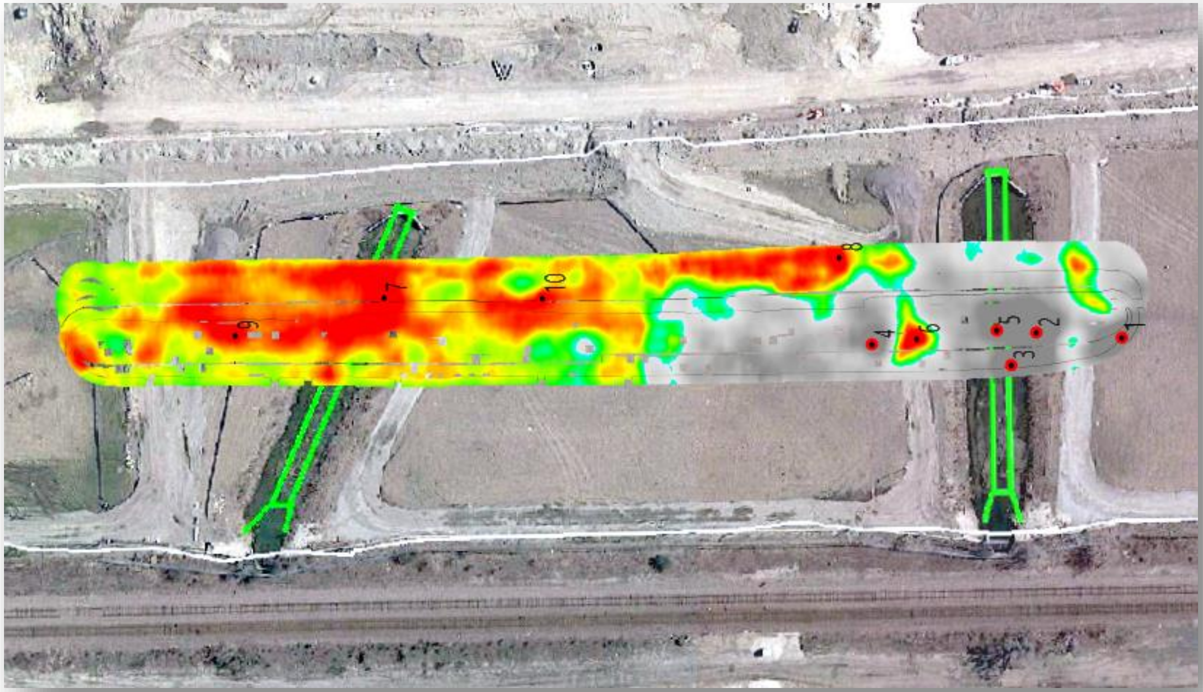
November 21, 2019

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 <u>does not</u> compensate for foundation deficiencies.
- <u>Uniform</u> pavement support is critical to performance but requires special controls.
- New technologies are needed to improve <u>mechanistic</u> pavement foundation construction.

Thick pavements can't cover up bad foundations!

Heavy loads accelerate foundation problems!

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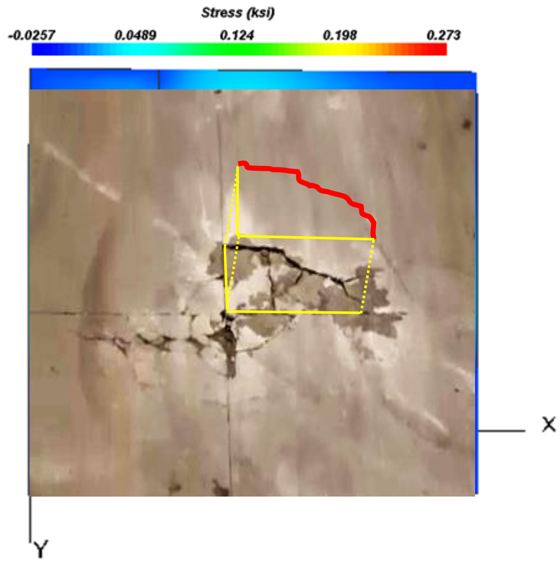
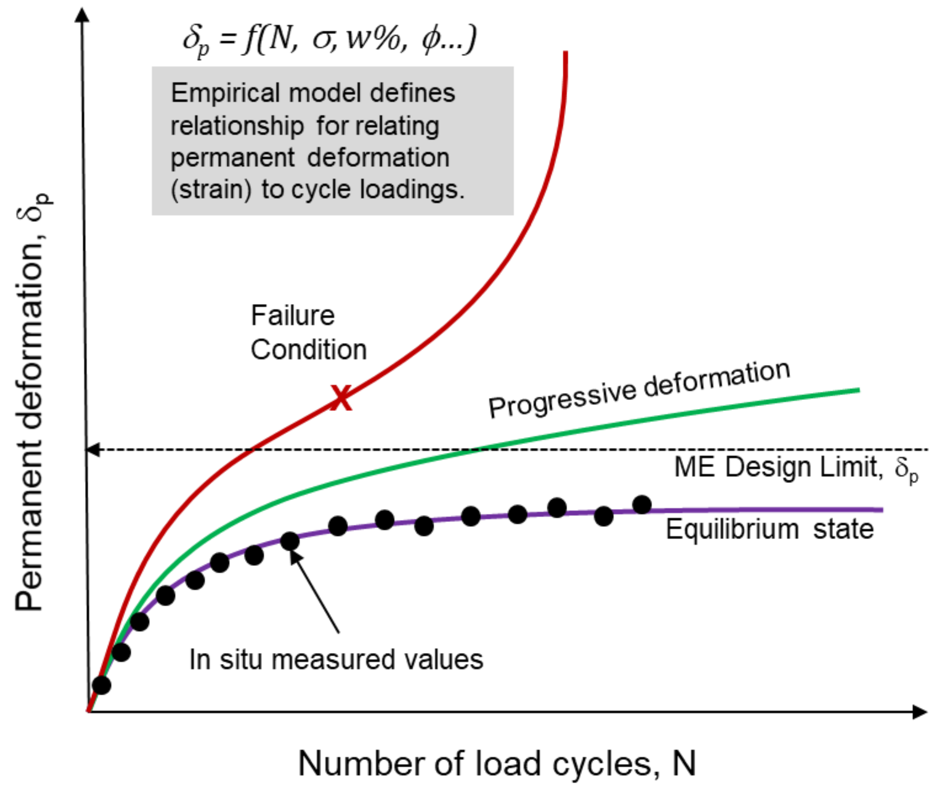
Research efforts with empirical modeling for predictions and mechanistic modeling to establish threshold limits are needed.

Mechanistic Modeling



Mechanistic modeling to validate influence of permanent deformation and set thresholds.

Empirical Modeling



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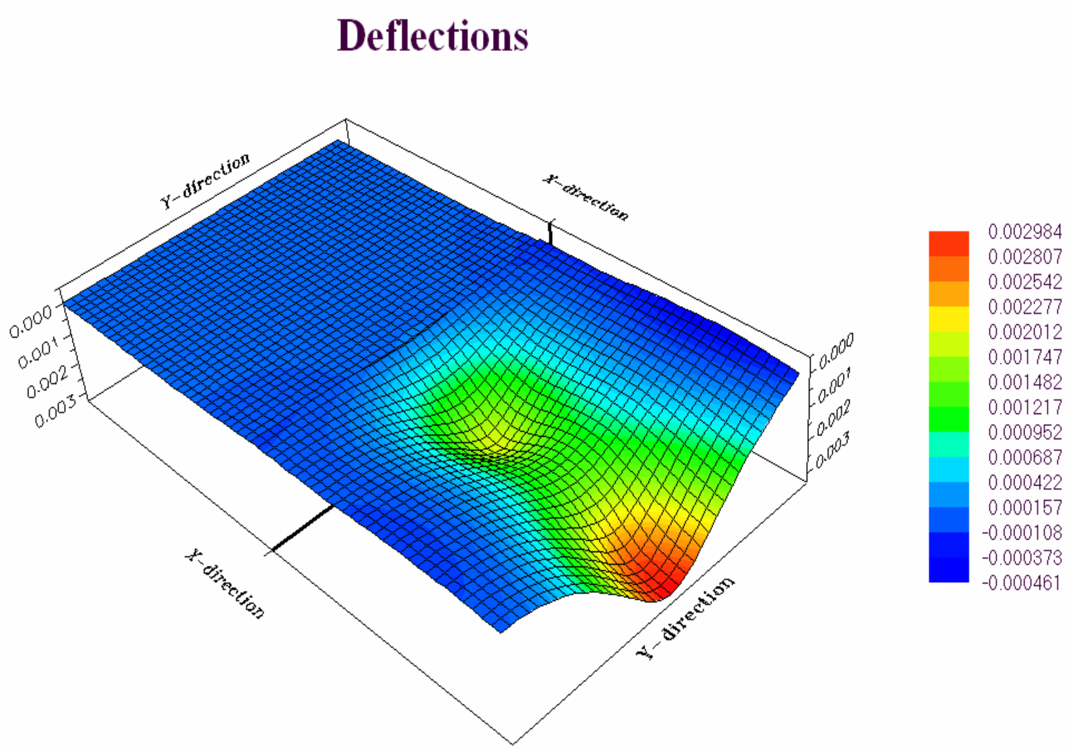
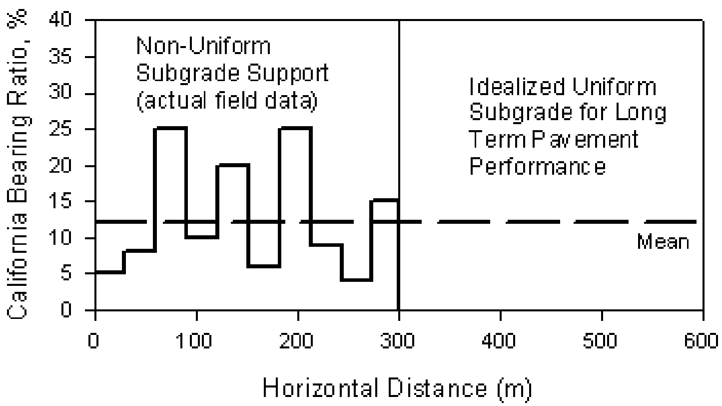
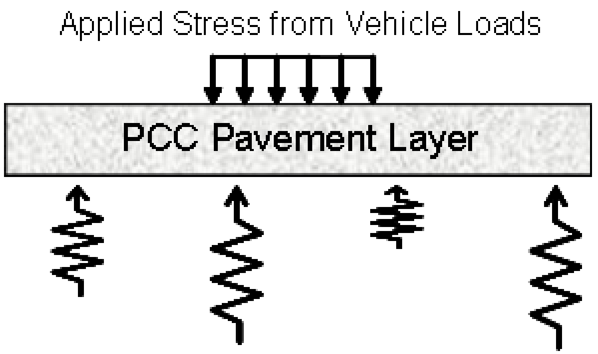
Non-uniform support results in localized stress concentrations under rigid pavements





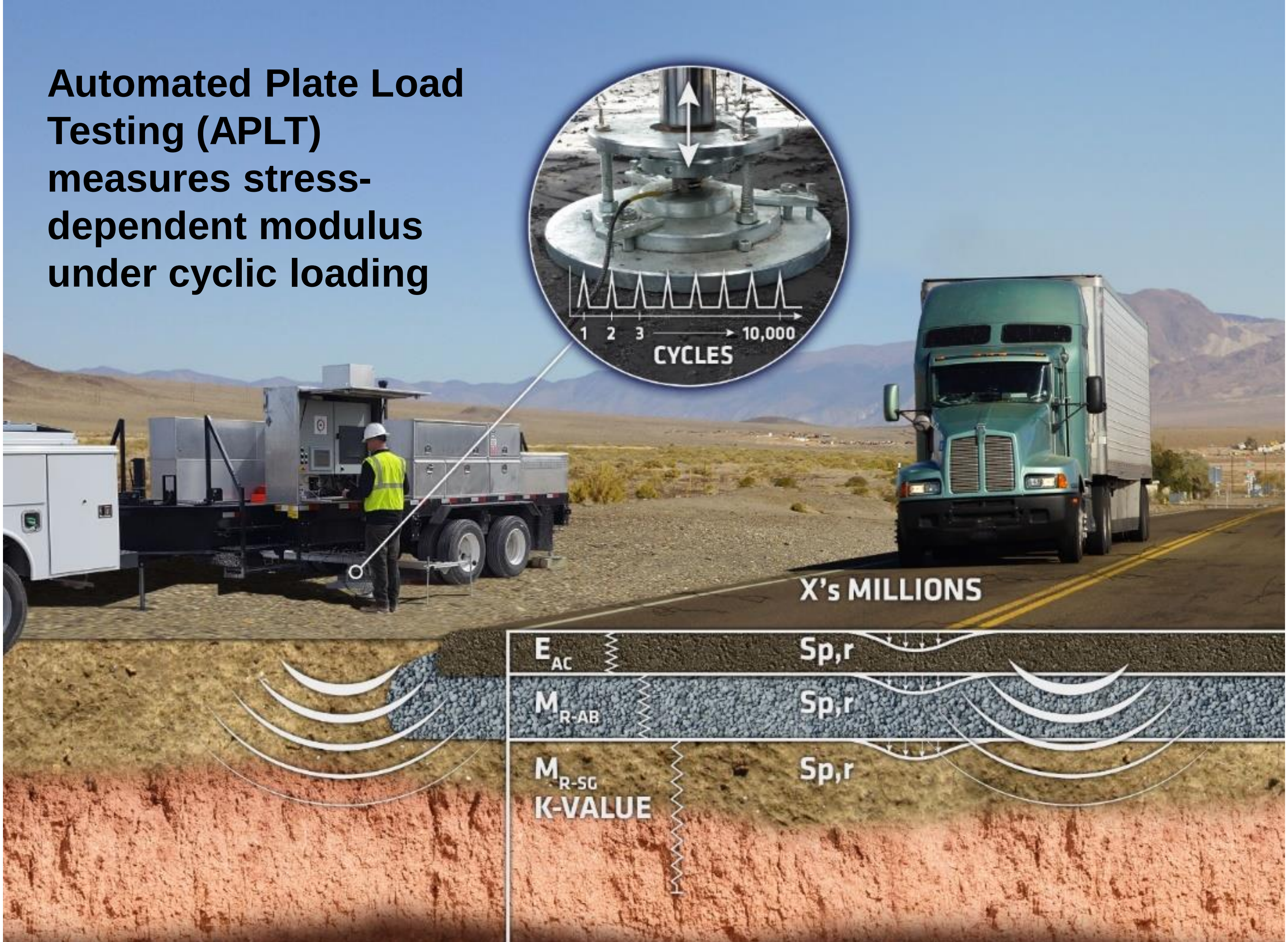


Non-uniform stiffness modeled using "springs" with modulus of subgrade reaction values estimated form in-situ tests

*Fatigue life increases **1.7 times** on average with uniform support*

(White et al. 2004)

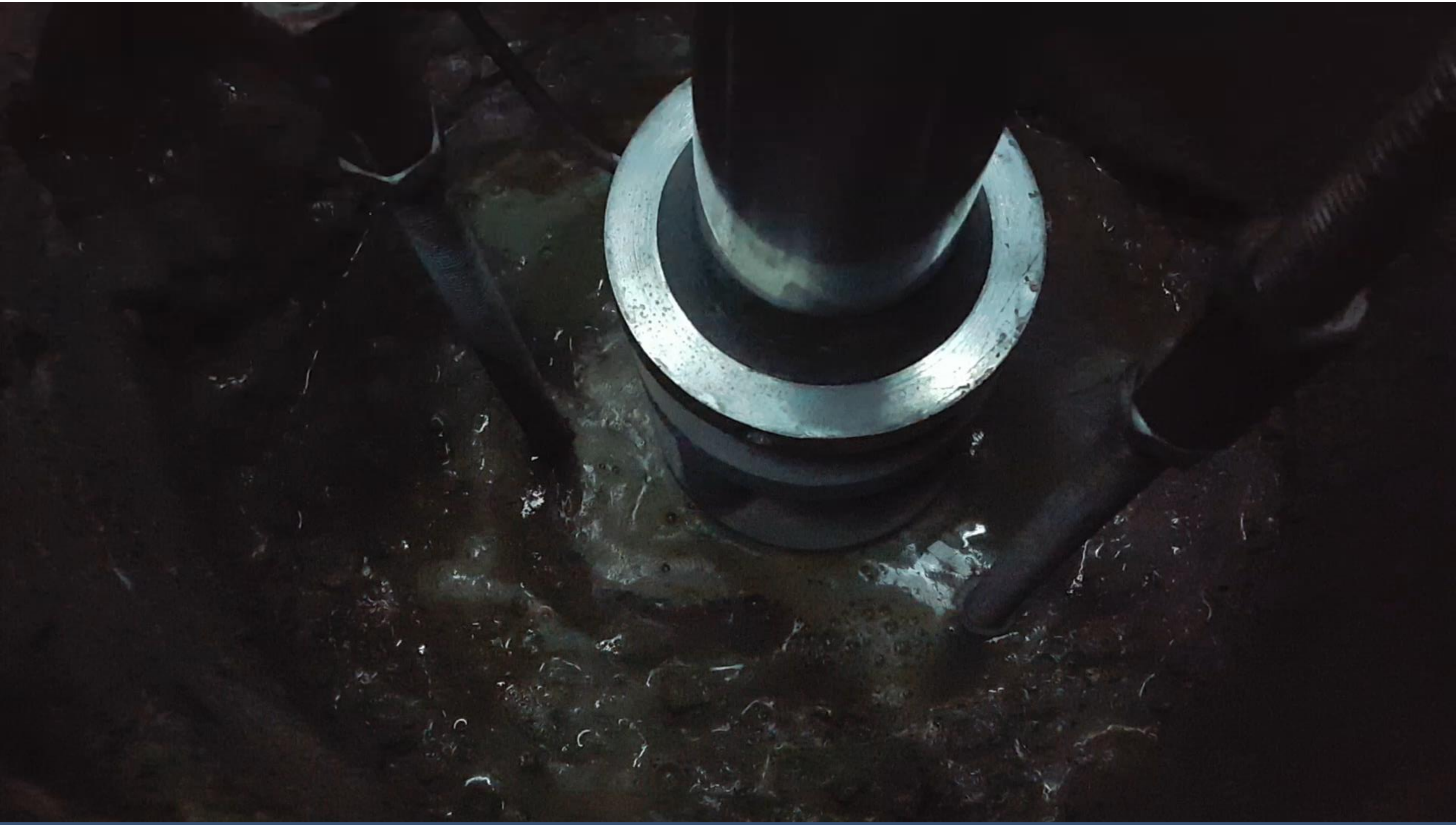
Automated Plate Load Testing (APLT) measures stress-dependent modulus under cyclic loading



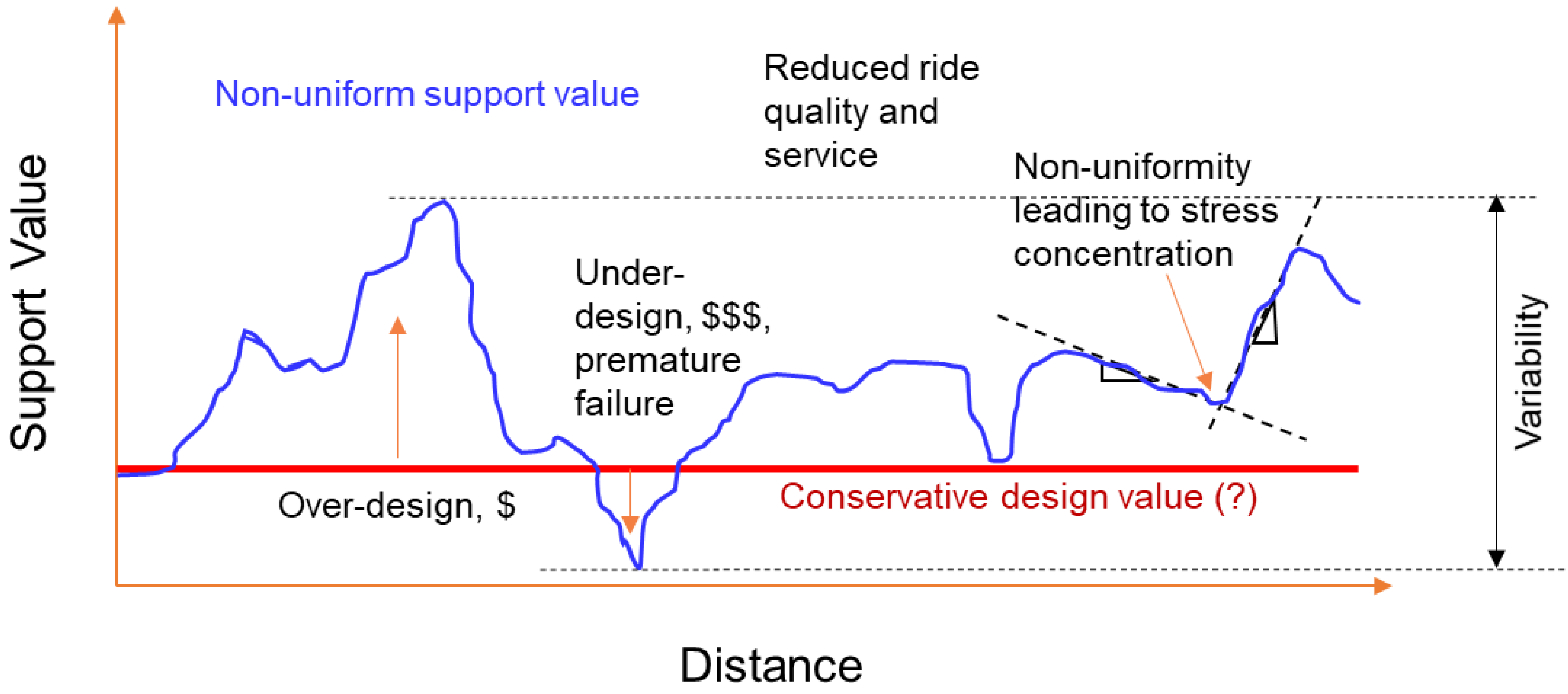
Subgrade Composite
M_r = 3,293 psi

Subbase/Subgrade Composite
M_r = 25,162 psi

Maintaining stability with proper draining is critical.



Spatially variable increases risks of reduced pavement life.



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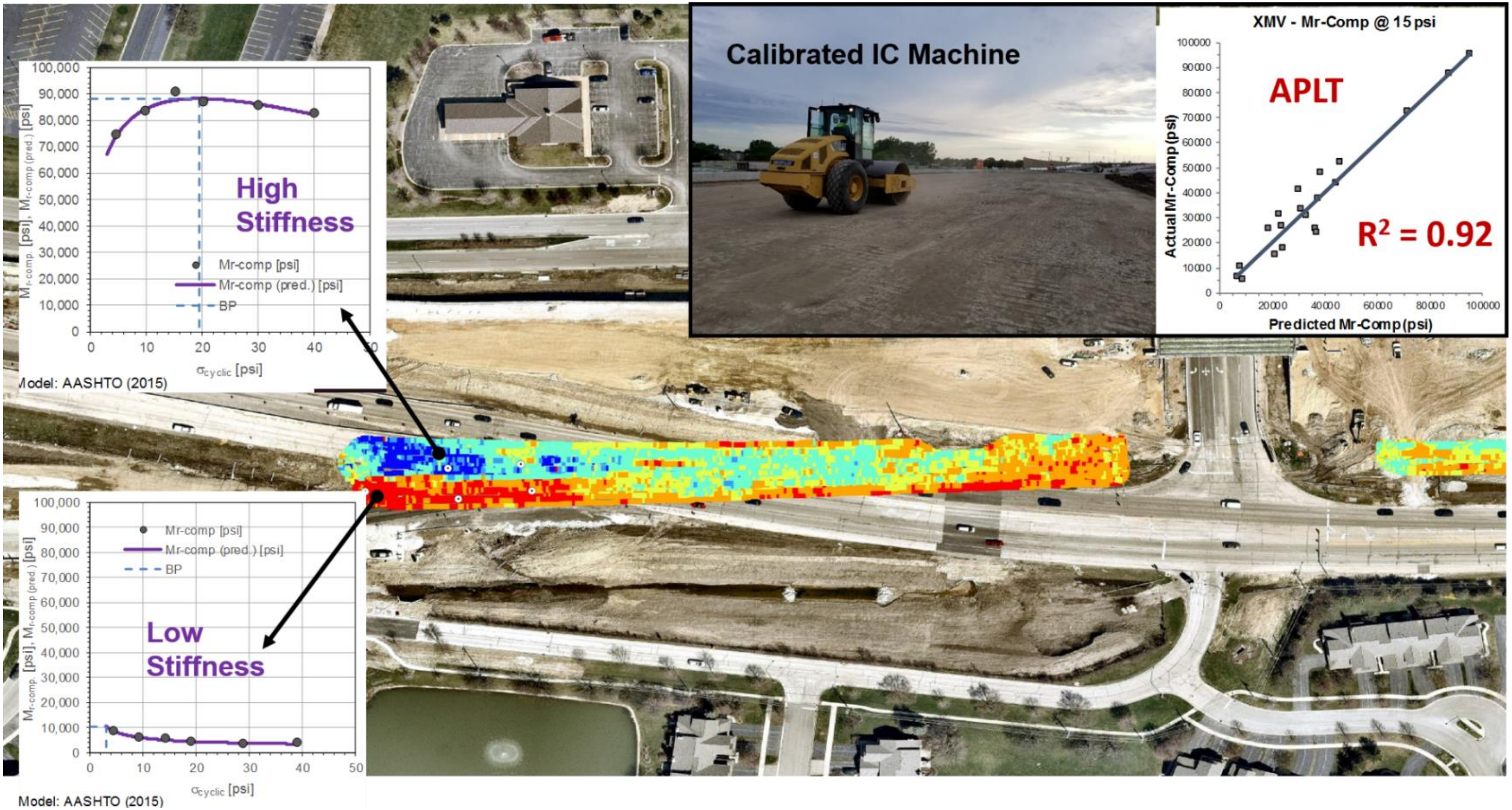
Subgrade: Spatial Map of Resilient Modulus

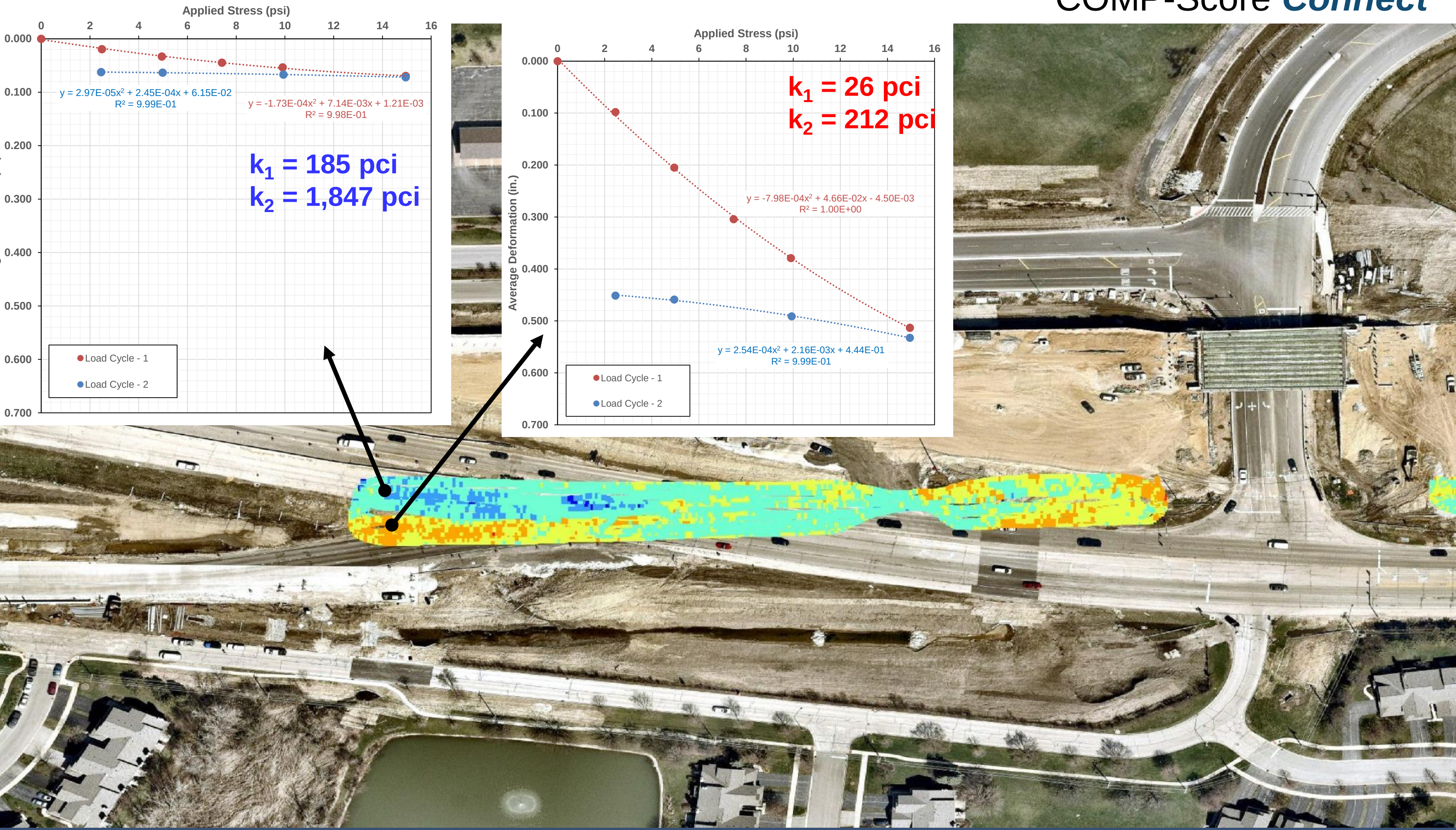
COMP-Score ***Connect***




Passed QC/QA process?

Aggregate Base: Spatial Map of Resilient Modulus

COMP-Score ***Connect***



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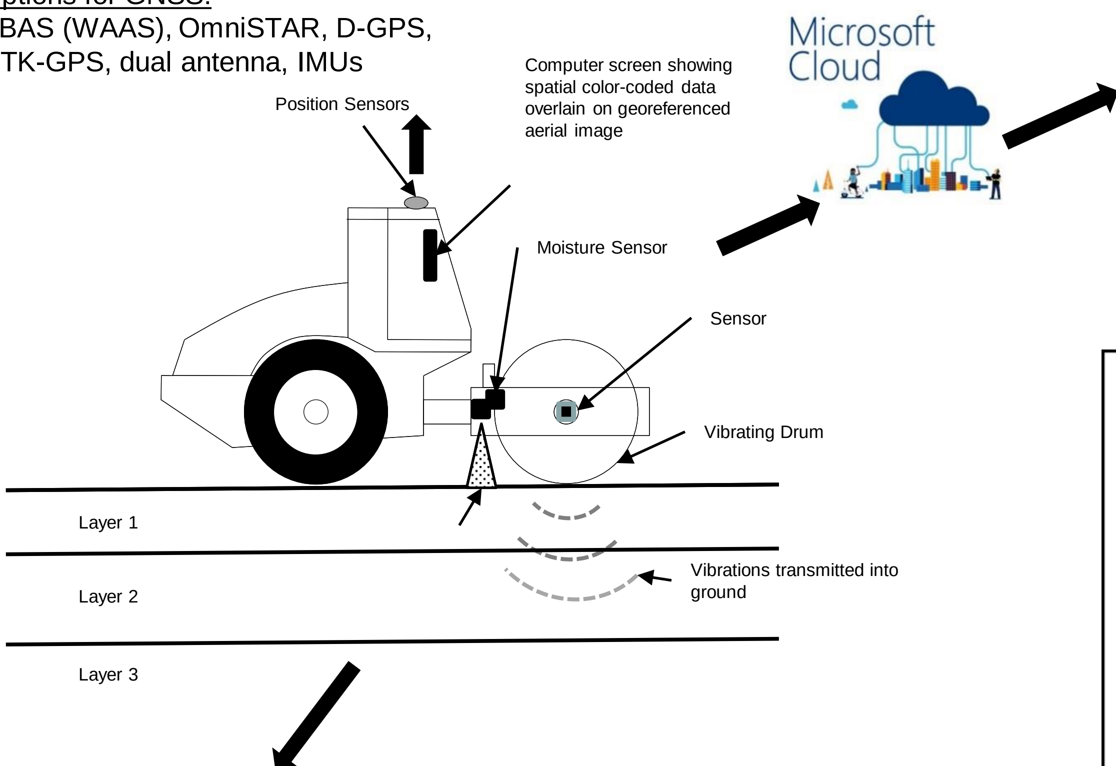
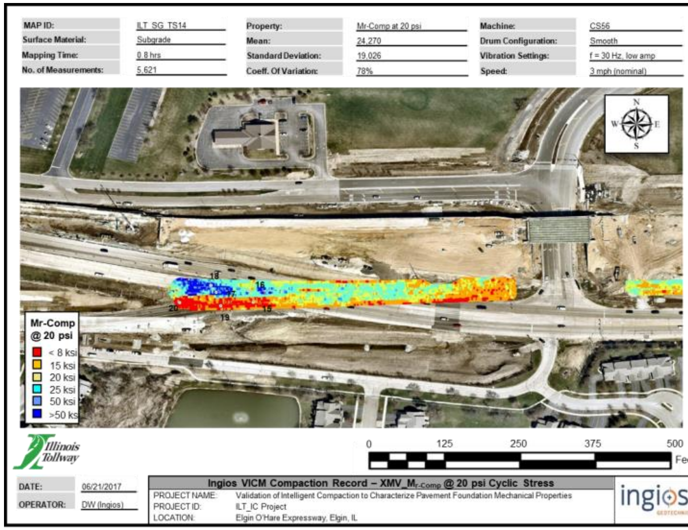
COMP-Score *Connect*

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

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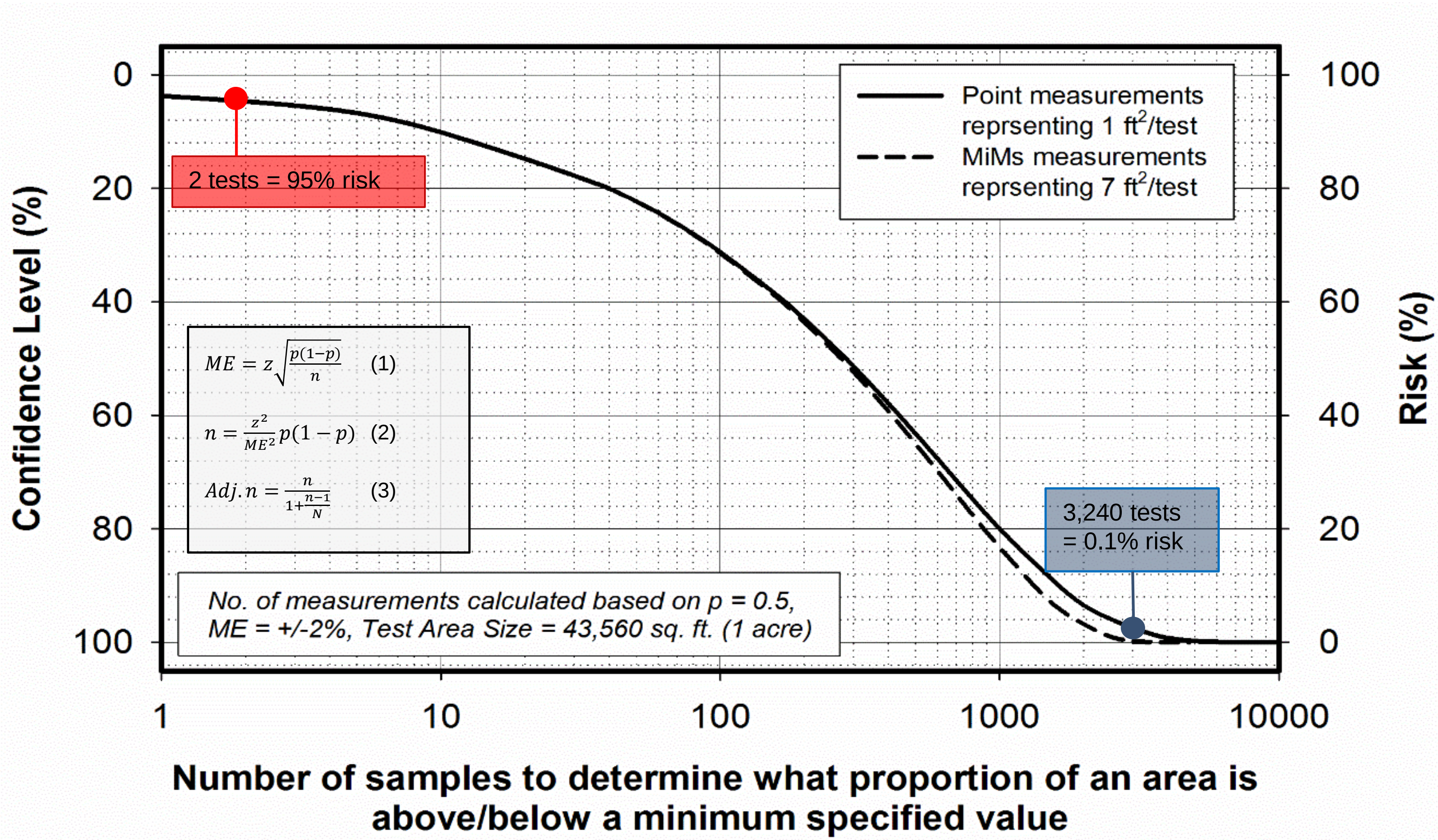
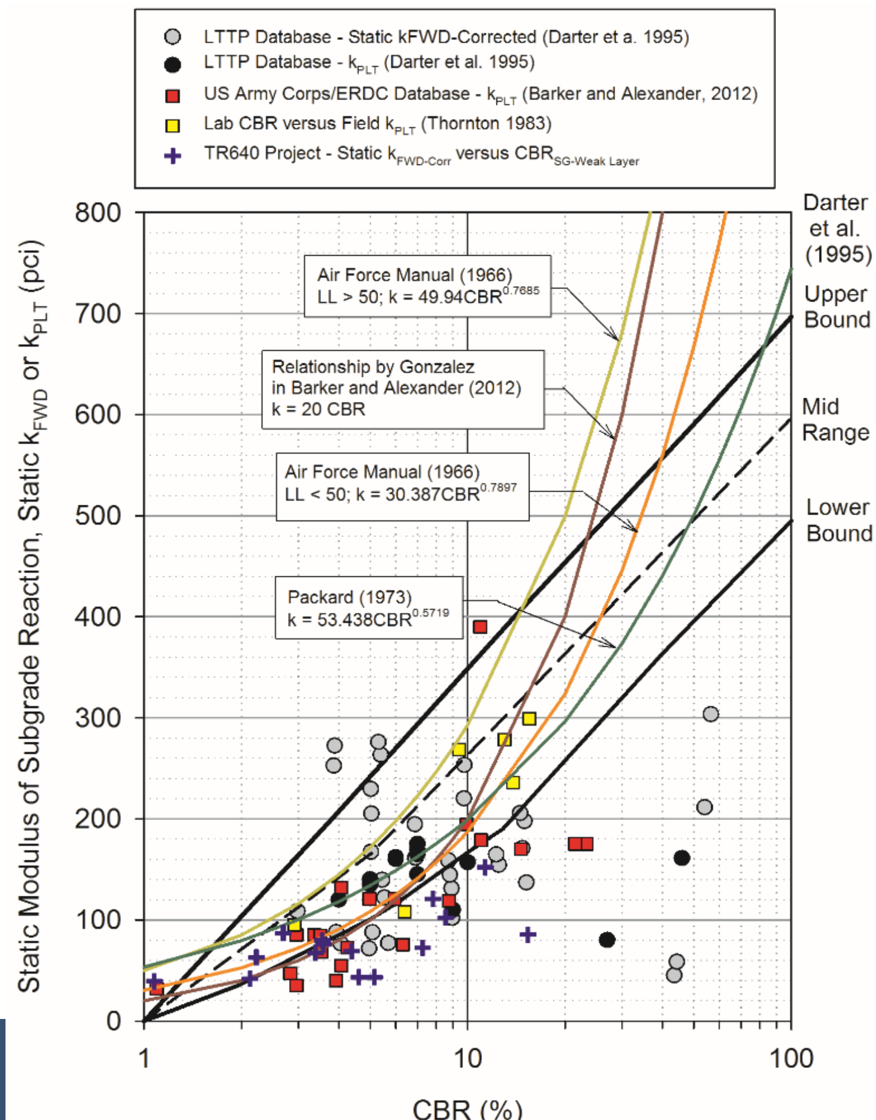
Decreasing Risk With Full Coverage Testing



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*".

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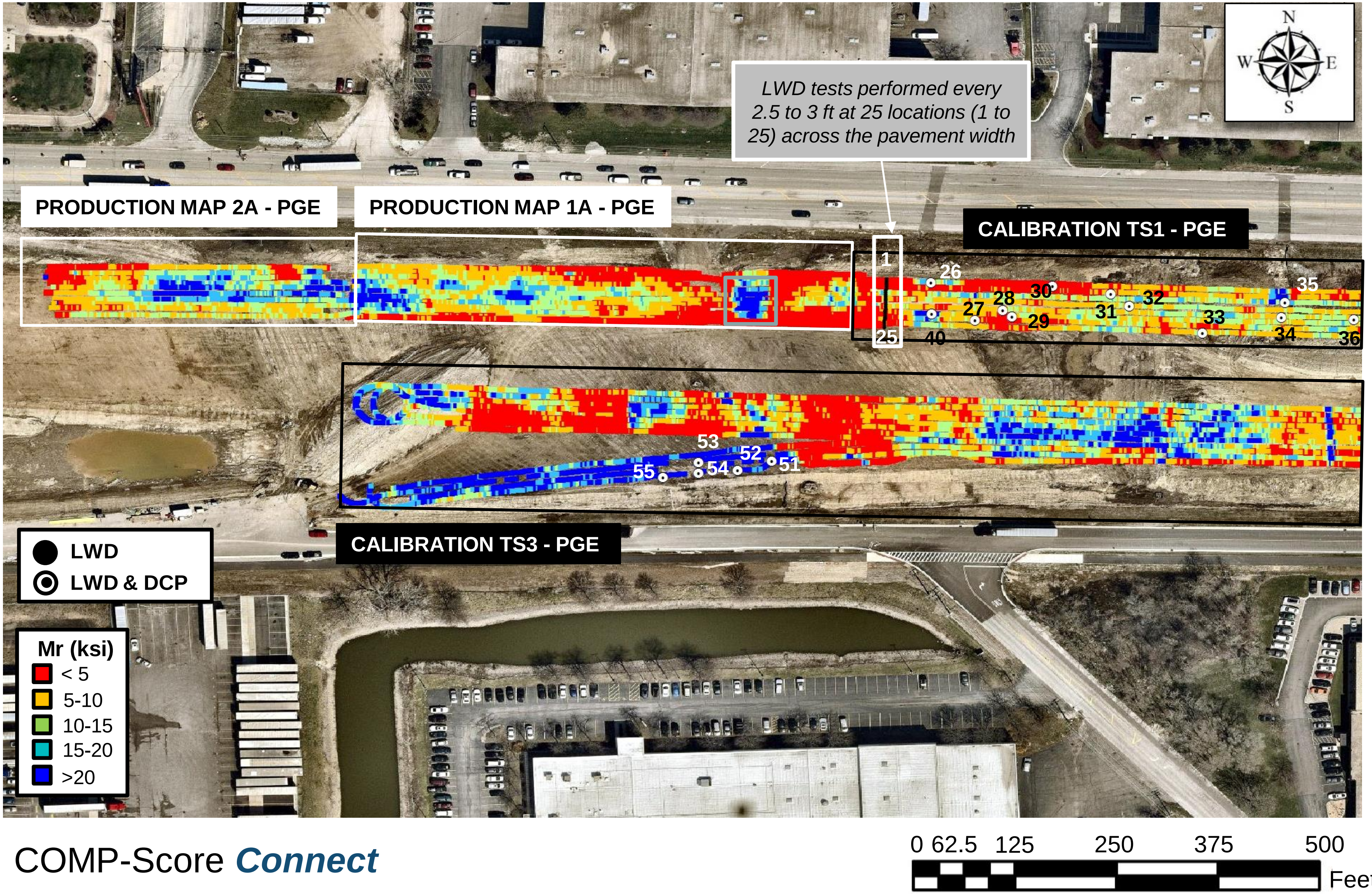
One QC/QA test to document, where?



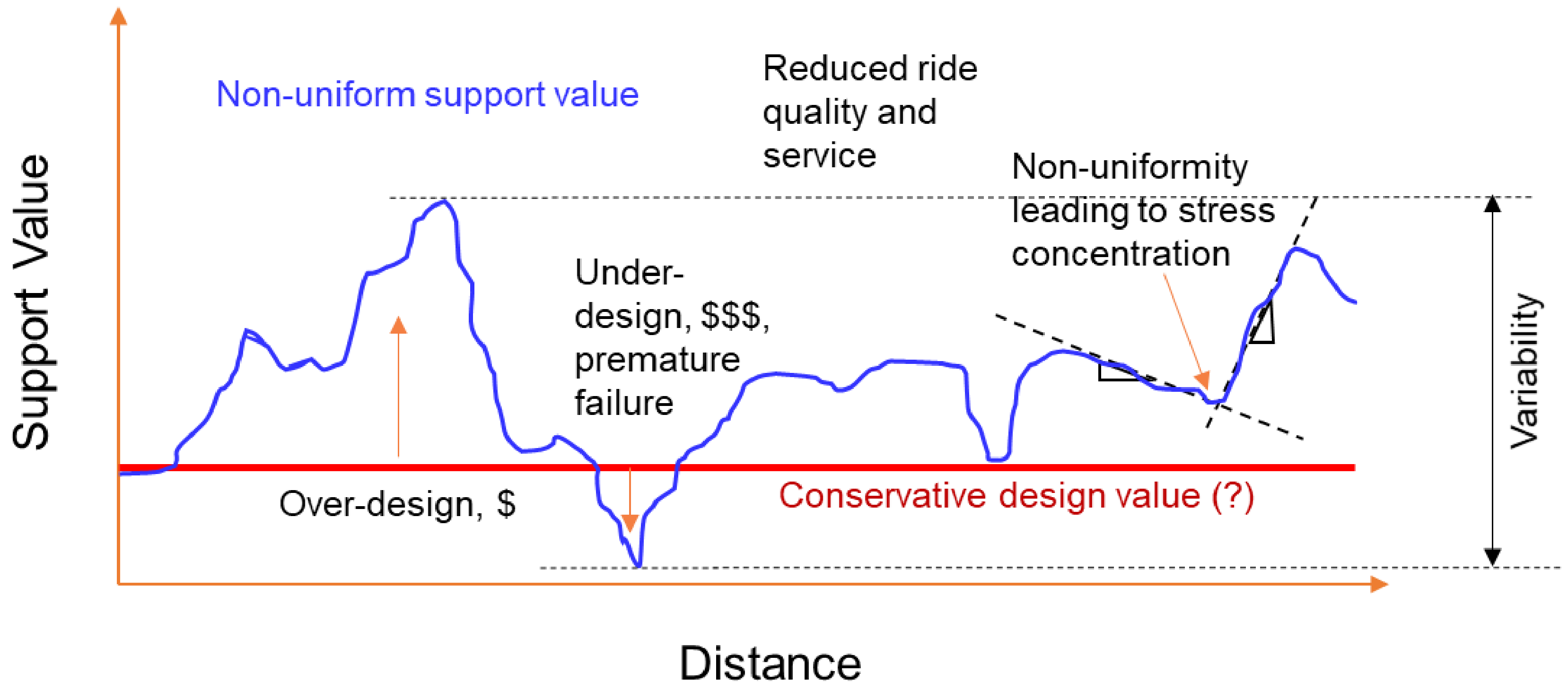
COMP-Score *Connect*

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...?



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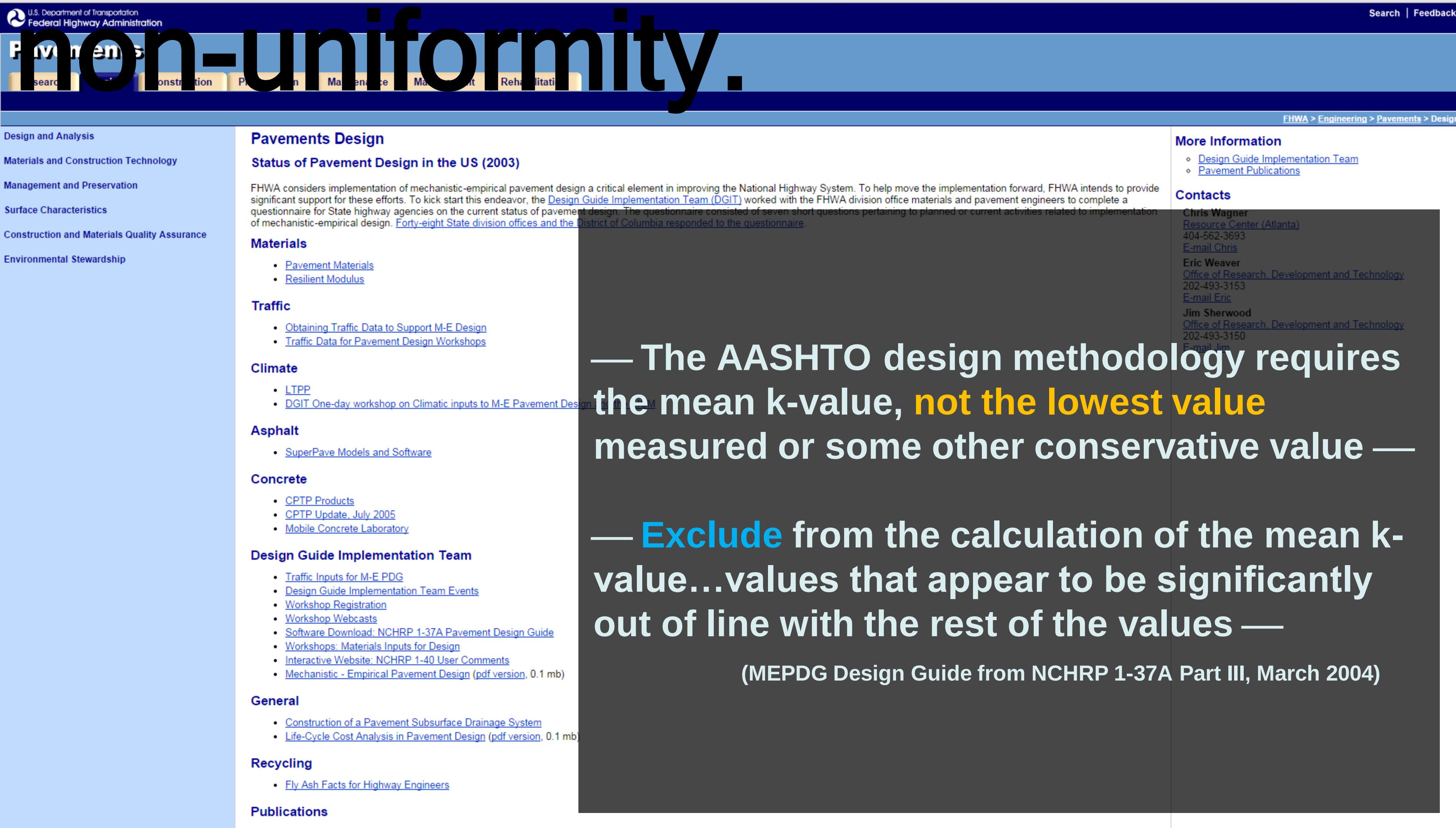
Pavement design excludes non-uniformity.

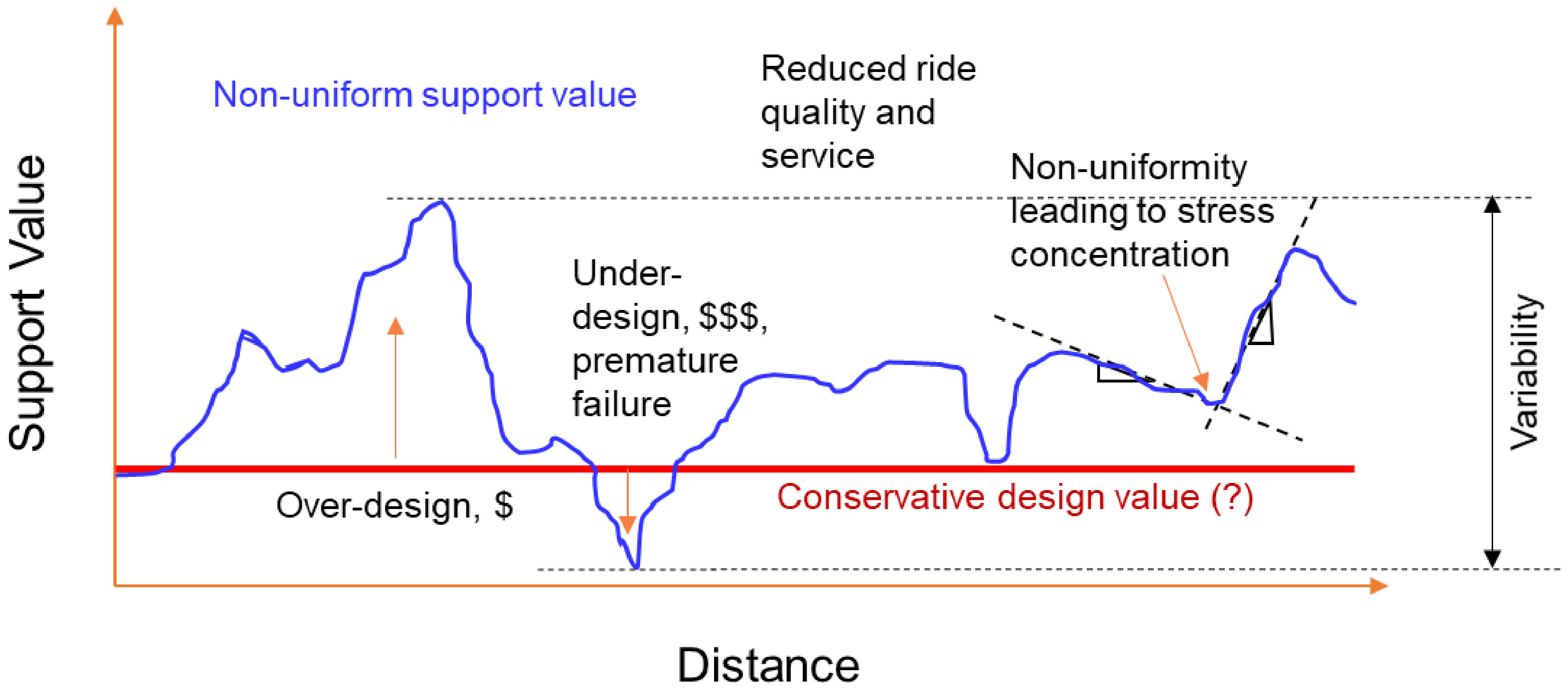


— The AASHTO design methodology requires the mean k-value, **not the lowest value** measured or some other conservative value —

— **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...?



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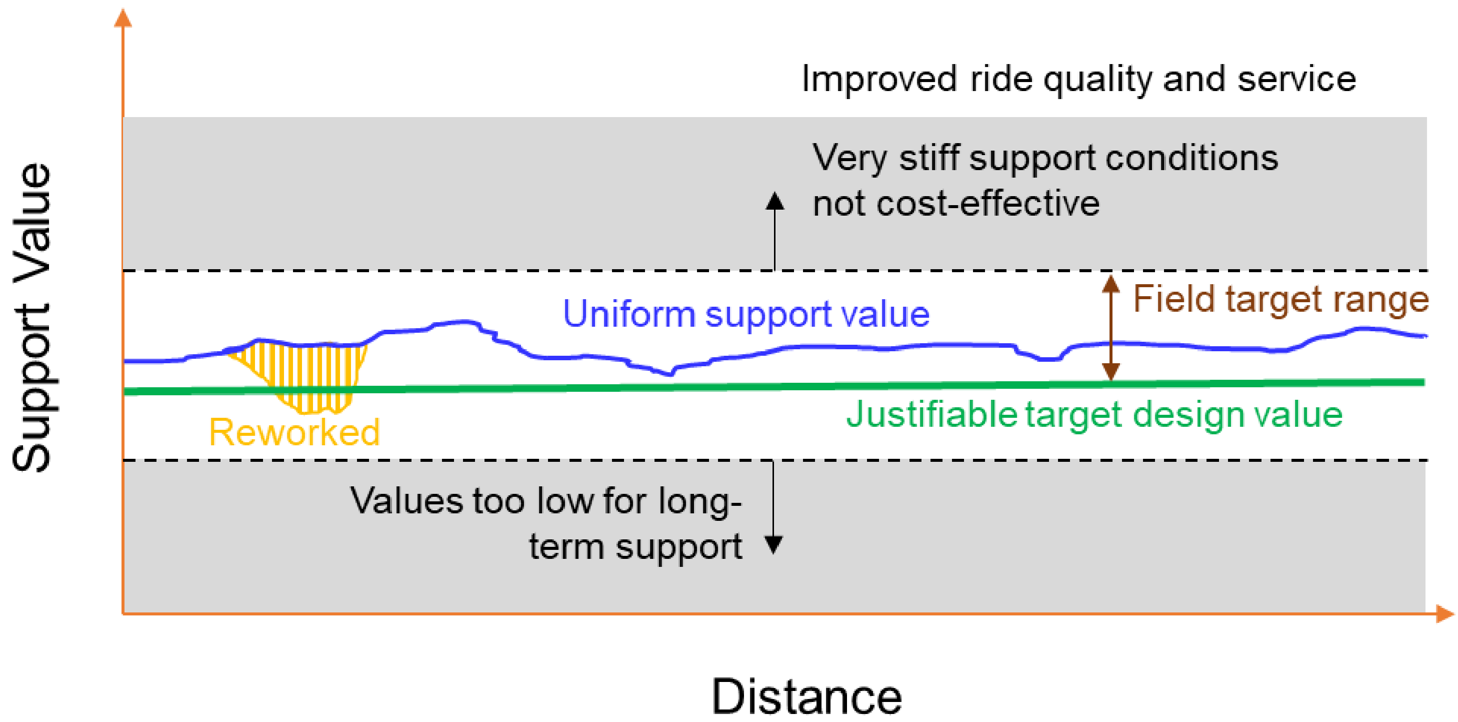
Reduce risks with improved field control to ensure design assumptions are verified!



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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.

SEMA CONSTRUCTION

Interstate Highway Construction

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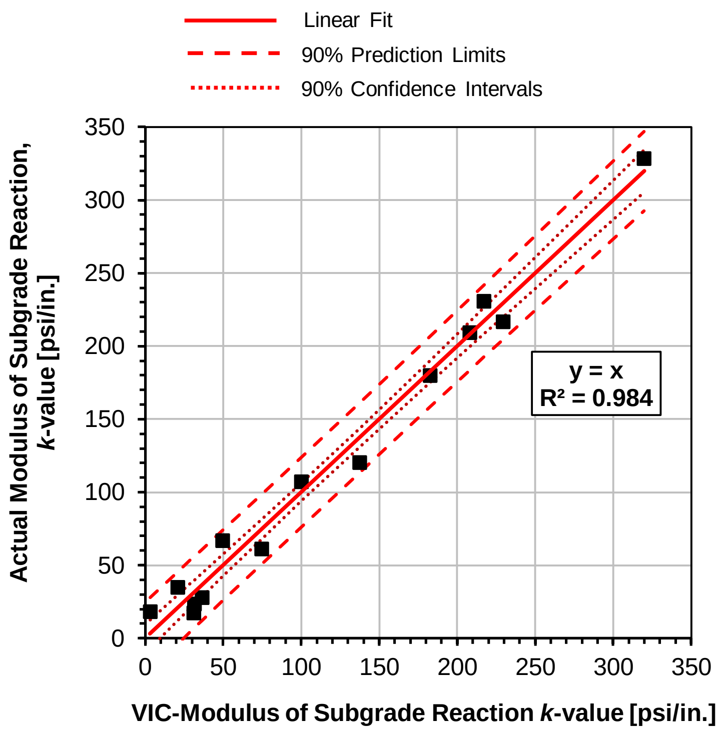
Aggregate base layer stabilized with geogrid.

APLTs used to calibrate VIC machine to resilient modulus.

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-value = 1.000 x VIC *k*-value + 0

Regression Statistics		
N	14	
R^2	**0.984**	
R^2(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 specifcation requirement of minimum $R^2 \geq 0.85$?

YES

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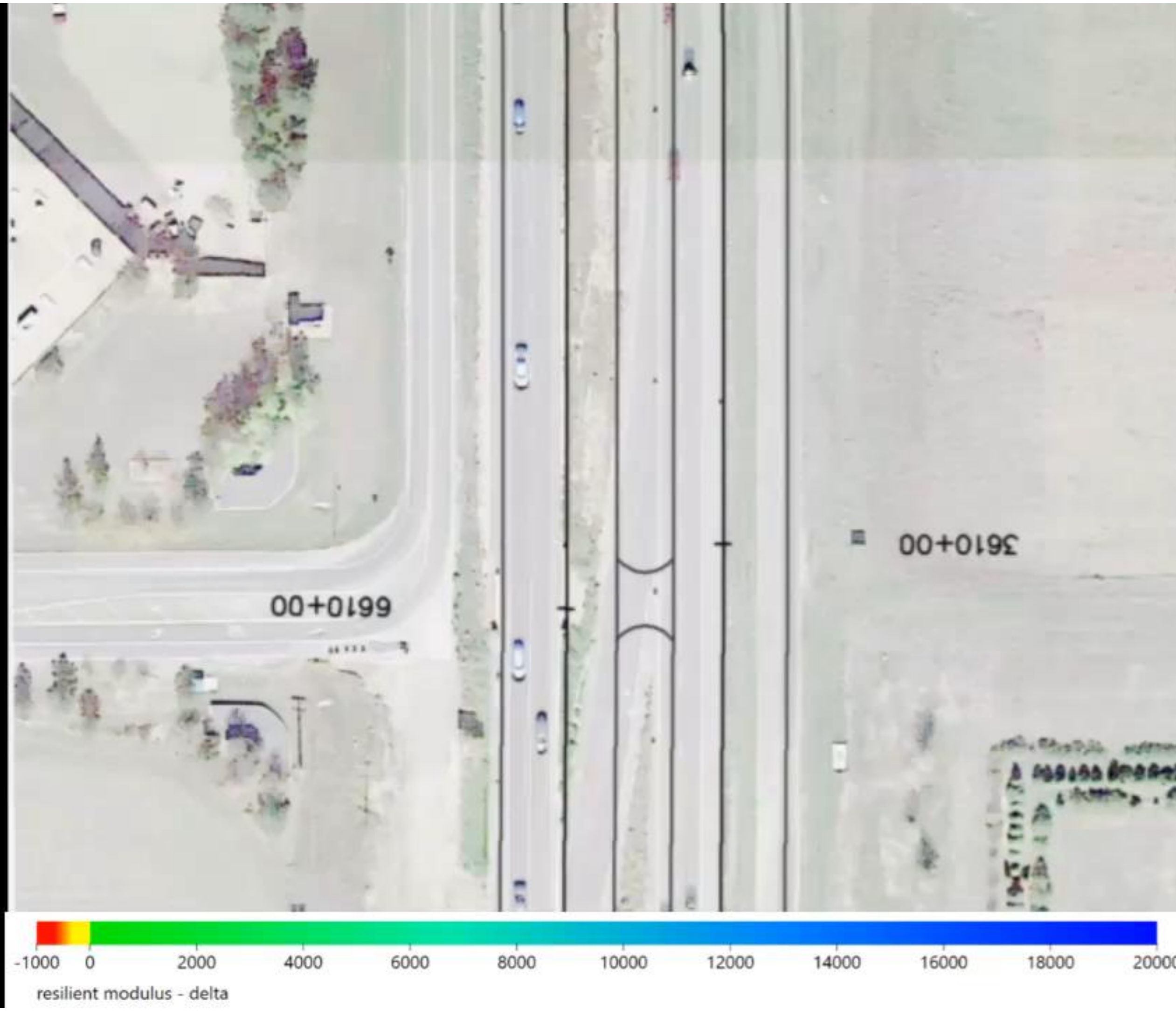
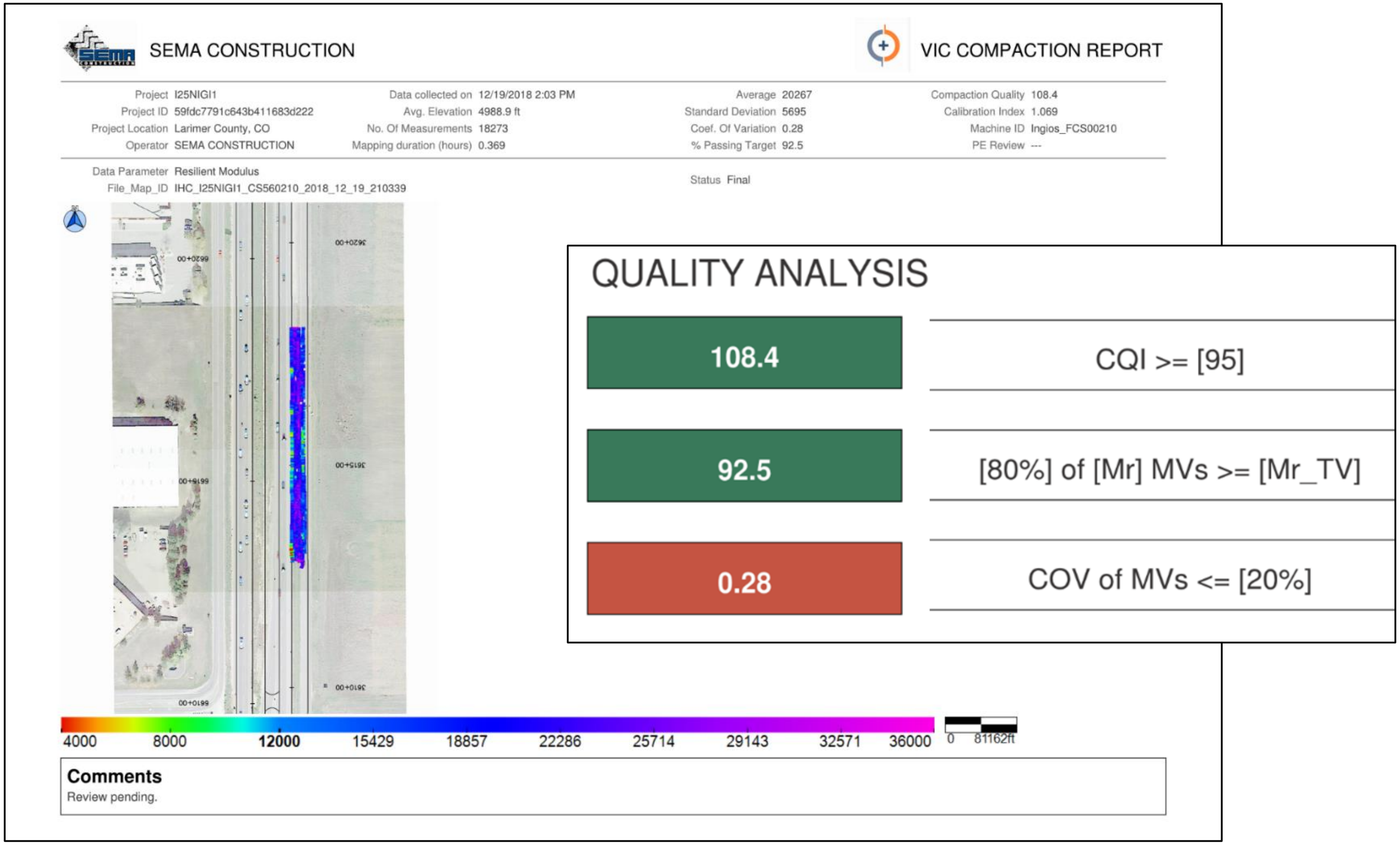


-1000 0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
resilient modulus - delta

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



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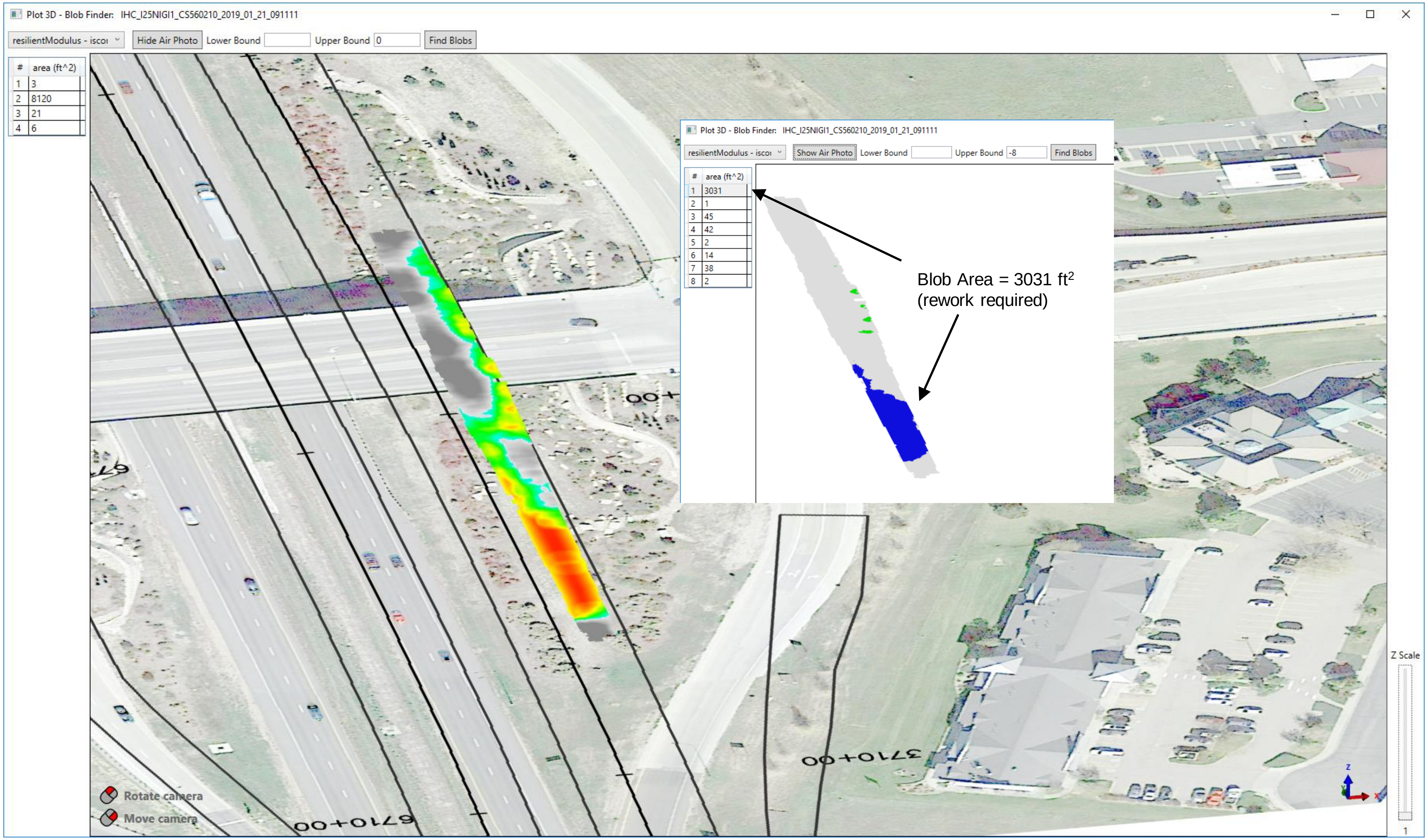
COMP-Score I^2 (rework areas) Blob Identifier for Rework Areas



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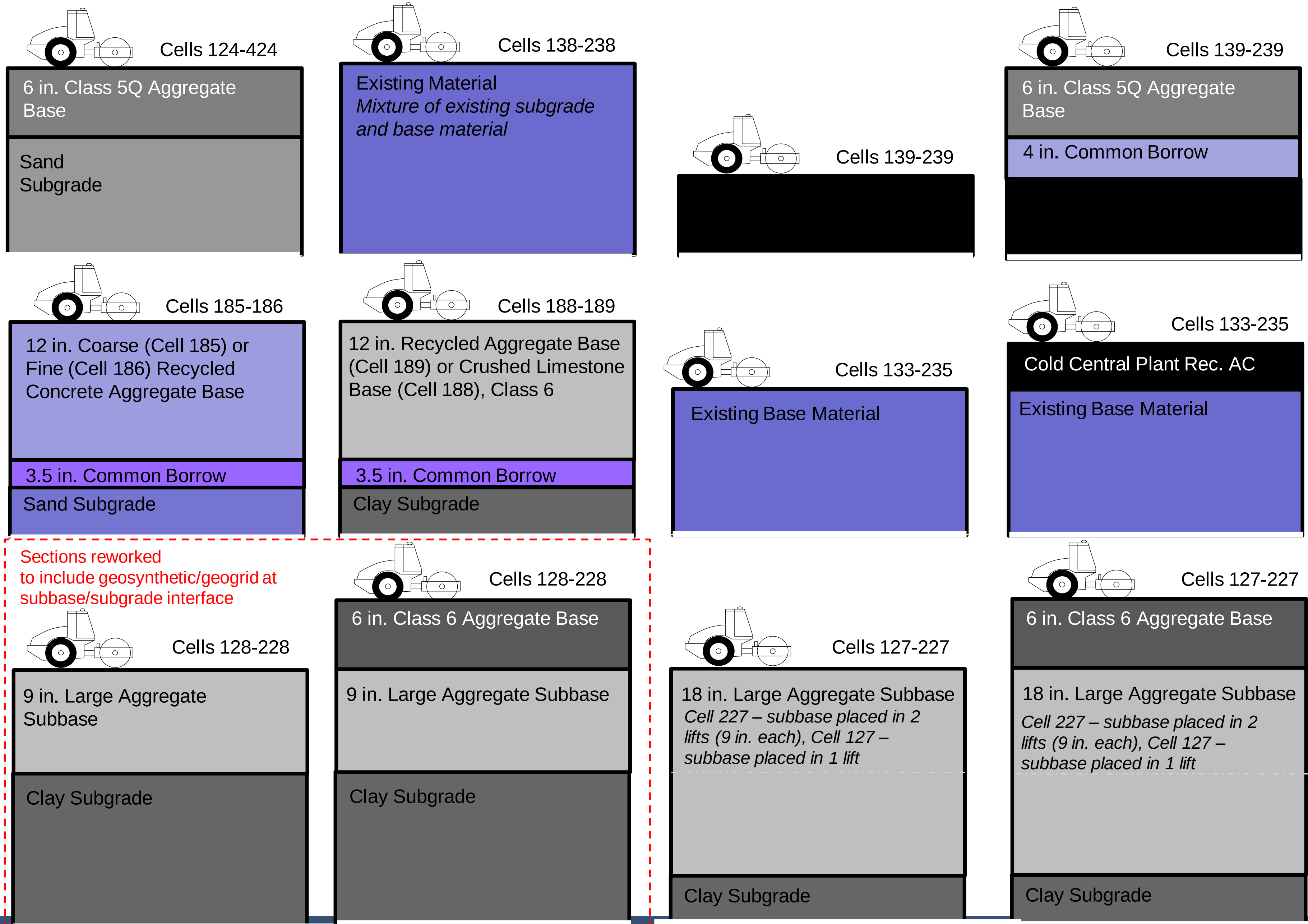

SUMMARY OF DIFFERENT CROSS-SECTIONS W/ VIC MAPPING

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

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

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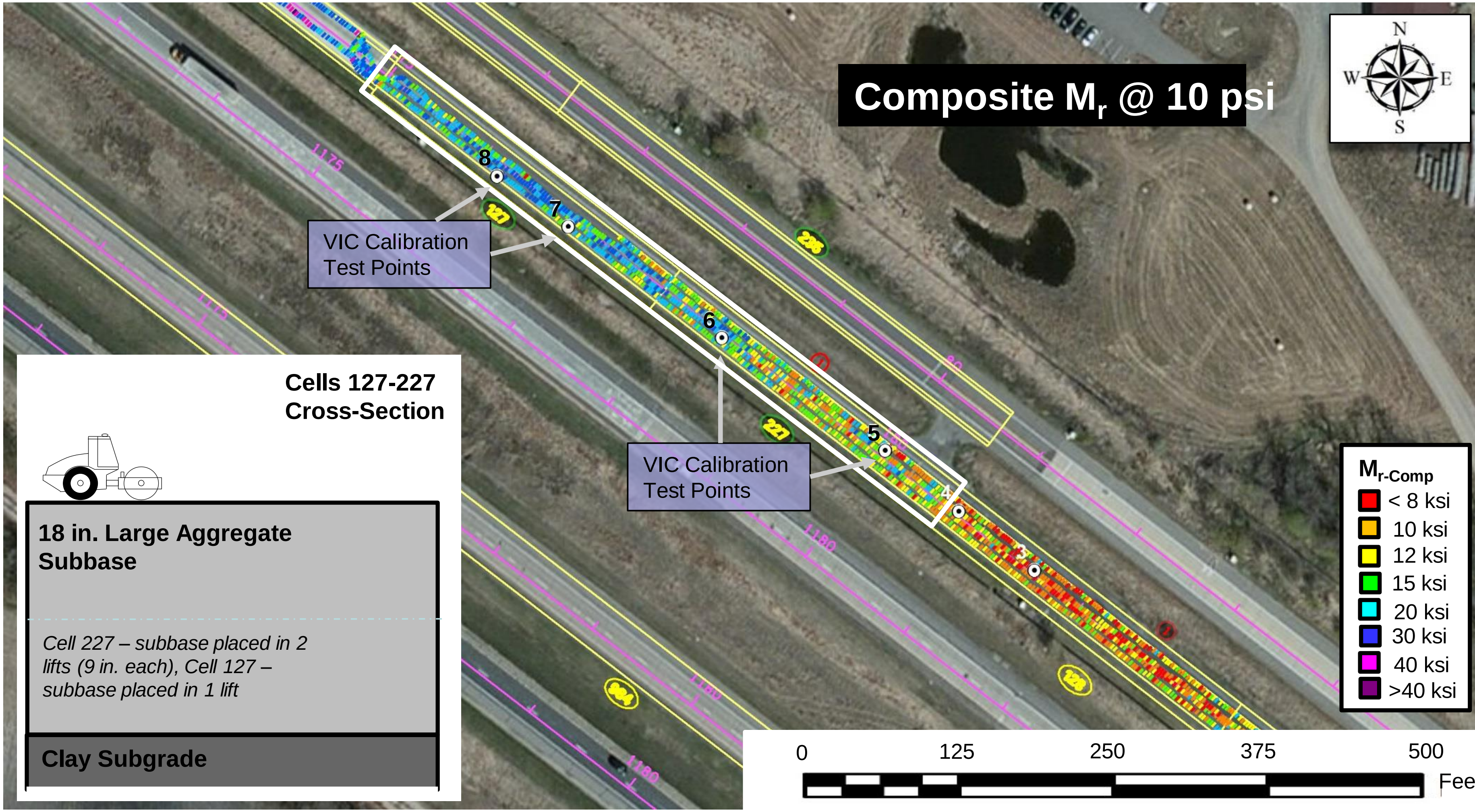
MAP ID:	Cells 127/227_Subbase		**Meas. Property:**	$M_{r\text{-}Comp}$ @ 10 psi plate contact stress		**Machine:** CS56
Surface Material:	Subbase		**Mean:**	17.5 ksi	13.1 ksi	**Drum Configuration:** Smooth
Mapping Time:	5 min	4 min	**Standard Deviation:**	4.4 ksi	3.7 ksi	**Vibration Settings:** f = 30 Hz, low amp
No. of Measurements:	332	412	**Coeff. Of Variation:**	25%	28%	**Speed:** 3 mph (nominal)



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

Ingios VIC Record – VIC_$M_{r\text{-}Comp}$ @ 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

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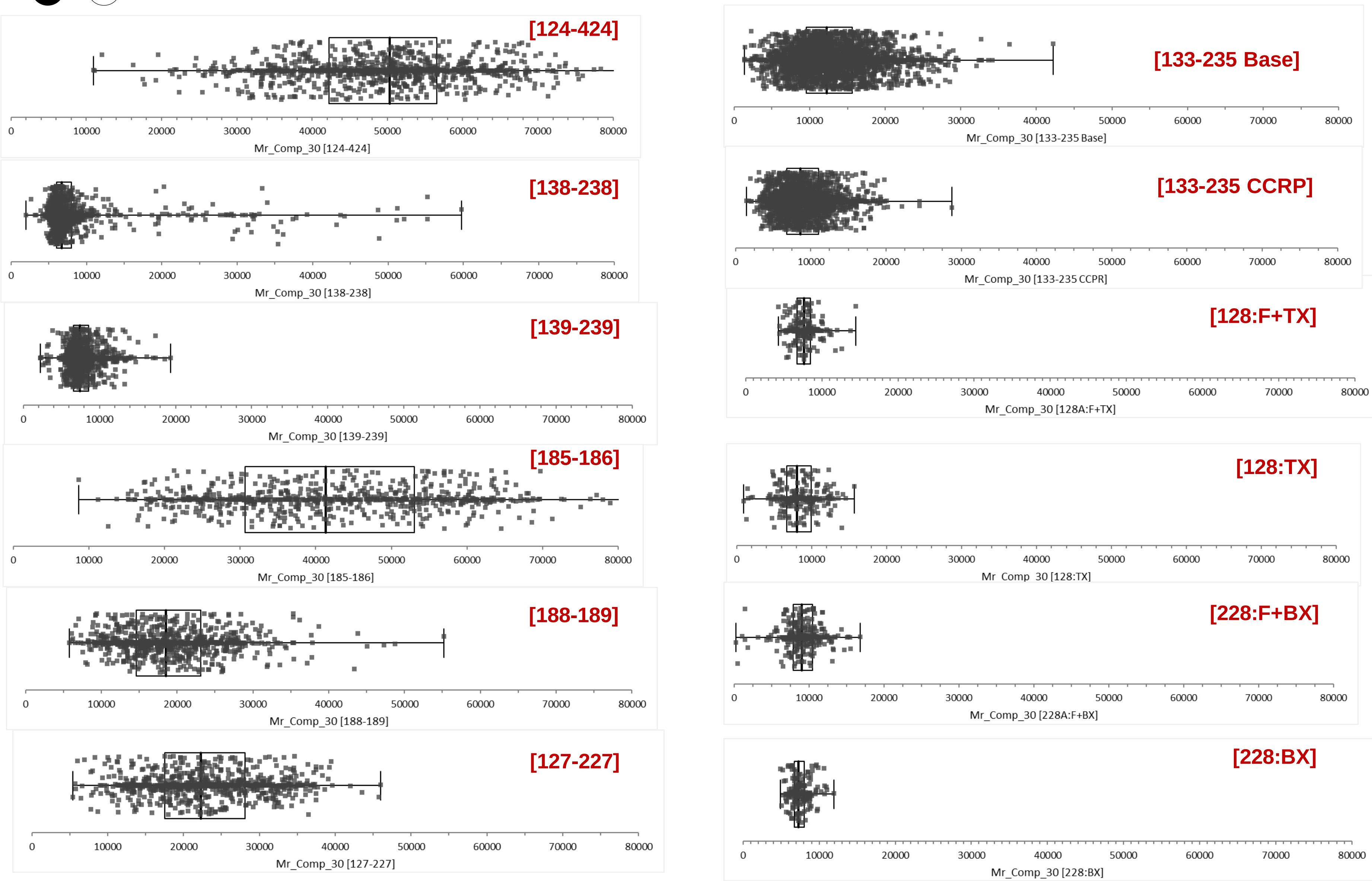
Box Plots – $M_{r\text{-}Comp}$_30 psi

COMP-Score *Connect*



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

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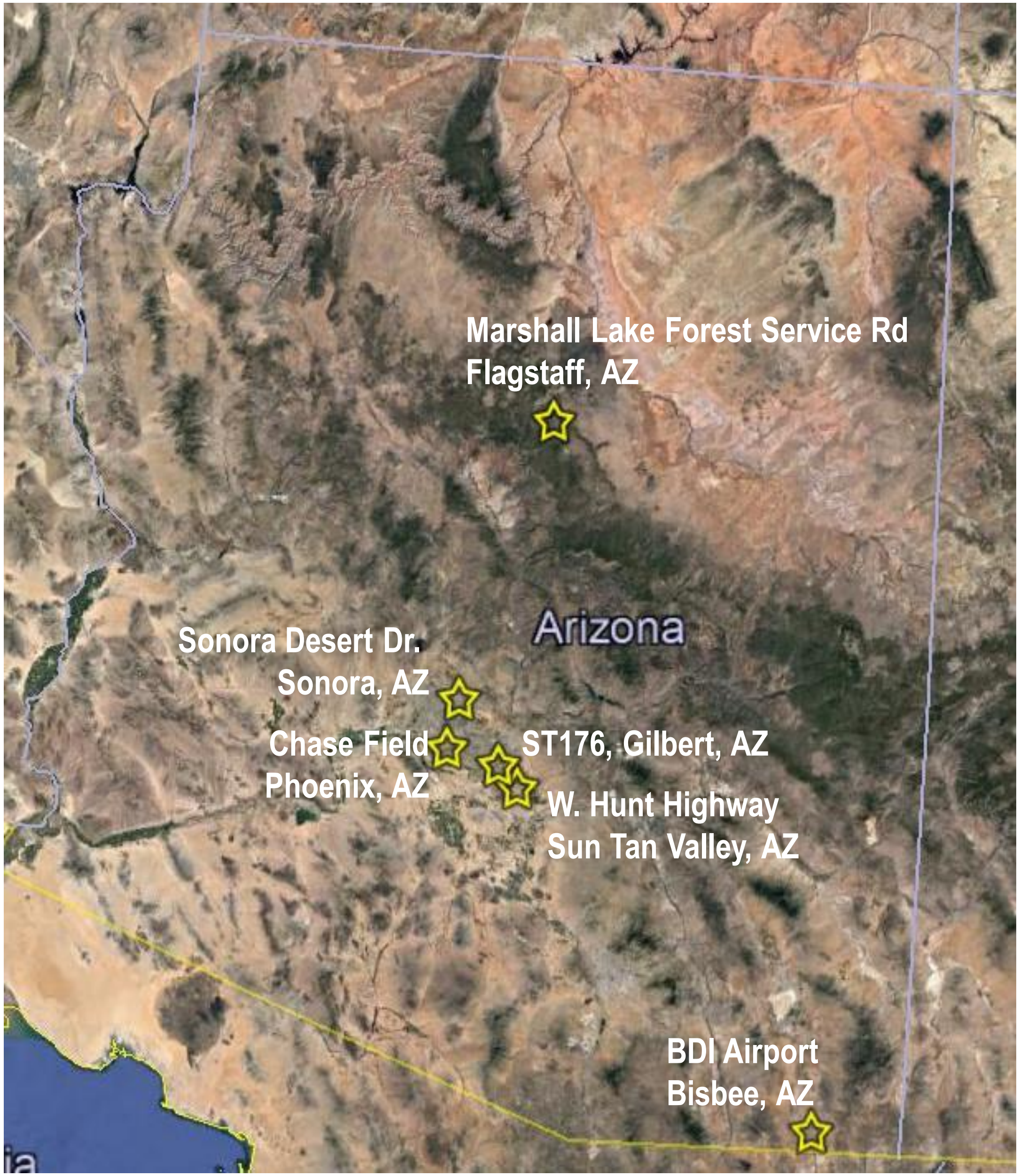

APLTs were performed at multiple project sites in AZ since 2015 to assess in-situ performance of geogrid stabilized pavement foundations.

Tensar®

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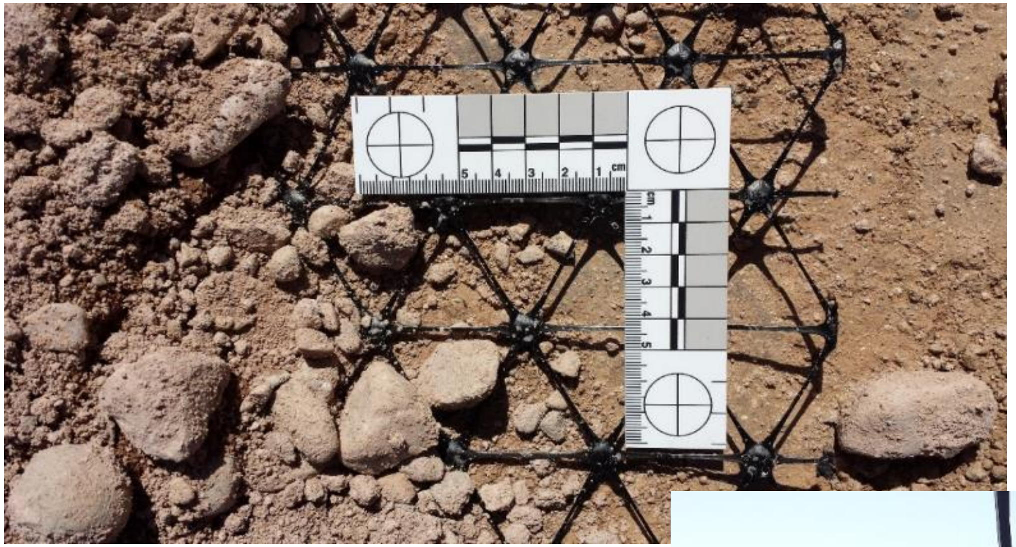
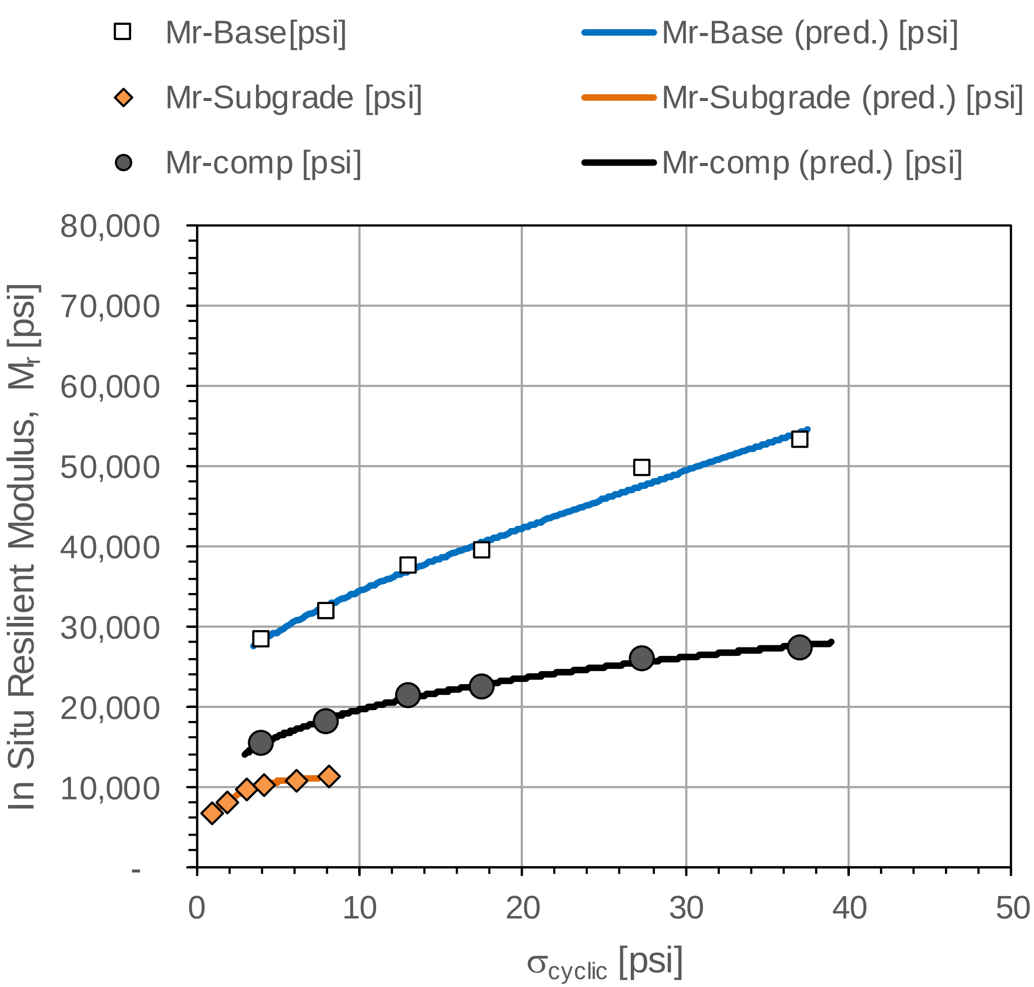
San Tan Valley, AZ – TX5 Geogrid



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.



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	

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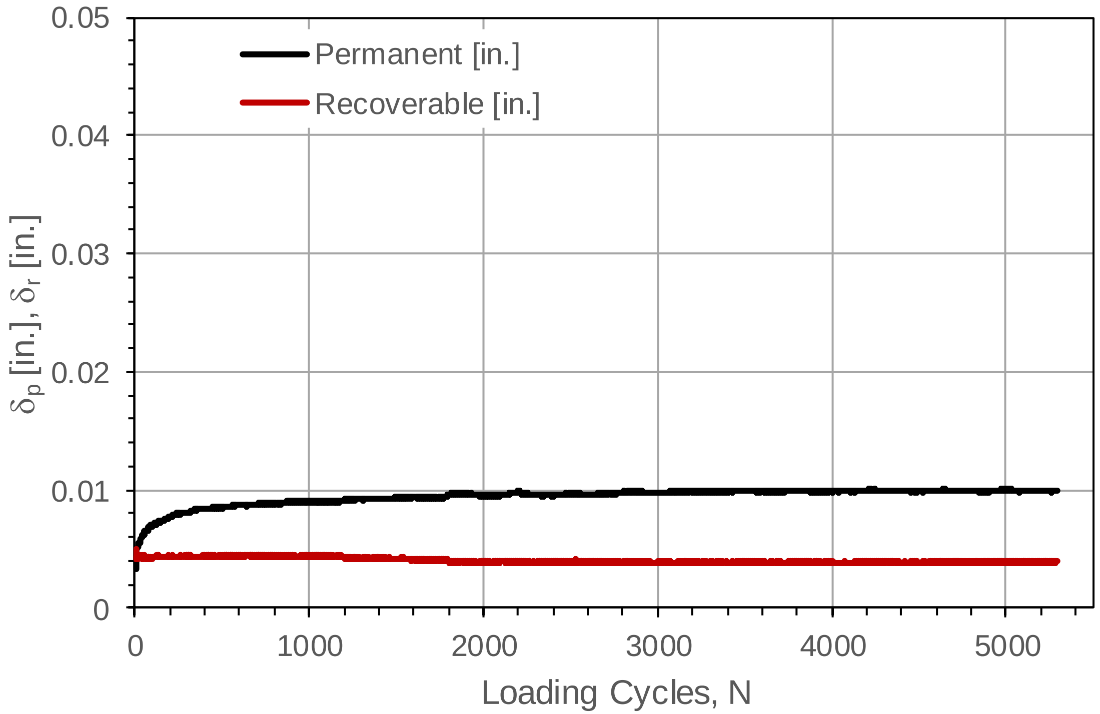
APLT extended cycle testing (5k cycles) allowed permanent deformation/rutting forecasting.



Permanent Deformation Prediction Parameters

C =	0.0048	
d =	0.0876	
R^2 =	0.9299	
N^* =	756	Cycles
δ_p at N^* =	0.0086	in.
Adj. δ_p at N^* =	0.0038	in.
$N_{0.05}$ =	>>10,000,000	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.

Contact Info:
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Thank you!