Intelligent Compaction Workshop on Mechanistic Based QC/QA

Presenter:

David J. White, Ph.D., P.E.

President and Chief Engineer

Technology Transfer for Intelligent Compaction Consortium (TTICC)
Federal Highway Administration Pooled Fundy Study TPF-5(233)

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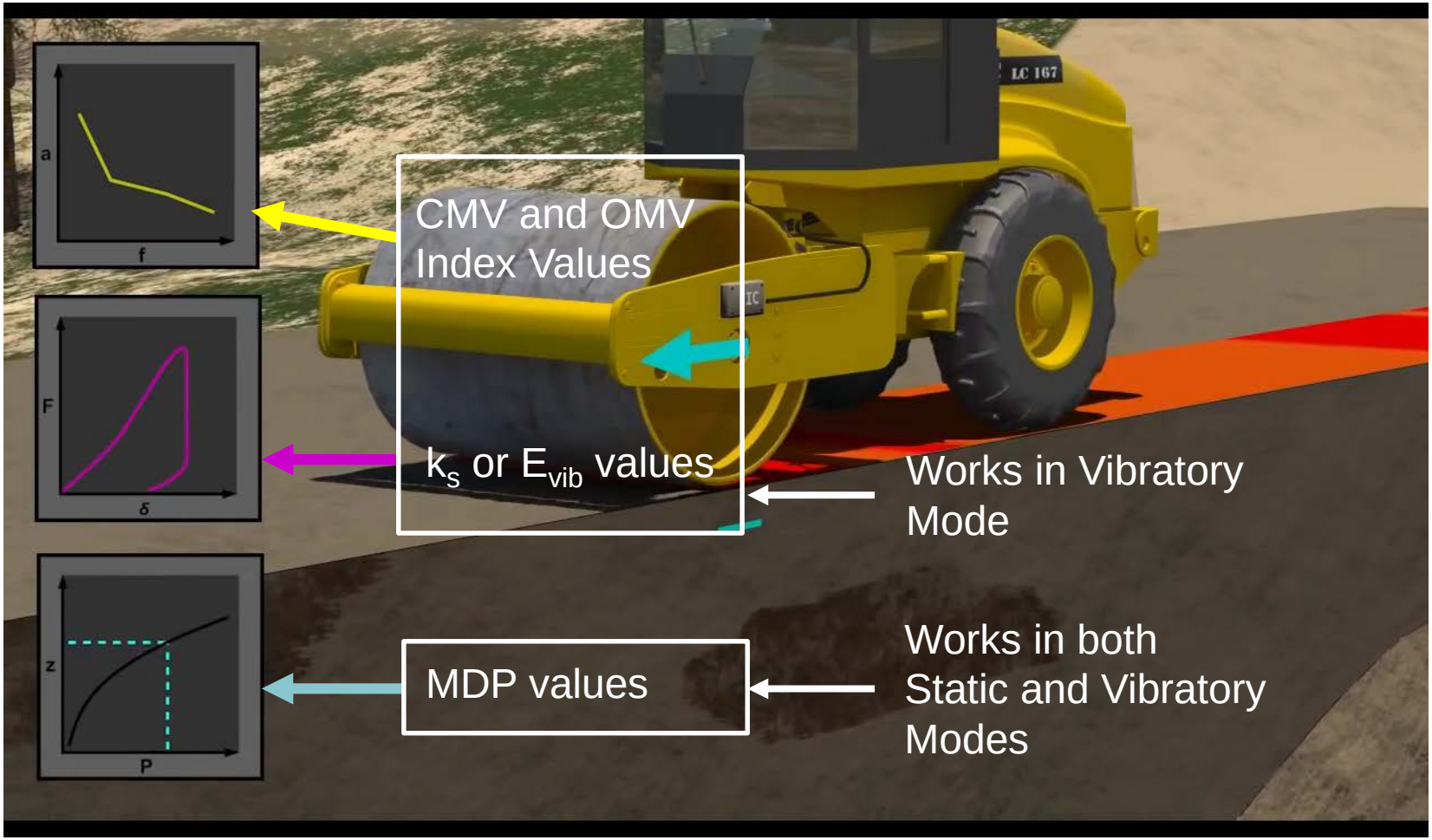
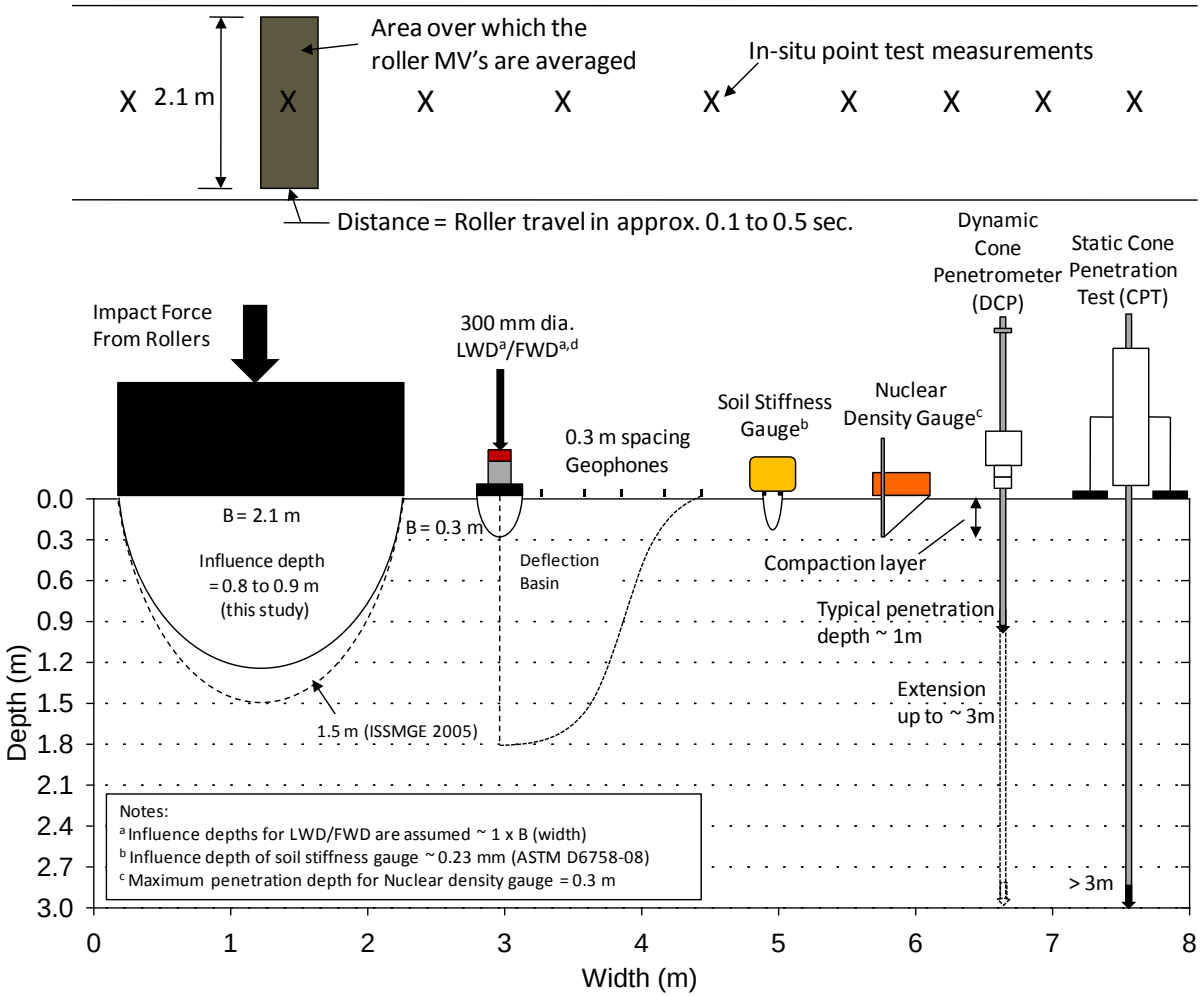
Overview of different IC measurements for Soils, Aggregate, and HMA

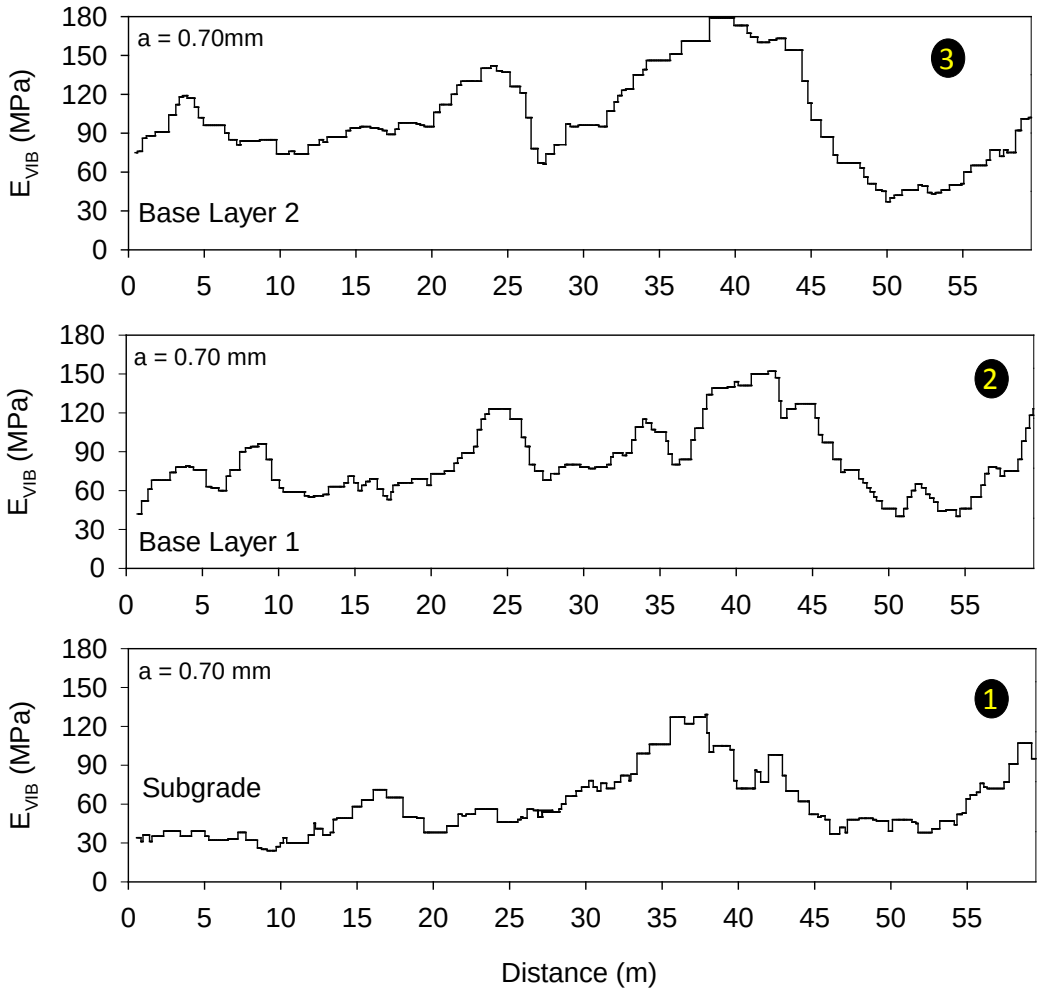


IC measurements have a deeper measurement influence depth than other *in situ* tests

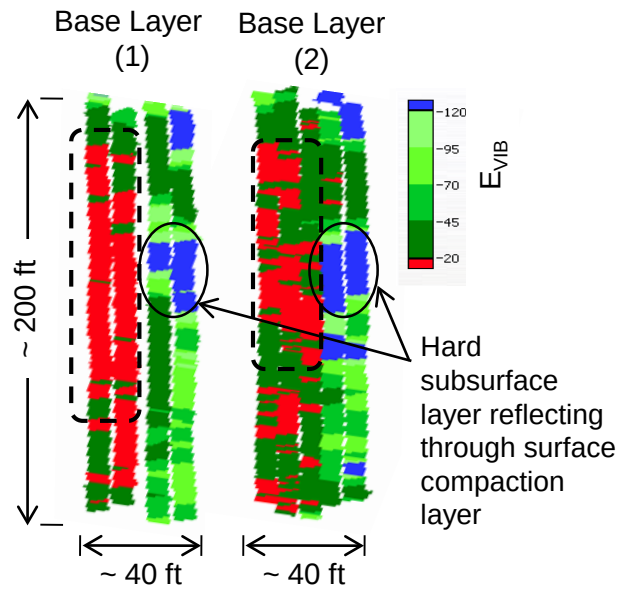


Vennapusa et al. (2012)

“Weak” areas in subgrade reflect to the surface



Aggregate Base – Base Layer 2 (6 inches)	3
Aggregate Base – Base Layer 1 (6 inches)	2
Clay Subgrade – Subgrade (10-12 inches)	1



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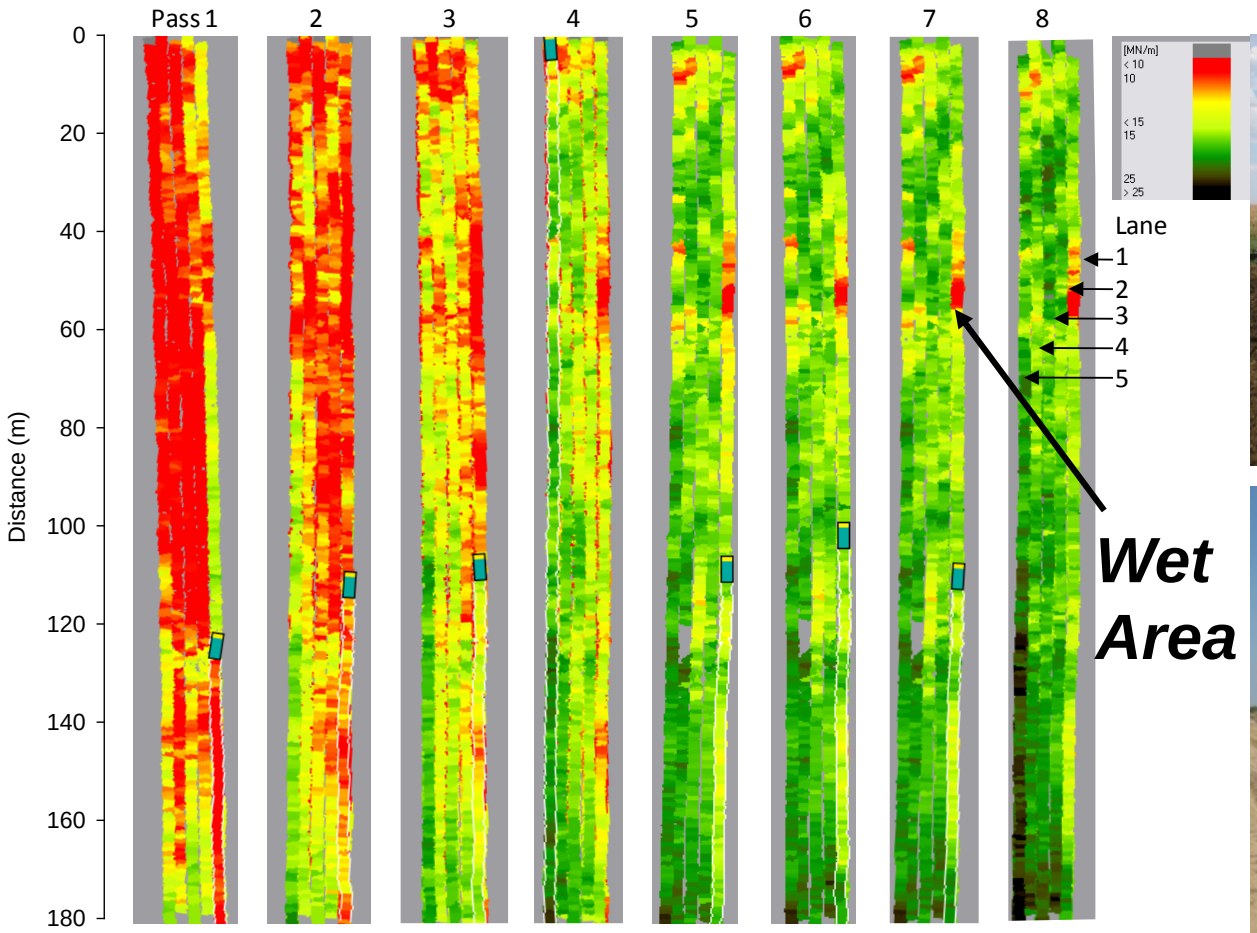
IC measurements over eight passes on lime stabilized subgrade show compaction improvement



White et al. (2008)

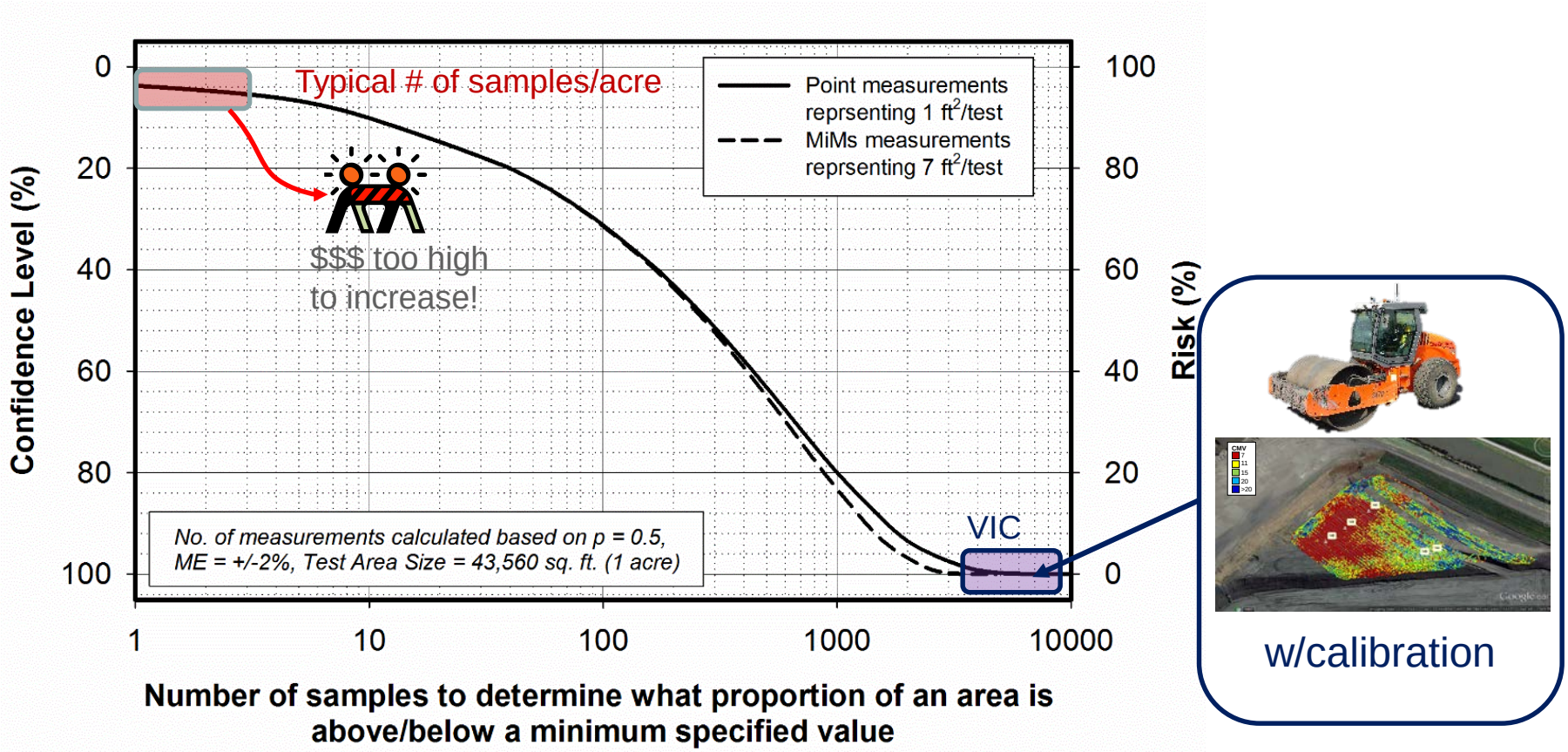
Perspective from contractor after using the IC roller on an earthwork project in Iowa

- “You can add a lot of road life with (road base) uniformity,” Taylor said. “States spend a lot of their transportation money on maintenance. If the base has no weaknesses, you’ll only have to replace a wear course from time to time. That is a huge cost savings at a time when every dime is being watched.”

- “Most of those passes are a waste,” Taylor said. “Many times on jobsites, we could probably get compaction densities with haul trucks. We might not even need rollers. But the specs call for eight passes, so we make them.”

- “You can’t leave technology like this on the shelf,” he said. “You would have better measurements, and better roads, at a lower cost. Those are tough points to argue.”

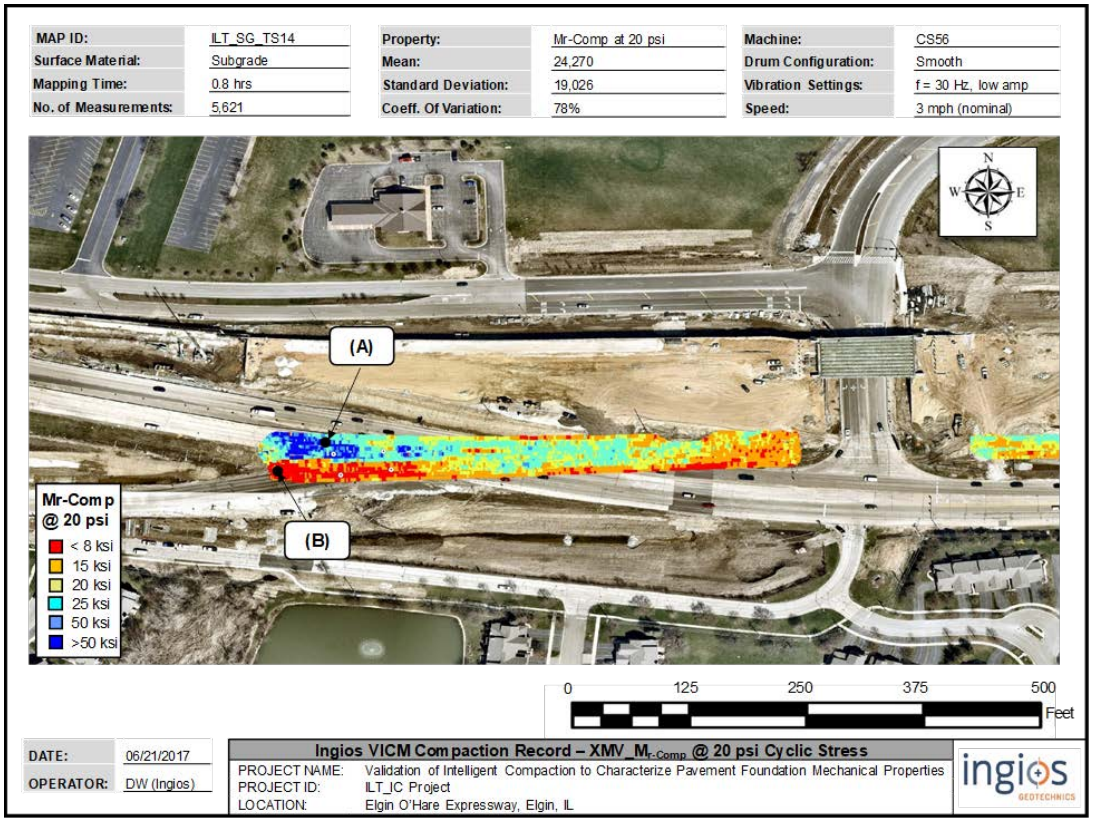
Statistics shows that risk is quantified and related to QC/QA test frequency



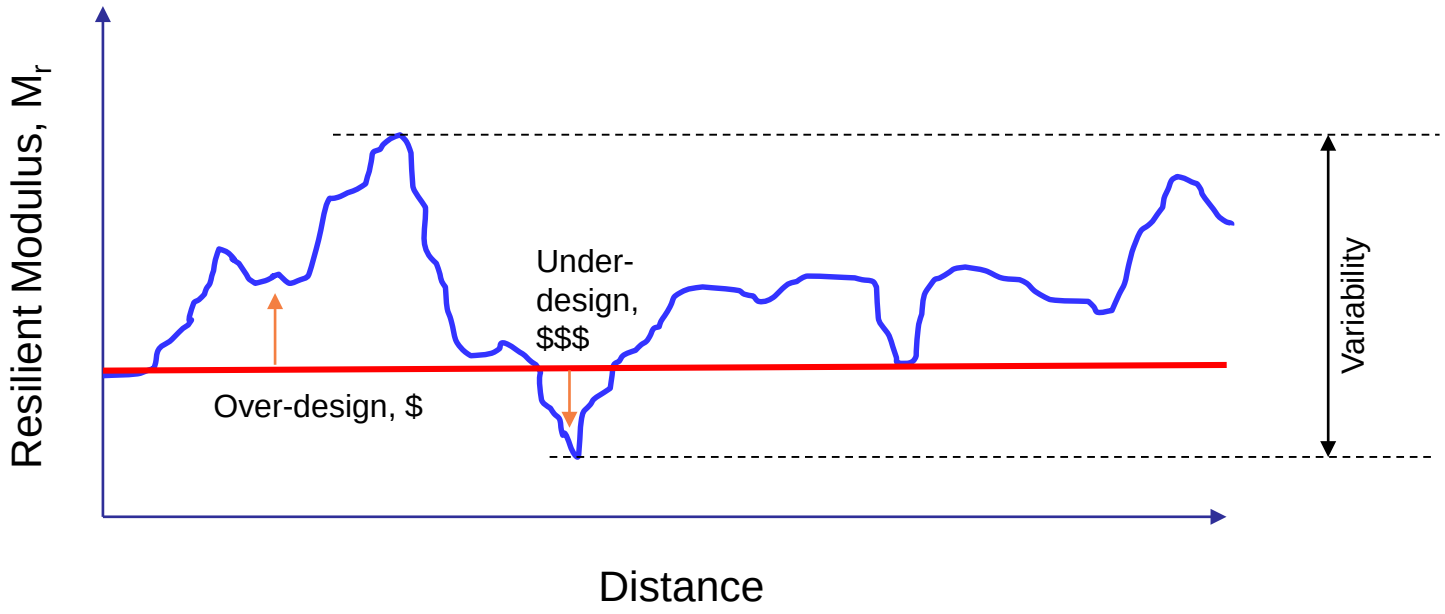
Intelligent Compaction Workshop on Mechanistic Based QC/QA: Illinois Tollway

Presenter:
David J. White, Ph.D., P.E. (Co-PI)
President and Chief Engineer

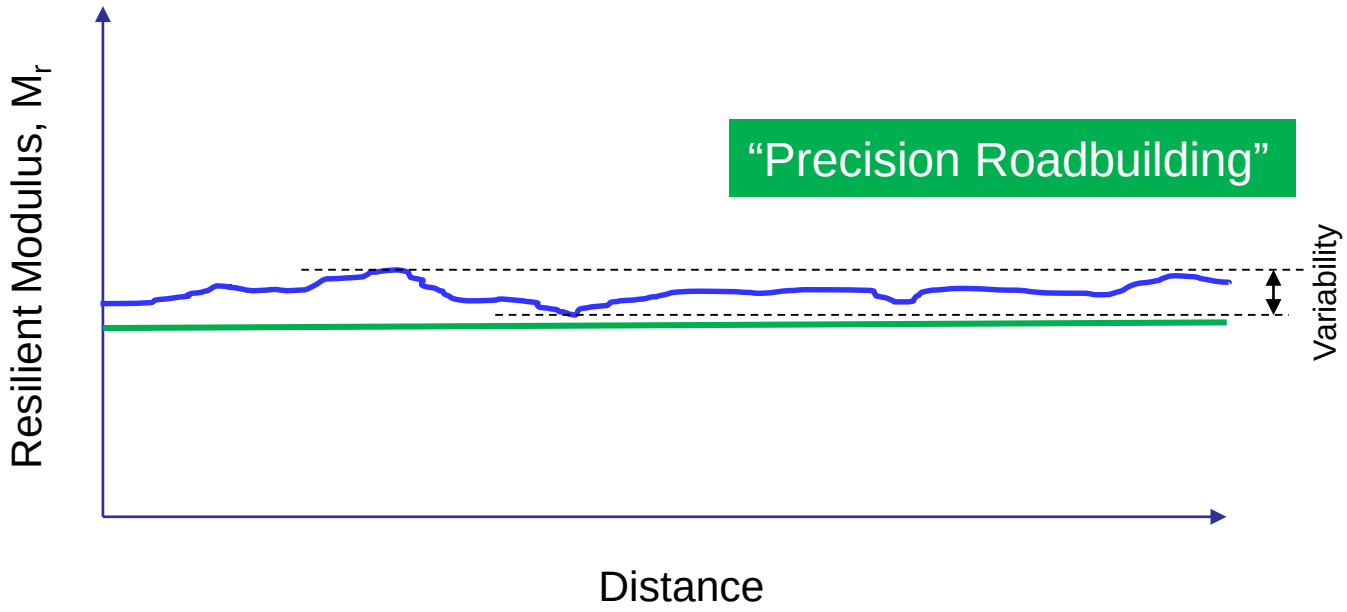
Co-Authors:
Prof. Erol Tutumluer, Ph.D. (PI)
Pavana Vennapusa, Ph.D., P.E.
William (Bill) Vavrik, Ph.D., P.E.
Maziar Moaveni, Ph.D.
Steven Gillen, P.E.



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



A better question might be… how can we field control and verify design assumption's?



Research Goals for Intelligent Compaction (IC) for Earthwork and Aggregates:

- Depend less on spot checks and density measurements
- Apply to performance related or based specifications
- Expedite construction by putting more control in the hands of the operator / contractor
- To make design – build projects easier to implement with more construction quality based on engineering performance, not specified means and methods
- Most importantly to build pavements more efficiently, cost wise, and better performing

Why Link IC to Modulus?

- Stiffness or modulus is a better predictor of pavement response under traffic loading
- Modulus better indicates the compactability for recycled materials that vary in specific gravity
- Higher modulus commonly relates well to better rutting resistance
- Modulus of a pavement base is used in M-E pavement design

There is national interest toward moving to Mechanistic Construction Testing and Verification of Design

- Mechanistic Construction Testing and Verification
  - *Strength, Modulus, and Deformation Testing*
  - *Uniformity and Modulus Mapping (Intelligent Compaction)*
- Supports Performance-Based Materials Selection

"*Pavement ME Design represents a quantum leap forward from previous processes*," (http://www.aashtoware.org)

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Illinois Tollway Research Objectives

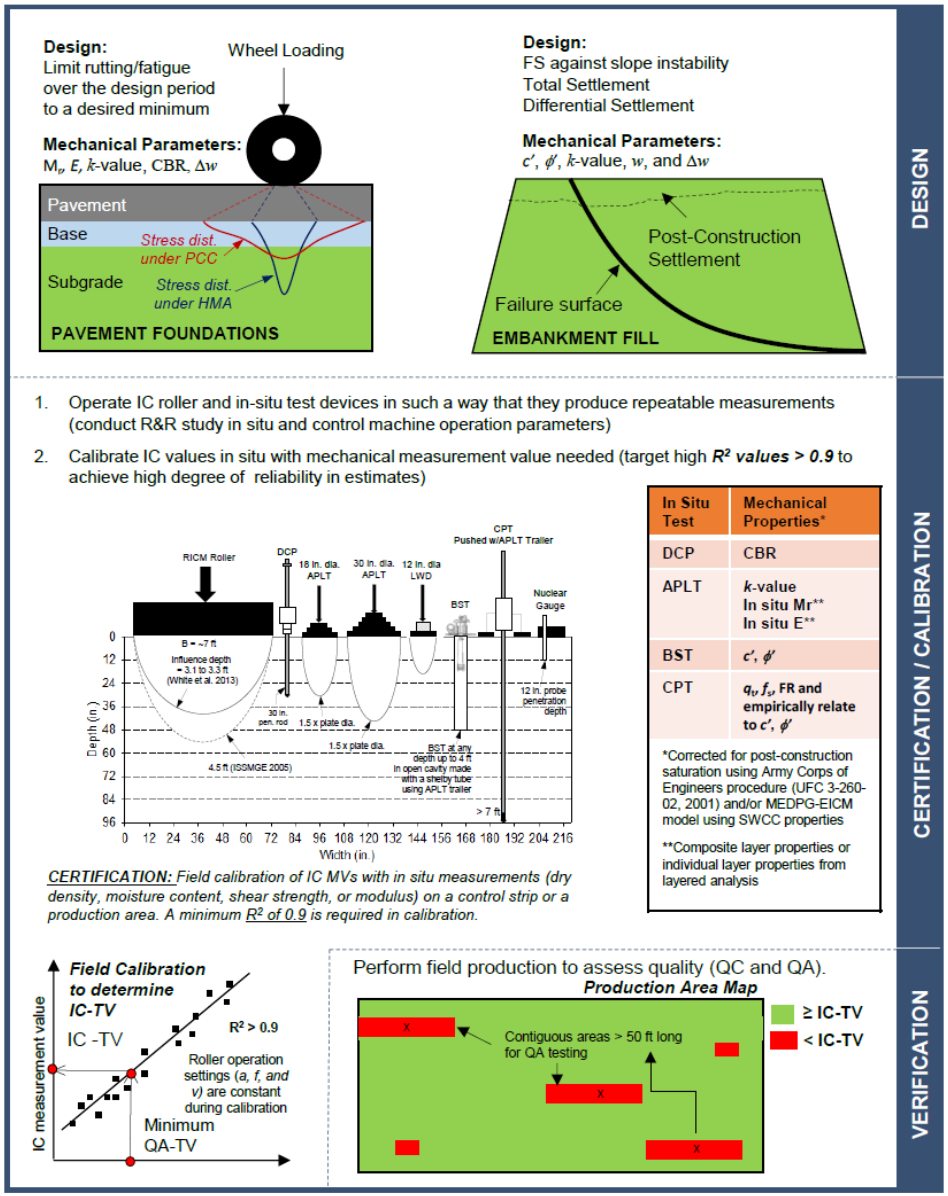
(1) Create a synthesis of literature that identifies methods used to compare IC measurements to soil mechanical properties, and the success of those methods.

(2) Develop a criteria or procedure for field validating the relationship between IC measurements and soil mechanical properties.

(3) Demonstrate the field calibration process using three different IC technology providers.

Concept of Field Certification / Calibration and Verification Process in Relationship with Design Assumed Mechanical Properties

Calibrate IC values in situ with mechanical measurement value needed (target high R^2 values > 0.9)



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Summary of Range of R^2 Values between Different IC Measurement Values

RICM Value	Soil Type	Mechanical Property	Range of R^2 values	References
CMV	Granular and Non Granular Soils	Elastic and Reload Modulus	0.2 to 0.9	Brandl and Adam (1997), White et al. 2011, 2013a, Vennapusa et al. 2012, Mooney et al. (2010)
		CBR	0.2 to 0.6	
		Dry Density	0 to 0.4	
CCV	Granular Non Granular Soils	Elastic and Reload Modulus	0.2 to 0.9	White et al. (2009), Mooney et al. (2010)
		CBR	0.2 to 0.4	
		Dry Density	0 to 0.1	
k_B	Granular Soil	Elastic and Reload Modulus	0 to 0.8	Preisig et al. (2006), Mooney et al. (2010)
		CBR	0.2 to 0.6	
		Dry Density	0 to 0.5	
E_{VIB}	Granular and Non Granular Soils	Elastic and Reload Modulus	0.3 to 0.9	White et al. (2010), Mooney et al. (2010)
		CBR	0.1 to 0.5	
		Dry Density	0 to 0.5	
MDP*	Granular and Non Granular Soils	Elastic Modulus	0.3 to 0.6	White et al. (2011) White et al. (2015)
		CBR	0.1 to 0.5	
		Dry Density	0.0 to 0.4	
XMV	CCP Stack	Elastic Modulus	0.97	Unpublished field study in 2014 at TVA Power Plant
	Granular and Non Granular	Resilient Modulus	0.96	White et al. (2014)

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Calibration performed to measure:

- **APLT –** In situ Composite Resilient Modulus (Mr-Comp) at 5 psi to 40 psi cyclic stresses at surface
- **APLT –** In situ Layered Resilient Modulus (RAP+PGE and Subgrade) at 5 psi to 40 psi cyclic stresses at surface
- **APLT –** In situ modulus of subgrade reaction (static k-value)
- **DCP –** CBR of RAP+PGE and Subgrade
- **LWD –** Dynamic Elastic Modulus (~15 psi dynamic stress)

Test Section 1 (10/13/16) using Hamm H 11i System

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Test Section 3 (10/13/16)

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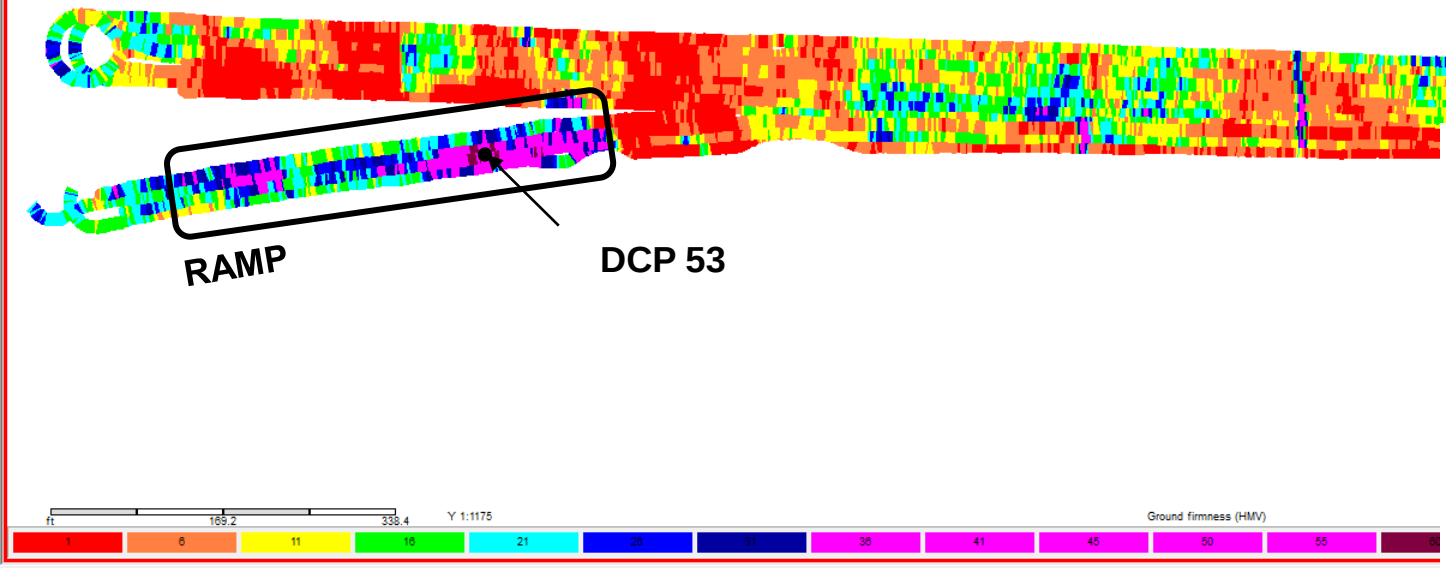
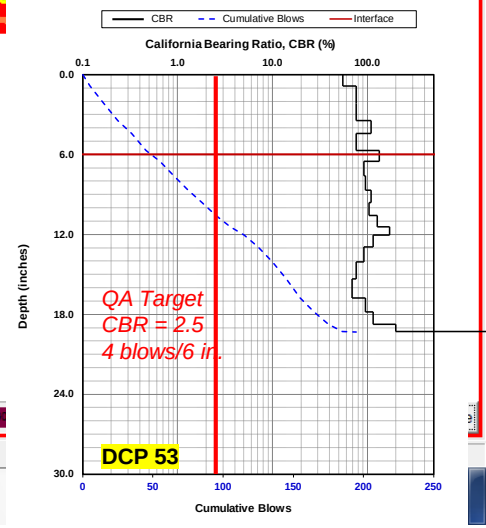
HCQ IL TOLLWAY ELGIN OHARE(27.10.2016 11-56-41) - RPCC MAP EB LANES PGE SECTION 3 - Asphalt base

File Site HAMM.network View Planning data Analysis Options ?

Test Section 3: PGE

5 LWD tests
5 DCP tests
Only in the ramp area





"Ground firmness"; Longitude: -87.9745477; Latitude: 41.9825755;

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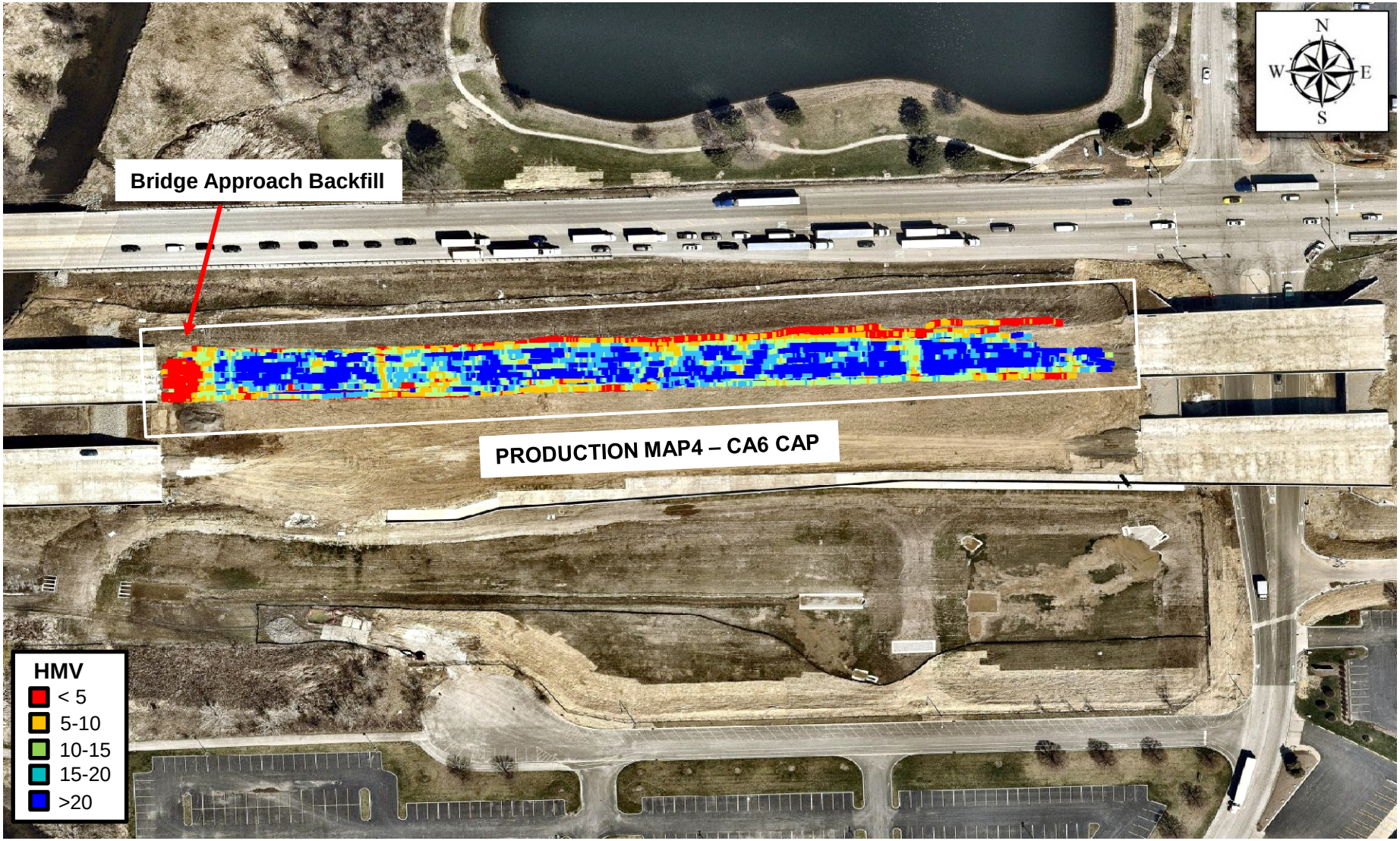

0 62.5 125 250 375 500 Feet

DATE:	10/18/2016
OPERATOR:	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

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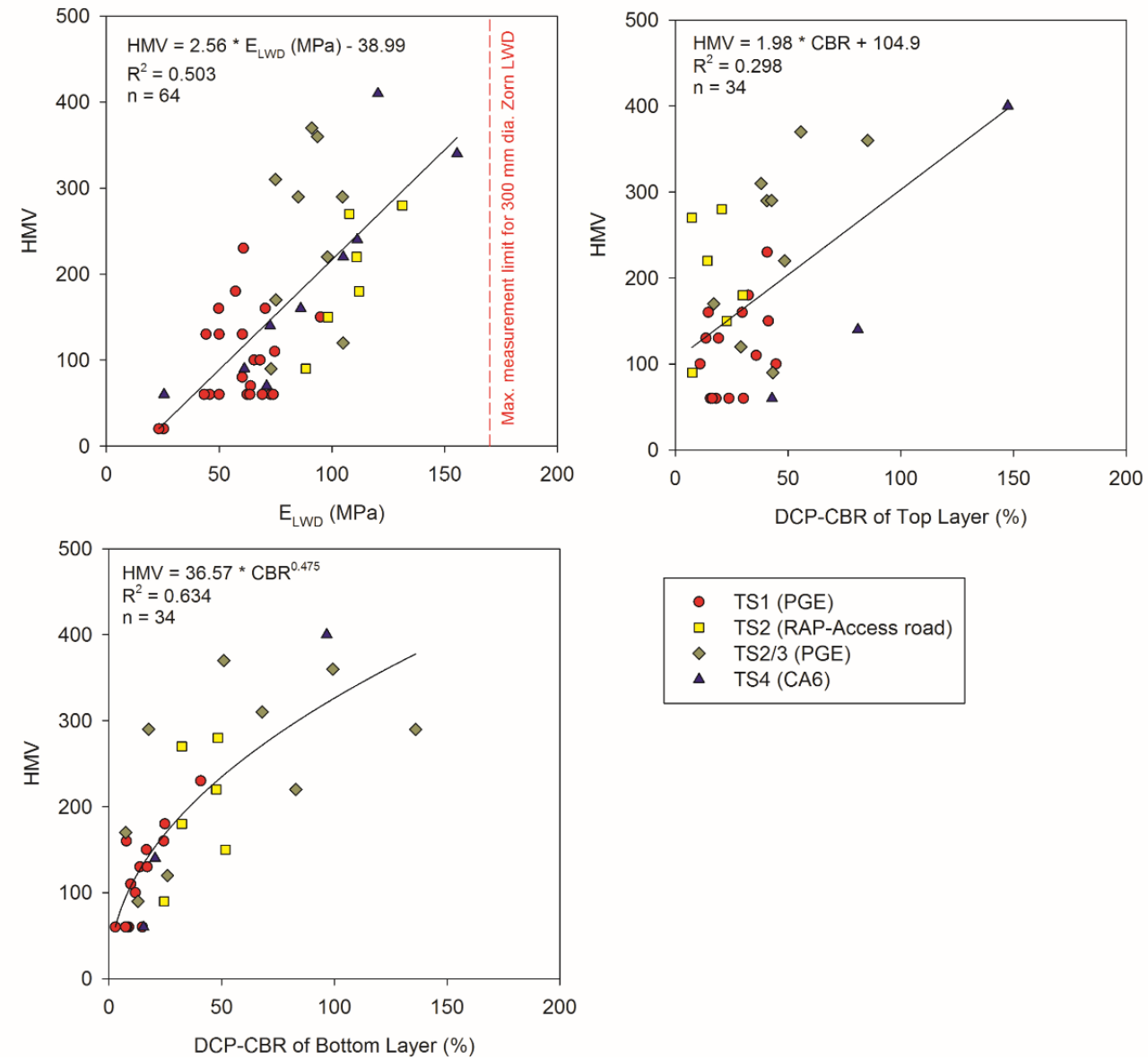
Calibration performed using LWD for in-situ E and DCP for CBR

Modest Correlation Quality Combining All Test Sections



TS14: Subgrade Layer

Thorndale Ave (EB)
Just West of Hamilton Lakes Dr. Overpass

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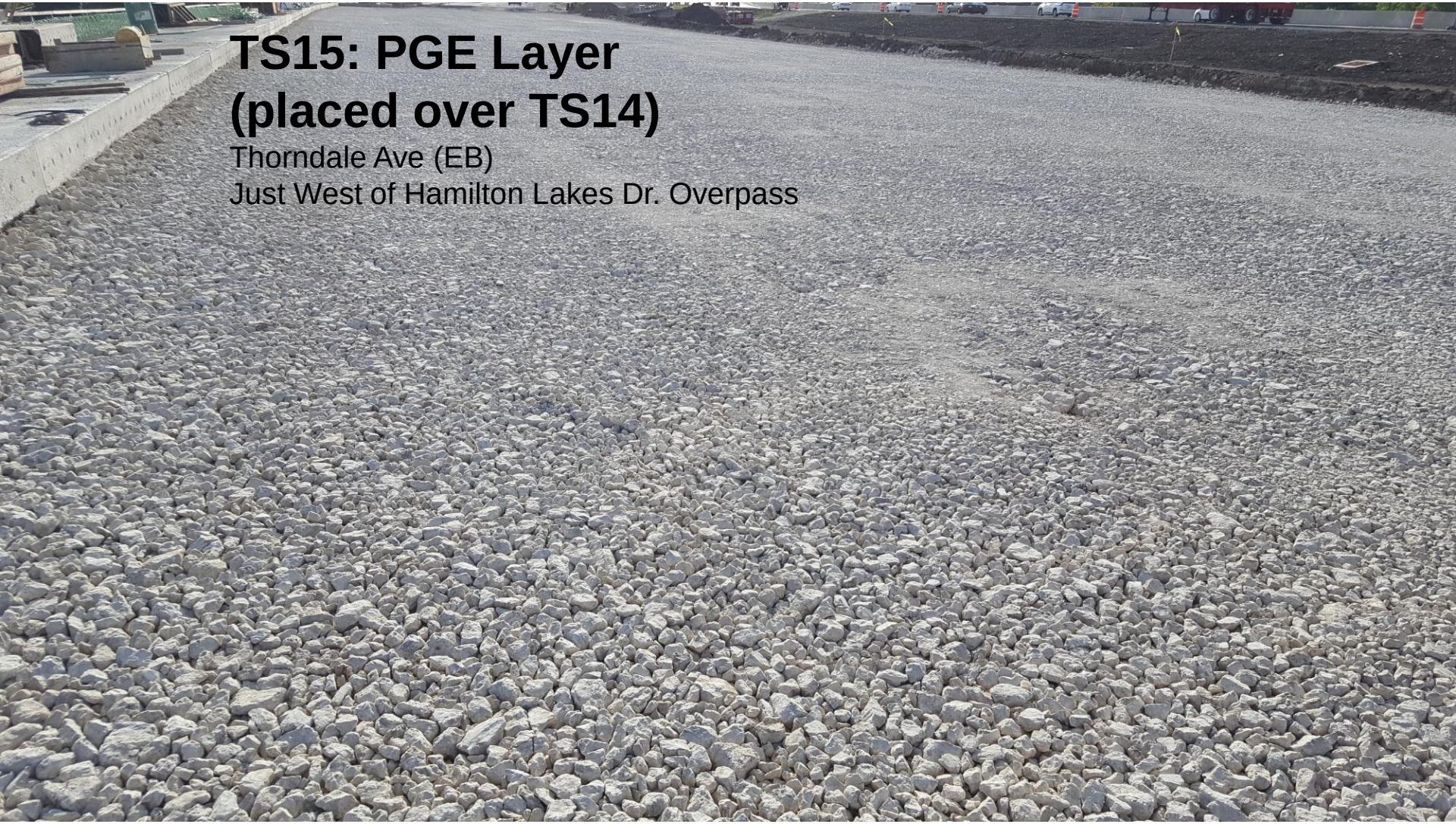

TS15: PGE Layer (placed over TS14)

Thorndale Ave (EB)

Just West of Hamilton Lakes Dr. Overpass

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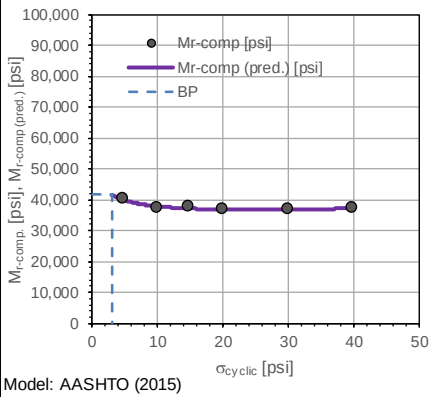
Calibration performed using APLT for In-Situ M_r and k-value

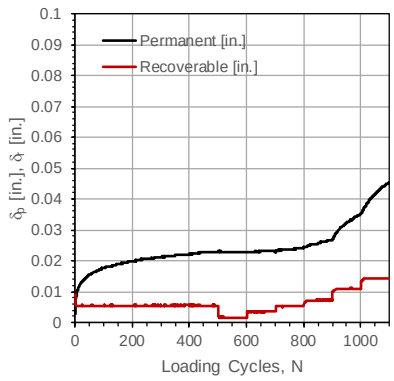
APLT to measure composite resilient modulus for cyclic stresses of 5, 10, 15, 20, 30, and 40 psi

Automated Plate Load Test [APLT]

Test:	In-situ Resilient Modulus [Mr]: Cyclic Loading, Composite, Stress-Dependent (5, 10, 15, 20, 30, 40)				
Date:	6/21/2017	Time:	4:52:56 PM	Test ID	**ILT_12_Mr_pt6**
Tested By	DW, HG, PV, JV	Location:	TS_13_SG	Sta.	NA
Latitude,N:	41.983776	Longitude,W:	88.010727	Elev. (ft):	710
Comments:	RAP CA6 testing, east bound Thorndale Ave. b/w/ Hamilton Lakes Dr. and No. Arlington Heights Rd.				

Step	N	σ_{cyclic} [psi]	$M_{r\text{-}comp}$ [psi]	$M_{r\text{-}comp\ (pred.)}$ [psi]	δ_p [in.]	$\Delta\delta_p$ [in.]	d =$\Delta\log(\delta_p)/\Delta\log(N)$	Near-linear Elastic
Conditioning	500	14.78	---	---	0.0230	---	0.198	---
1	100	4.74	40,146	39,993	0.0228	-0.0003	-0.255	Y
2	100	9.93	37,282	37,907	0.0231	0.0001	0.397	Y
3	100	14.78	37,837	37,182	0.0243	0.0013	0.493	Y
4	100	19.99	36,788	36,875	0.0267	0.0037	0.642	Y
5	100	29.95	36,776	36,872	0.0351	0.0121	0.694	N
6	100	39.80	37,222	37,210	0.0454	0.0223	0.829	N





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	2,570.6	1.61E-08
k^*_2	-0.109	3.98E-02
k^*_3	0.522	9.11E-02
Adj. R^2	0.867	
Std. Error [psi]	436	

$M_{r\text{-}comp\ (pred.)\text{-}BP}$ [psi]	41,643
$\sigma_{cyclic\text{-}BP}$ [psi]	3.0

Deflection basis measurement kit

In-situ Resilient Modulus [Mr]: Cyclic Loading, Composite, Stress-Dependent	
Project Name:	Illinois Tollway - IC Research
Project ID:	Elgin O'Hare Extension - IL Tollway
Location:	IL390 (West of O'Hare), Itasca, IL

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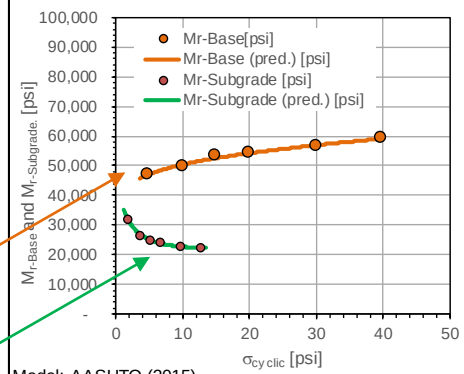
APLT to measure layered analysis resilient modulus for cyclic stresses of 5, 10, 15, 20, 30, and 40 psi

Automated Plate Load Test [APLT]

Test:	In-situ Resilient Modulus [Mr]: Cyclic Loading, Composite, Stress-Dependent (5, 10, 15, 20, 30, 40)				
Date:	6/21/2017	Time:	4:52:56 PM	Test ID	**ILT_12_Mr_pt6**
Tested By	DW, HG, PV, JV	Location:	TS_13_SG	Sta.	NA
Latitude:	41.983776	Longitude:	88.010727	Elev. (ft):	710
Comments:	RAP CA6 testing, east bound Thorndale Ave. b/w/ Hamilton Lakes Dr. and No. Arlington Heights Rd.				

Step	N	$\sigma_{cyclic_surface}$ [psi]	$M_{r\text{-}Base}$[psi]	$M_{r\text{-}Base\ (pred.)}$ [psi]	$\sigma_{cyclic_Int.}$ [psi]	$M_{r\text{-}Subgrade}$ [psi]	$M_{r\text{-}Subgrade\ (pred.)}$ [psi]	Modulus Ratio
Conditioning	500	14.78	---	---	---	---	---	---
1	100	4.74	47,208	47,059	1.79	32,080	31,851	1.47
2	100	9.93	49,576	50,407	3.51	26,619	27,100	1.86
3	100	14.78	53,570	52,483	5.01	25,154	25,084	2.13
4	100	19.99	54,120	54,243	6.66	24,027	23,832	2.25
5	100	29.95	56,455	56,925	9.69	22,906	22,774	2.46
6	100	39.80	59,299	59,088	12.58	22,391	22,525	2.65



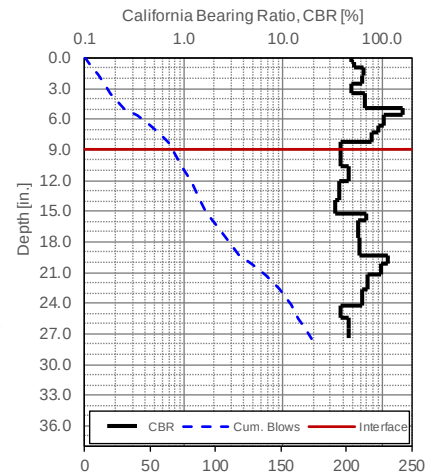
Base (stress-stiffening)

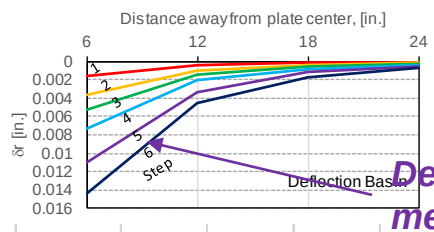
Subgrade (stress-softening)

Model: AASHTO (2015)

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

Parameter	Value	P-Value
$k^*_{1\ (Base)}$	3243.9	2.19E-08
$k^*_{2\ (Base)}$	0.080	1.11E-01
$k^*_{3\ (Base)}$	0.191	4.89E-01
Adj. R^2	0.972	
Std. Error [psi]	729	
$k^*_{1\ (Subgrade)}$	1260.0	1.01E-06
$k^*_{2\ (Subgrade)}$	-0.432	2.13E-03
$k^*_{3\ (Subgrade)}$	2.607	1.32E-02
Adj. R^2	0.993	
Std. Error [psi]	297	





Deflection basis measurement

In-situ Resilient Modulus [Mr]: Cyclic Loading, Layered Analysis, Stress-Dependent	
Project Name:	Illinois Tollway - IC Research
Project ID:	Elgin O'Hare Extension - IL Tollway
Location:	IL390 (West of O'Hare), Itasca, IL

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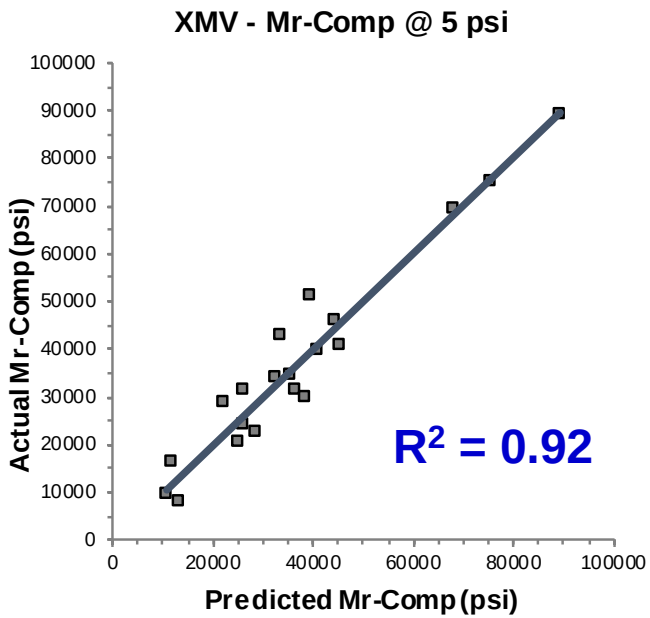
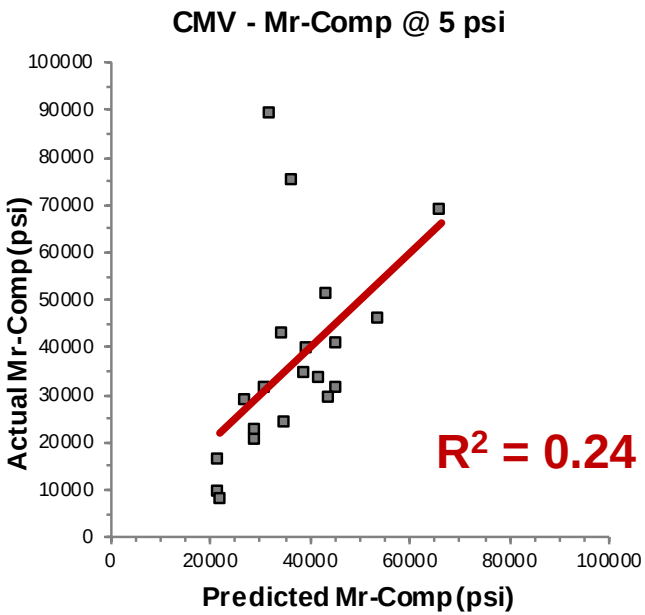
VIC Calibration Performed on Subgrade, PGE, and RAP Materials: 06/21-06/23/2017

RAP Capping, Subgrade, and PGE`

Ingios XMV vs. CMV Calibration Results (Mr-Comp at 5 psi – similar trends for all Mr values)

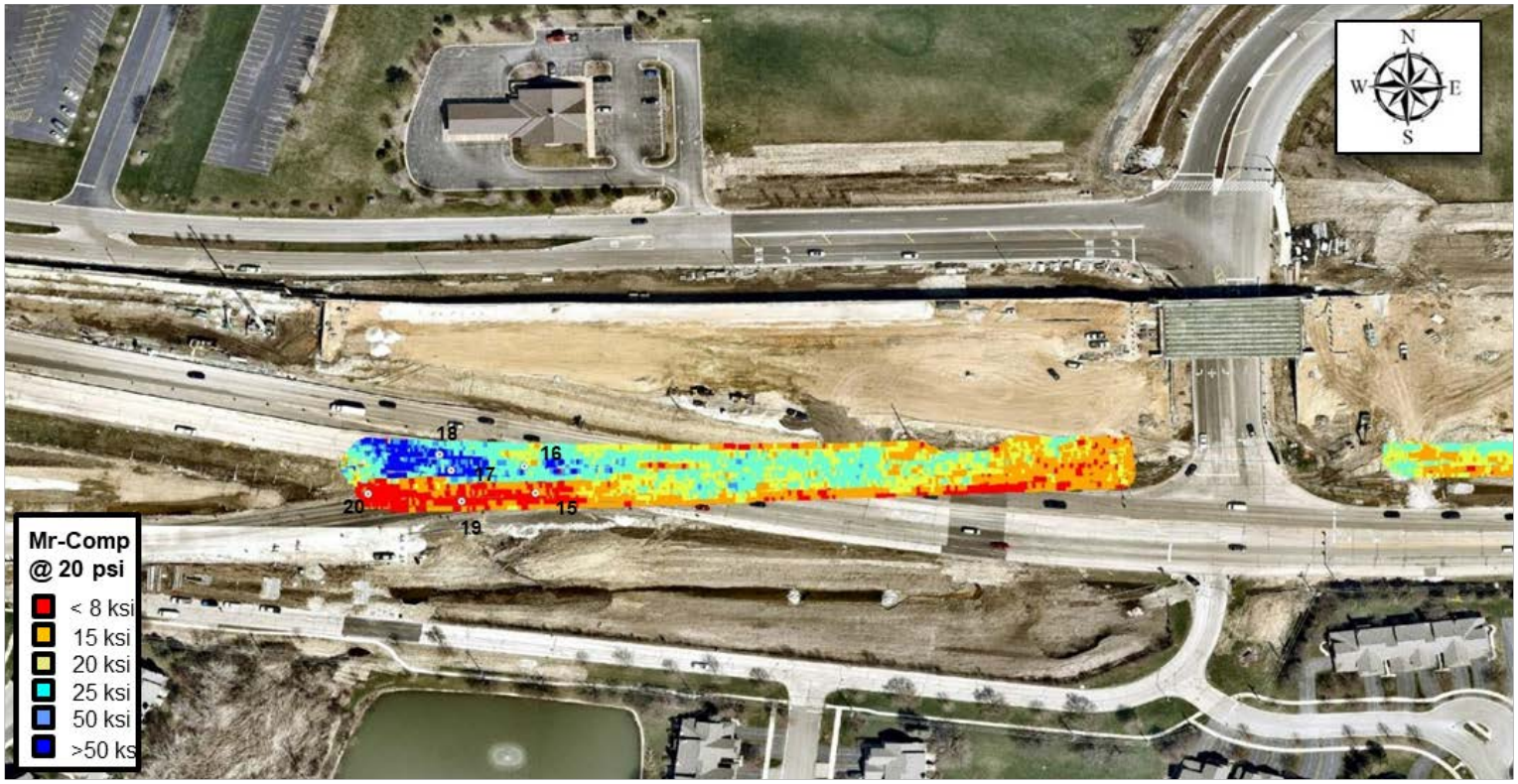


n	20	F	p-value
R^2	0.936	54.47	<0.0001
R^2 adjusted	0.918		
SE of fit (RMSE)	6025.2		



n	20	F	p-value
R^2	0.279	0.00	<0.0001
R^2 adjusted	0.239		
SE of fit (RMSE)	18398.6		

MAP ID:	ILT_SG_TS14	**Property:**	Mr-Comp at 20 psi	**Machine:**	CS56
Surface Material:	Subgrade	**Mean:**	24,270	**Drum Configuration:**	Smooth
Mapping Time:	0.8 hrs	**Standard Deviation:**	19,026	**Vibration Settings:**	f = 30 Hz, low amp
No. of Measurements:	5,621	**Coeff. Of Variation:**	78%	**Speed:**	3 mph (nominal)



0 125 250 375 500 Feet

DATE:	06/21/2017
OPERATOR:	DW (Ingios)

Ingios VICM Compaction Record – XMV_$M_{r\text{-}Comp}$ @ 20 psi Cyclic Stress

PROJECT NAME:	Validation of Intelligent Compaction to Characterize Pavement Foundation Mechanical Properties
PROJECT ID:	ILT_IC Project
LOCATION:	Elgin O'Hare Expressway, Elgin, IL

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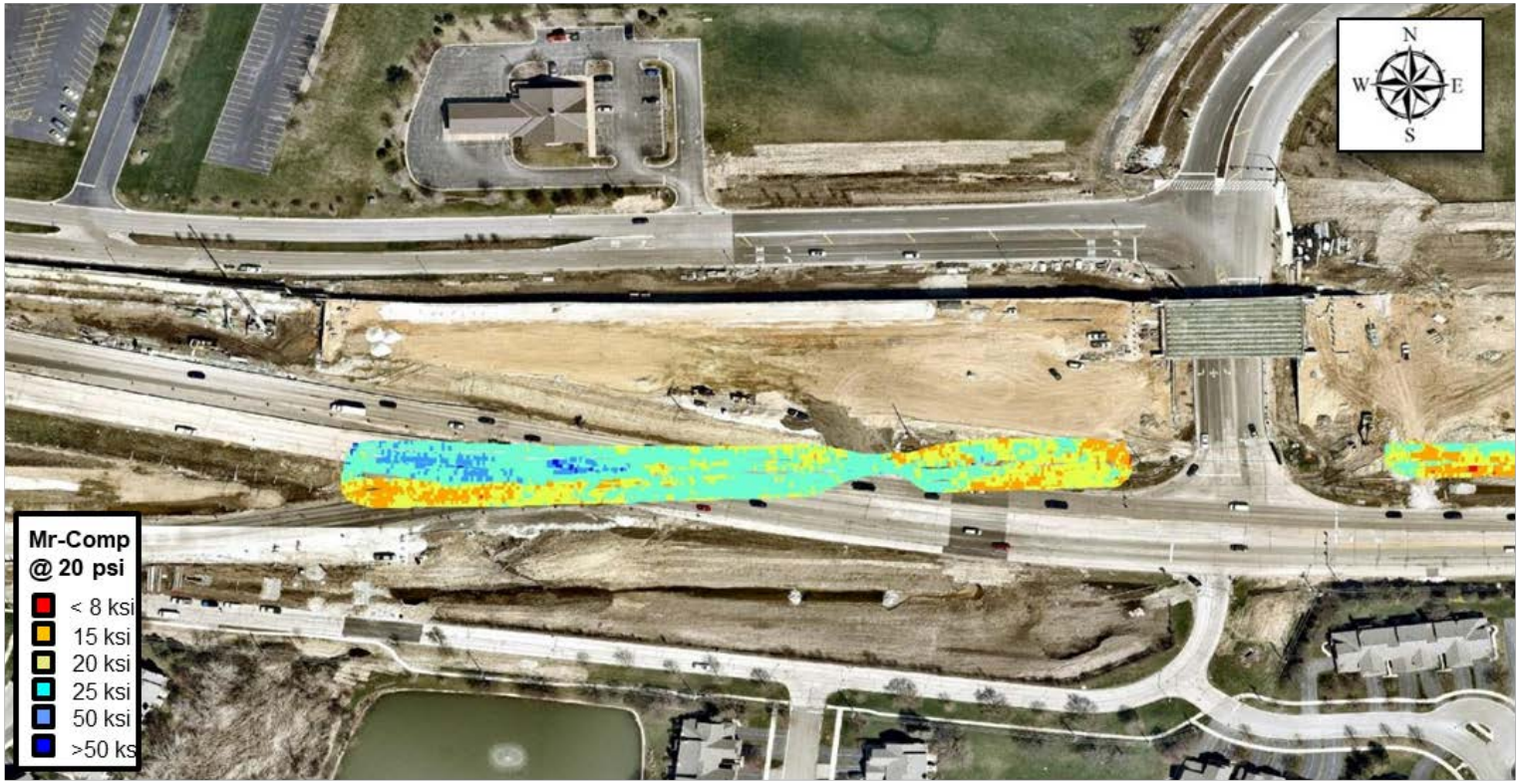
MAP ID:	ILT_PGE_TS15	**Property:**	Mr-Comp at 20 psi	**Machine:**	CS56
Surface Material:	PGE	**Mean:**	28,754	**Drum Configuration:**	Smooth
Mapping Time:	1.4	**Standard Deviation:**	12,280	**Vibration Settings:**	f = 30 Hz, low amp
No. of Measurements:	4,844	**Coeff. Of Variation:**	43%	**Speed:**	3 mph (nominal)



0 125 250 375 500 Feet

DATE:	06/21/2017
OPERATOR:	DW (Ingios)

Ingios VICM Compaction Record – XMV_$M_{r\text{-}Comp}$ @ 20 psi Cyclic Stress

PROJECT NAME:	Validation of Intelligent Compaction to Characterize Pavement Foundation Mechanical Properties
PROJECT ID:	ILT_IC Project
LOCATION:	Elgin O'Hare Expressway, Elgin, IL

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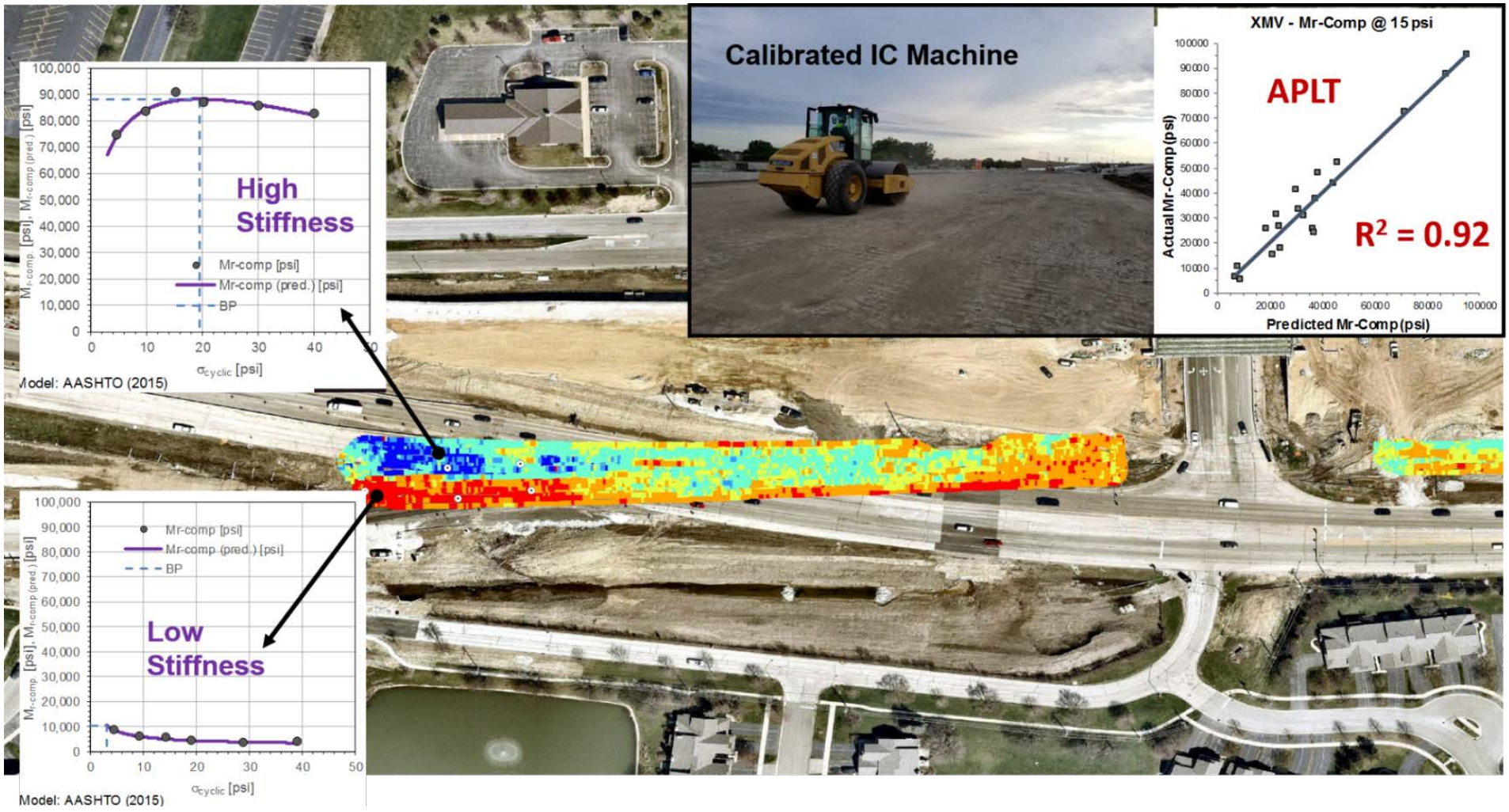
Subgrade: Spatial Map of Resilient Modulus



Passed QC/QA process?

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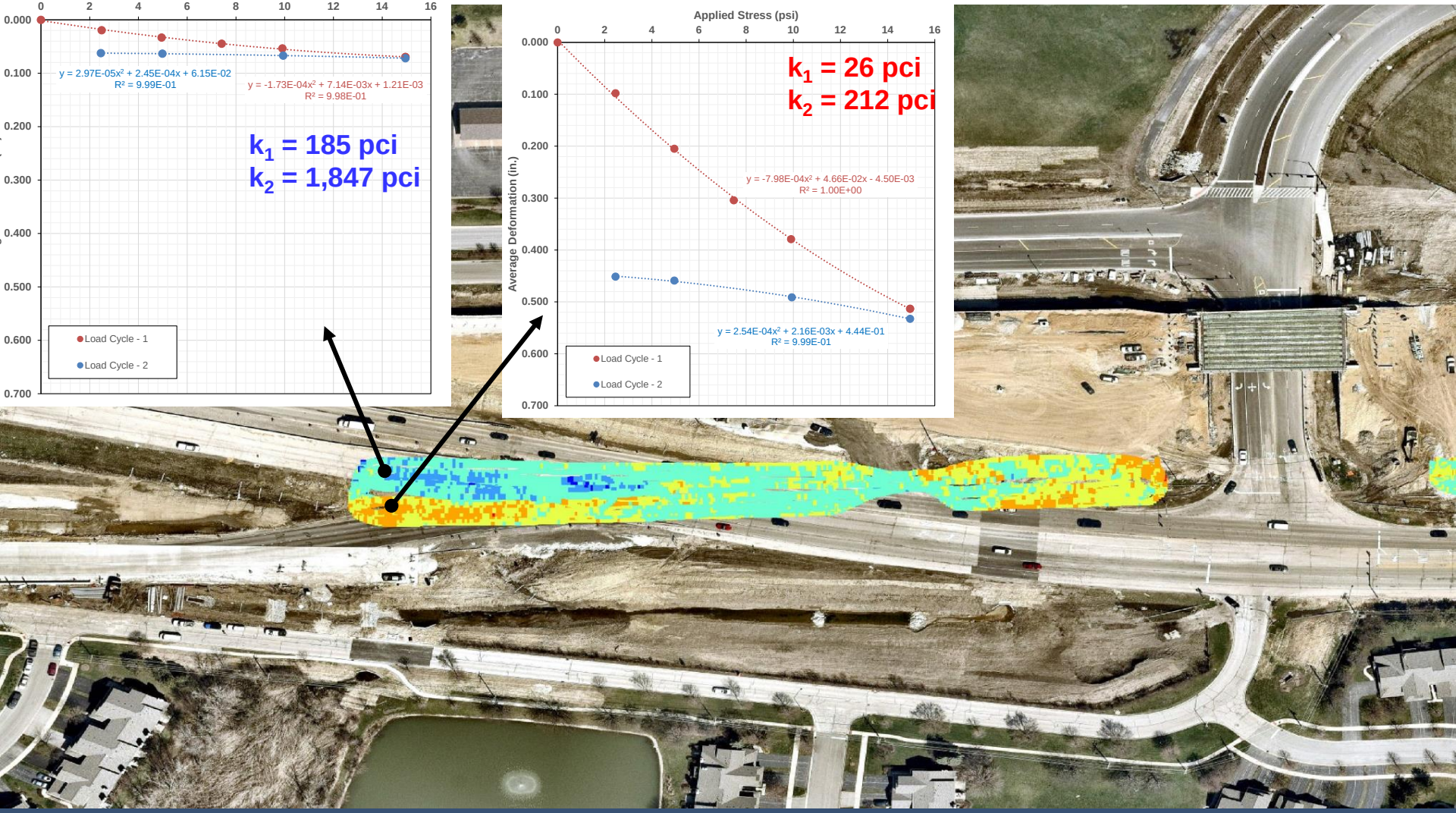
Subgrade: Spatial Map of Resilient Modulus



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Findings and What's Next…

- Spatial variability in modulus identified.
- Calibrated results demonstrate application for near real-time modulus mapping when calibrated.
- Specification developed to be used in parallel with conventional testing.
- Two proposed project in 2018
- Working on data management and engineering reporting tools.

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