Building Better Road Foundations by Taking Advantage of Emerging Technologies

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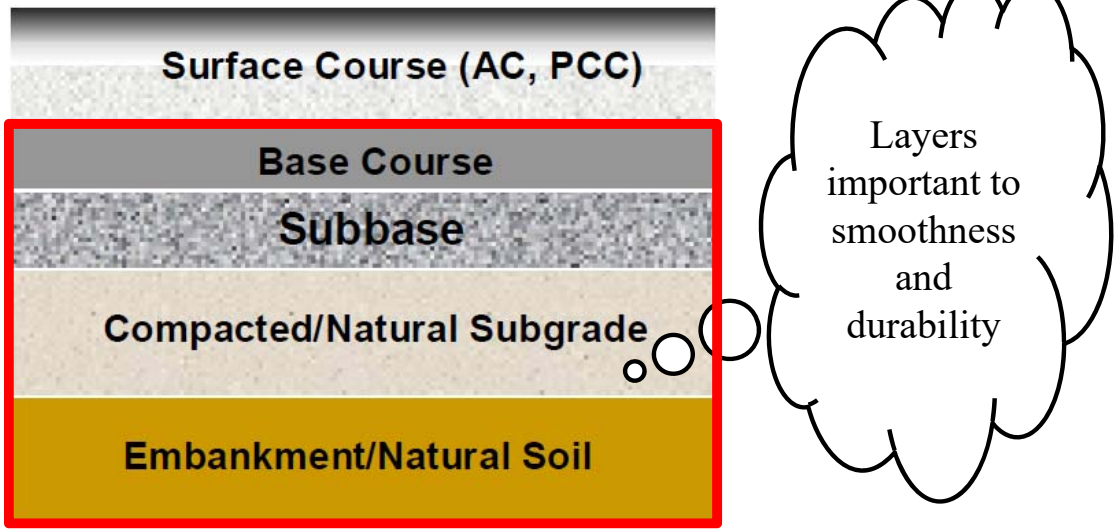
Role of Transportation System

Safety Smoothness Durability



Layers important to smoothness and durability

Source of Problem

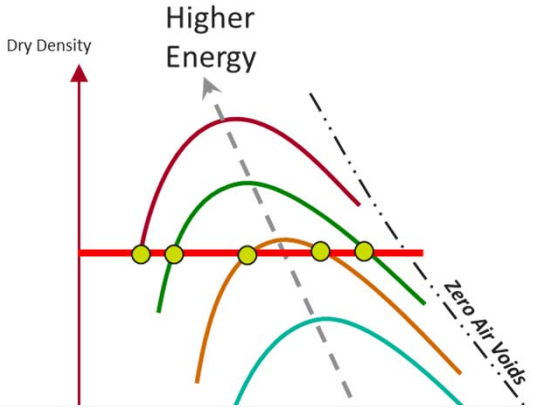
Flexible Pavements

	Insufficient Base Stiffness/Strength	Insufficient Subgrade Stiffness/Strength	Moisture/Drainage Problems	Freeze/Thaw	Swelling	Contamination	Erosion	Spatial Variability
Fatigue Cracking	X	X	X	X		X		
Rutting	X	X	X	X		X		
Corrugations	X							
Bumps				X	X			X
Depressions	X		X	X		X		X
Potholes			X	X				X
Roughness	X	X	X	X	X	X		X

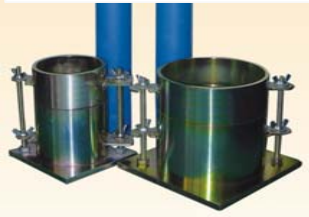
Rigid Pavements

	Insufficient Base Stiffness/Strength	Insufficient Subgrade Stiffness/Strength	Moisture/Drainage Problems	Freeze/Thaw	Swelling	Contamination	Erosion	Spatial Variability
Fatigue Cracking	X	X	X	X		X	X	
Punchouts (CRCP)	X	X	X	X		X	X	
Pumping			X				X	
Faulting	X		X	X	X	X	X	
Roughness	X		X	X	X	X	X	X

Traditional Density-Based Compaction



- They did the best they could with what was available to them ~70 years ago to solve a major problem
- Engineering community pragmatically agreed that these tests improve quality, even though not perfect



Famous Quotes of Ralph Proctor

- Strength is not achieved by density alone.
- Optimum moisture is for compaction.

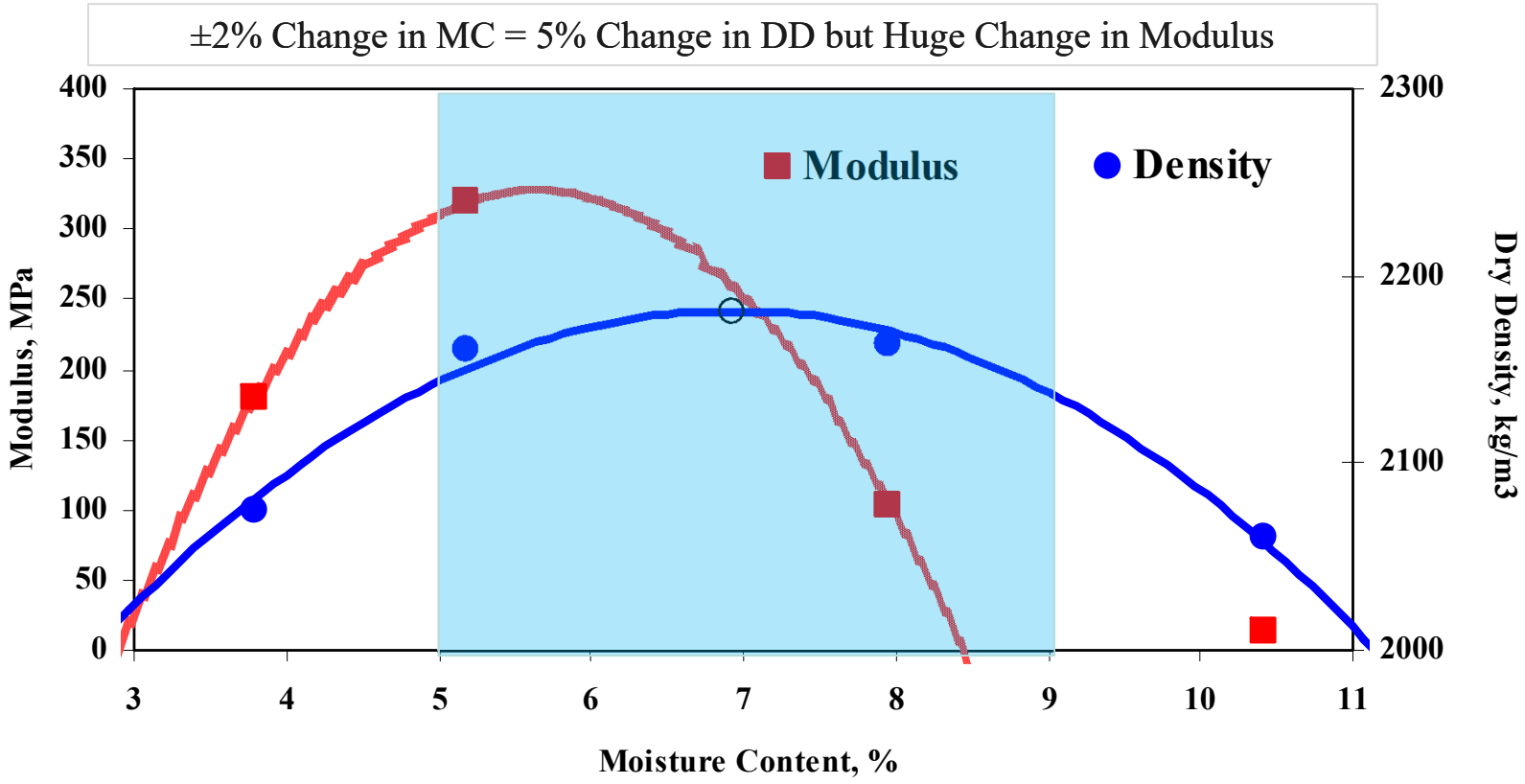
Proctor(1945), Trans 110, ASCE

- "No use is made of actual peak dry weight."
- "Measure of soil compaction used is penetration resistance."

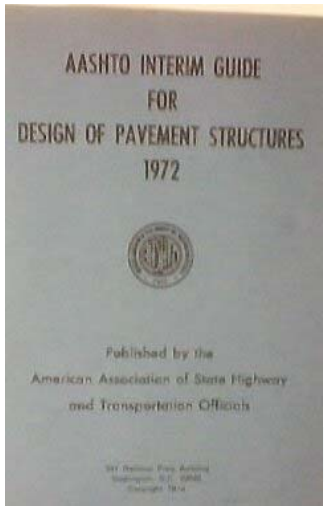
Proctor Penetrometer

Courtesy of John Siekmeier

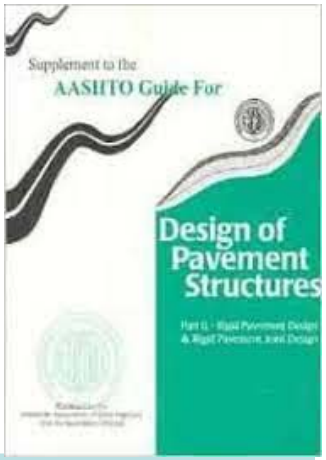
In Support of Proctor Quotes



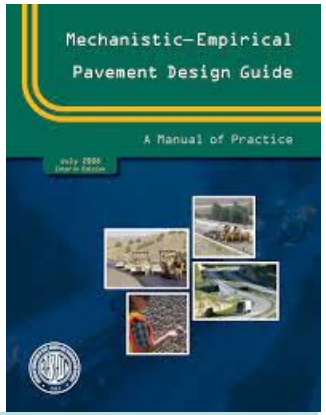
We have come a long way since then in Design!!



1970's



1990's



2000's

2010's

Modulus!! ***Modulus!!***

We have come a long way equipment wise!!

1950's

1970's

1980's

1990's

2000's

2010's

Modulus!! Modulus!! Modulus!!

We have come a long way in Pavement Analysis!!

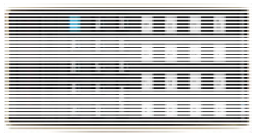
Modulus!! Modulus!! Modulus!!

Deflection? Cool!!

1950's

How to use deflection?

1970's



I am not getting any younger!!

1980's

How to implement effectively?

1990's

What index to use for network level?

2000's

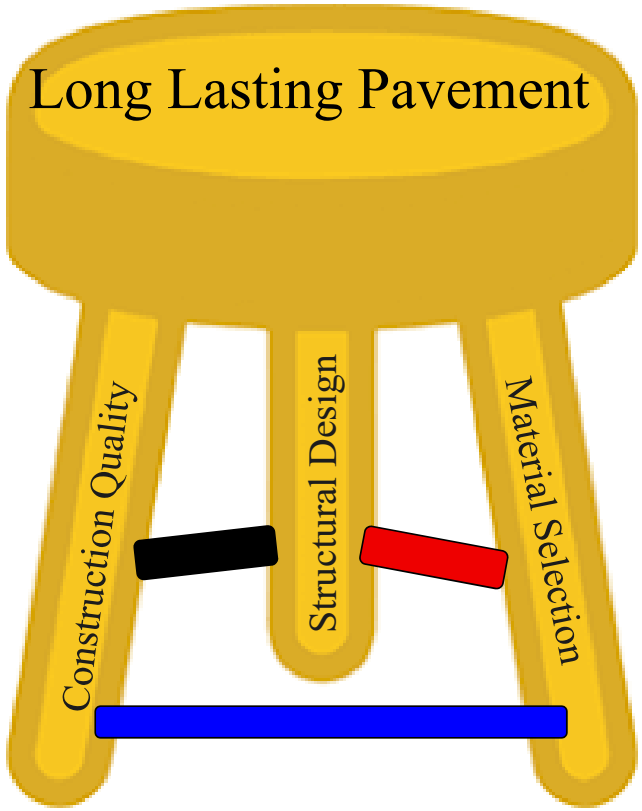
diagnose structural health?

2020's

Yet the State of Practice in Earthwork!!

- **We do not check whether the modulus designer assumed is achieved**
- **We do not check whether the material selected provides the modulus assumed by designer**
- **We assume Lab Moisture-Density Curve represents Field Compaction process**

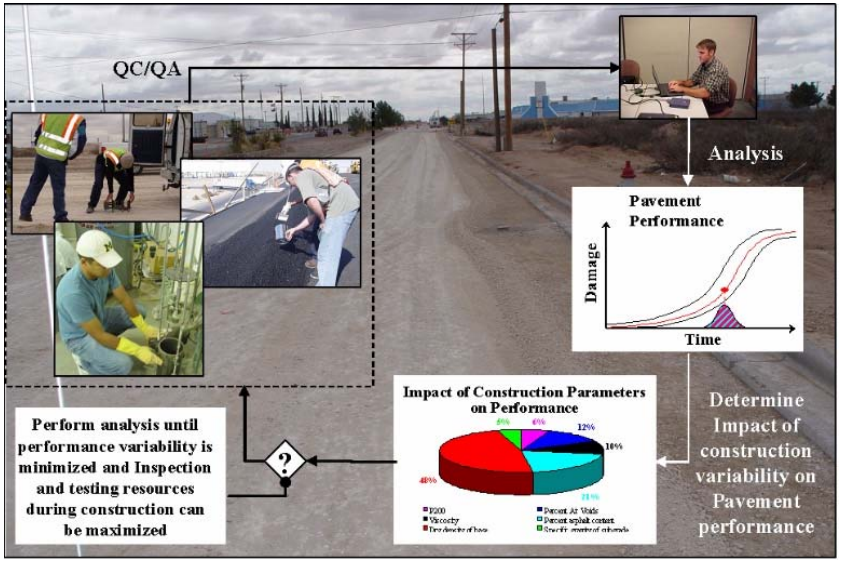
Not a good position to be



Eventual Goal

to ensure that pavement lasts for a pre-defined life *uniformly*

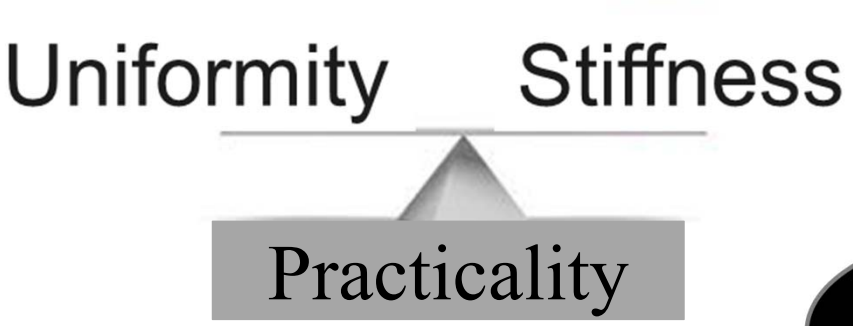
Transition from QAQC to Performance Management

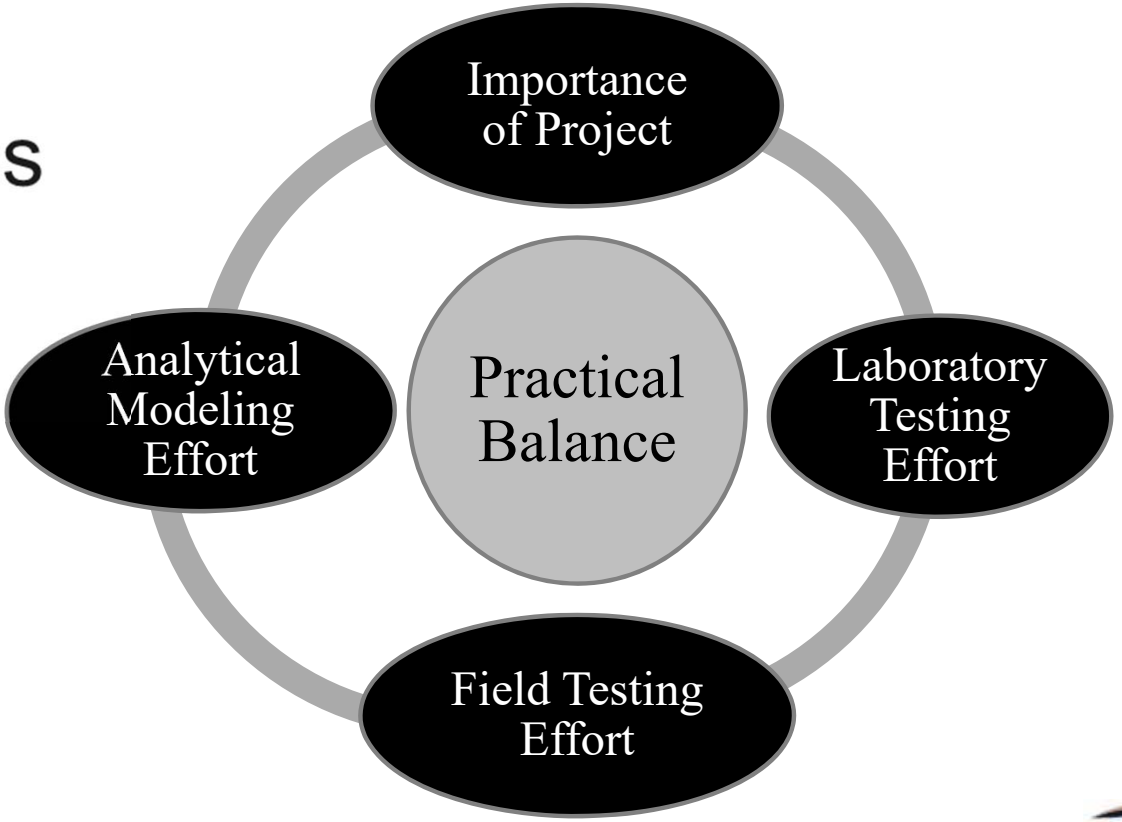


One way to reach it:

- Settle on a design methodology ***(e.g., Pavement ME)***
- Define Parameters that are directly important to performance ***(e.g., modulus)***
- Focus on these parameters

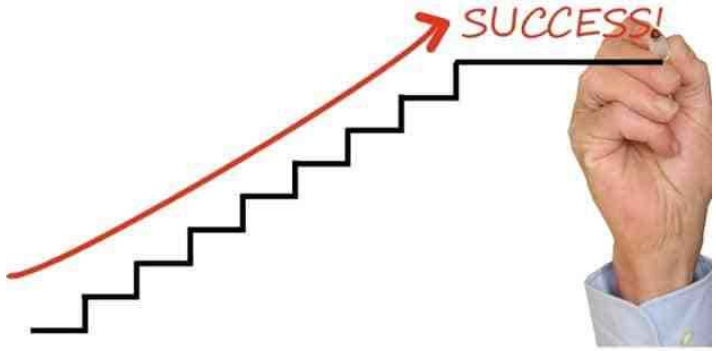
Appropriate Performance Management





Major Steps for Appropriate Performance Management

1. **Selecting Suitable Material**
2. **Selecting Appropriate Design Parameters**
3. **Selecting Target Field Values**
4. **Conducting Field Process Control**
5. **Establishing Acceptance Process**



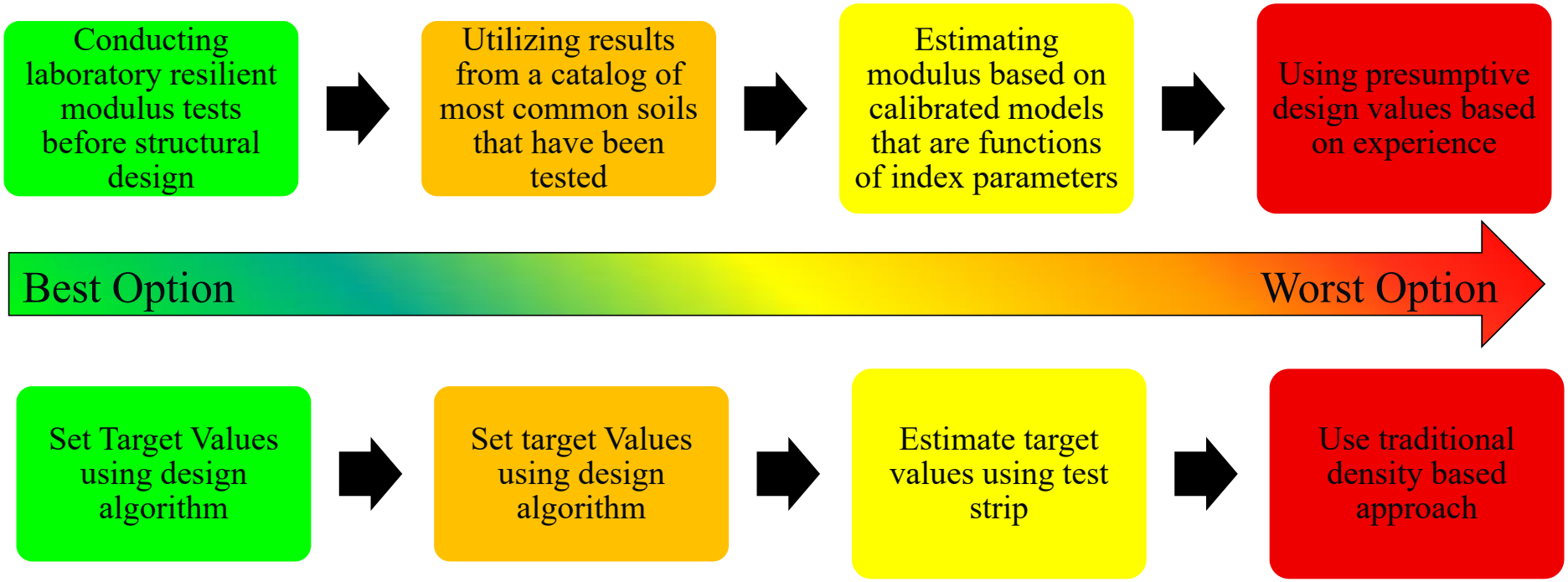
Selecting Suitable Material

A stiff/strong material does not correspond to a durable material.

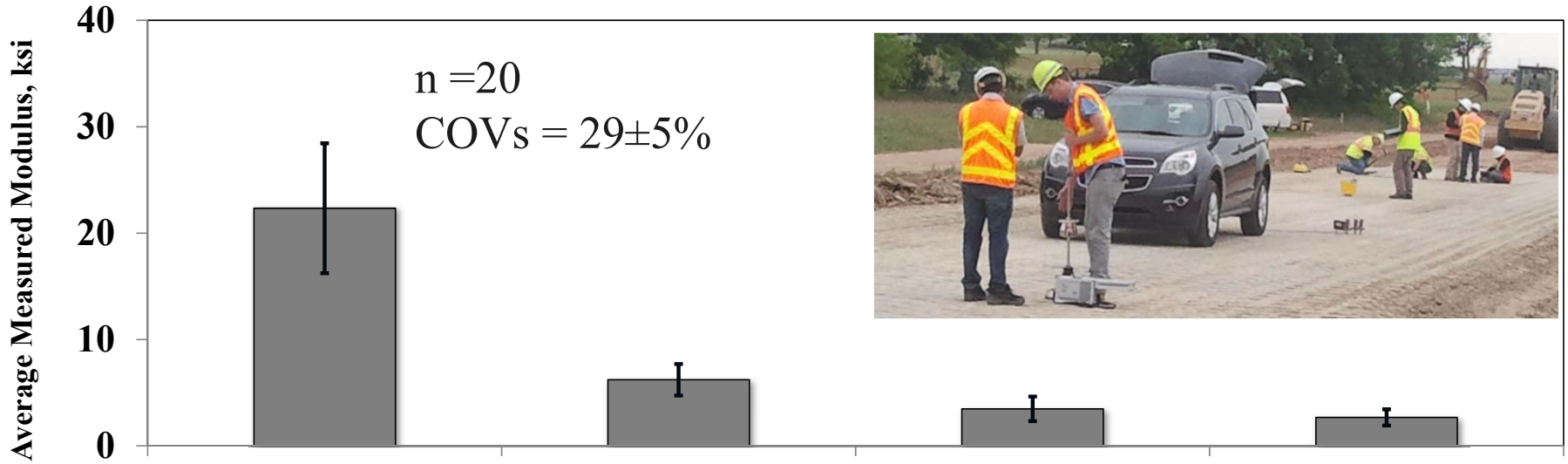
- **Parameters, such as hardness of aggregates, percent fines and plasticity should be controlled for durability.**

Do not abandon specifications on this subject

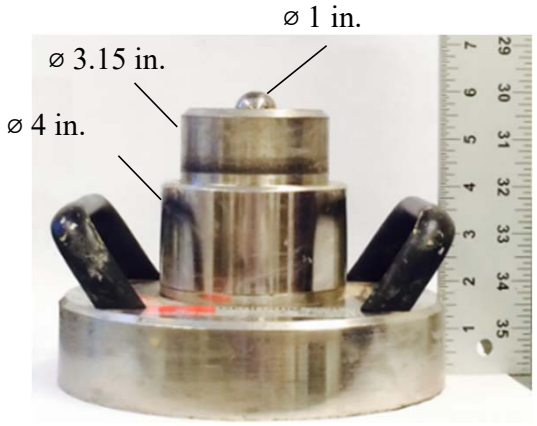
Selecting Appropriate Design Parameters



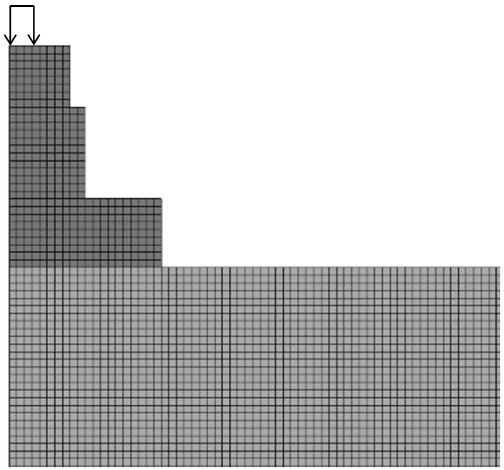
Selecting Target Field Moduli: Which Equipment?

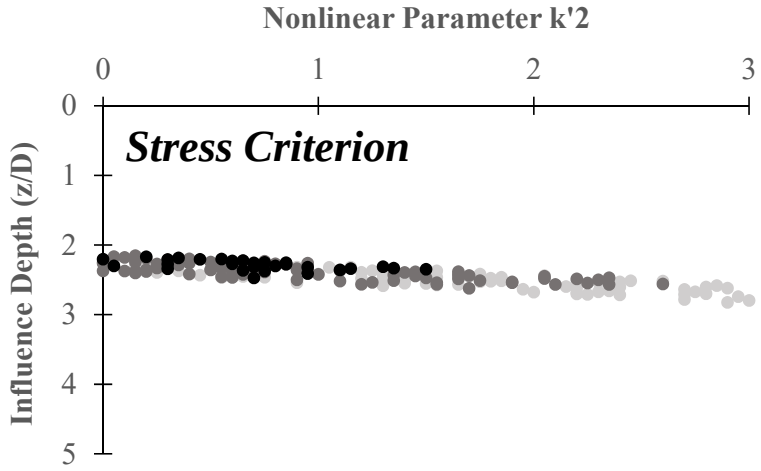


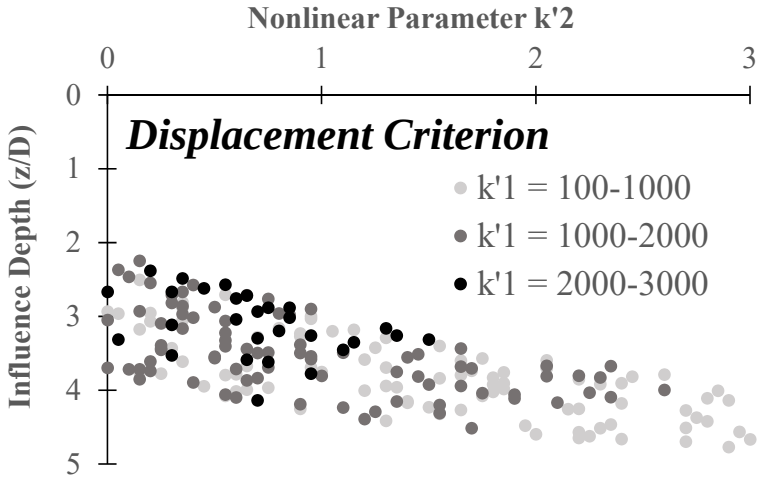
Depth of Influence for LWD



⌀ 8 in. loading plate

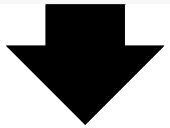






Selecting Target Field Moduli

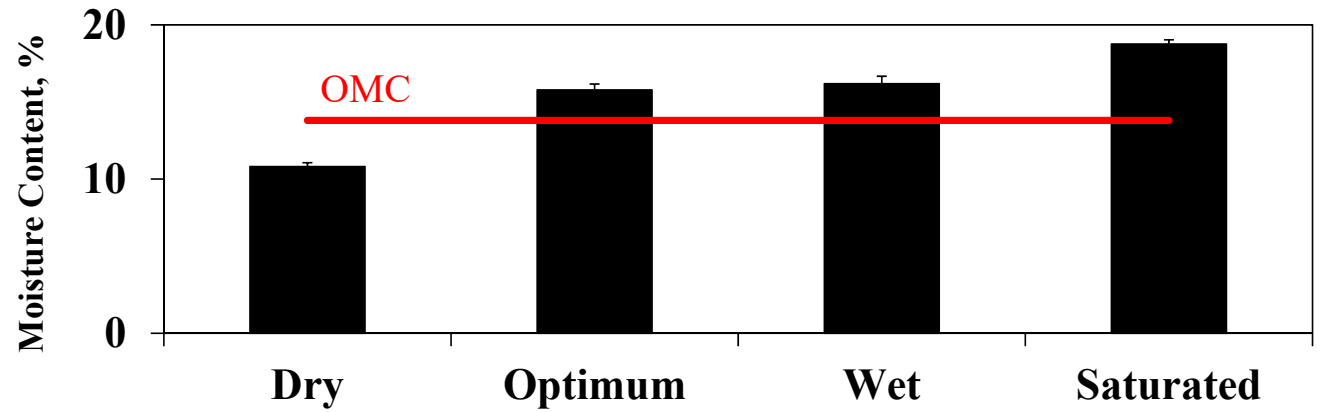
- **Input**
  - Thickness of each layer
  - Poisson's ratio of each layer
  - Modulus of each layer

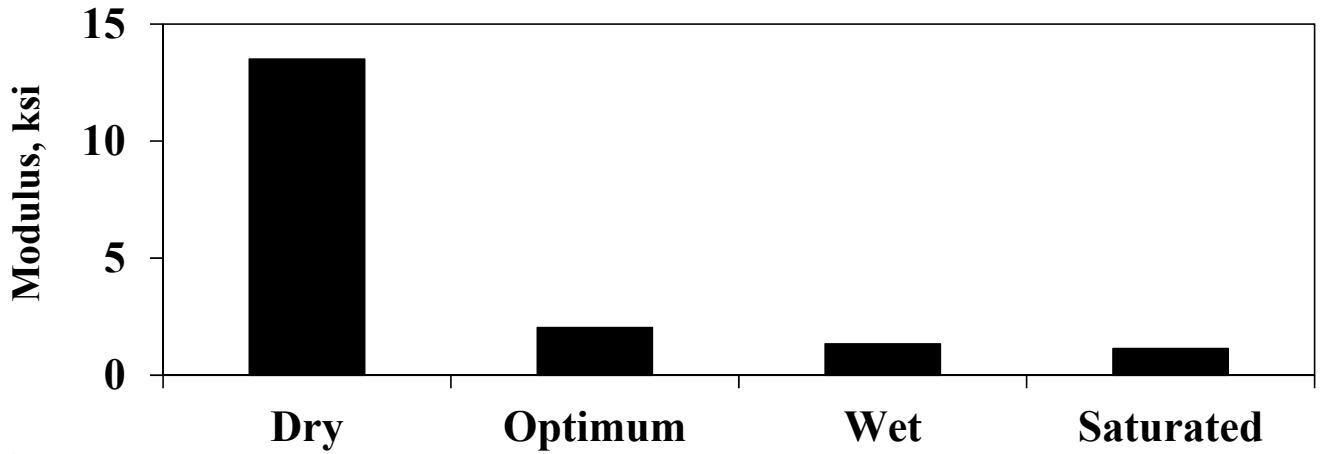


Can easily be part of design

- **Output**
  - ***Target Deflection***

Impact of Moisture Content at Compaction

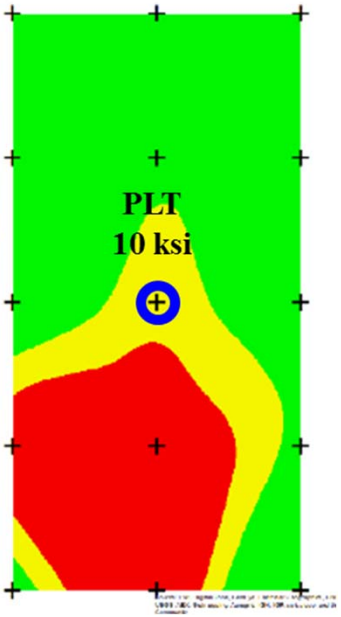




Field Process Control

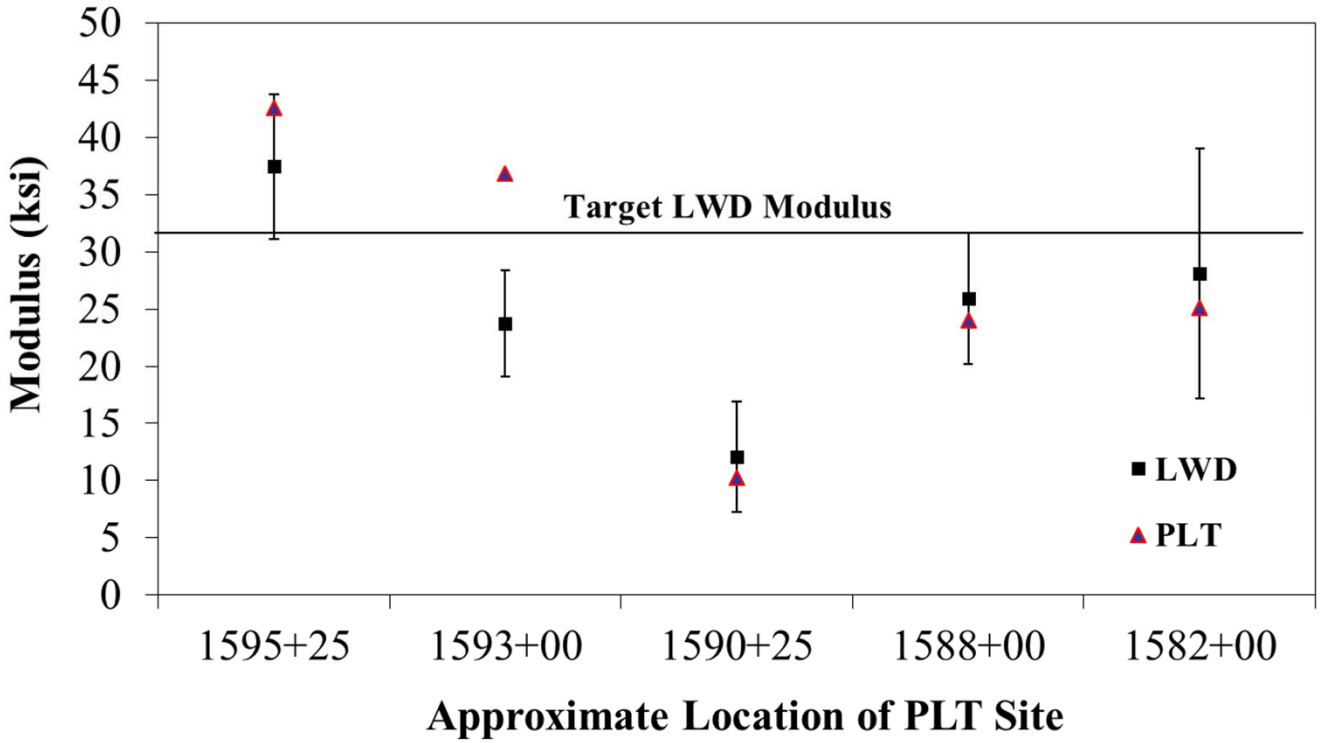
Changes in material and moisture content have significant impact on modulus	Process control will ensure a more uniform and higher quality final product.	Quantifying variability is important to achieve uniformity
Need a strategy to manage variability	Need to ensure a rigid process control not less	Intelligent compaction can be used for this purpose

Field Process Control: Manage Variability



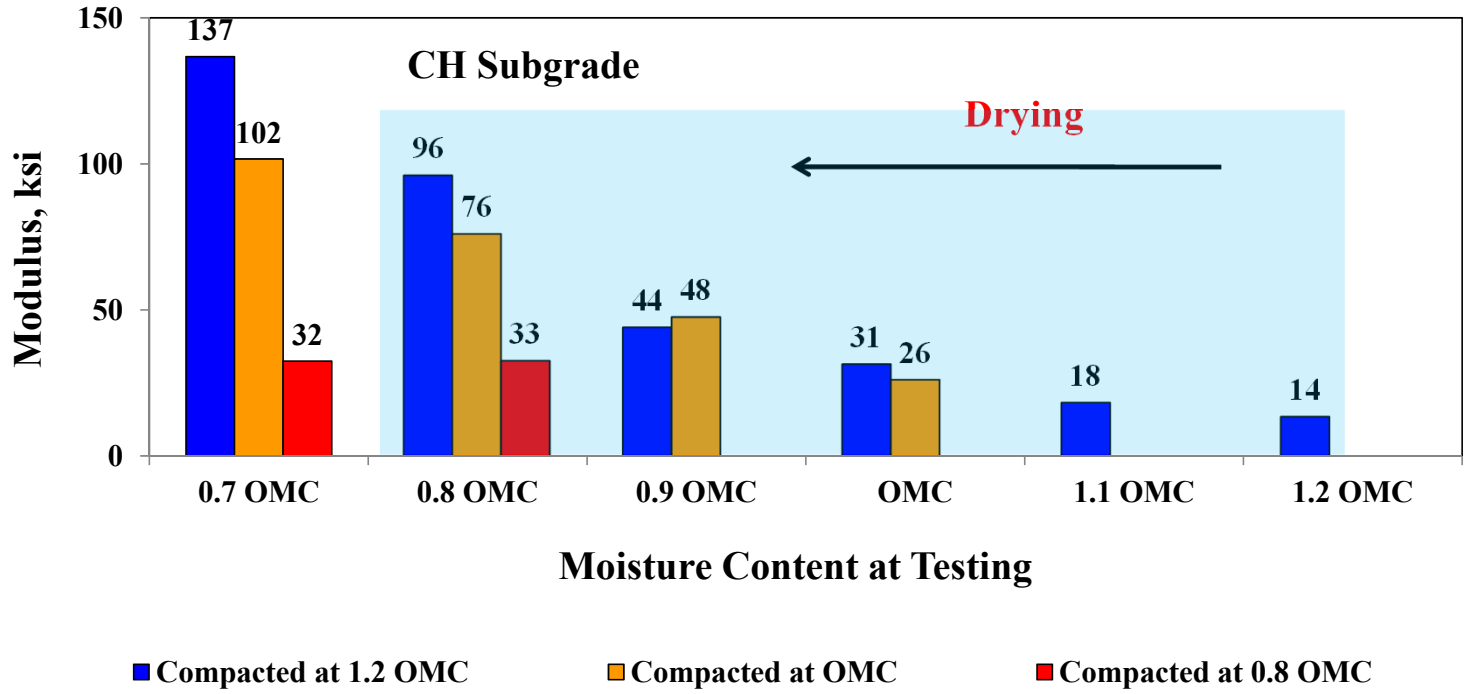
Mean – 10
STDEV – 4
COV - 40%
LWD, ksi

- 3 - 8
- 9 - 10
- 11 - 21



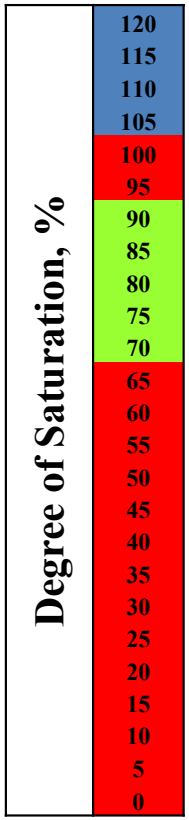
Use statistics to manage variability

Field Process Control: Moisture Content



Constant Density Specimens prepared at MDD

Field Process Control: *Unsaturated Soil Principles*



Moisture Content, %

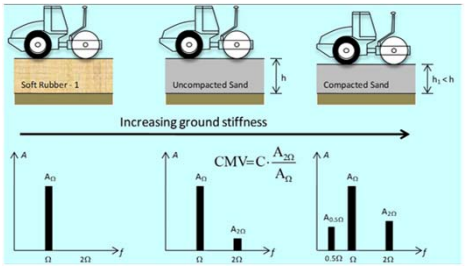
Dry Density, pcf	5%	7%	9%	11%	13%	15%	17%	19%	21%	23%	25%
90	15%	22%	28%	34%	40%	46%	53%	59%	65%	71%	77%
95	17%	24%	31%	38%	45%	52%	59%	66%	72%	79%	86%
99	19%	27%	35%	43%	50%	58%	66%	74%	81%	89%	97%
104	22%	31%	39%	48%	57%	66%	74%	83%	92%	101%	109%
109	25%	35%	45%	55%	65%	75%	85%	95%	105%	115%	125%
115	29%	40%	52%	64%	75%	87%	98%	110%	121%	133%	145%
121	34%	48%	61%	75%	88%	102%	116%	129%	143%	156%	170%
127	41%	57%	74%	90%	106%	123%	139%	155%	172%	188%	204%
133	51%	71%	91%	111%	131%	152%	172%	192%	212%	233%	253%
140	65%	91%	118%	144%	170%	196%	222%	248%	274%	300%	327%
147	90%	127%	163%	199%	235%	271%	308%	344%	380%	416%	452%
154	143%	200%	257%	314%	371%	428%	486%	543%	600%	657%	714%

$$S_r = \omega \, G_s \, \rho_d / (G_s \, \rho_w - \rho_d)$$

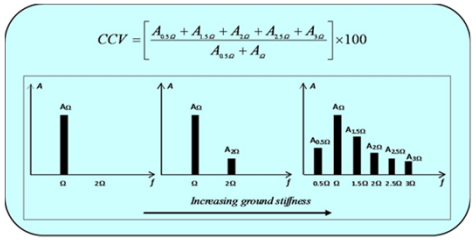
G_s = specific gravity
ρ_d = dry mass density
ρ_w = mass density of water

Intelligent Compaction for Uniformity

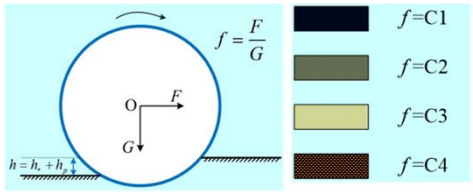
CMV



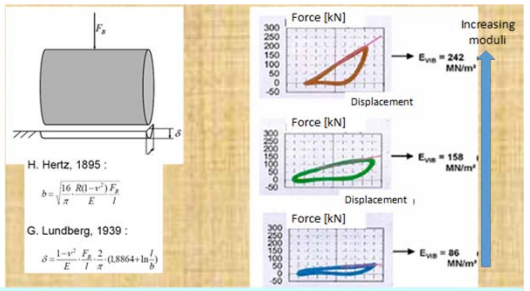
CCV



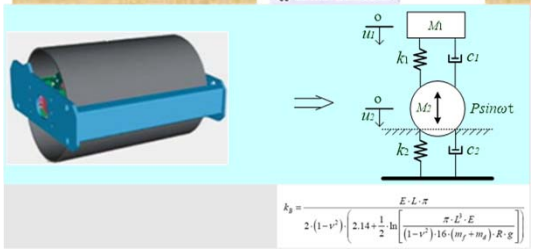
MDP



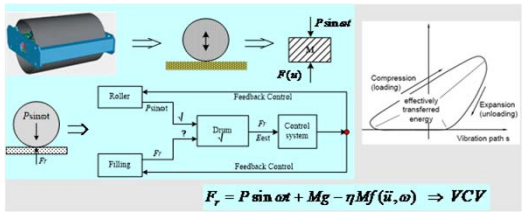
$$MDP = P_g - WV\left[\sin\theta + \frac{a}{g}\right] - (mV + b)$$



E_{vib}



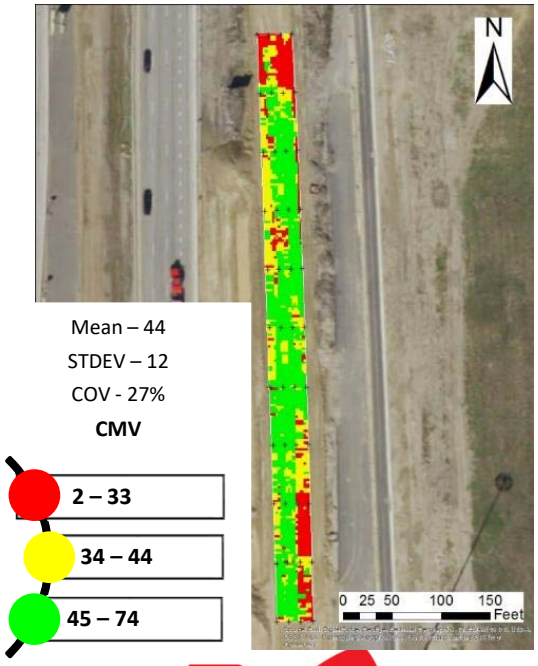
K_b



VCV

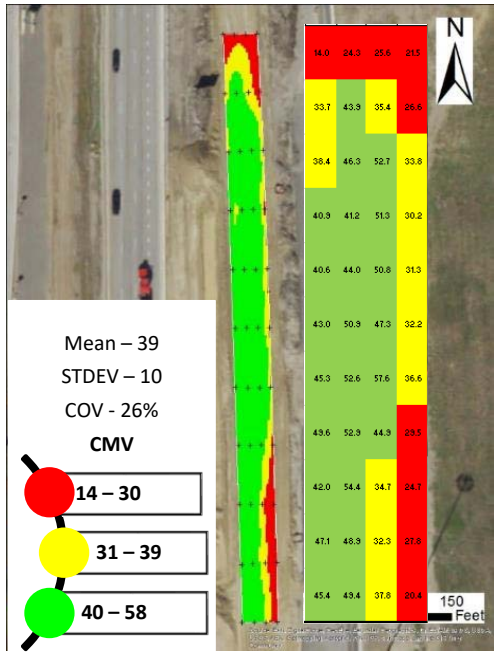
Field Process Control: Uniformity

Traditional

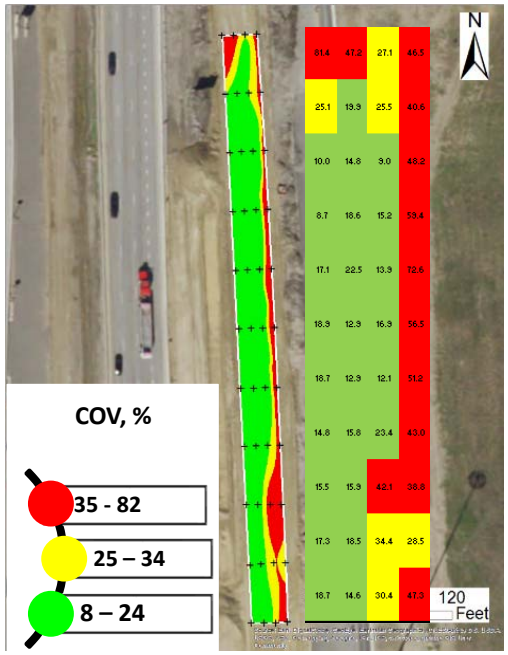


Gridding
Kriging

Sublot Concept



CMV



COV of CMV

Step 5: Acceptance Process

Based on moisture-adjusted deflection

$$d_{adj} = d_{meas} / (K_{lab\text{-}field} \; K_{moist})$$

Include in target value for convenience

$K_{lab\text{-}field}$ adjusts for differences in lab and field moduli at same moisture content and density

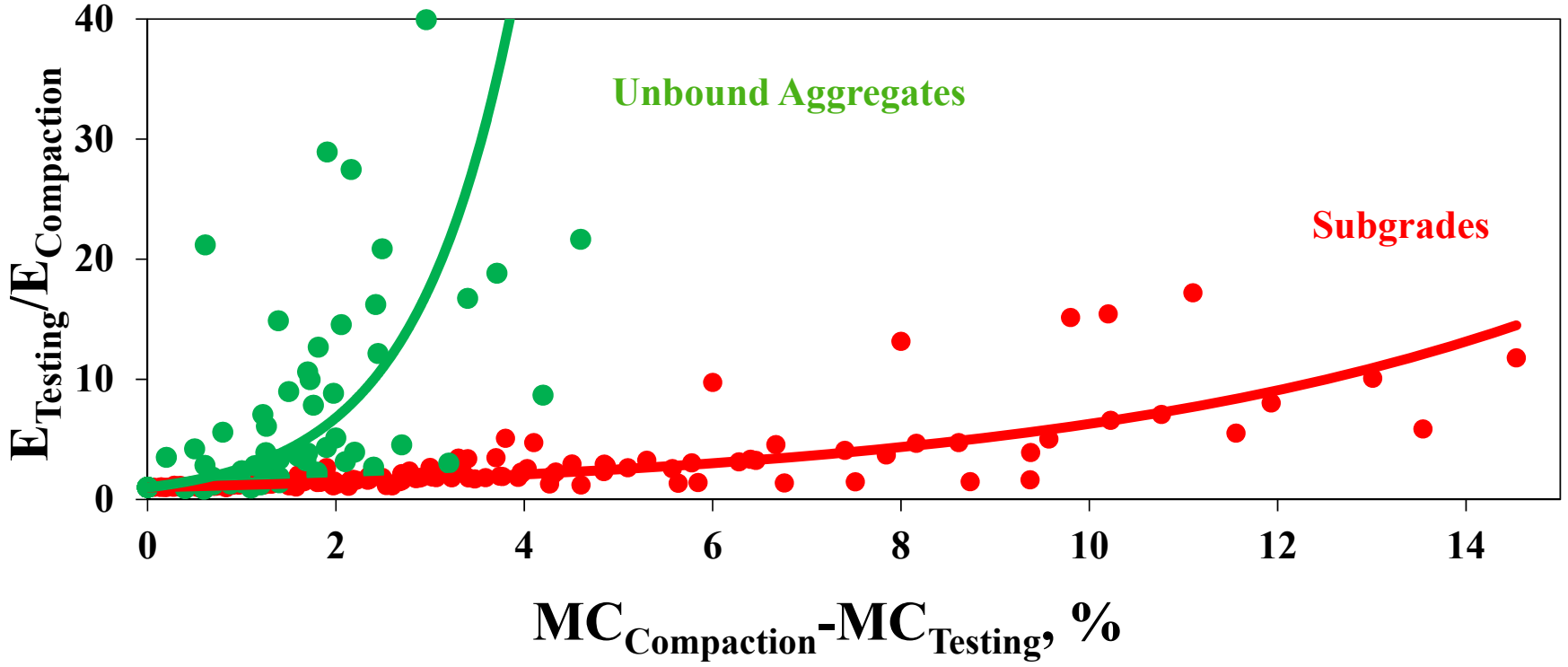
K_{moist} adjusts for differences in compaction and testing moisture contents.

Impact of Delay in Testing

$$K_{moist} = e^{\eta(\omega C - \omega T)}$$

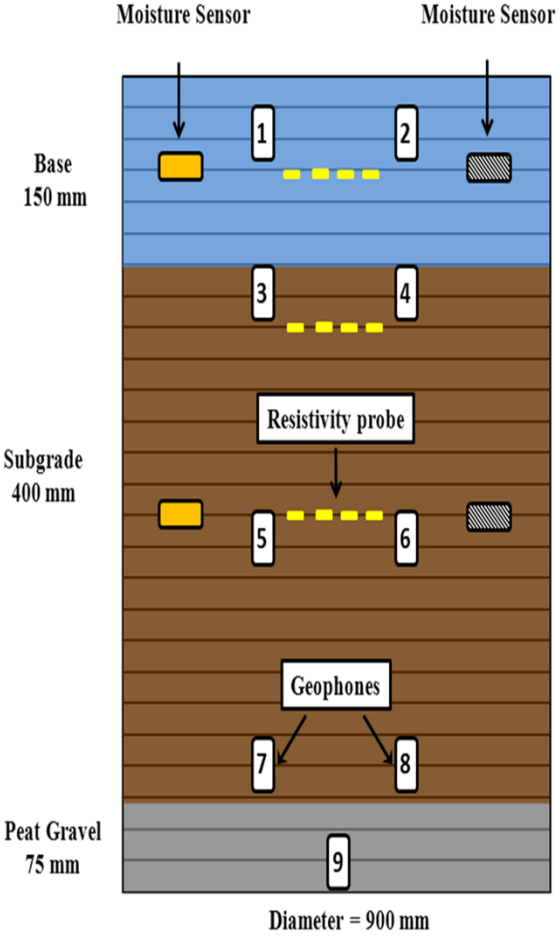
η = 0.18 for subgrades

η = 1.19 for unbound aggregates

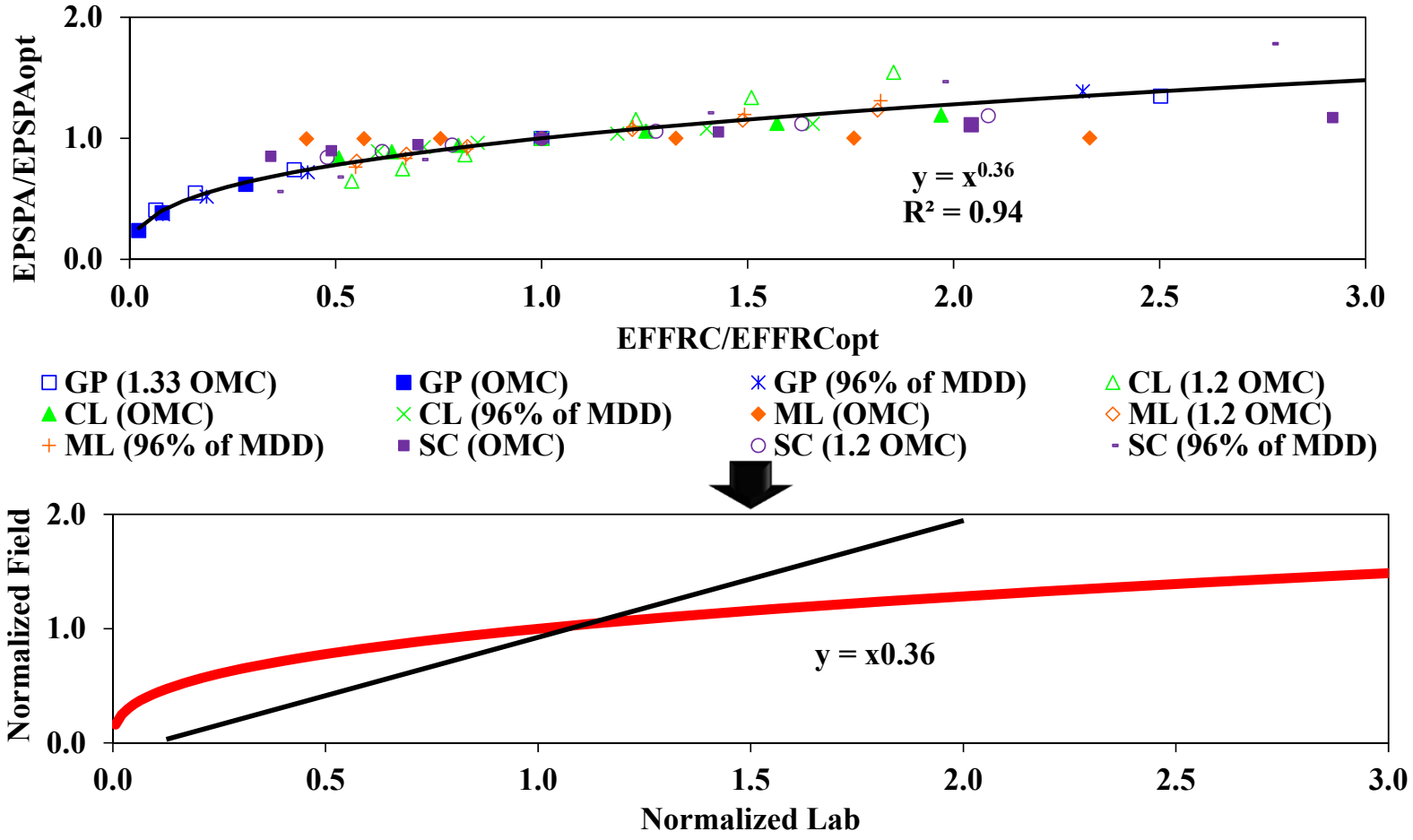


Field to lab Relationship

over 30 specimens



Lab vs. Field Moduli



Service Life

LWD
12" Lime Treated Subgrade

Chainage (ft)	LWD Modulus (ksi)			
	D	C	B	A
250	6	5	4	5
225	6	6	7	6
200	7	5	6	6
175	7	6	4	6
150	16	9	11	7
125	14	10	6	6
100	9	6	7	6
75	8	6	5	6
50	9	5	6	8
25	5	4	5	8
0	6	4	5	8

+

LWD
12" Base + 8" LTS

LWD Modulus (ksi)			
D	C	B	A
43	38	51	32
38	35	41	43
27	30	46	26
33	35	39	30
34	31	36	36
36	35	45	34
37	29	39	30

Backcalculation
12" Base

LWD Modulus (ksi)			
D	C	B	A
66	82	122	74
57	66	162	151
43	74	151	58
71	107	160	75
68	90	104	87
153	148	240	79
106	98	148	60

Simulation
Tandem Axle
Rutting

7.5" HMA
500 ksi

12" Base
50 ksi

12" LTS 10 ksi
Subgrade

Comparison

Service Life Reduction

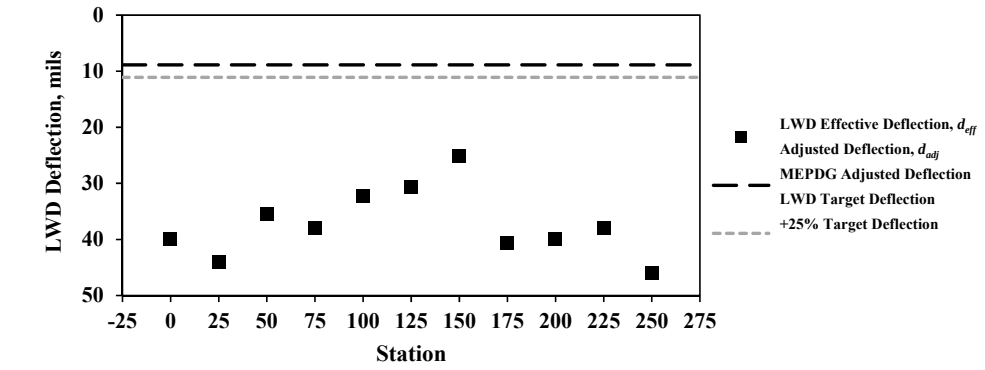
Life reduction %			
D	C	B	A
234%	84%	180%	44%
168%	87%	57%	75%
52%	34%	94%	26%
55%	44%	49%	33%
65%	29%	48%	62%
38%	31%	64%	57%
52%	20%	50%	44%

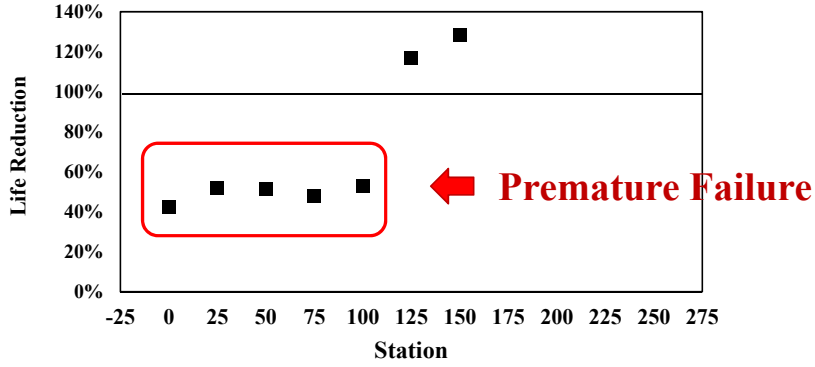
Red < 75% of Average Value

Red < 75%

Service Life Reduction

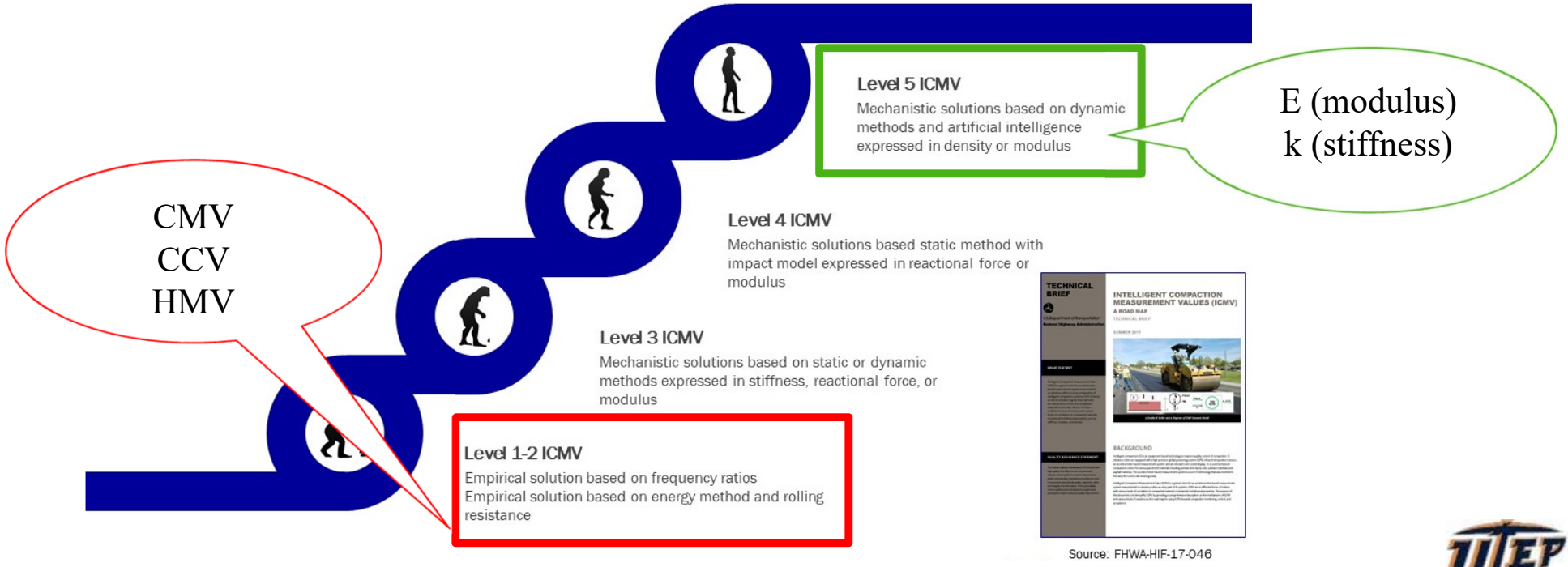
Chainage (ft)	Life reduction %			
	D	C	B	A
250				
225				
200				
175				
150	234%	84%	180%	44%
125	168%	87%	57%	75%
100	52%	34%	94%	26%
75	55%	44%	49%	33%
50	65%	29%	48%	62%
25	38%	31%	64%	57%
0	52%	20%	50%	44%





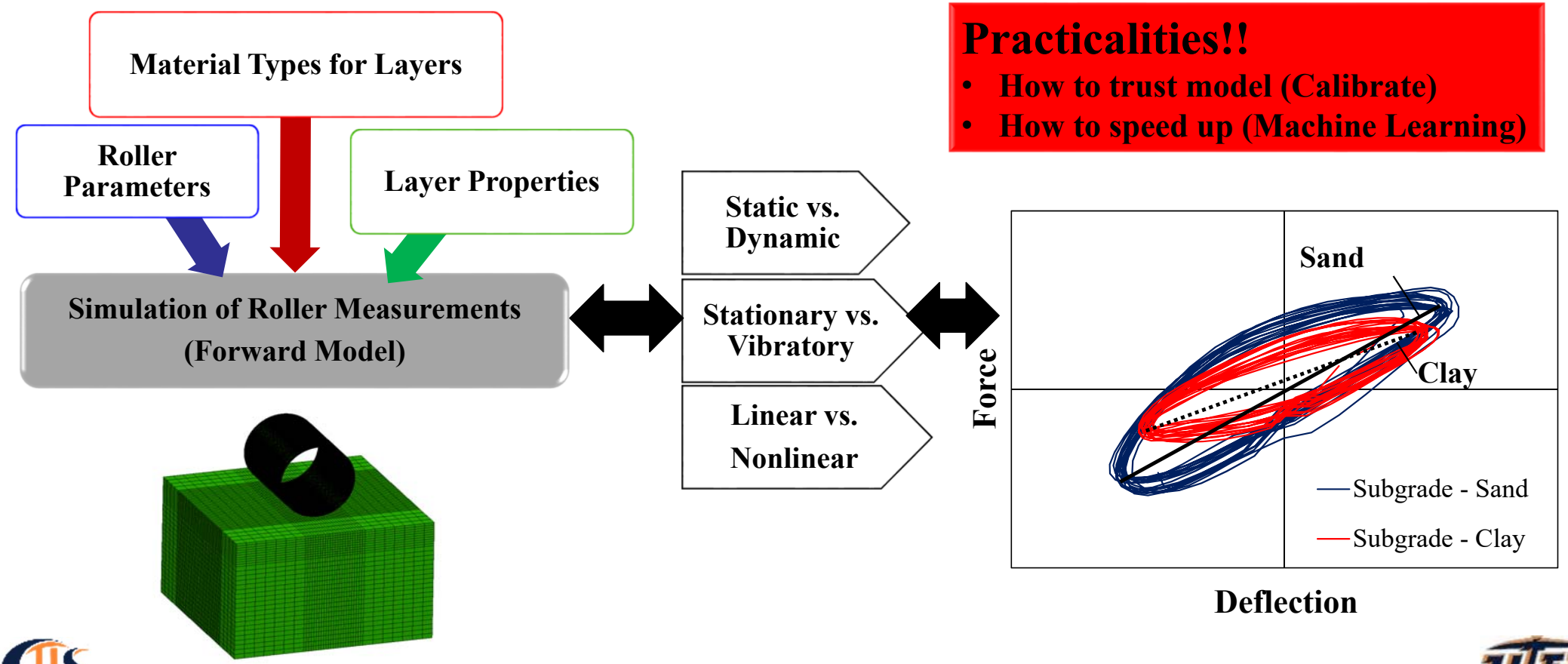
What is New and Exciting!!

Incorporating Intelligent Compaction in Performance Management

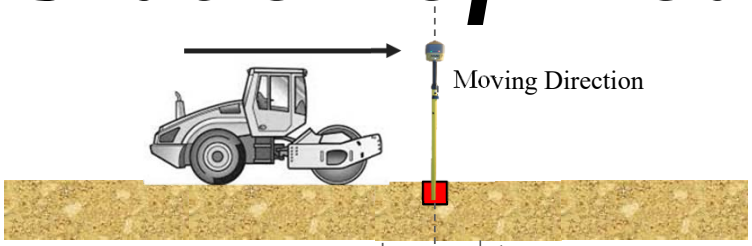


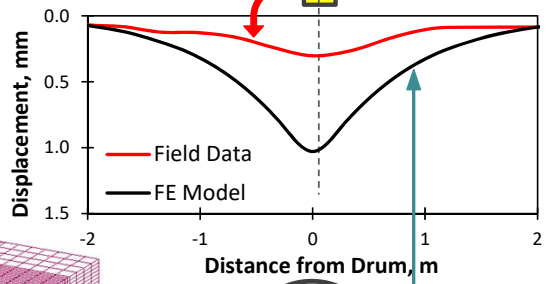
Source: FHWA-HIF-17-046

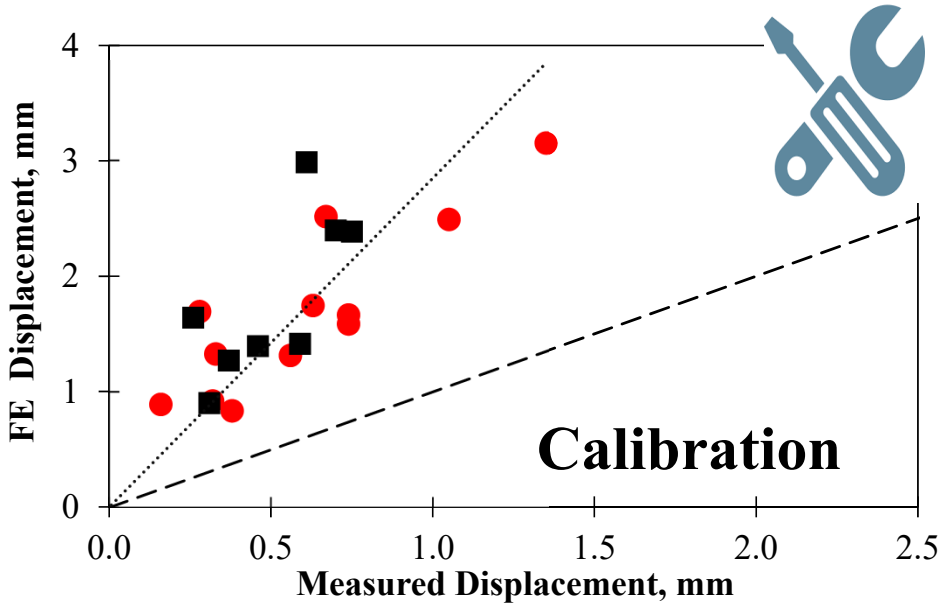
Need for Sophisticated Forward Model!!



Calibration of Model

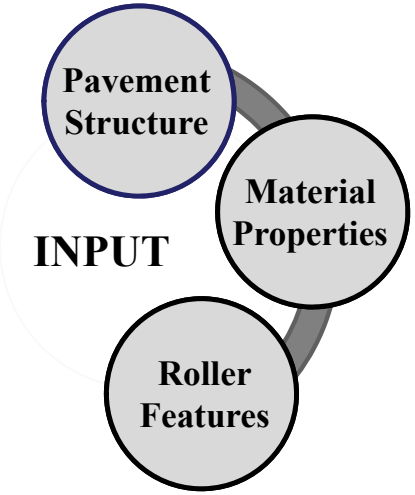


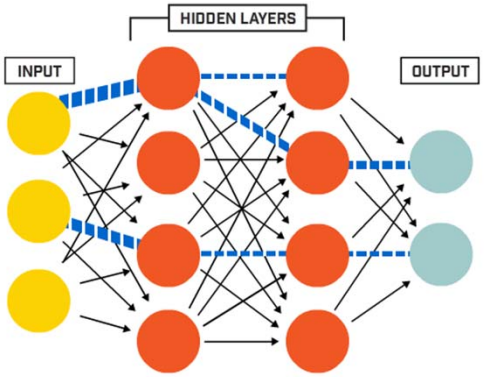




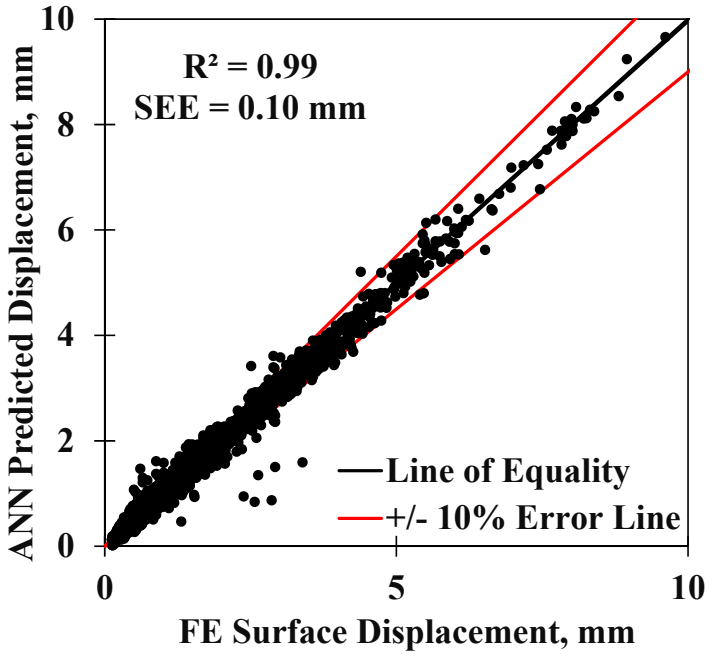
Machine Learning as Forward Modeler

Artificial Neural Networks (ANN)

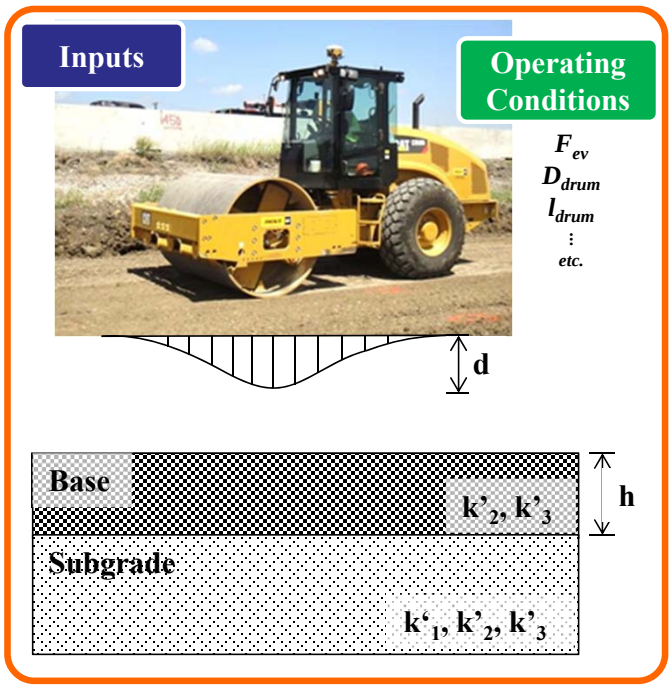


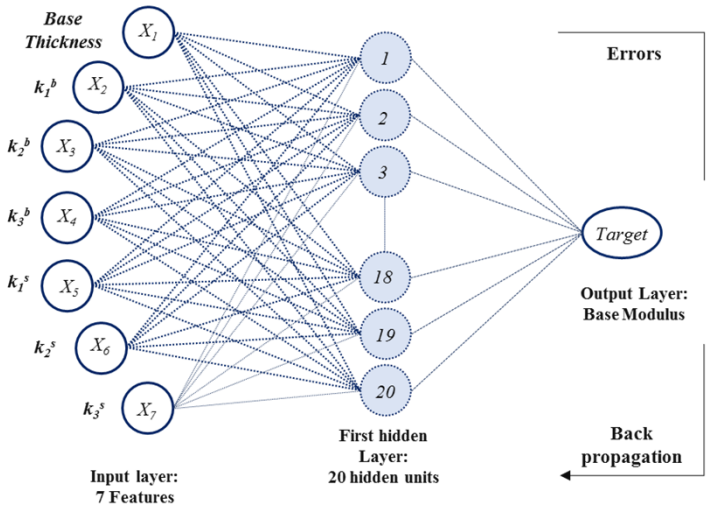


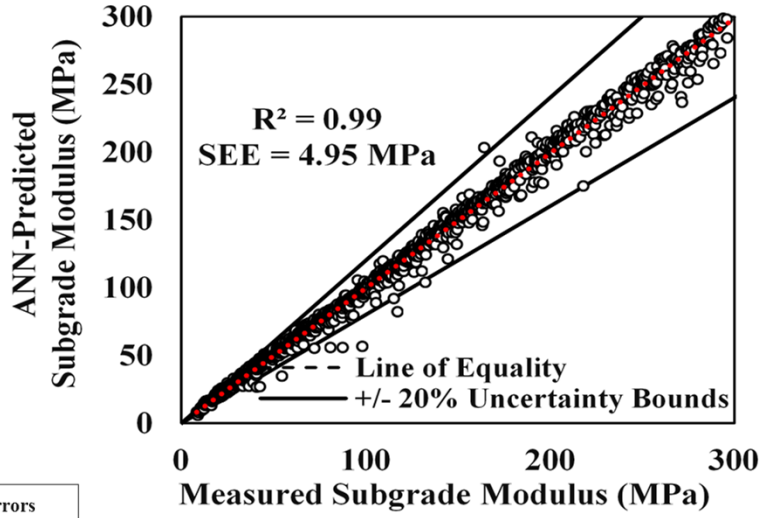
Instantaneous Responses



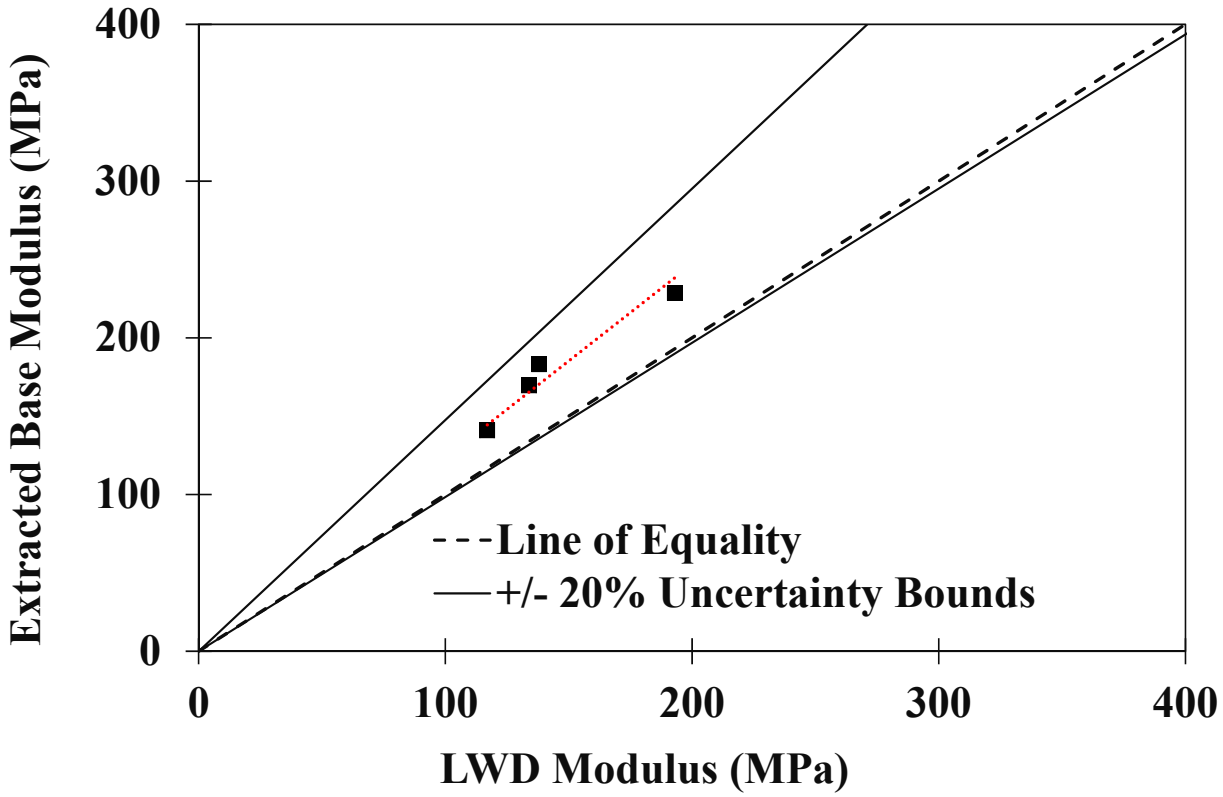
Estimation of E or k



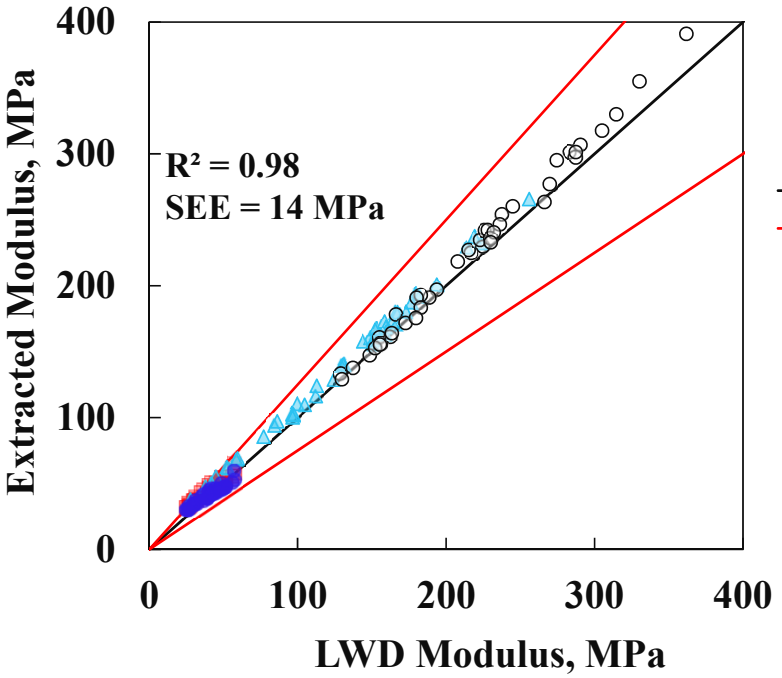




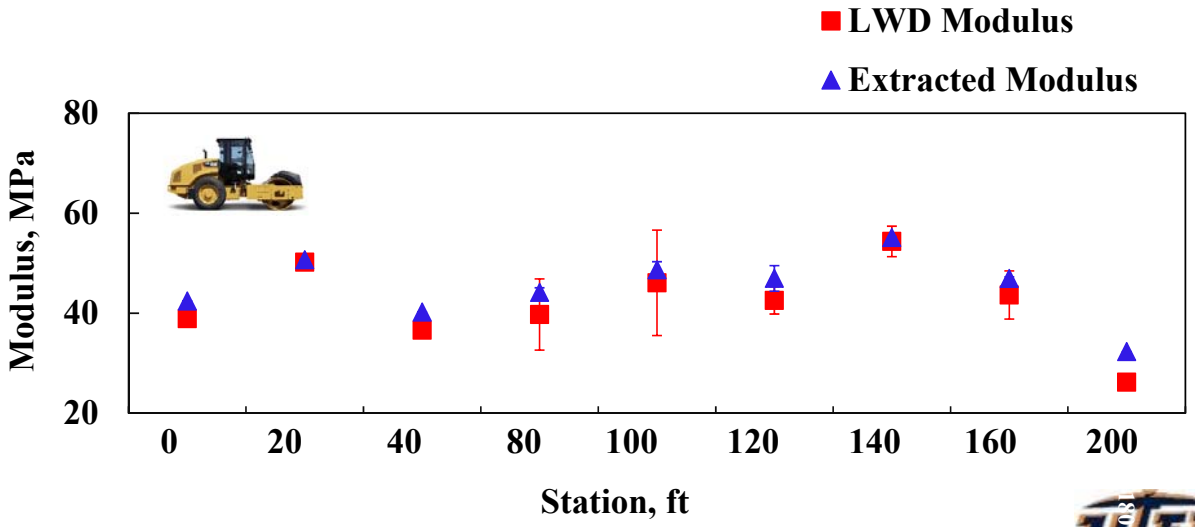
Importance of Local Calibration



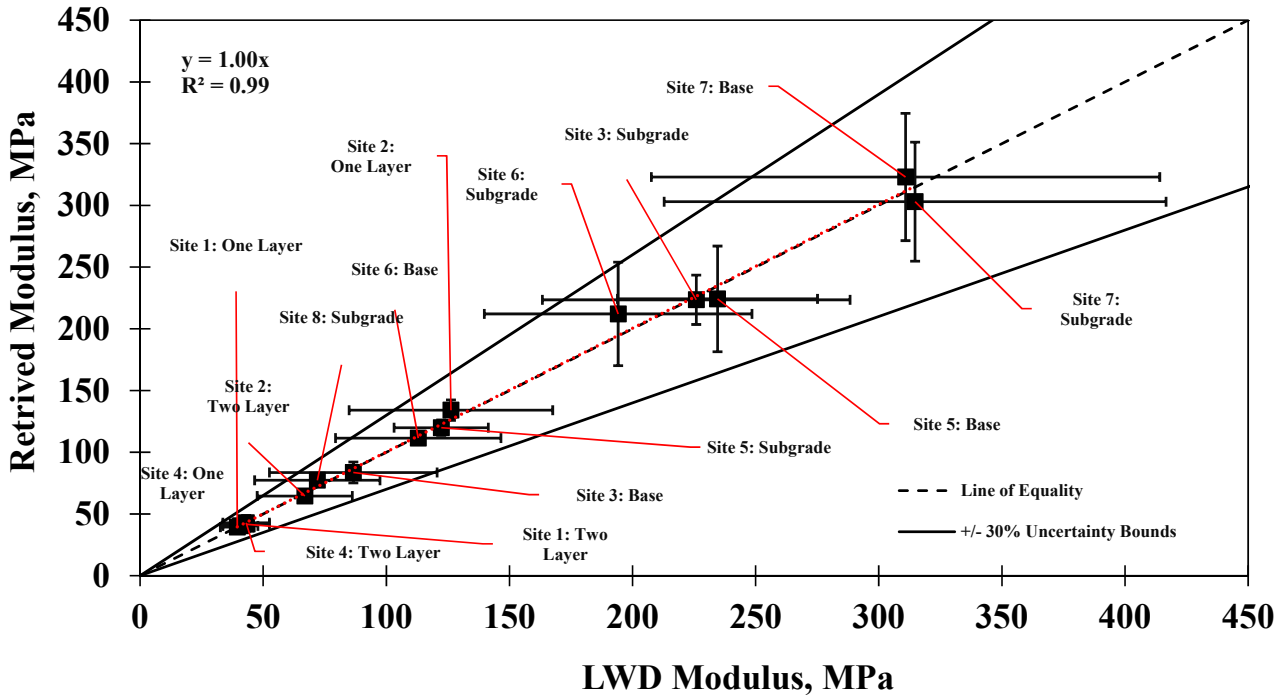
Estimating Modulus using Artificial Intelligence



Site 1
Site 2
Site 3
Site 4
Line of Equality
+/- 25% Uncertainty Bounds



Retrieved Modulus vs. LWD Modulus

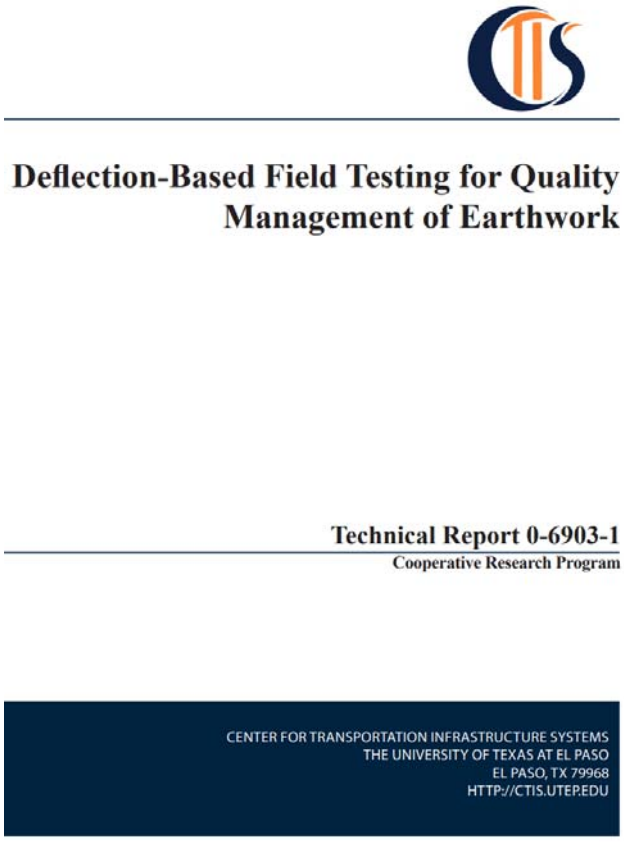


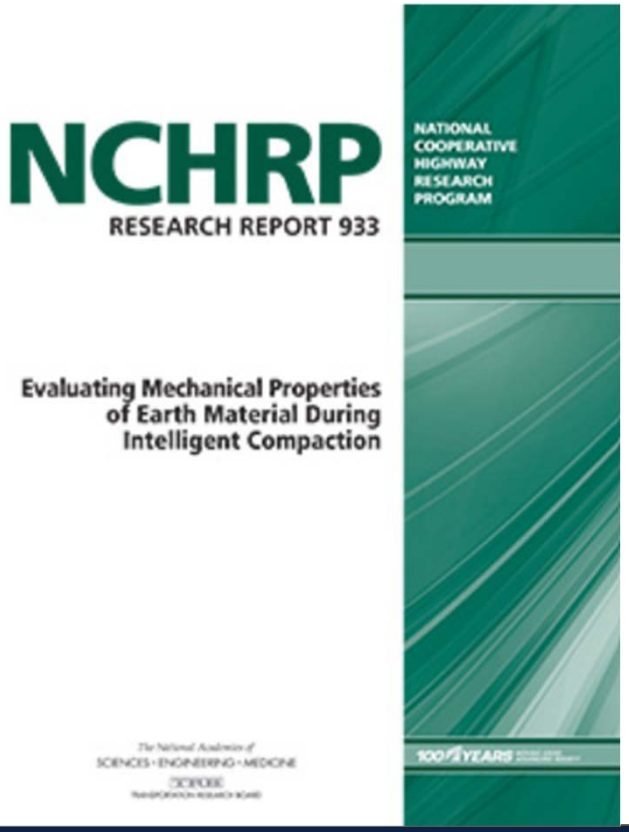
Concluding Remarks

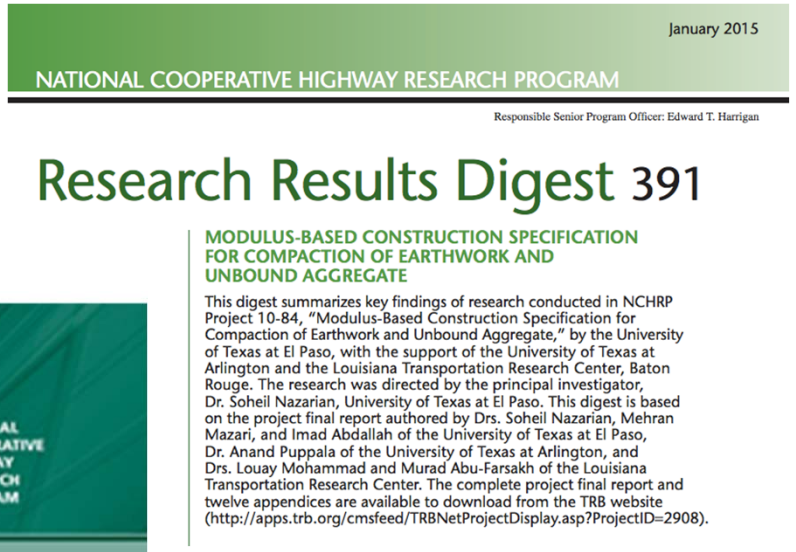
- They did the best they could with what was available to them ~70 years ago to solve a major problem
- Engineering community pragmatically agreed that those tests improve quality, even though not perfect

Let's us pragmatically work toward implementing modulus-based technology to improve further construction quality **even though not perfect**

More info!!


Deflection-Based Field Testing for Quality Management of Earthwork
Technical Report 0-6903-1
Cooperative Research Program
CENTER FOR TRANSPORTATION INFRASTRUCTURE SYSTEMS
THE UNIVERSITY OF TEXAS AT EL PASO
EL PASO, TX 79968
HTTP://CTIS.UTEP.EDU


NCHRP
RESEARCH REPORT 933
Evaluating Mechanical Properties of Earth Material During Intelligent Compaction
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM


January 2015
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Responsible Senior Program Officer: Edward T. Harrigan
Research Results Digest 391
MODULUS-BASED CONSTRUCTION SPECIFICATION FOR COMPACTION OF EARTHWORK AND UNBOUND AGGREGATE
This digest summarizes key findings of research conducted in NCHRP Project 10-84, "Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate," by the University of Texas at El Paso, with the support of the University of Texas at Arlington and the Louisiana Transportation Research Center, Baton Rouge. The research was directed by the principal investigator, Dr. Soheil Nazarian, University of Texas at El Paso. This digest is based on the project final report authored by Drs. Soheil Nazarian, Mehran Mazari, and Imad Abdallah of the University of Texas at El Paso, Dr. Anand Puppala of the University of Texas at Arlington, and Drs. Louay Mohammad and Murad Abu-Farsakh of the Louisiana Transportation Research Center. The complete project final report and twelve appendices are available to download from the TRB website (http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2908).

Thank you!!

A number of colleagues and students

- Cesar Tirado
- Sergio Rocha
- Mehran Mazari
- Aria Fathi