In Situ Modulus Measurement Using APLT for State Wide ME Design Calibration

STIC
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What is Mechanistic QC/QA/PC?

Mechanistic QC/QA/PC refers to in situ verification of properties assumed in design – Typically M_r or k values

Design Guide	Rigid Pavement	Flexible Pavement
AASHTO 1972	Mod. of subgrade reaction, k	Soil support value Structural layer coefficient.
AASHTO 1986 AASHTO 1993	k for subgrade, k_{comp} if base layer is present	Resilient modulus (M_r) for subgrade and base
AASHTO 2008	M_r (stress-dependent constitutive model) for subgrade and base	
PCA 1984	k for subgrade, k_{comp} if base layer is present	N/A
Asphalt Institute	N/A	Resilient modulus (M_r) for subgrade

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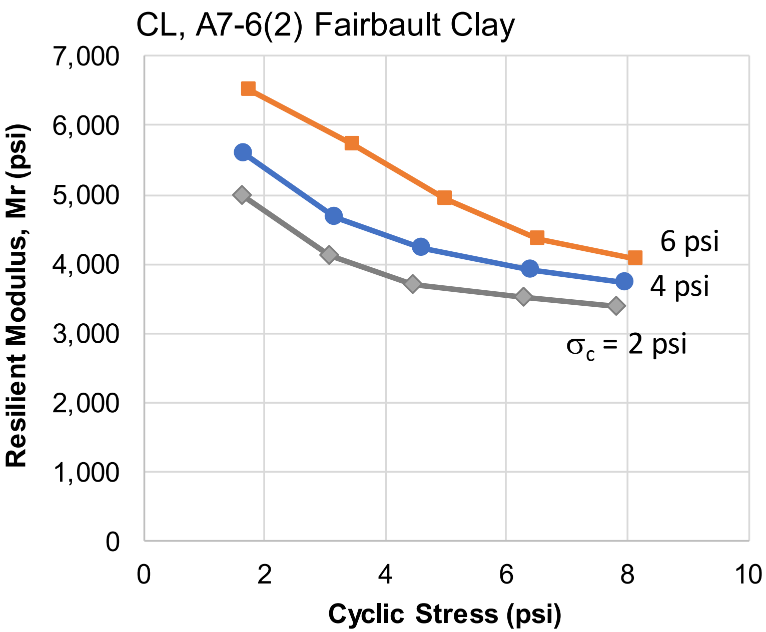
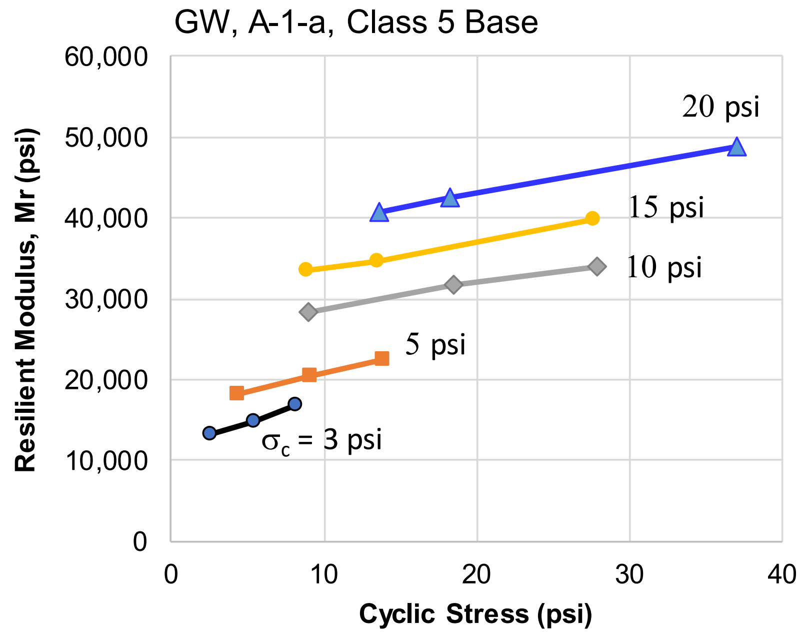
Mechanistic parameters are: Stress-Dependent

Fine-grained materials exhibit stress-softening behavior

Coarse-grained materials exhibit stress-hardening behavior





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

AASHTO (2015) Universal Model

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How are the foundation input parameters measured?

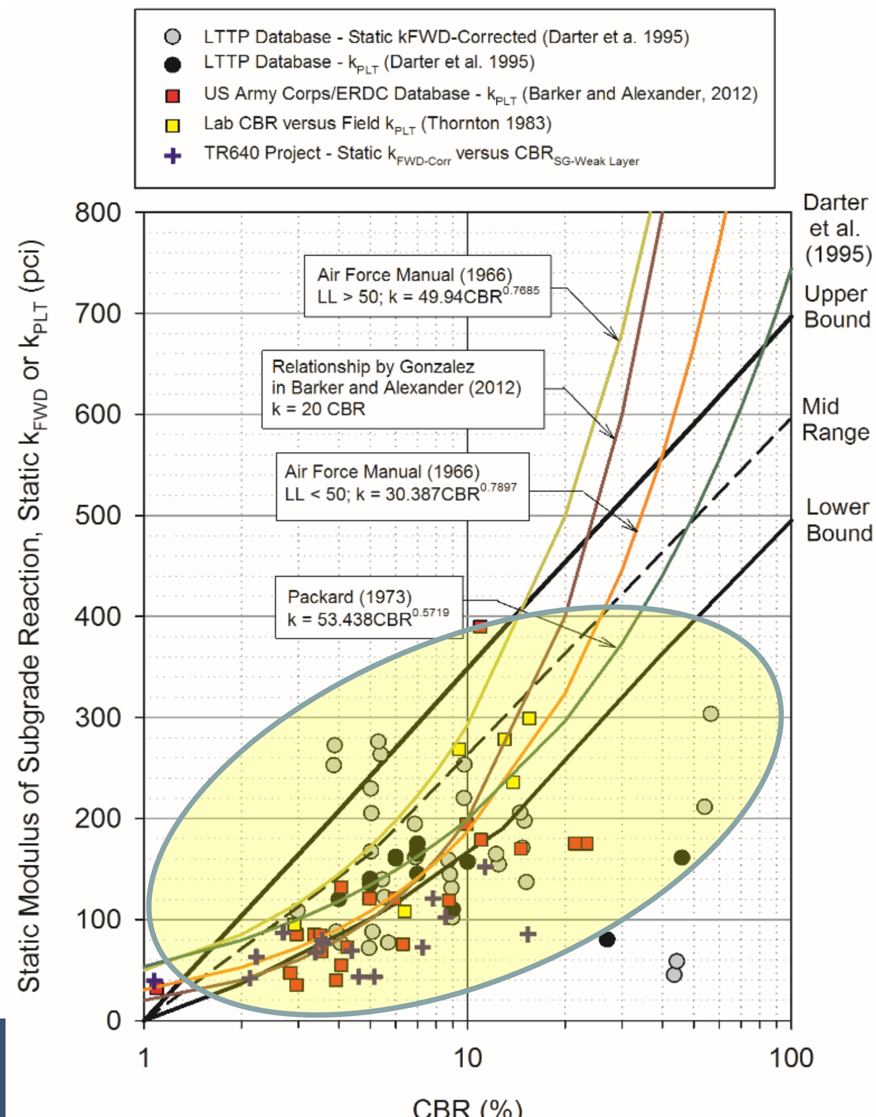
Direct measurement methods

- Static (repetitive or non-repetitive) plate load testing
- Laboratory resilient modulus testing

Indirect measurement methods (empirical relationships)

- Falling weight deflectometer (FWD) testing
- Light weight deflectometer (LWD) testing
- CBR testing
- DCP testing
- R-Value testing
- Relative compaction
- Soil classification results

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

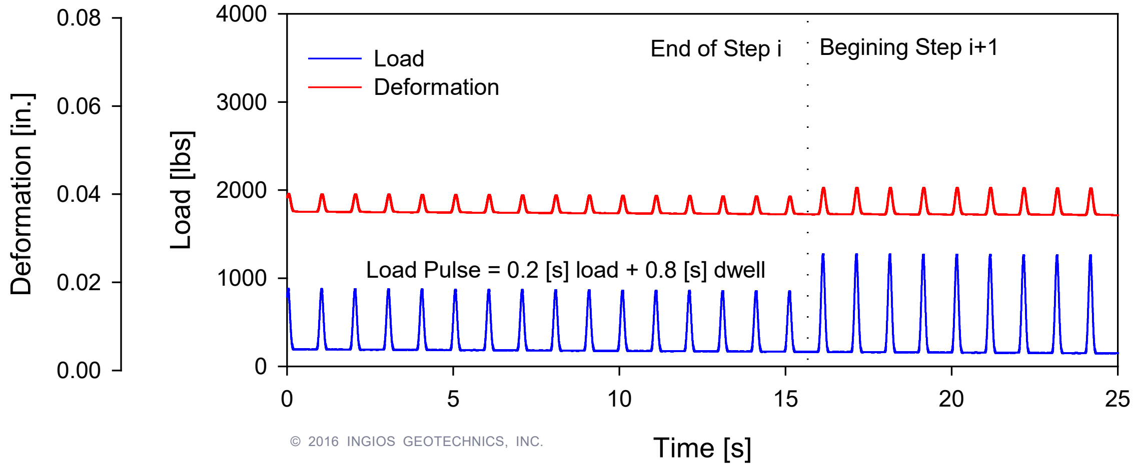


Example of empirical relationships to estimate k-value from CBR

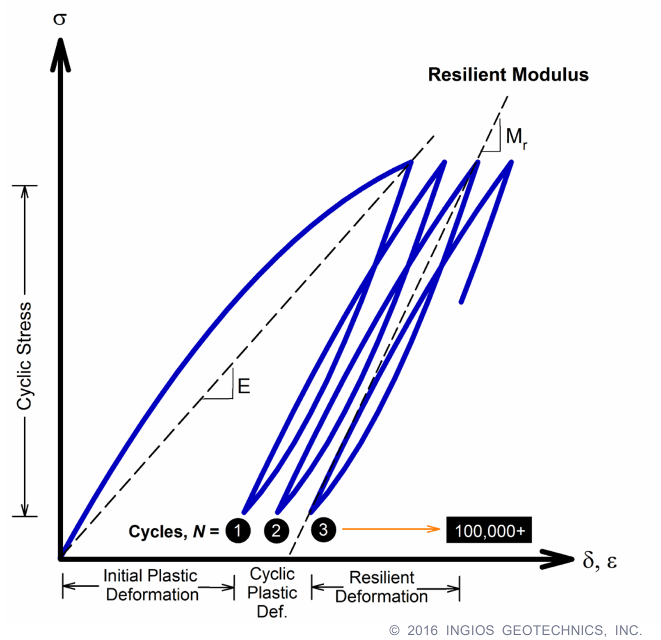
Terzaghi (1955) noted when describing coefficients of subgrade reaction, "*widespread among engineers*" is the "*erroneous conception*" that the "*numerical value of coefficient of subgrade reaction depends exclusively on the nature of the subgrade*", and without proper consideration of the test methods,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

APLT – Real Time Resilient Modulus

APLT imparts controlled load pulses (e.g., 0.15 sec pulse + 0.45 sec dwell)



Measure permanent and resilient deflections



$E = (1-\nu^2)\, f\, \sigma_o\, (a / d_0)$

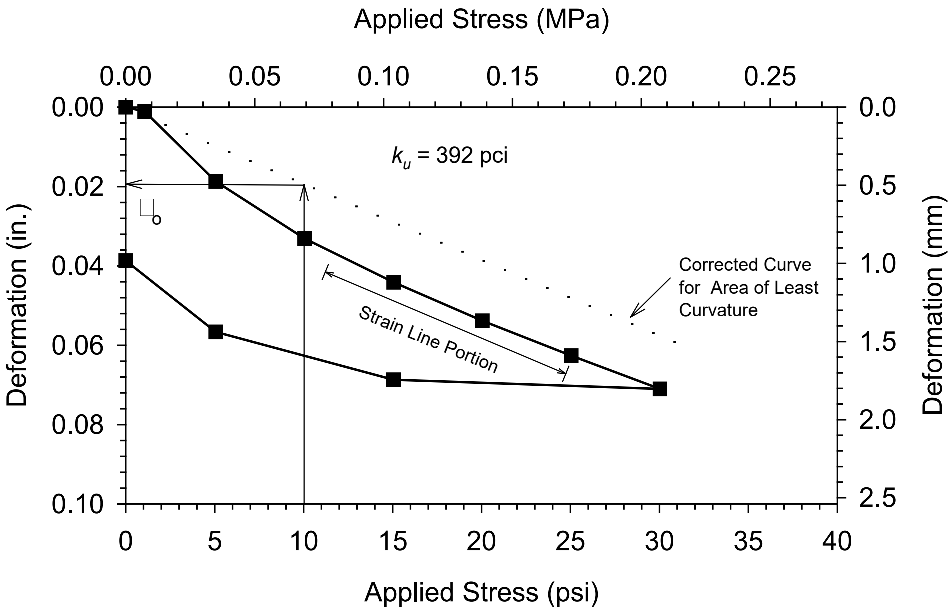
d_o = ***Elastic*** deformation

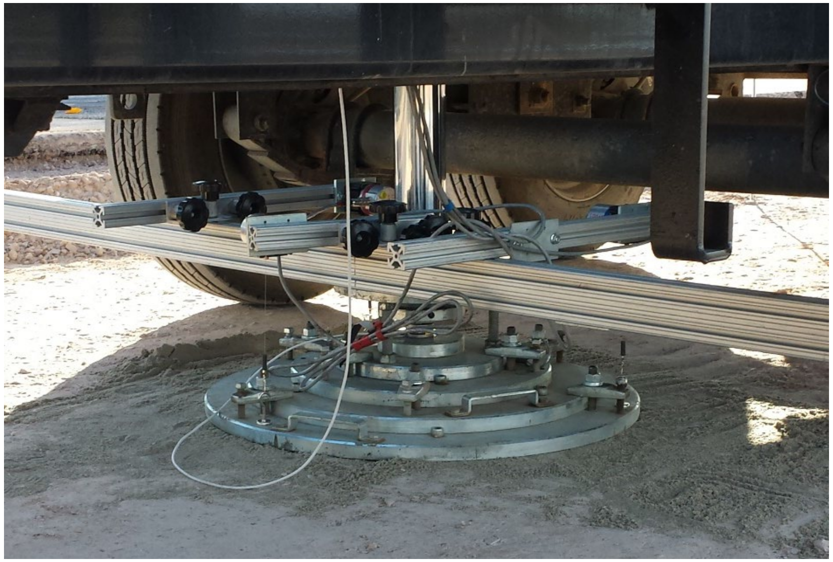
$M_r = (1-\nu^2)\, f\, \sigma_o\, (a / d_r)$

d_r = ***recoverable*** deformation

APLT can perform static and cyclic plate load test in accordance with U.S. and European Standards

30 in. Static Plate Load Test according to AASHTO T222, ASTM D1196, and CRD-C 655-95





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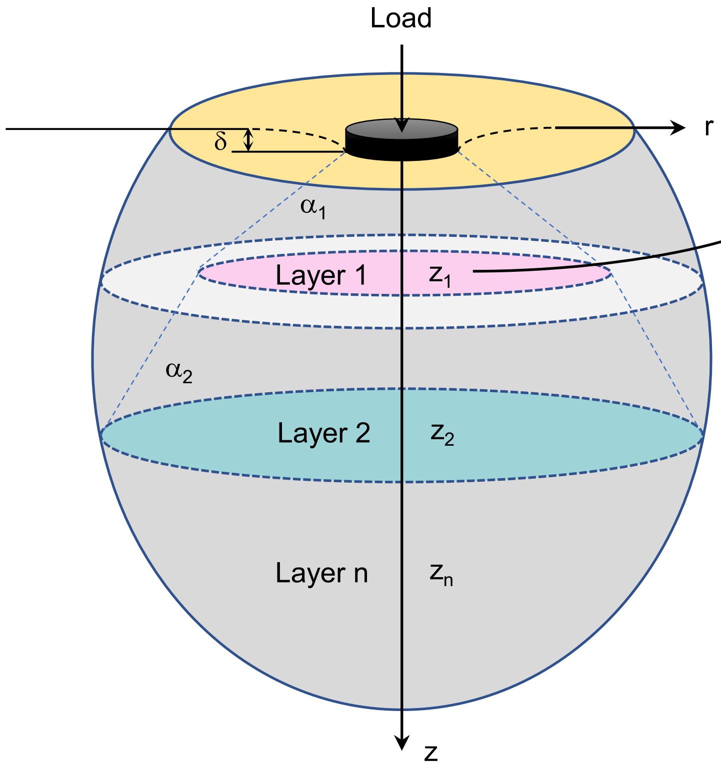
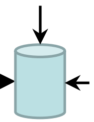
In situ APLT overcomes limitations of lab testing.



(a) In situ APLT test condition

Challenges with Laboratory Testing



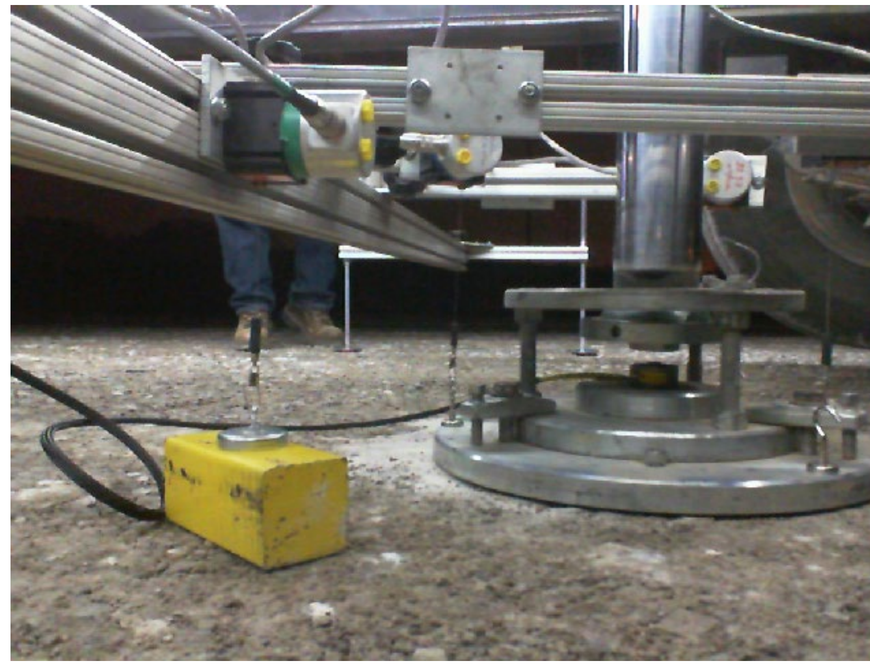
1. Limited to small sample sizes (100 mm to 200 mm diameter specimens).
2. Must remove larger particles (19 mm to 25 mm diameter particles).
3. Does not account for interaction between different material layers.
4. Boundary conditions are altered from field conditions.
5. Many inherent laboratory experimental limitations including sample preparation.
6. Does not determine modulus for multiple layers or account for in situ stress transfer

(b) Lab sample test condition

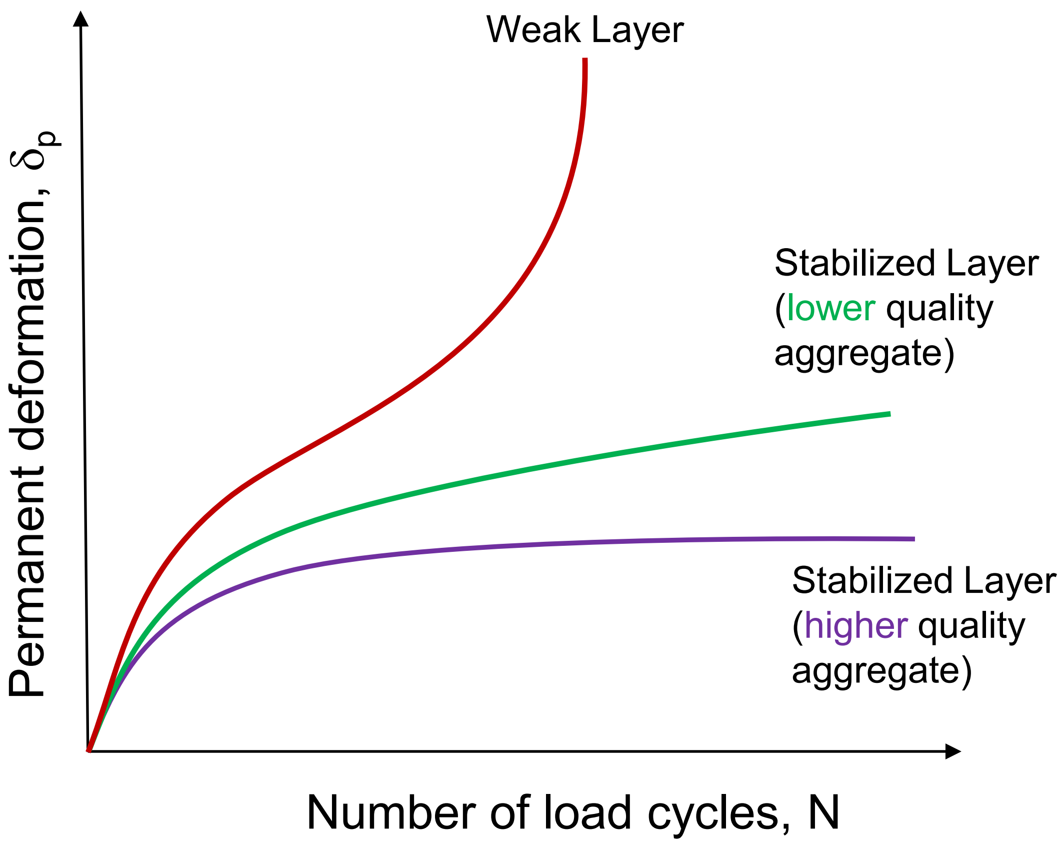
Foundation layer resistance to permanent deformation is KEY to long-term pavement performance

Subgrade Composite
M_r = 3,293 psi

Subbase/Subgrade Composite
M_r = 25,162 psi



A power model describes the permanent deformation versus load cycles response to provide deformation forecasting comparisons.



$$\delta_p = CN^d$$

f (material type, physical state, and stress conditions, Li and Selig 1994)

f (shear stress magnitude, aggregate abrasion resistance, resiliency of stabilizer)

Monismith et al. (1975) described the power model relationship for relating permanent strain to cycle loadings.

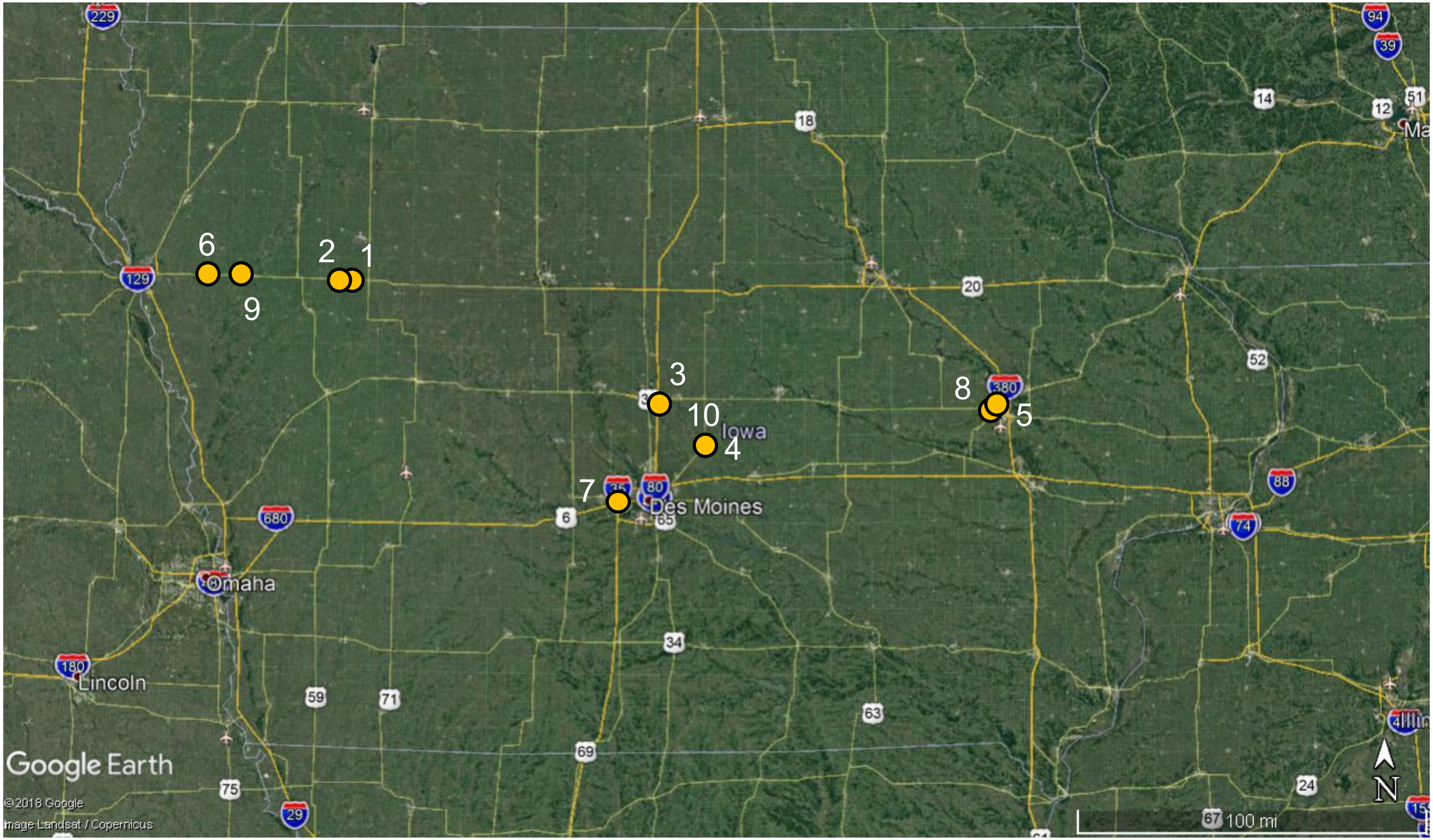
Post-compaction permanent strain is a function of the shear stress magnitude and can reach an equilibrium state following the “shakedown” concept (see Dawson and Feller 1999).

APLT offers direct measurements and significant advantages over FWD & LWD testing

Feature	FWD	Ingios APLT
Is the test automated? [i.e., No operator bias]	YES	YES
Can the test be used for testing on pavement layers to determine in situ modulus values?	YES	YES
Can the test results be used to determine layered moduli values?	YES (see Note 1)	YES
Can controlled cyclic loading be applied?	NO (see Note 2)	YES
Can extended conditioning cycles be applied prior to testing?	NO	YES
Are peak deformations measured during testing?	YES	YES
Are rebound deformations measured to calculate in situ resilient modulus (M_r)?	NO	YES
Are permanent deformations (rutting) measured during testing?	NO	YES
Can load pulse durations/loading frequencies and confinement be controlled to simulate traffic loading?	NO	YES
Can the results be used to determine frequency-dependent moduli values for testing on visco-elastic HMA layers	NO	YES
What is the duration of each test?	5 min (3-6 drops)	5 to 30 min. (100 to 1,400 load cycles)
Is the test safe to perform on roadways with some traffic control?	YES	YES

[1]Only uses peak deformations, so true resilient modulus cannot be determined. Further, no conditioning cycles are applied to achieve a "near-linear-elastic" state, per assumptions in backcalculation analysis. See feature # 4, 5, and 6.
[2]Multiple loads can be dropped, but the load pulses are not controlled with a defined load and dwell times.

Field testing was performed at 10 project sites selected by Iowa DOT



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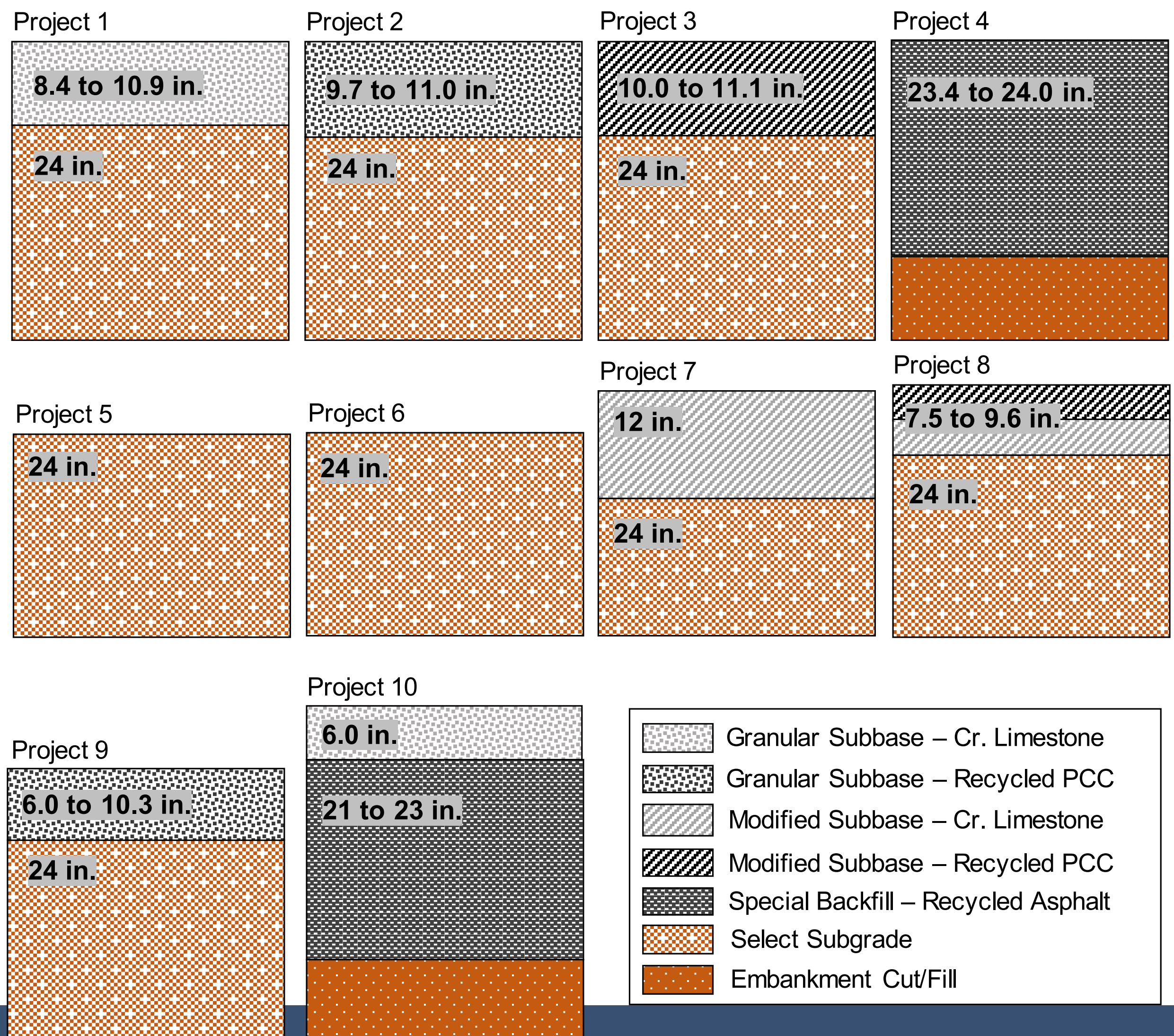
Different typical foundation layer support conditions were evaluated at the 10 project sites.



Project 2: Hwy 20 EB near Moville, IA - 10/19/2017
[Recycled Granular Subbase over Select Subgrade]

Project 3: I35N-US30E Ramp, Ames, IA – 10/28/2017 [Select Subgrade & Modified Subbase]

Project 4: Hwy 330 near Hwy 65 – 11/2/2017
[2 ft of Special Backfill (RAP) Subgrade Improvement]

Project 5: Hwy 100 N., Linn County – 11/3/2017 [Select Subgrade]

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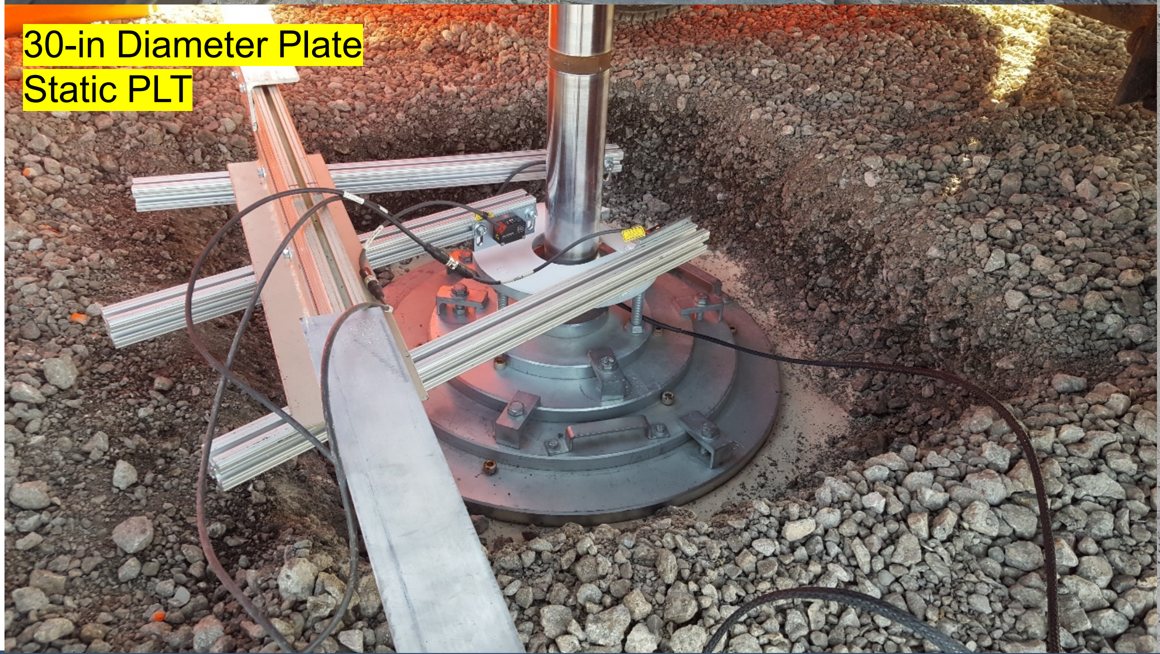
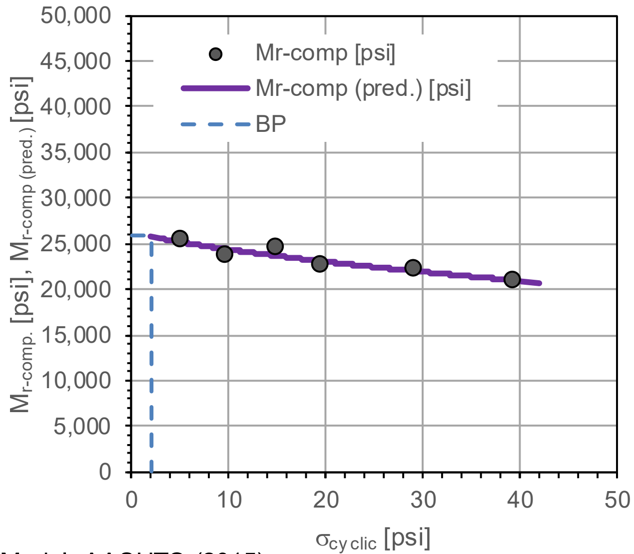
Project 9: US20, Woodbury County – 05/16/2018 [Recycled Granular Subbase over Select Subgrade]

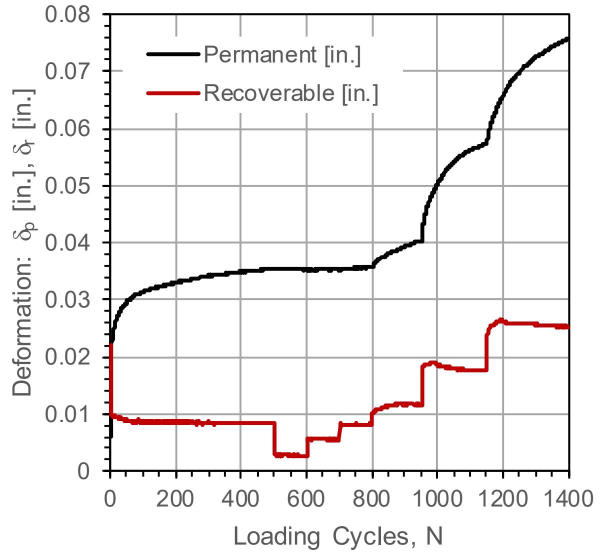

12 in. Diameter Plate
Cyclic PLT with 2-Layered Kit


30-in Diameter Plate
Static PLT


Dynamic Cone Penetrometer

Example test results: Composite M_r – 11 in. Modified Subbase over Select Subgrade





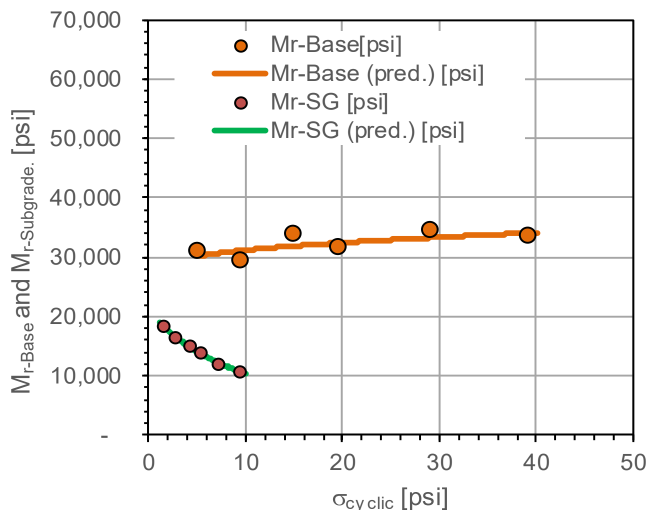
Model: AASHTO (2015)

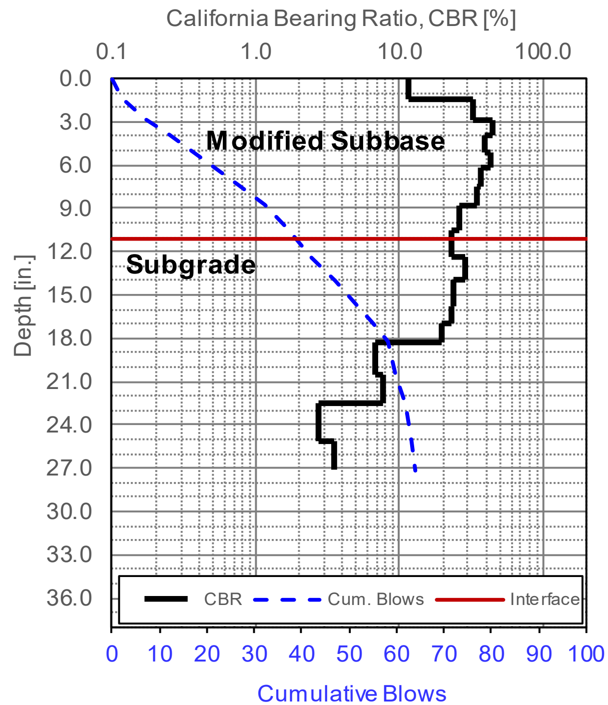
$$M_{r-comp} = k_1^* P_a \left(\frac{\theta}{P_a}\right)^{k_2^*} \left(1 + \frac{\tau_{oct}}{P_a}\right)^{k_3^*}$$

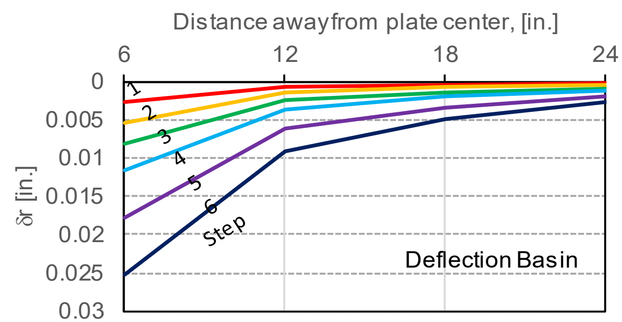
Parameter	Value	P-Value
k^*_1	1,759.7	2.29E-07
k^*_2	-0.008	9.21E-01
k^*_3	-0.551	3.66E-01
Adj. R^2	0.835	
Std. Error [psi]	626	

$M_{r\text{-}comp\ (pred.)\text{-}BP}$ [psi]		25,812
	$\sigma_{cyclic\text{-}BP}$ [psi]	2.0

Example test results: Layered M_r (Base and SG) values – 11 in. Modified Subbase over Select Subgrade







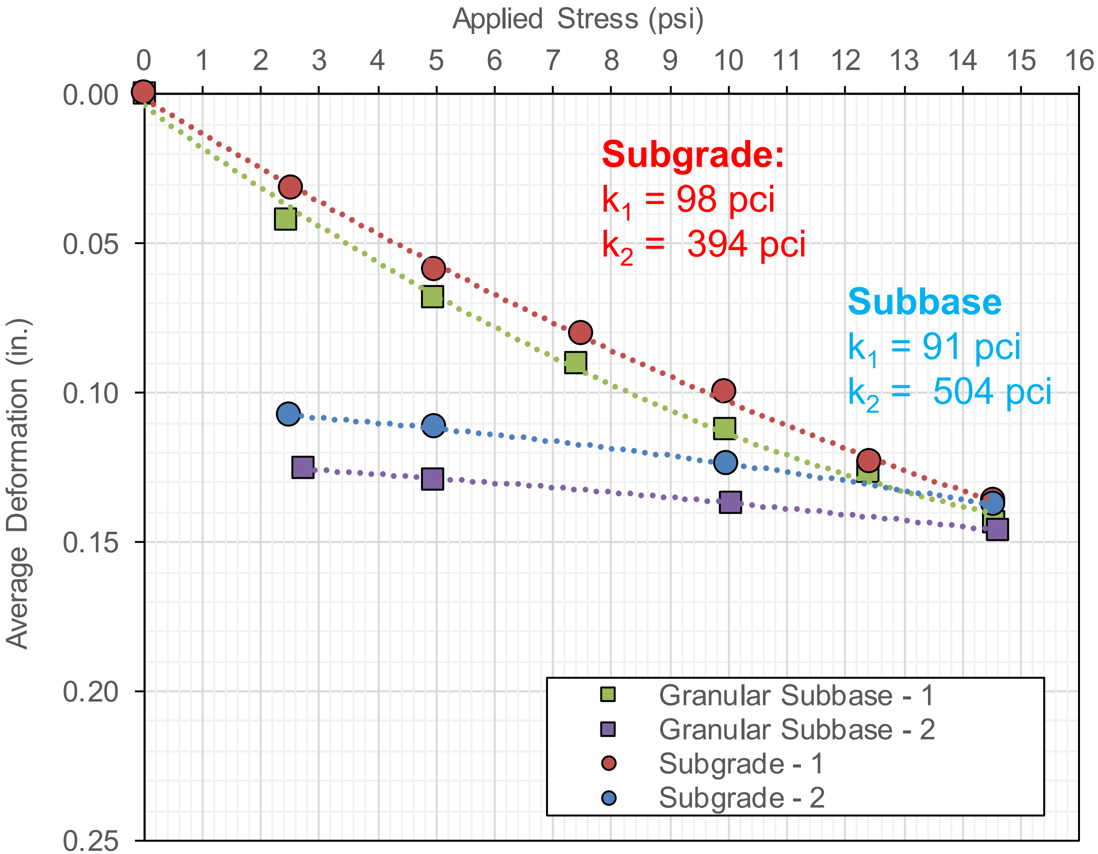
Model: AASHTO (2015)

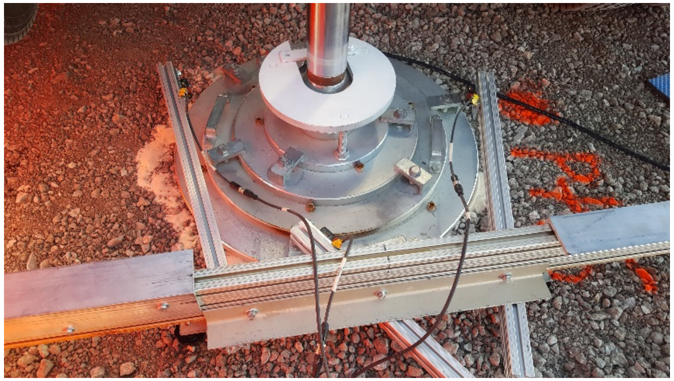
$$M_r = k_1^* P_a \left(\frac{\theta}{P_a}\right)^{k_2^*} \left(1 + \frac{\tau_{oct}}{P_a}\right)^{k_3^*}$$

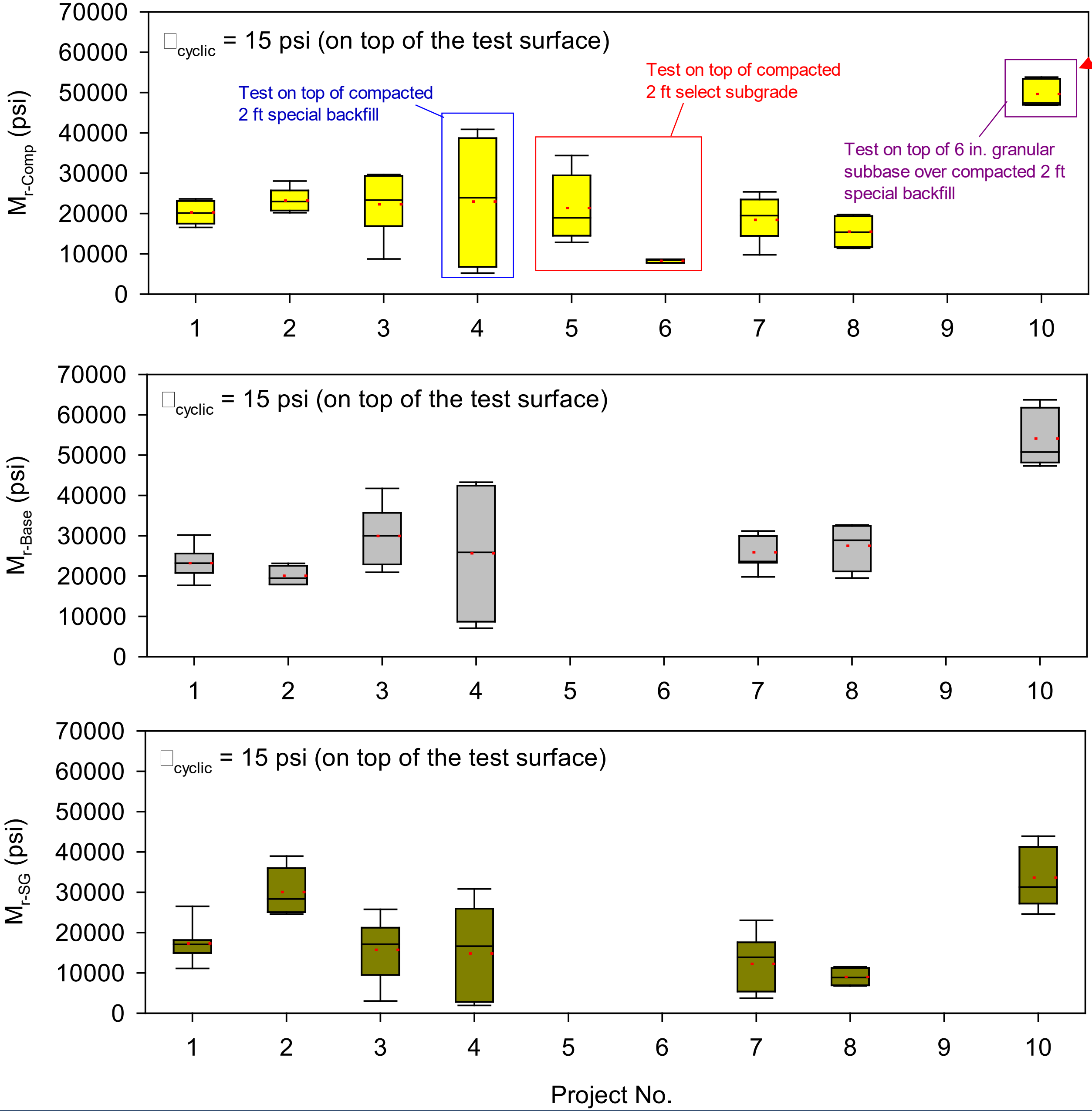
Parameter	Value	P-Value
k^*_1 (Base)	2053.0	1.02E-06
k^*_2 (Base)	0.037	7.91E-01
k^*_3 (Base)	0.151	8.74E-01
Adj. R^2	0.405	
Std. Error [psi]	1095	
k^*_1 (SG)	1298.3	3.89E-06
k^*_2 (SG)	-0.094	2.23E-01
k^*_3 (SG)	-3.858	1.86E-02
Adj. R^2	0.997	
Std. Error [psi]	155	

Project 2: Static PLTs conducted on subbase layer and the underlying subgrade showed similar *k* values.

[11 in. Recycled Granular Subbase over Select Subgrade]





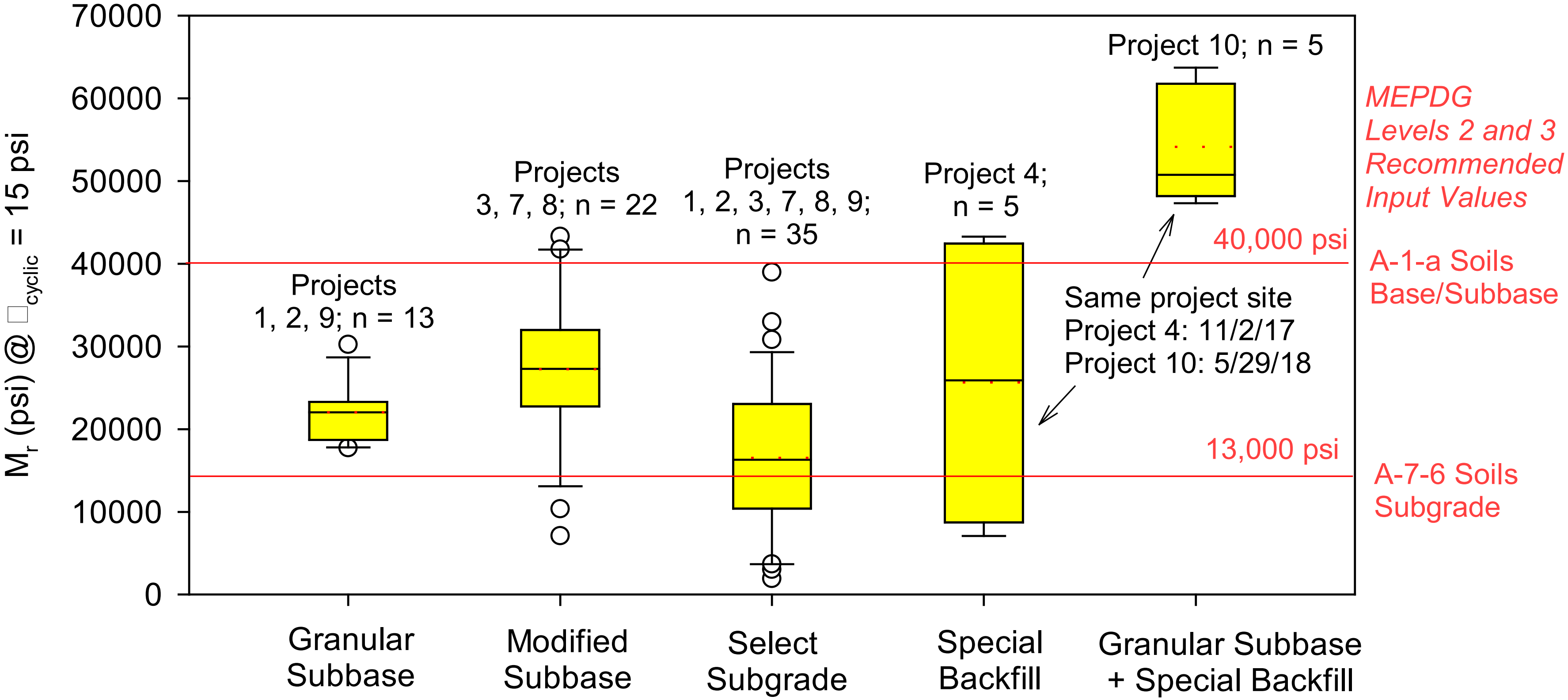


Site with granular subbase over 2 ft of special backfill provided the highest support values.

Results show that there are variations in M_r values at each site and across the state, that are not adequately accounted for in design.

COV = 5% to 82% at each site.

How reliable is it to assume "typical" M_r values proposed in the ME Design for a given material type?



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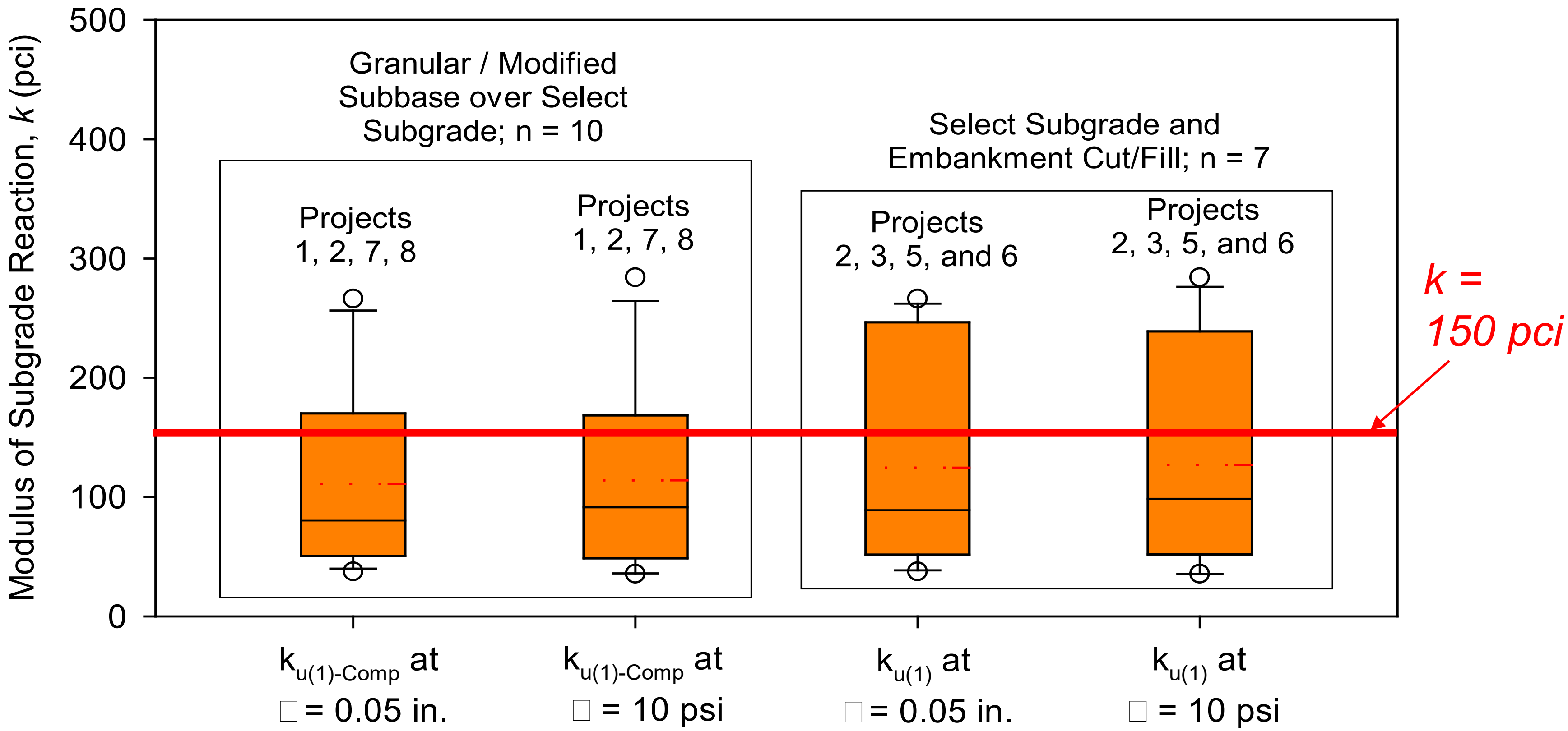
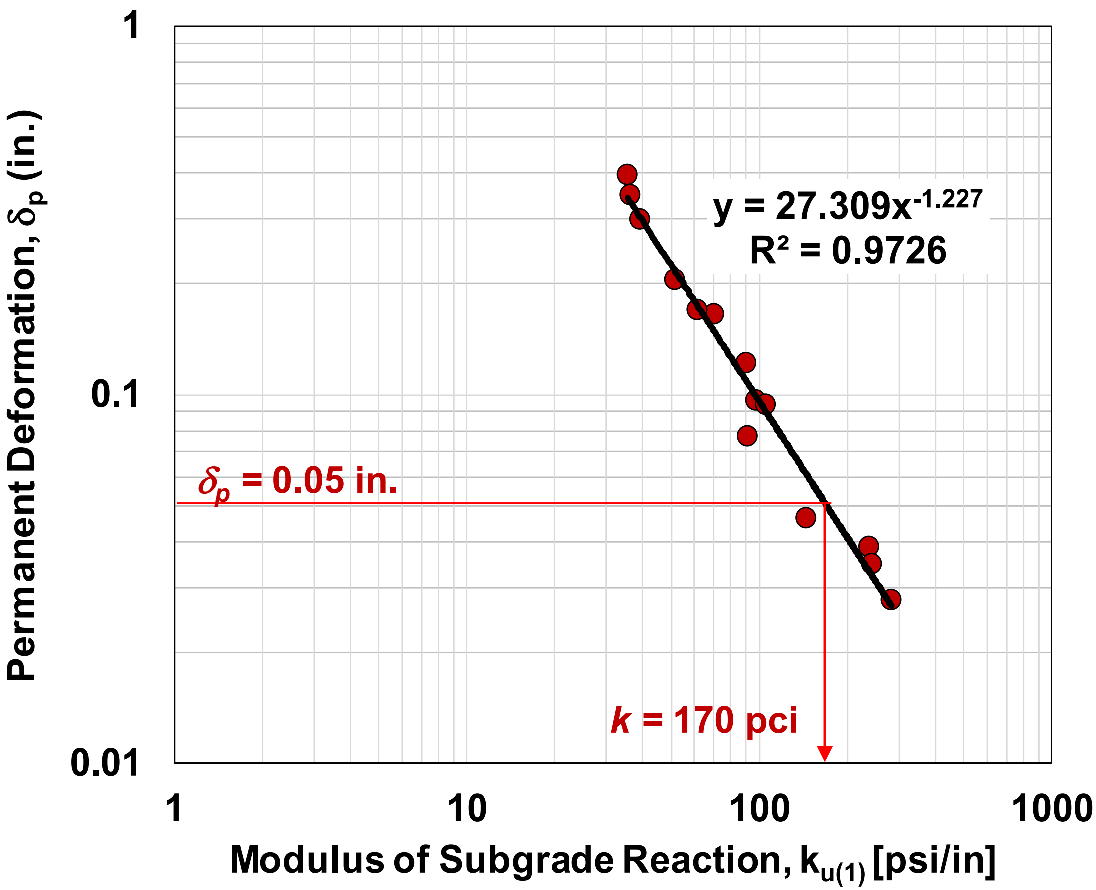
How reliable is it to assume "typical" k values proposed in the ME Design for a given material type?

***k* = 150 pci is typically assumed for rigid pavement design in IA.**



Static PLT results show that there is a strong relationship between k-value and δ_p



δ_p = 0.05 in. critical for void beneath pavement

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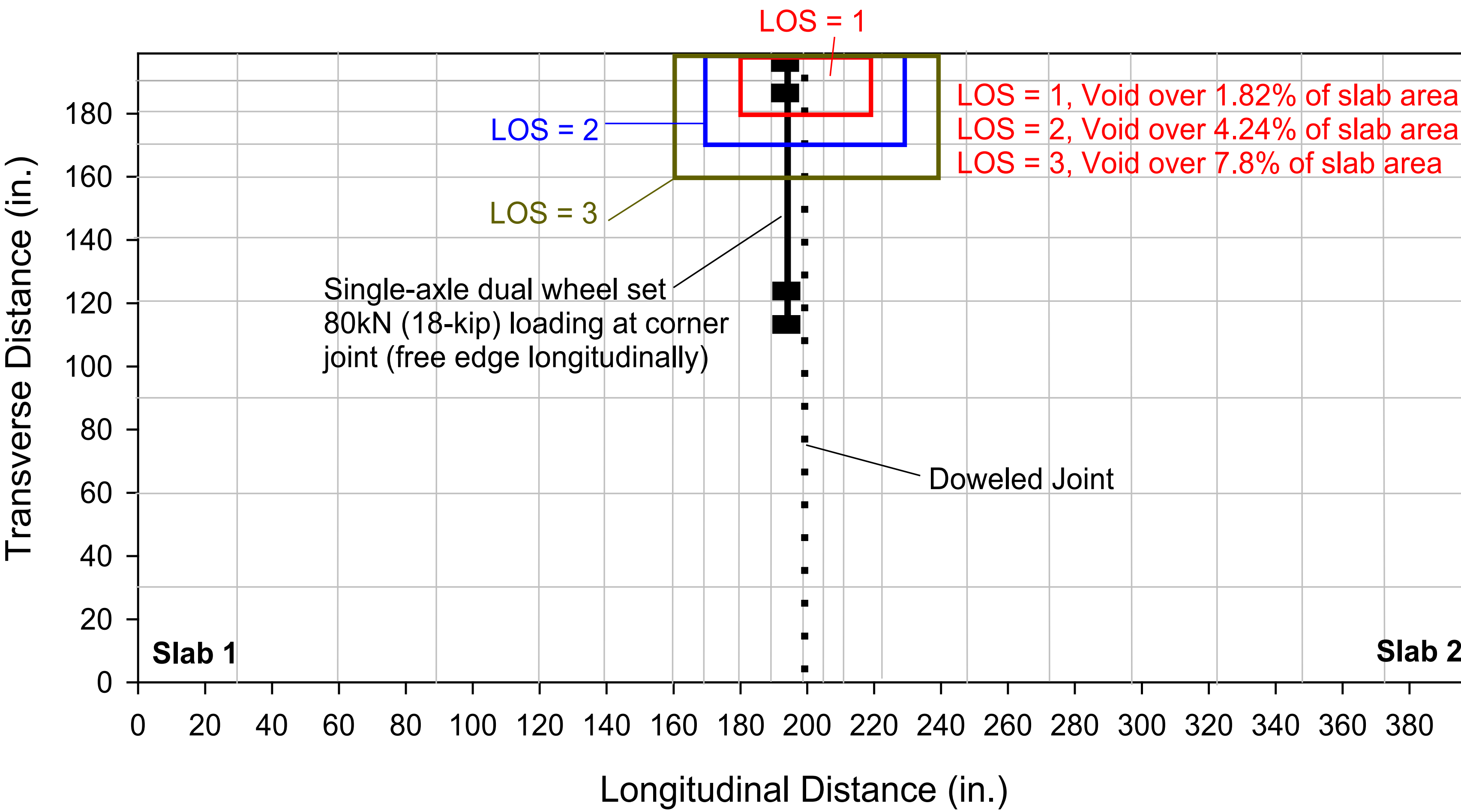
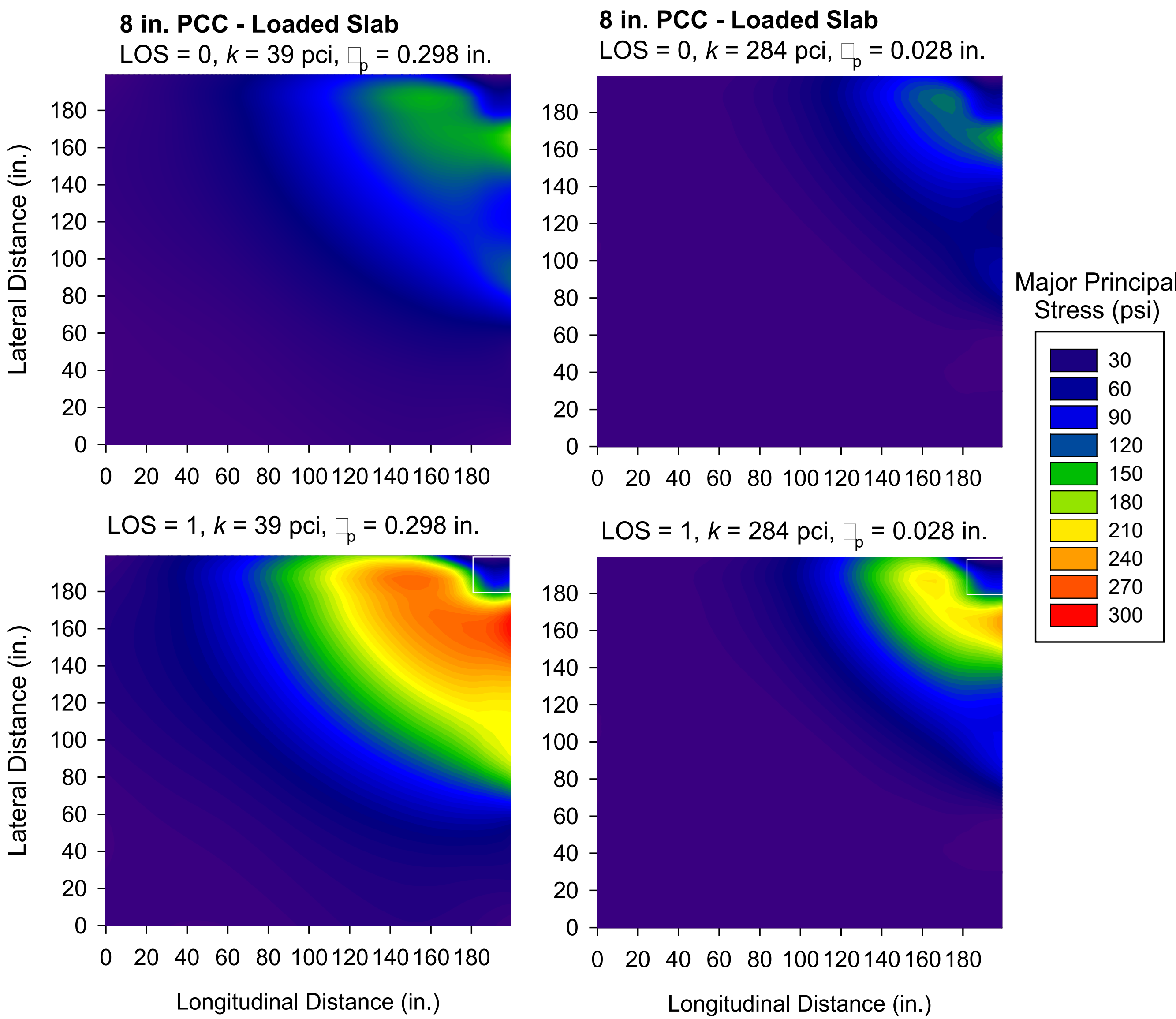
FE analysis was conducted on a Jointed PCC pavement to analyze pavement stresses and impact of δ_p

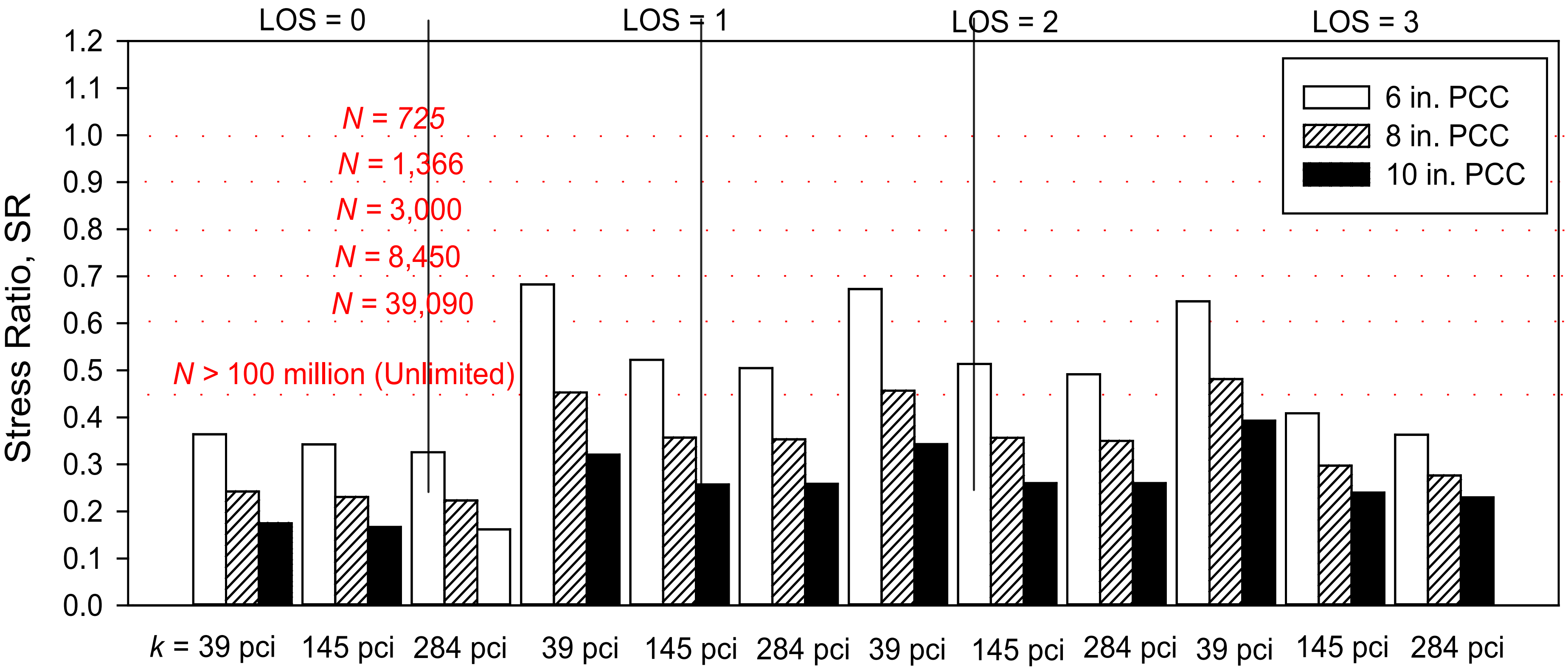




Bending stresses in the pavement layer are more significantly influenced by the δ_p than *k*-value.

Analysis of SR values for different *k*-value and LOS cases for different *H* revealed that…

δ_p and H are the MOST significant parameters in controlling the bending stresses. *k*-value alone is not the most significant factor.



KEY Outcomes of this project are:

- ✓ M_r values are variable across the state and within each project site. C_v between 5% and 80% at each site.
- ✓ k-values across the site varied between 35 and 300 pci. 11 out of 14 tests showed < 150 pci.
- ✓ Sites with 2 ft of special backfill material provided higher Mr values than other sites.
- ✓ Typical values provided in the ME Design guide based on soil classification are not reliable.
- ✓ δ_p from static PLT varied between 0.05 and 0.4 in., with 11 out of the 14 tests > 0.05 in. critical limit.

KEY Outcomes of this project are:

- ✓ FE analysis showed that the two most important factors to reduce bending stresses in the pavement layer are Pavement Thickness and δ_p
- ✓ Bending stresses calculated can be misleading just by simply changing the *k* or M_r without accounting for LOS due to δ_p.

MEPDG Field Local Calibration

GOAL: Reduce bias and increase precision of the empirical models used to predict performance indicators

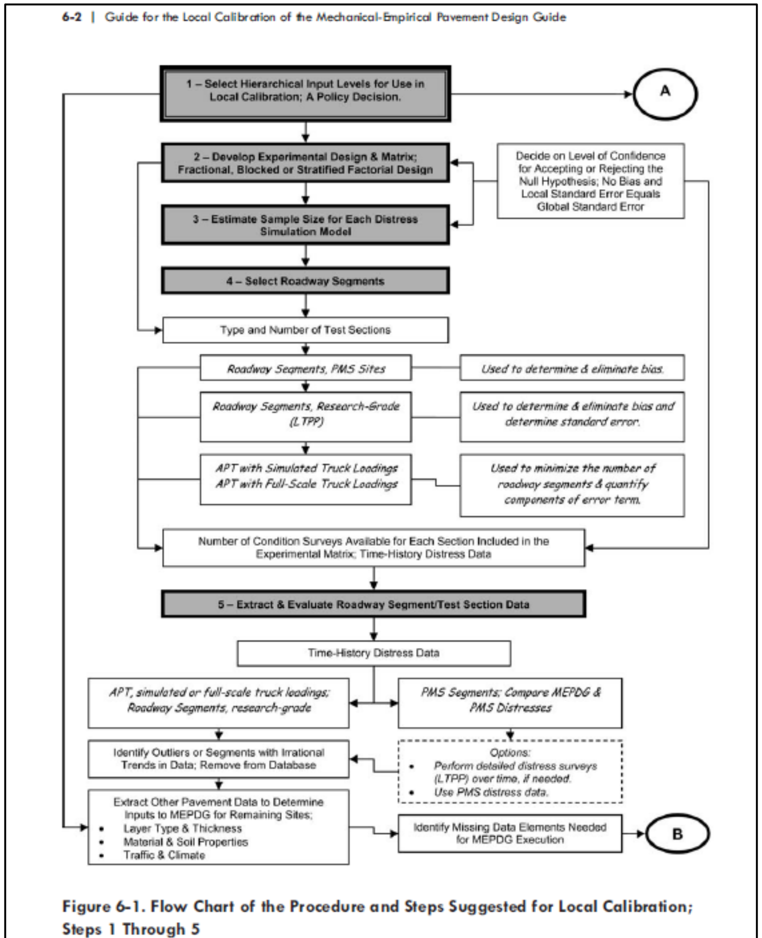
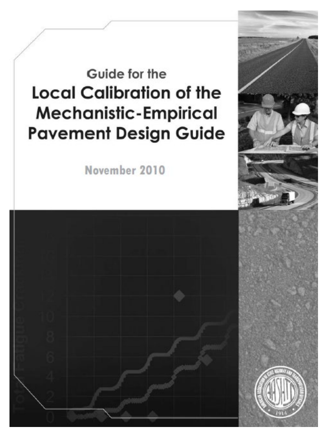


Figure 6-1. Flow Chart of the Procedure and Steps Suggested for Local Calibration; Steps 1 Through 5

AASHTO (2010) guide provides a 11 step procedure to perform local calibration. It covers:

- Developing an experimental plan,
- Estimating the sample size
- Selecting the roadway segments
- Collecting the required field data, and
- assessing bias/standard error in the global calibration factors for local conditions



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MEPDG Field Local Calibration

GOAL: Reduce bias and increase precision of the empirical models used to predict performance indicators

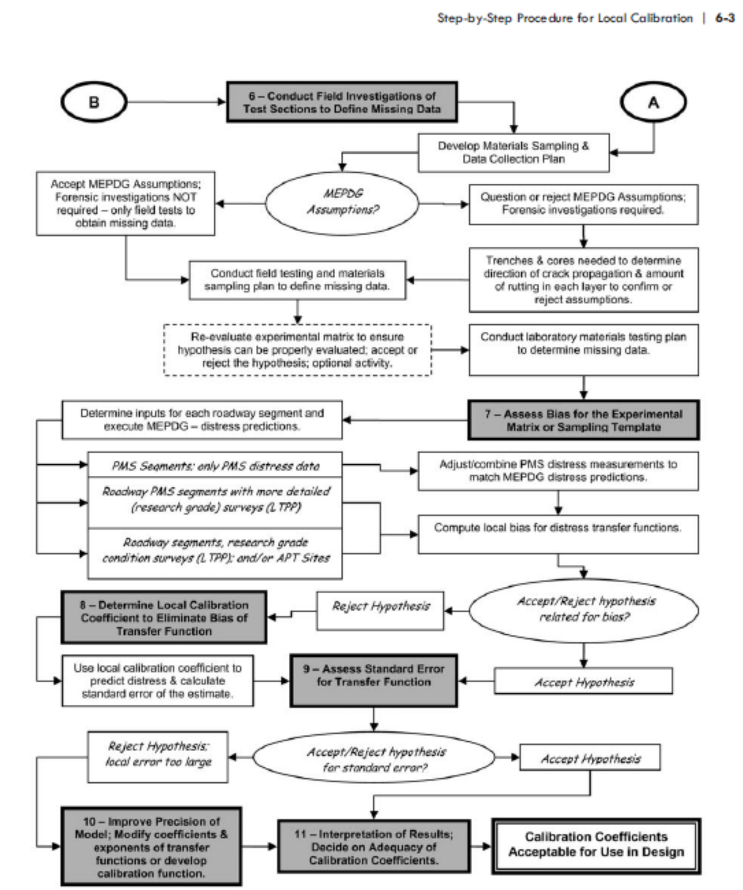
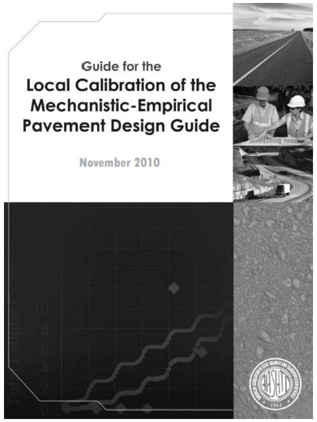


Figure 6-2. Flow Chart of the Procedure and Steps Suggested for Local Calibration; Steps 6 Through 11

STEP 6: Field and forensic investigations to confirm or obtain any missing key input parameter values for the roadway segment selected

*APLTs can be used to provide an **accurate measure** of stress-dependent M_r values and k_1, k_2, and k_3 regression parameters, and permanent deformation.*



MEPDG Field Local Calibration

GOAL: Reduce bias and increase precision of the empirical models used to predict performance indicators

Step-by-Step Procedure for Local Calibration | 6-3

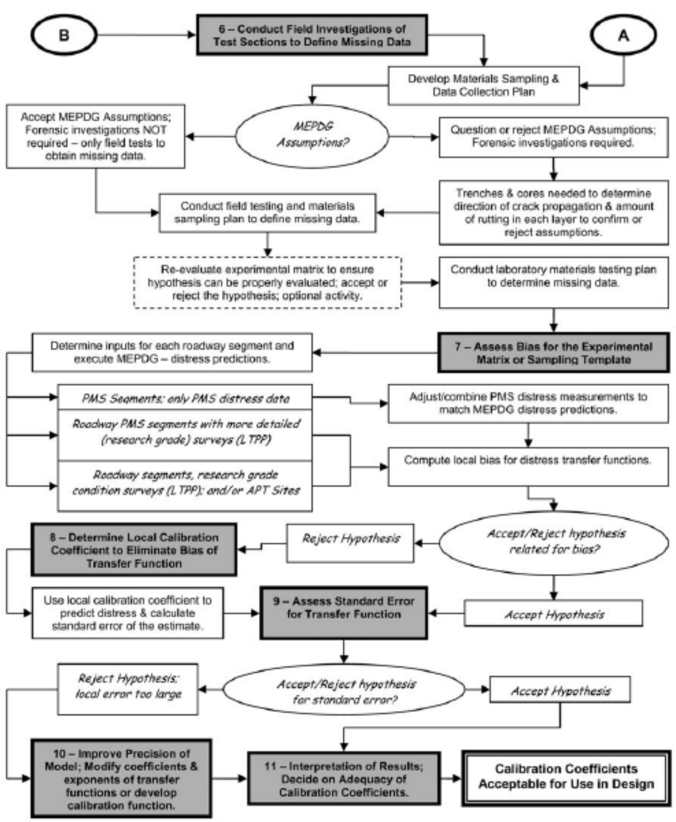
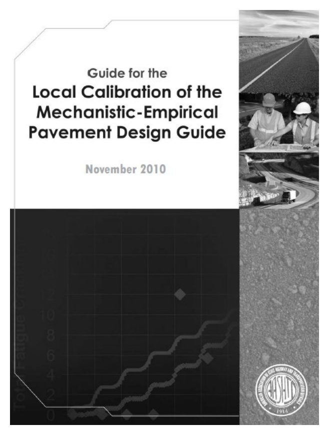


Figure 6-2. Flow Chart of the Procedure and Steps Suggested for Local Calibration; Steps 6 Through 11

Calibration sites typically involves existing pavement sites with some level of distress.

Test sites with georeferenced *mechanistic* measurements during construction can also be utilized for future calibration as distresses develop.



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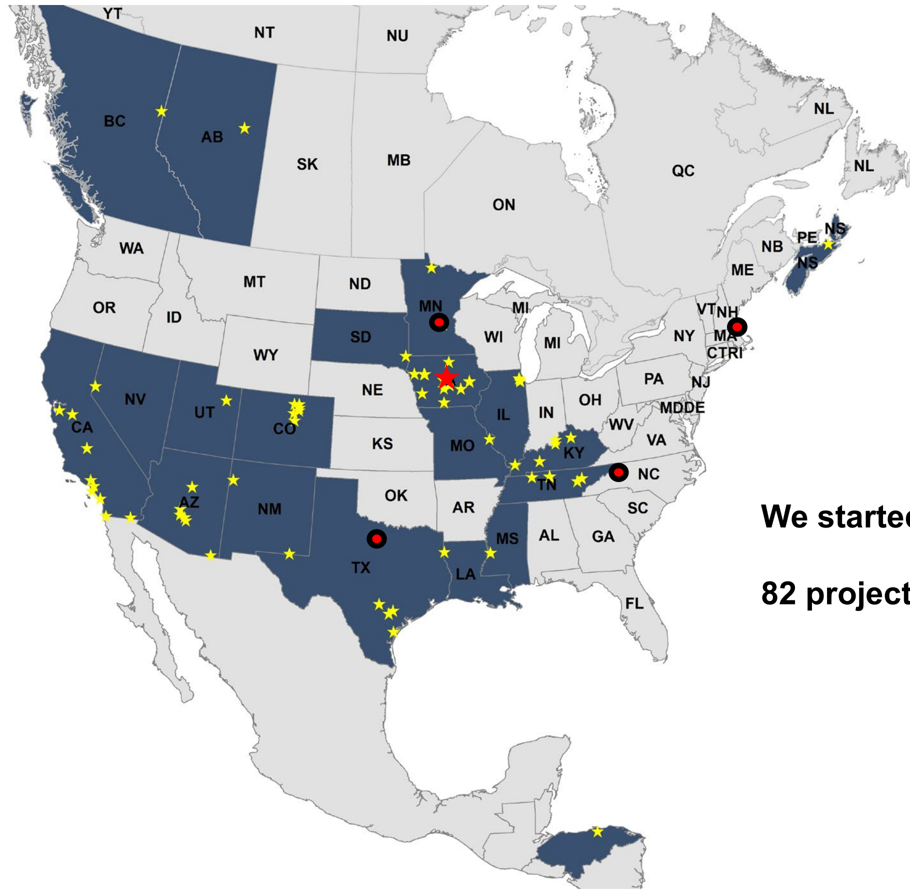

We started in 2015.

82 projects to-date.