U.S.ARMY

USE OF LIGHT-WEIGHT DEFLECTOMETERS FOR QUALITY CONTROL OF BACKFILL LAYERS FOR AIRFIELD PAVEMENT REPAIRS

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Geotechnical and Structures Laboratory

Background

1 - Debris removal

2 - Upheaval marking

3 – Saw cutting

4 - Excavation

5 - Backfill

6 – Quality assessment

7 – Surface cap

LWD Comparison

	Option 1	Option 2	Option 3
Manufacturer	Zorn Instruments	Olson Instruments	Dynatest
Model	ZFG 3.0	LWD-1	3032
Drop mass	22 lbm	22 lbm	22 lbm
Impulse Load	1,589 lbf	1,550 lbf	1,700 lbf
Deflection measurement	Acceleration sensor	Seismic transducer (geophone)	Seismic transducer (geophone)
Drop height	44.5 in.	24 in.	33.5 in.
Total Weight	66 lbm	59 lbm	48 lbm
Power source	4 AA batteries	Rechargeable	USB powered control box
Results display	Hand-held data collector, SD card, or thermal printer	Laptop: WinLWD Acquisition & Analysis Software	Bluetooth connection to smartphone app
ASTM E2583 Compliant	--	--	Yes
ASTM E2835 Compliant	Yes	Yes	--
Optional configurations	Drop weight options: 22 or 33 lbm Diameter of base plate options: 5.9 or 11.8 in.	Drop weight options: 11 or 22 lbm Diameter of base plate options: 3.9, 5.9, 7.9, or 11.8 in. Additional geophone attachments	Drop weight options: 11, 22, 33, or 44 lbm Diameter of plate options: 11.8 or 5.9 in. Additional geophone attachments

Performing a measurement with the LWD

<u>ASTM E2583-07:</u> Standard Test Method for Measuring Deflections with a LWD (Reapproved 2020)

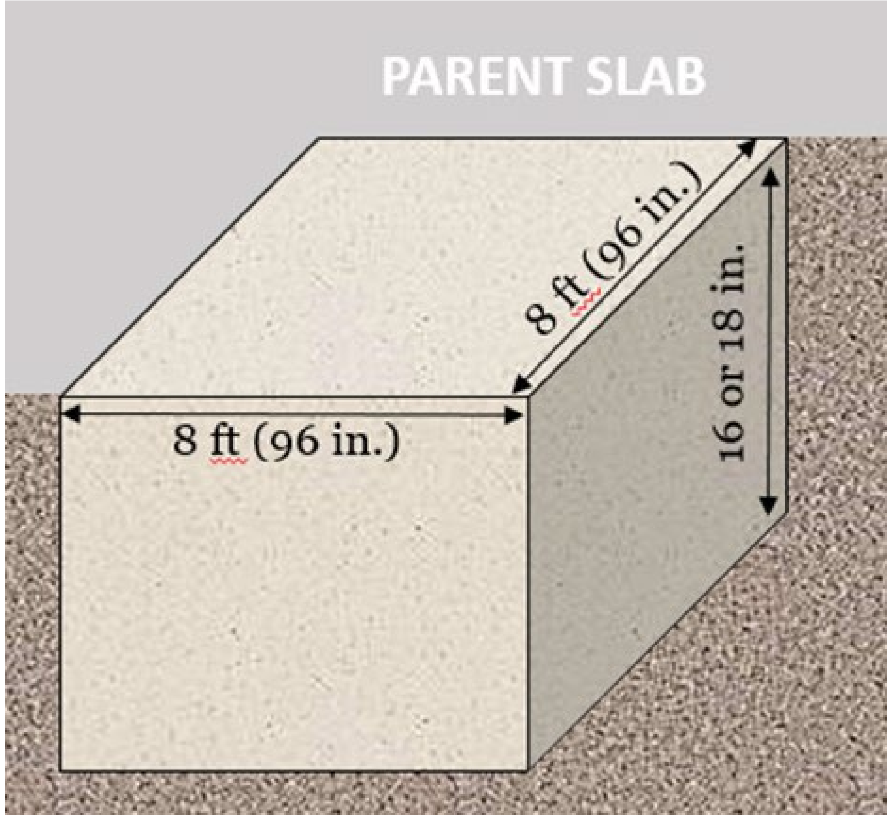
1. **Ensure the bottom of the LWD's plate is clean**
2. **Place the plate on the soil to ensure it is in full contact with the soil**
   - **Seat and level plate**
3. **Raise the weight to desired drop height and release the weight**
   - **Record the resulting peak deflection and peak load**
4. **Perform the drop for 2 additional sequences**
   - **If variability is greater than 3%, note variability in report**

Performing a measurement with the LWD

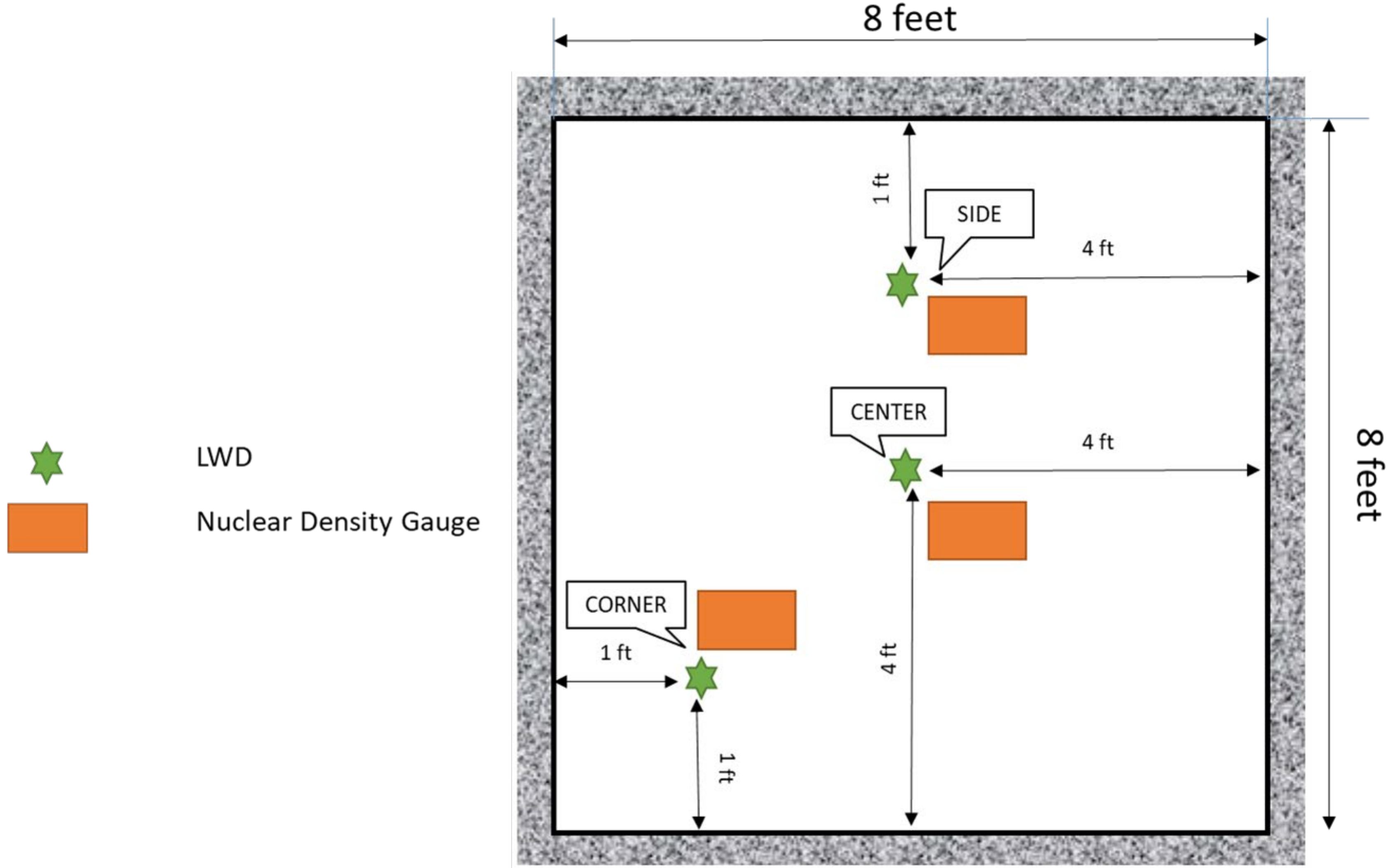
ASTM E2835-21: **Standard Test Method for Measuring Deflections Using a Portable Impulse Plate Load Test Device**

1. Rotate plate left and right 45 °
2. Perform 6 drops
   - First 3 drops are seating drops
   - Final 3 drops are used for analysis
3. Raise the weight to desired drop height and lock position
   - Ensure rod is vertical
4. Release weight (allowing it to fall freely)
   - Catch the weight after the rebound and return to locked position
5. Record resulting peak deflection values

Test section construction

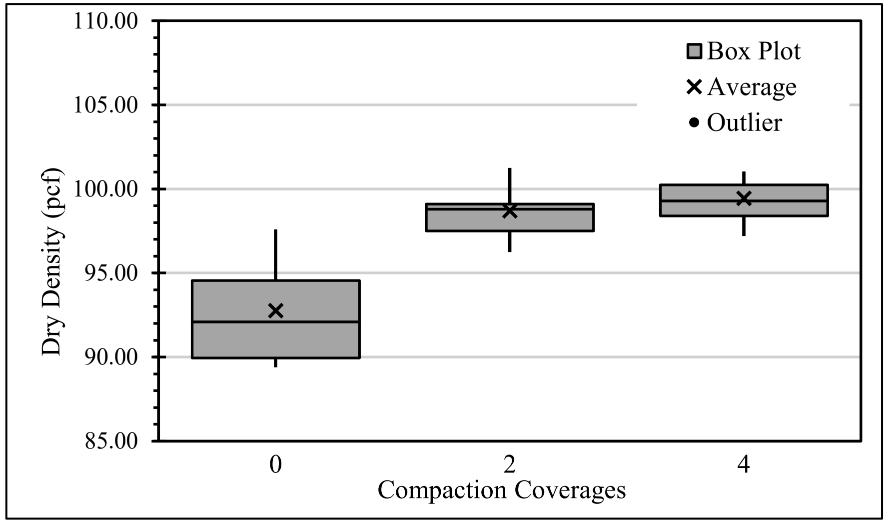


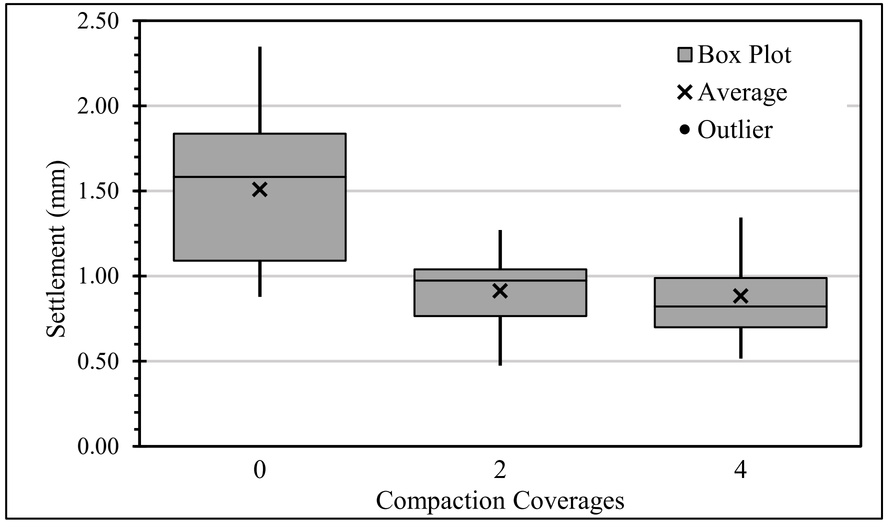
Testing Locations



Criteria Development

SAND:





Maximum settlement: 1.000 mm

Assessment Criteria

Soil type	Compaction equipment	Compaction coverages required	Maximum settlement (mm)
Beach sand	Plate compactor	4	4.600
Natural sand	Plate compactor	4	1.000
Cement stabilized soil	Jumping jack and plate compactor	4	3.400
PCC debris with sand	Jumping jack and plate compactor	2	1.000
Limestone	Jumping jack	4	2.750
Silt	Jumping jack	4	0.900
Silty sand	Jumping jack	4	2.400
Lean clay	Jumping jack	4	1.700
Clayey sand	Jumping jack	4	0.600

Questions?

TRB Webinar

Implementation of a Non-destructive Method of Compaction Quality Assurance Using Lightweight Deflectometer

Zahra (Niosha) Afsharikia, PhD

WSP USA

February 23, 2023

Contributing Projects

Transportation Pooled Fund Study

TPF-5(285) 2013-2017

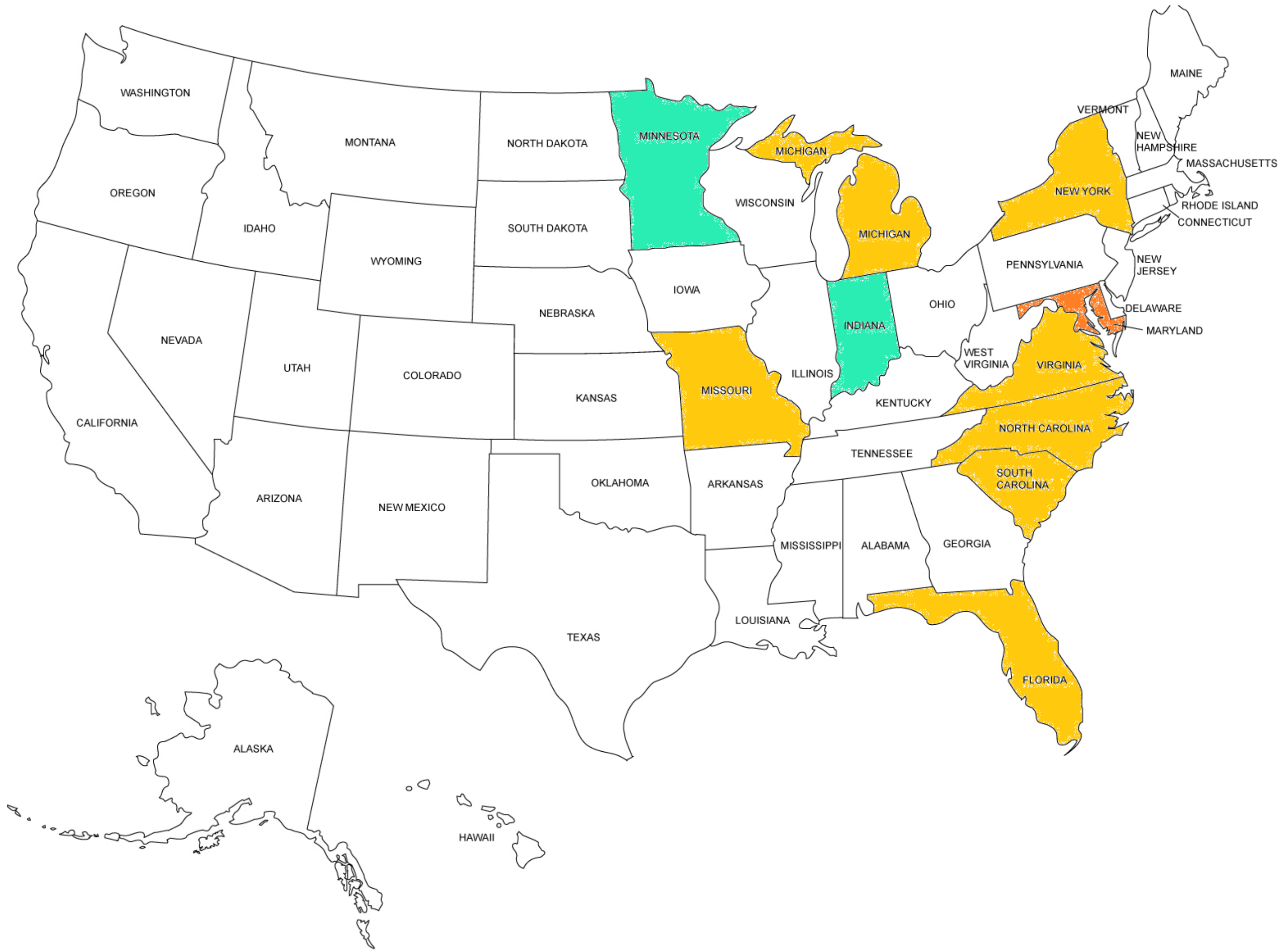
Standardizing LWD Measurements for Compaction QA and Modulus Determination in Unbound Bases and Subgrades

MDOT SHA SPR Research Project

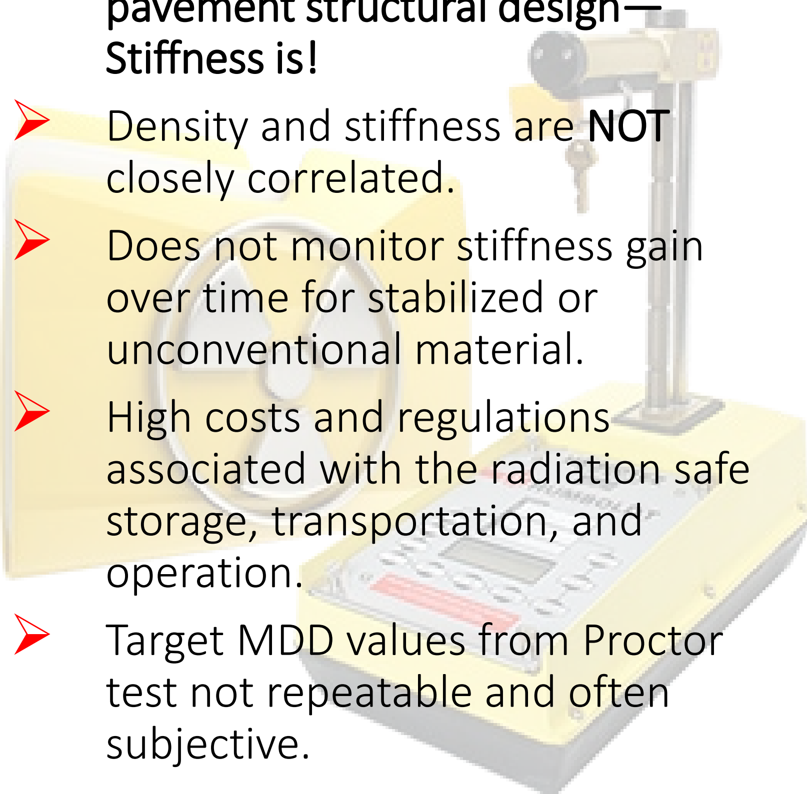
SHA/UM/4-51 2017-2019

Implementation of LWDs for Modulus Based Compaction Quality Assurance of Unbound Materials in the State of Maryland

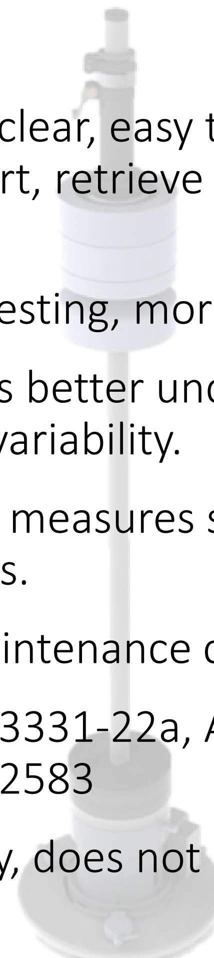
Transportation Pooled Fund Study TPF-5(285) Participating Agencies



Motivation



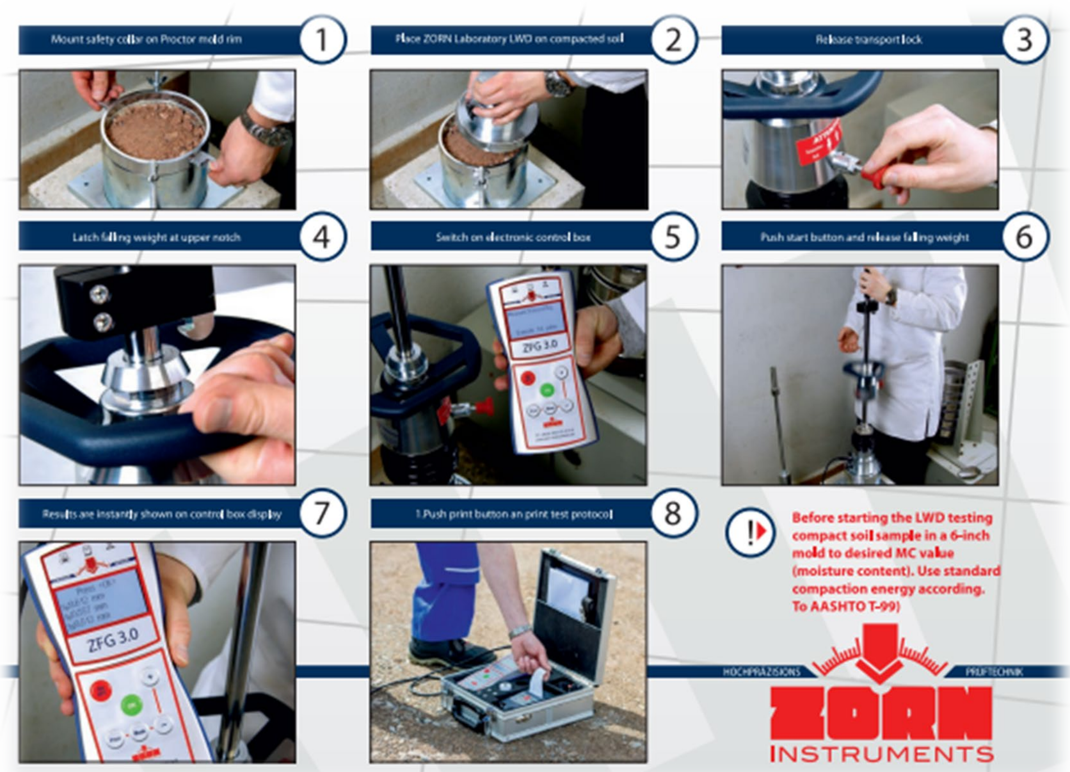
- **Density is NOT an input to pavement structural design—Stiffness is!**
- Density and stiffness are **NOT** closely correlated.
- Does not monitor stiffness gain over time for stabilized or unconventional material.
- High costs and regulations associated with the radiation safe storage, transportation, and operation.
- Target MDD values from Proctor test not repeatable and often subjective.



- ✓ Non-nuclear, easy to store and transport, retrieve and analyze data.
- ✓ Faster testing, more testing
- ✓ Provides better understanding of spatial variability.
- ✓ Directly measures surface modulus.
- ✓ Low maintenance cost
- ✓ ASTM E3331-22a, ASTM E2835, ASTM E2583
- ✗ Typically, does not measure MC

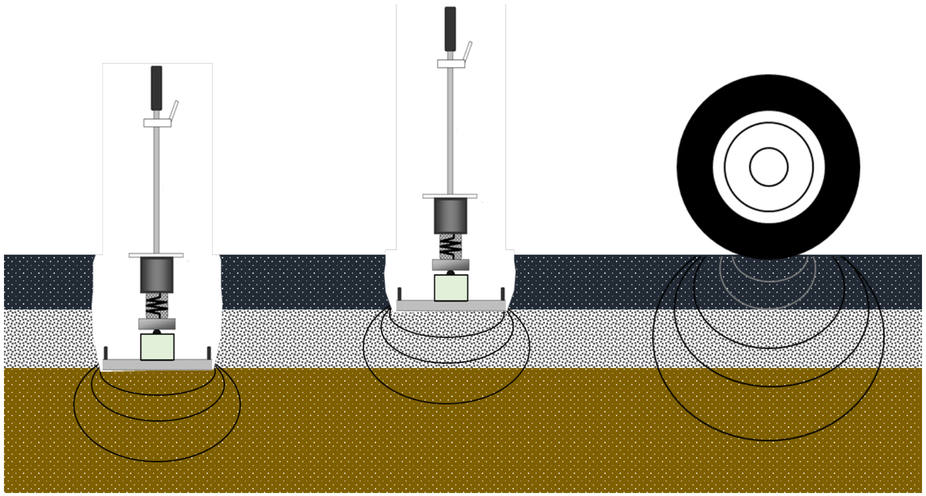
Objective

Develop a straightforward procedure for stiffness-based compaction QC/QA using LWDs that is suitable for practical implementation by field inspection personnel.



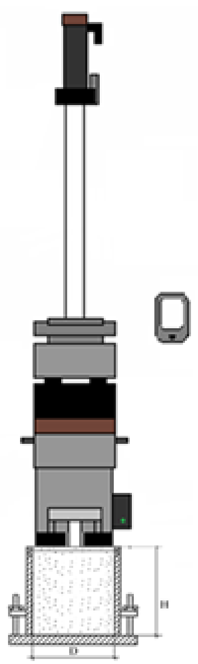
Challenges

1. Different configurations and measurements for different LWDs
2. Determination of target stiffness
3. Moisture content: Measurement and effect on stiffness
4. Effect of stress level
5. Application to layered systems
6. Practicality in the lab and field



Compaction QA Methodology

E_{LWD_Mold} at multiple MC and P/P_a



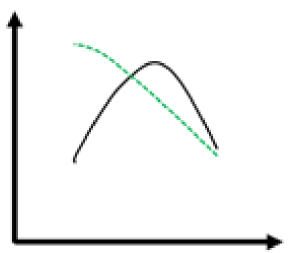
Lab

Establish

$E_{LWD\_Target} =$ f(MC, P/P_a, layering)

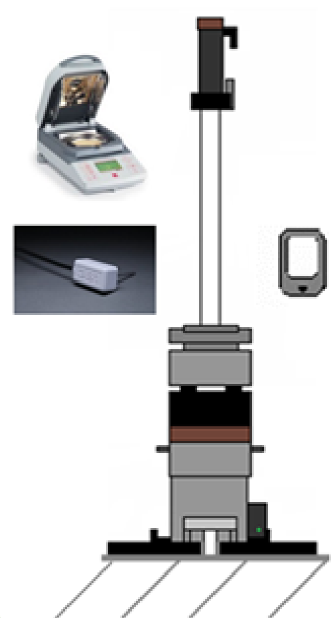
$E_{LWDonMold}$ - - - - -

Dry Density ———



Measure:

- E_{LWD_Field}
- MC



Field

Compaction Criteria:

$$\frac{E_{LWD\_Field}}{E_{LWD\_Target}} \geq cst$$

$$MC = OMC \pm \Delta$$

Zorn ZFG3000 LWD

Zorn Instruments

LWD-01 by Olson Engineering


Olson Instruments Inc.

Dynatest 3031 LWD

Dynatest Consulting Inc.

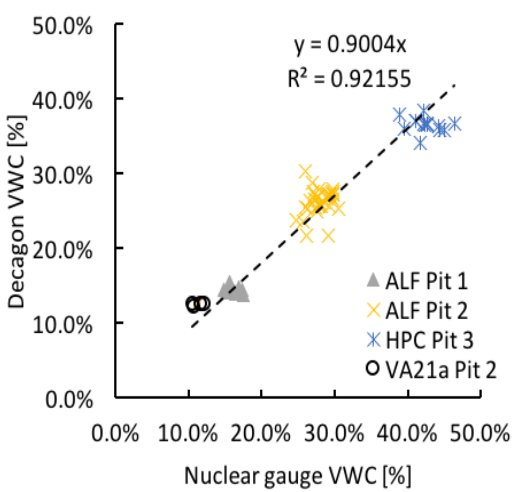
(Circa 2016)

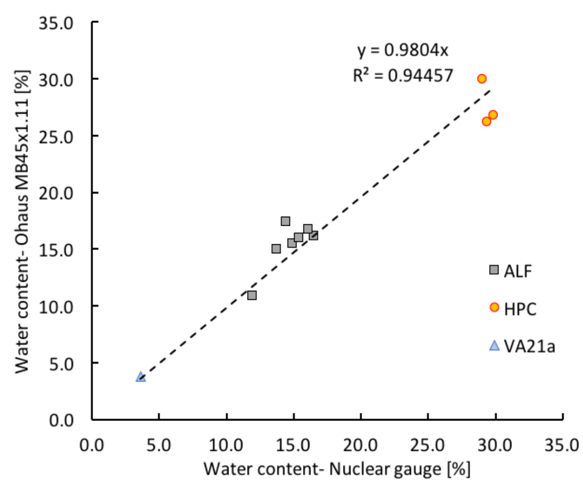
Device configuration			LWD		
	plate diameters	unit	Zorn ZFG3000	Dynatest 3031	Olson 01
Total device weight (10 kg weight)	100 mm	[kg]	30.1	19.8	27.1
	150 mm	[kg]	30.2	20.1	24.8
	200 mm	[kg]	30.4	20.5	26.7
	300 mm	[kg]	30.2	23.3	26
Drop weight		[kg]	10, 5	5, 10, 15, 20	3.6, 5, 10
Maximum drop height		[cm]	72.4	83.8 adjustable	60 adjustable
Load cell available		[-]	No	Yes	Yes
Deformation sensor	type	[-]	Accelerometer	Geophone +2 optional external geophones	Geophone
	range	[mm]	0.2–30 (±0.02)	0–2.2 (±0.002)	N/A
Plate type		[-]	Solid	Annulus	Solid
Type of buffer		[-]	Spring	Flat Rubber-adjustable	Spring

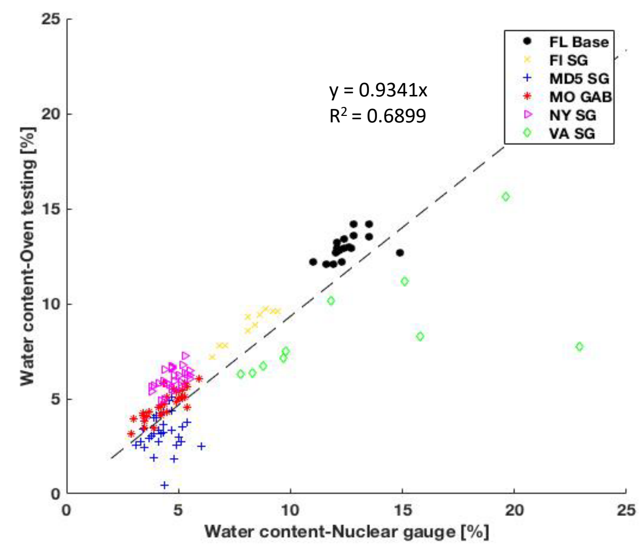
Decagon GS-1 ruggedized volumetric water content (VWC) sensor

Ohaus MB45 moisture analyzer

Troxler 3440 Nuclear moisture-density gauge





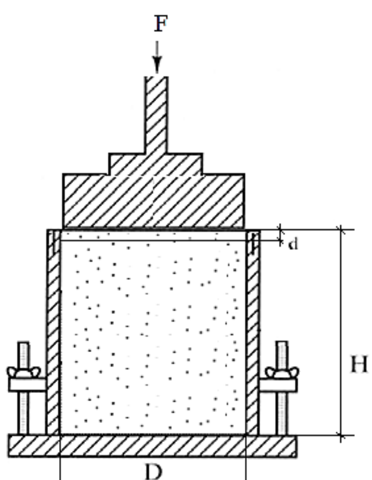


LWD Drops on Proctor Mold (E_{LWD_Mold})

Theory of elasticity for a cylinder of elastic material with constraint lateral movement imposed by the rigid mold:

$$E = \left(1 - \frac{2v^2}{1 - v}\right)\frac{4H}{\pi D^2}k$$

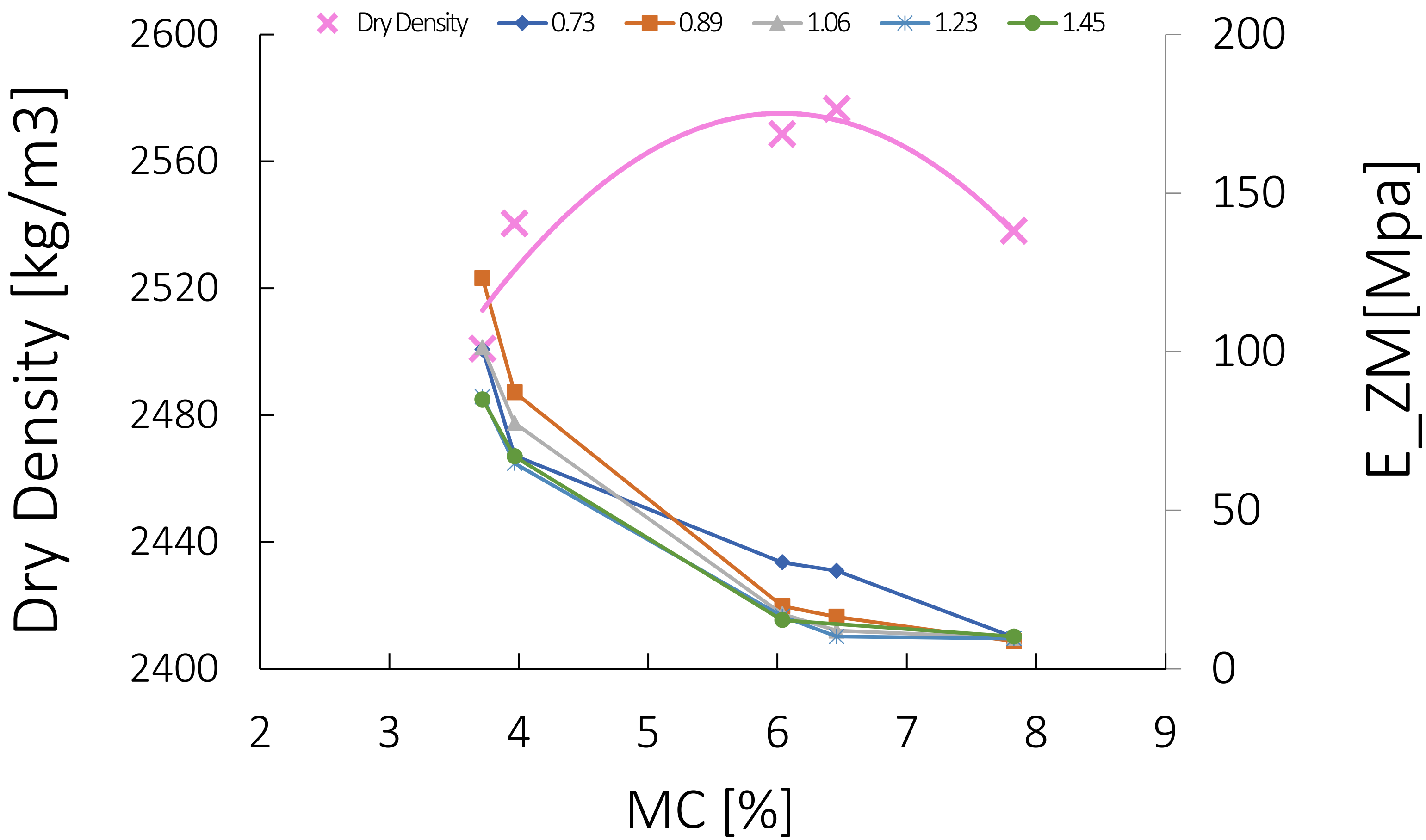
v = Poisson's ratio (assumed)
H = height of the mold
D = the diameter of the plate or mold
k = soil stiffness =F/δ as calculated by LWD device



Varying Stress Levels:

LWD type	Drop Heights [inches]					
Zorn	1	2	3	4	5	12.5
Dynatest	1	2	3	4	5	7 or 12.5
Olson	1	2	3	4	5	8.5

LWD Testing on Proctor Mold – Example Results



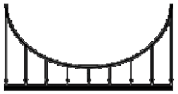
E_ZM: Zorn LWD modulus on Proctor mold
Legend shows variable P/Pa (0.73, 0.89, up to 1.45) corresponding to different drop heights (1, 2, up to 8 in.)

LWD Testing in the Field (E_{LWD_Field})

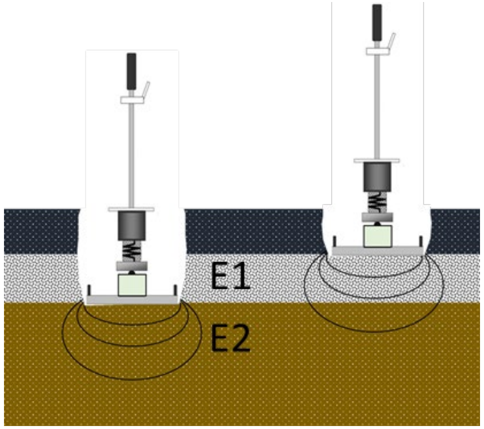
Boussinesq equation:

$$E = \frac{2k_s\left(1-\upsilon^2\right)}{Ar_0}$$

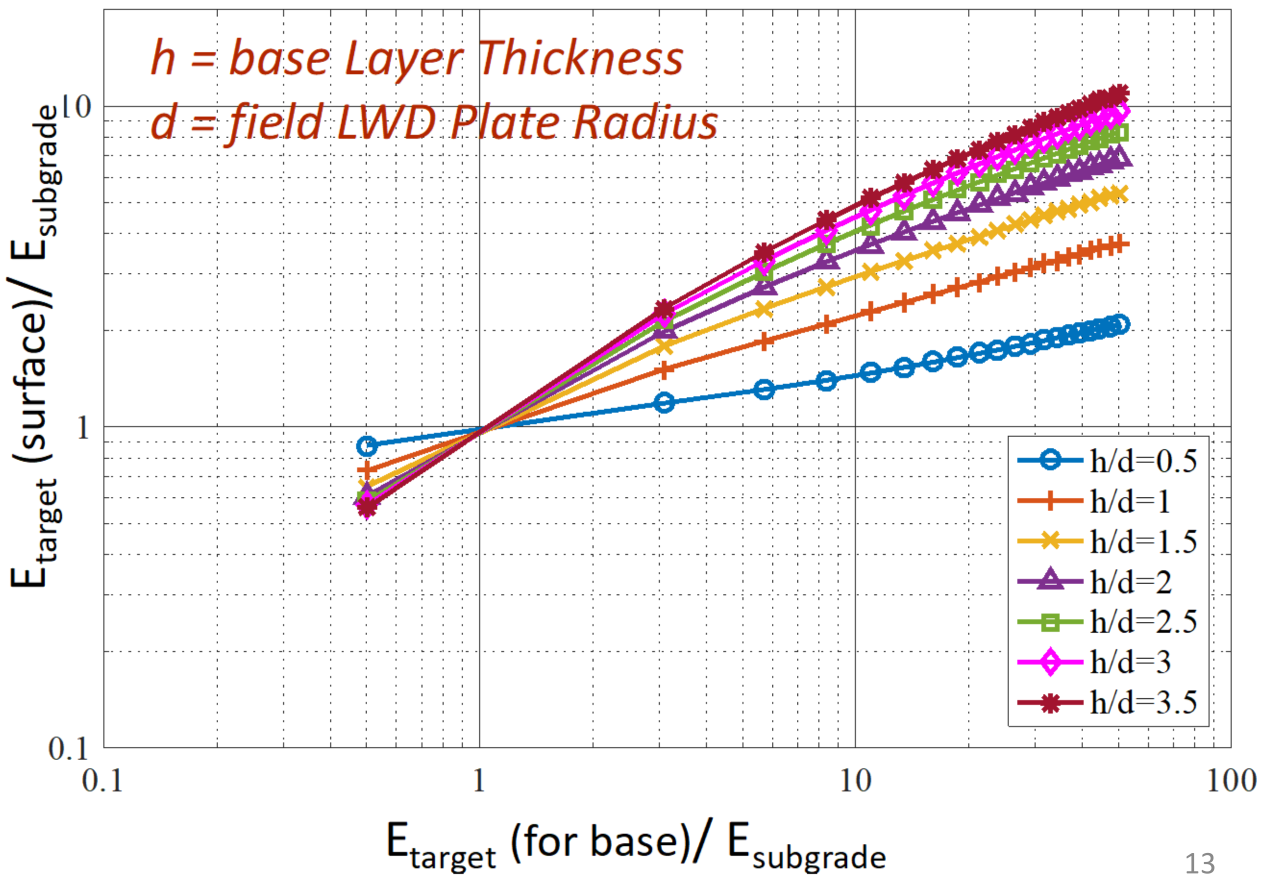
v= Poisson's ratio (assumed)
r_0= plate radius
k_s = soil stiffness =F/δ as calculated by LWD device
F= LWD peak applied load (measured or assumed)
δ = LWD measured peak deflection
A= stress distribution factor (assumed)

Soil type	Factor (A)	Stress distribution Shape
Uniform (mixed soil)	π	
Granular material (parabolic)	$3\pi/4$	
Cohesive (inverse-parabolic)	4	

LWD Testing on Layered System



(Burmister, 1945)



Field Projects in the Pooled Fund Study

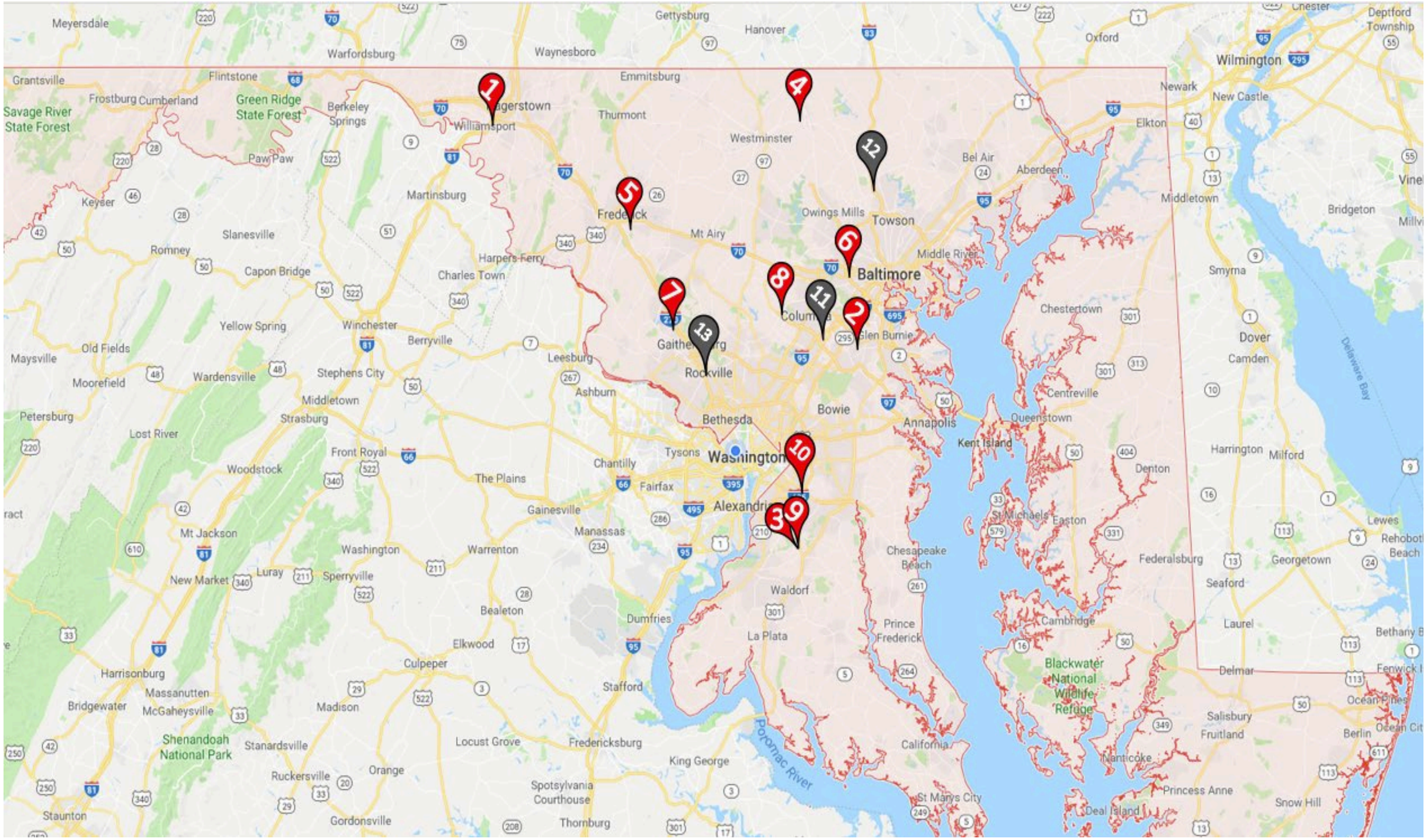
	Location	Soil Type	AASHTO Classification	Unified Classification	
1	Virginia	Subgrade	A-3	SP-SM	Poorly graded sand with silt
2	Maryland	MD5 Waste contaminated embankment	A-1-a	SW	Well graded sand with gravel
3		MD5 Subgrade	A-2-7	SP	Poorly graded sand with gravel
4		MD 337, Deep GAB	A-2-7	GW-GM	Well graded gravel with silt and sand
5		MD404 sand overlaying Subgrade	A-2-7	SP	Poorly graded sand
6		MD 404 Subgrade	A-2-6	SP	Poorly graded sand
7		MD 404 Base	A-2-7	GP-GM	Poorly graded gravel with silt and sand
8	New York	Embankment	A-3	SP	Poorly graded sand
9	Indiana	Cement modified Subgrade	A-2-4	SW	Well graded sand with gravel
10		Virgin Subgrade	A-2-4	SW-SM	Well graded sand with silt and gravel
11		Base	A-1-a	GW	Well graded gravel with sand
12	Missouri	Subgrade	A-3	SP	Poorly graded sand with gravel
13		Base	A-3	GW	Well graded gravel with sand
14	Florida	Subgrade	A-2-7	SP	Poorly graded sand
15		Base	A-3	SP	Poorly graded gravel with sand

Air temperature: 15-33 C

Humidity: 40%-70%

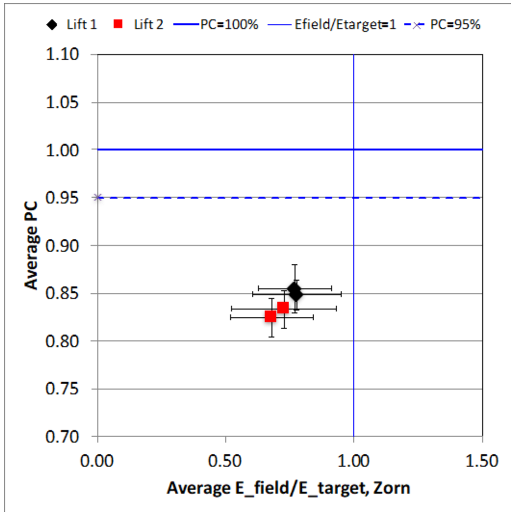
Wind speed: 0-10 km/hr

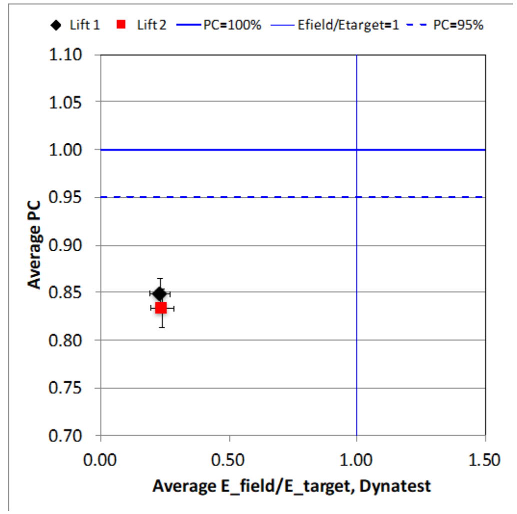
Location of Projects for MDOT Implementation

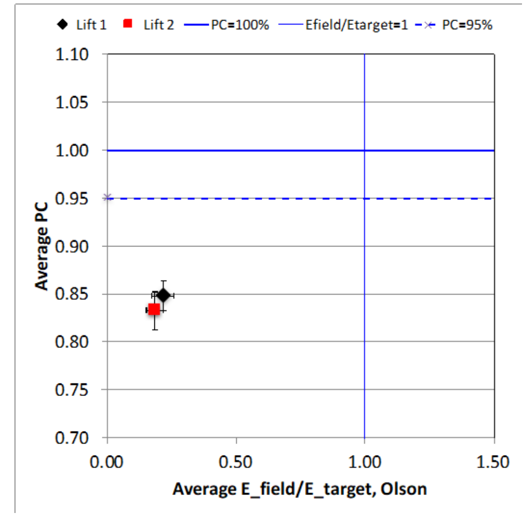


NY embankment compaction

2 lifts of 8-12”, tested right after compaction + 2 rounds at hourly increments



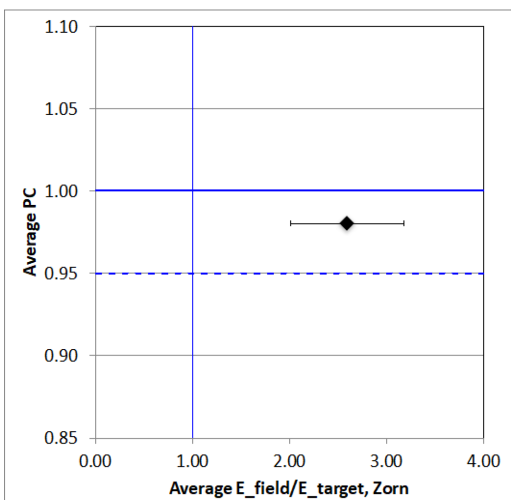


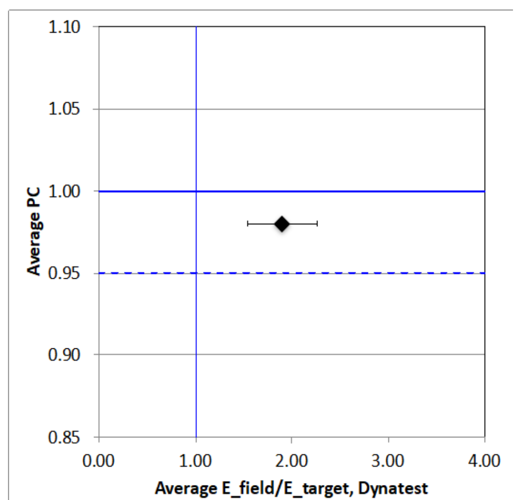


MD337 GAB (1 layer)

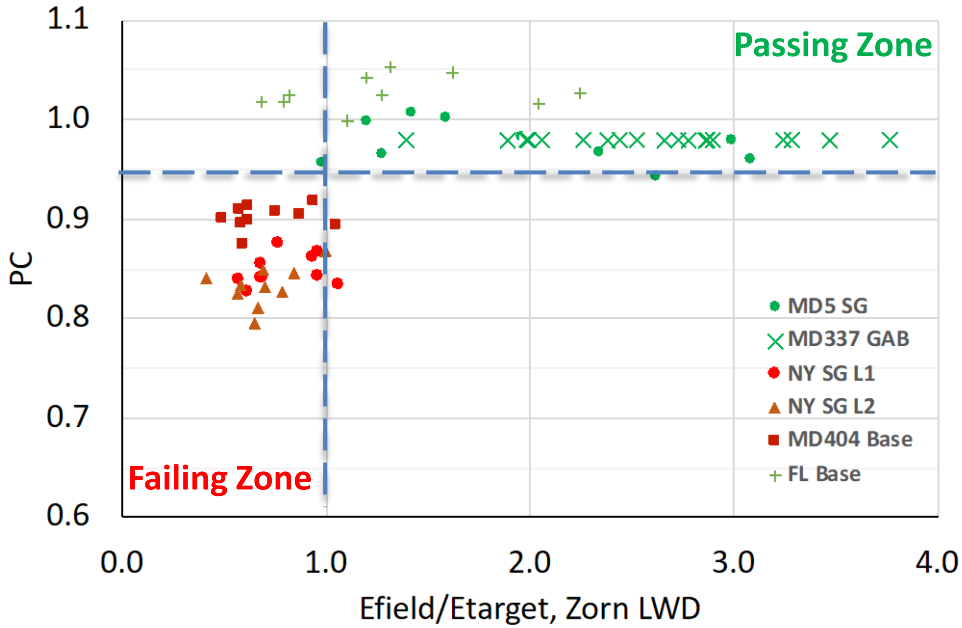
✧ *Failed*

6” GAB placed over 2’ of compacted GAB, tested after compaction



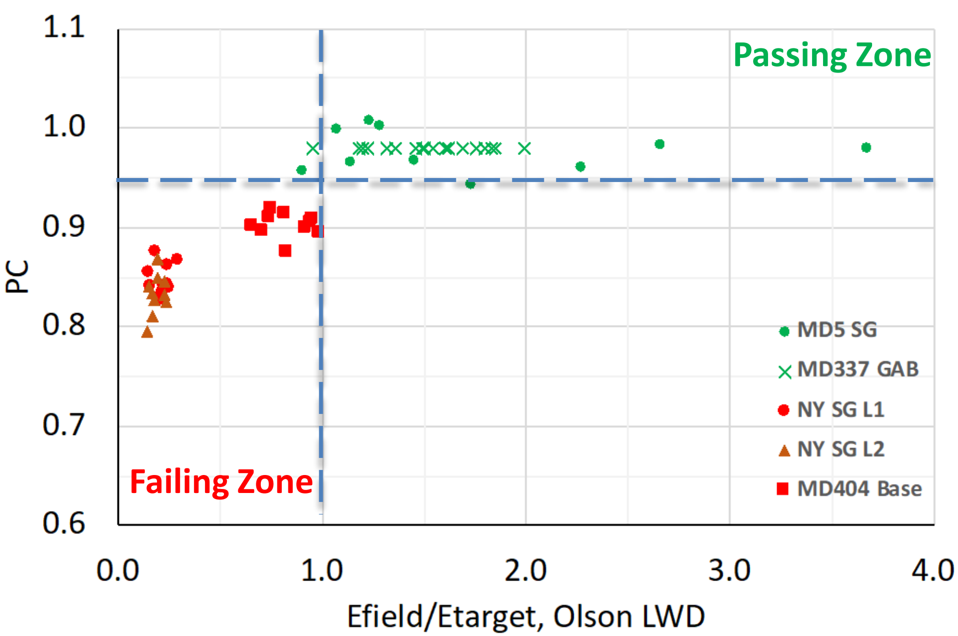


✓ *Passed*

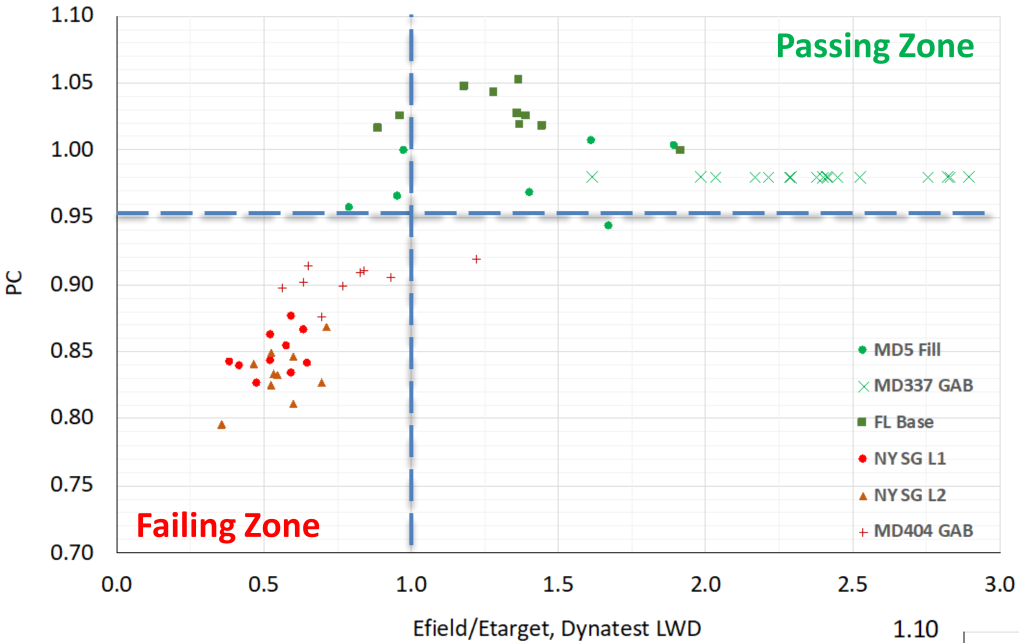


Zorn LWD
Pooled Fund Study

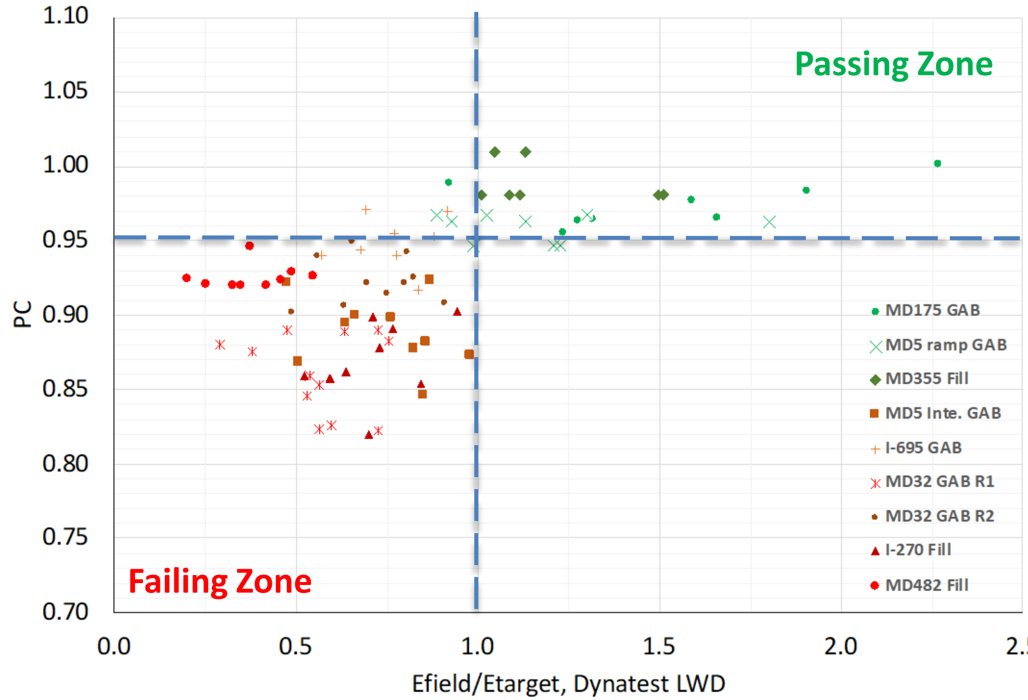
Olson LWD
Pooled Fund Study



Dynatest LWD
Pooled Fund Study



Dynatest LWD
MD SHA Study



Two Proposed Specifications

1- Laboratory Determination of Target Modulus Using LWD drops on Compacted Proctor Mold:

- Sample preparation
- Testing procedure
- Determination of optimum MC
- Determination of target E_{LWD_Target}

Standard Method of Test for

Laboratory Determination of Target Modulus Using Light-Weight Deflectometer (LWD) Drops on Compacted Proctor Mold

AASHTO Designation: TP 123-01 (2017)

1. SCOPE

1.1. This test method describes the procedure to determine the target modulus (or deflection) required for compaction quality control of geomaterials using Light Weight Deflectometer (LWD) drops on a compacted Proctor mold in the laboratory.

1.2. The same LWD type in terms of brand name, buffer stiffness, and deflection

2- Compaction Quality Control Using LWD

- In-situ LWD testing procedure and frequency
- In situ MC testing
- Target modulus adjustment for two-layer systems
- Evaluation of in situ MC for acceptance
- Evaluation of $E_{LWD\_Field}/E_{LWD\_Target}$ for acceptance

Standard Method of Test for

Compaction Quality Control Using Light Weight Deflectometer (LWD)

AASHTO Designation: TP 456-01 (2017)

1. SCOPE

1.1. This test method describes the procedure to assure the compaction quality of a road base or subgrade by comparing the field surface moduli to the laboratory determined target moduli using a Light Weight Deflectometer (LWD).

1.2. The same LWD type in terms of brand name, buffer stiffness, and deflection measurement location (on top of the plate or on top of the soil layer) used for the laboratory target modulus testing must be used during the field testing. This is to eliminate differences between measurements from different devices.

1.3. This procedure shall be performed within two hours after compaction to eliminate the effect of surface drying on the modulus values. This method does not count for post compaction wetting/drying and environmental effects.

1.4. An appropriate in situ method of soil water content measurement shall be used to rapidly determine the moisture content at the time of compaction and testing.

Published ASTM E3331-22a Specification

Link

ASTM E3331-22a

Standard Test Method for Measuring Target Modulus Using Light Weight Deflectometer (LWD) on Compacted Proctor Mold Samples

Significance and Use

5.1 LWDs are intended to be used as a tool to ensure adequate compaction of unbound materials. Adequate soil compaction of infrastructure projects will provide load capacity, stability of the soil, decrease permeability, and prevent or reduce the settlement of supported pavements and structures. The target modulus or deflections are used to establish QA/QC acceptance criteria for the LWD tests in the field.

5.2 This test method covers the determination of target acceptance modulus values of unbound materials based on measuring LWD deflections on laboratory proctor mold samples at varying moisture contents.

5.3 This standard test method provides a target modulus calculation that accounts for the constrained conditions (in the compaction mold) of the test sample. The intent is to be able to compare the results from the laboratory samples to those of similar materials in the field at similar stress levels.5

5.4 The target modulus or deflections may be either correlated directly to pavement or structure performance or used to determine *in situ* material characteristics of the pavement or structure foundation layers.6

Implementation Recommendation

Local field verification/calibration:

- Range of projects representing typical soil conditions (base, subgrade)
- LWD on mold testing in laboratory
- Both conventional nuclear gauge and LWD approaches in field
- Compare PC vs. $E_{LWD\_Field}/E_{LWD\_Target}$
- Establish appropriate compaction specification threshold (cst) or PWL:

$$\frac{E_{LWD\_Field}}{E_{LWD\_Target}} \geq CST$$

- Develop confidence in procedures

New Designs - Zorn Lab LWD, Field LWD, and Application Link

Link

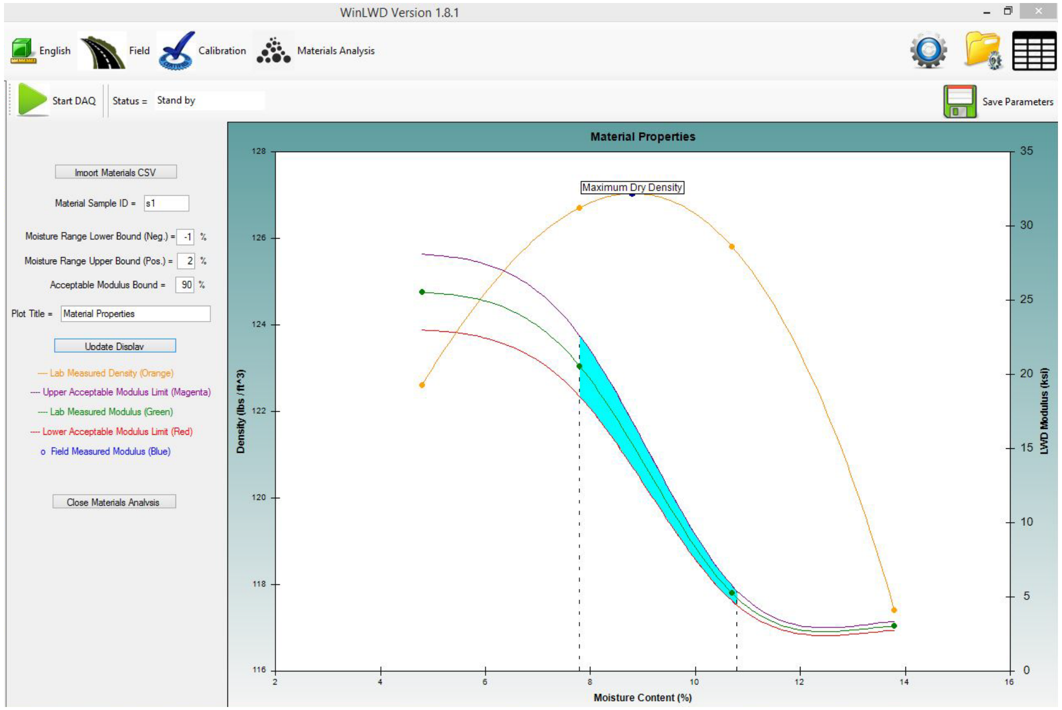
Pictures taken during TRB 2023

LWD for Proctor mold to determine characteristics that provide a soil-specific assessment of the degree of soil compaction.

Web application for a quick comparison of measurement data, for data evaluation and easy creation of high-quality test protocols.

Olson Lab LWD and Application [Link]

[Link]



Pictures courtesy Olson Instruments

- Shorter and lighter weight (3.6 kg) lab unit
- Dell^{TM} sunlight viewable tablet
- WinLWD software and app
- GPS
- Configuration and stress distribution input
- Stores density and MC of mold

Questions?

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