Appendix G
On-Site TAC Meeting Presentation

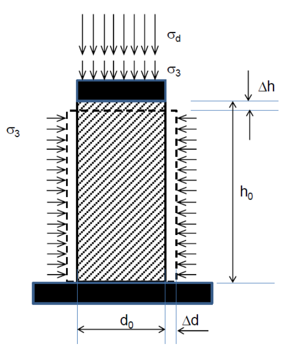
"Laboratory Testing" (Khosravifar)

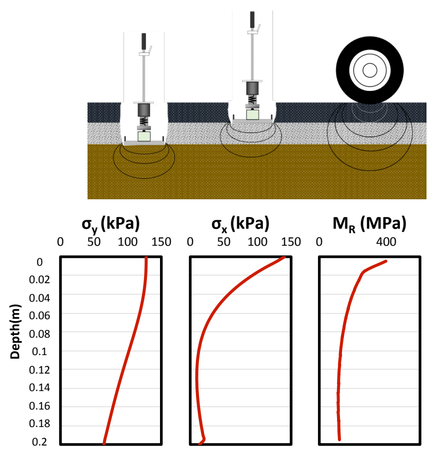
Standardizing the Lightweight Deflectometers for Modulus Determination and Compaction Control of Unbound Material

June 2 - 3, 2015
University of Maryland College Park

Recap of Key Issues

- Stress effects
  - Confining stress stiffening effects on M_R
  - Deviator stress softening effects on M_R





Stress States under LWD versus

1. Design traffic load
2. Laboratory Resilient Modulus (M_R)

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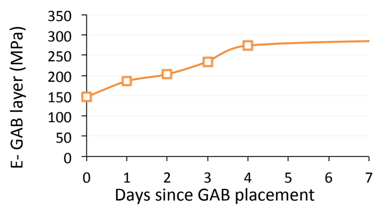
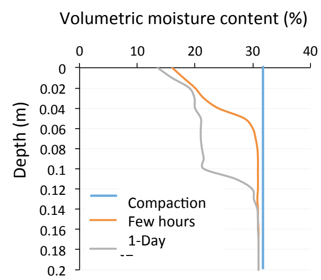
Key Issues

- Moisture effects
  - Compaction moisture effects on M_R
  - Drying profile history (limited time duration)
  - Drying (post-compaction moisture) effects on M_R (stiffening)



Khosravifar, Asefzadeh, Schwartz (2013)



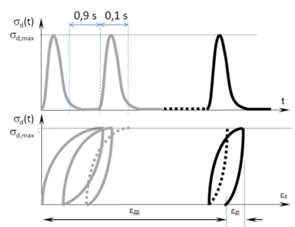
After Yanful, E. K., and Choo, L. (1997)

3

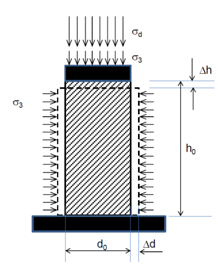
Model Refinement

Three main parts of the model:

- Stress effects -> Resilient Modulus (M_R) – Various Constitutive Model



$M_R = \sigma_d / \varepsilon_r$



$$M_R = (p_a)^\wedge k_1 + (\theta / p_a)^\wedge k_2 + (\sigma_d / p_a + k_5)^\wedge k_3 + (\sigma_3 / p_a)^\wedge k_4 + (p / p_a)^\wedge k_6$$

Reference	Variables	Restrictions on k_i
Hicks and Monismith	q	$k_3 = k_4 = k_5 = k_6 = 0$
Uzan	q, s_d	$k_4 = k_5 = k_6 = 0$
M-EPDG model	q, s_d (or t_{oct})	$k_4 = k_6 = 0$, $k_5 = 1$
Thompson and Robnett	s_d	$k_2 = k_4 = k_5 = k_6 = 0$
Barksdale and Itani	s_d, s_3, p	$k_2 = k_5 = 0$

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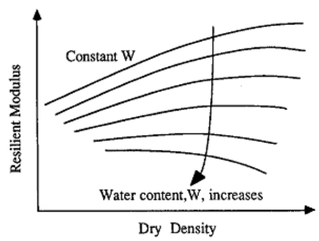
Model Refinement

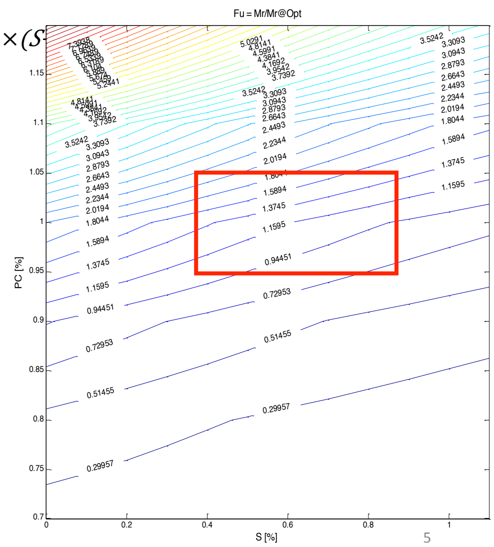
Three main parts of the model:

- Moisture and Density effects -> Environmental Factor Scenario

$$F_u = 10^{\left(a + \frac{b-a}{1+e^{\left(\ln\frac{-b}{a} + k_m \times (S - S_{opt})\right)}}\right)} \times 10^{C_2\,(\mathrm{PC}-100)}$$



(Li & Selig, 1994)



Model Refinement

Three main parts of the model:

- Moisture and Density effects →

Empirical Environmental factor models and Models based on Unsaturated soil mechanics principal might not be precise enough for the purpose of this work

↓

Experimental model using data from small scale LWD testing on Proctor mold can be an alternative

Small Scale Laboratory Experiments

Objective

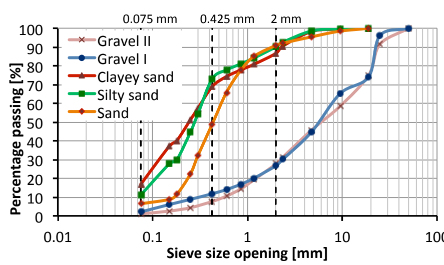
- Characterize the test materials,
- Evaluate the parameters for stress-dependent modulus model,
- Assess the effect of compaction moisture content and density on modulus

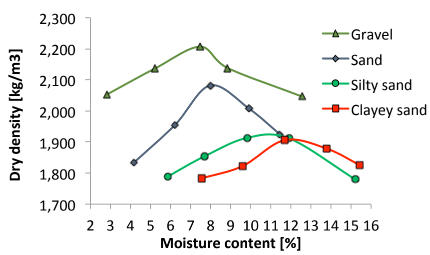
Tests Performed

- Grain size distribution
- Soil classification
- Moisture- density measurements
- Resilient Modulus (M_R)
- LWD testing on Proctor molds → To assess moisture, density, stress dependency

Small Scale Laboratory Experiments

Soil	C_u	C_c	G_s	v
Gravel	26.7	2.3	2.68	0.35
Sand	2.2	1.3	2.63	0.38
Silty-sand	4.4	1.3	2.66	0.42
Clayey-sand	0.6	0.1	2.67	0.42





Soil	OMC [%]	MDD [kg/m³]
Gravel	7.5	2210
Sand	8.2	2082
Silty-sand	11.0	1922
Clayey-sand	12.0	1910

Standard Proctor test- AASHTO T99

Small Scale Laboratory Experiments

Resilient Modulus Tests

@ 15 sequences according to AASHTO T-307
+
10 high stress levels comparable with those exposed by LWD tests on Mold

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Small Scale Laboratory Experiments

Resilient Modulus Tests

The results will be discussed in more detail:

1. Mr @ low stress levels
2. Mr @ high stress levels
3. Mr @ various MC
4. Mr @ various DD (modified vs. Standard)
5. Mr prediction models:
   - MEPDG (function of bulk stress, deviator stress),
   - Barksdale and Itani (function of confining pressure, deviator stress)

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Small Scale Laboratory Experiments

LWD testing on Proctor molds

Tests performed using all three LWDs.
Tests performed using variable drop heights to assess Stress dependency: On the two LWD with load cell test

1. LWD testing concurrent to Proctor compaction test at Modified and Standard energy levels
2. LWD testing during drying process
   a. Drying process/ compacted at OMC.
   b. Drying process/ compacted at OMC+2%.
   c. Drying process/ compacted at OMC-2%.

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

$$\sigma_r=\sigma_z\times\frac{v}{1-v}$$

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Small Scale Laboratory Experiments

LWD testing on Proctor molds

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Small Scale Laboratory Experiments

LWD testing on Proctor molds

The results will be discussed in more detail:

1. $E_{LWDonMold}$ @ various stress levels
2. $E_{LWDonMold}$ @ for the three LWDs
3. $E_{LWDonMold}$ @ various moisture levels
4. $E_{LWDonMold}$ @ various DD (modified vs. Standard)

↓

- Comparisons between Triaxial M_R and $E_{LWDonMold}$
- Use of M_R and $E_{LWDonMold}$ for evaluation of field tests.

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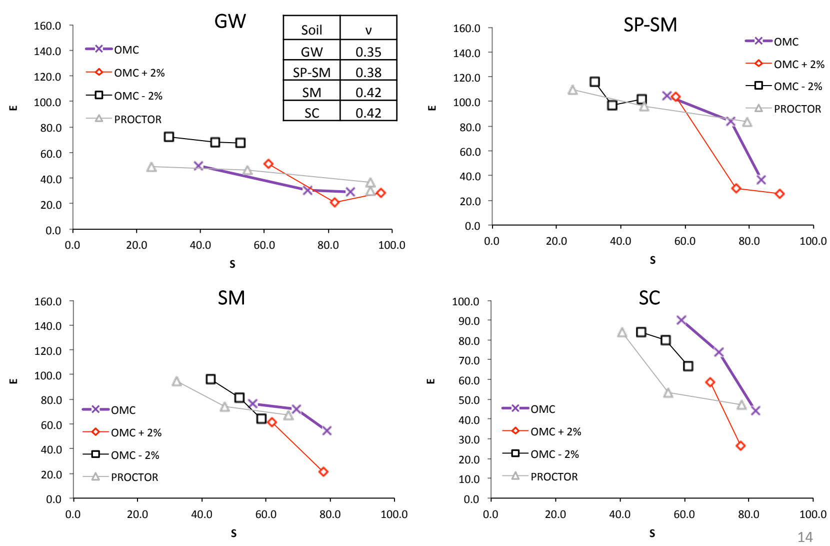
Small Scale Laboratory Experiments

LWD testing on Proctor molds



Soil	v
GW	0.35
SP-SM	0.38
SM	0.42
SC	0.42

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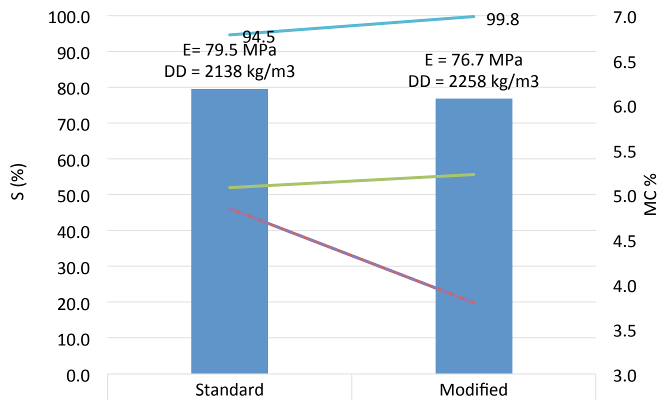
Small Scale Laboratory Experiments

LWD testing on Proctor molds GW soil



	Standard	Modified
E	79.5	76.7
S @testing	52.0	55.6
PC [%]	94.5	99.8
MC@Compaction	4.8	3.8
MC@Testing	4.8	3.8

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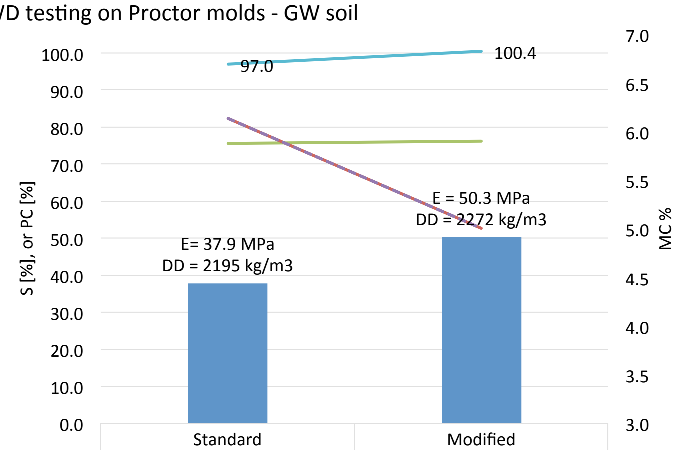
Small Scale Laboratory Experiments

LWD testing on Proctor molds - GW soil



	Standard	Modified
E	37.9	50.3
S @testing	75.6	76.3
PC [%]	97.0	100.4
MC@Compaction	6.1	5.0
MC@Testing	6.1	5.0

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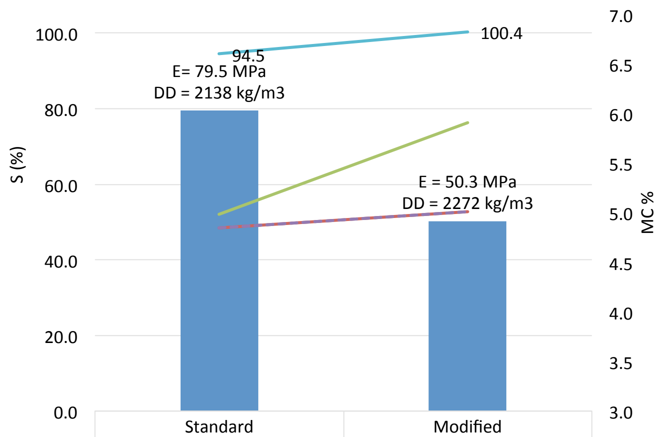
Small Scale Laboratory Experiments

LWD testing on Proctor molds - GW soil



	Standard	Modified
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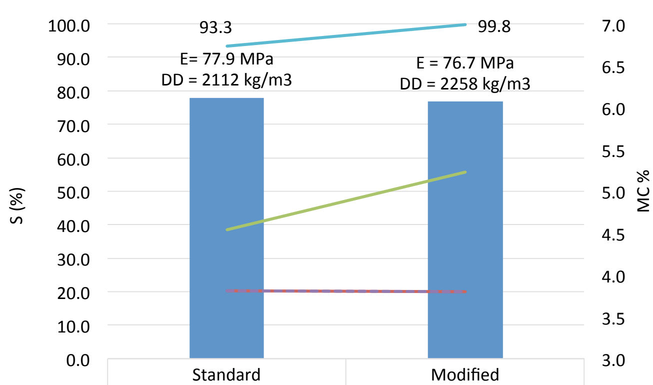
Small Scale Laboratory Experiments

LWD testing on Proctor molds - GW soil



	Standard	Modified
E	77.9	76.7
S @testing	38.4	55.6
PC [%]	93.3	99.8
MC@Compaction	3.8	3.8
MC@Testing	3.8	3.8

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Small Scale Laboratory Experiments

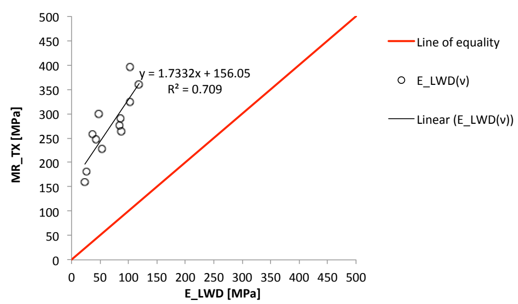
Comparison of moduli from LWD tests on Mold and Triaxial Resilient Modulus tests

There is a strong correlation between the two BUT M_R is about twice the $E_{LWDonMold}$

There are differences in

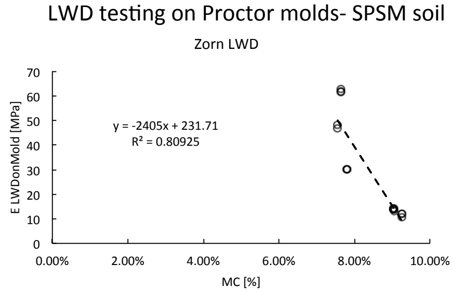
1. **Induced stress levels,**
2. **Error from assuming Poisson's ratio,**
3. **Permanent strain in LWD testing on Mold**

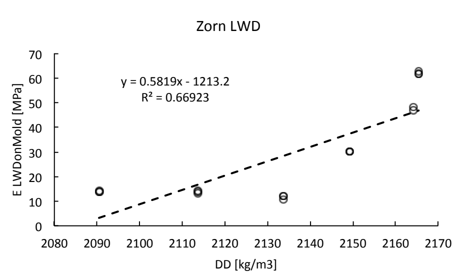
Details on how to correct for these points to follow



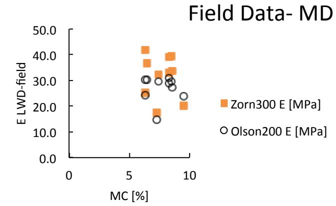
Small Scale Laboratory Experiments

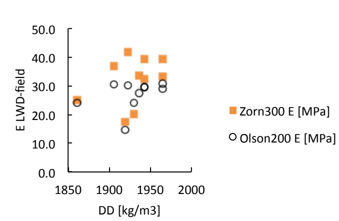
LWD testing on Proctor molds- SPSM soil



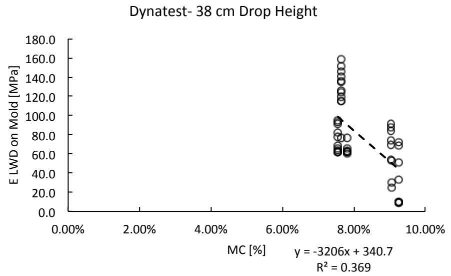


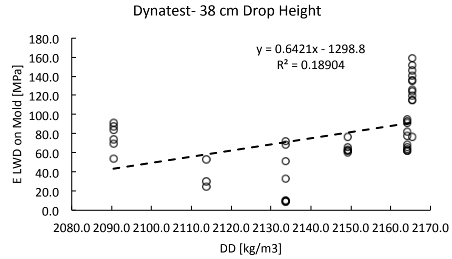
Field Data- MD 404





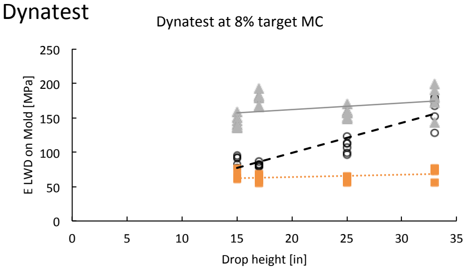
Small Scale Laboratory Experiments

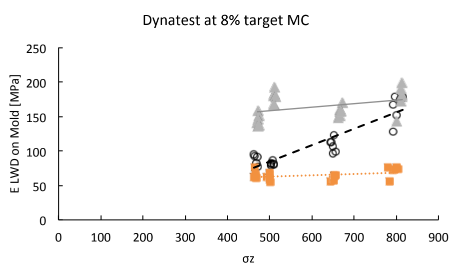




Small Scale Laboratory Experiments

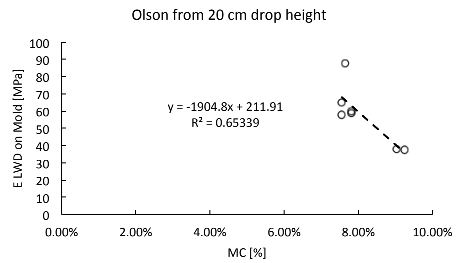
Stress Dependency - Dynatest

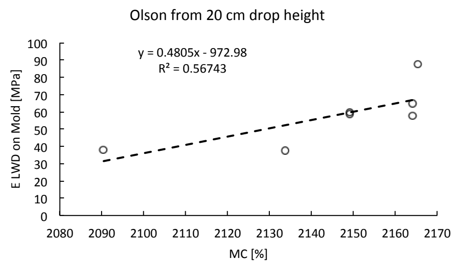




Small Scale Laboratory Experiments

Moisture and Density Dependency Olson





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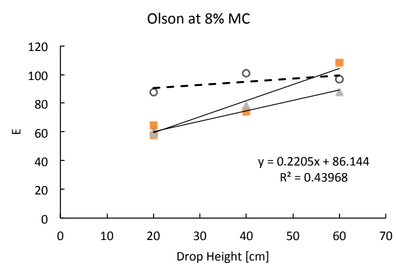
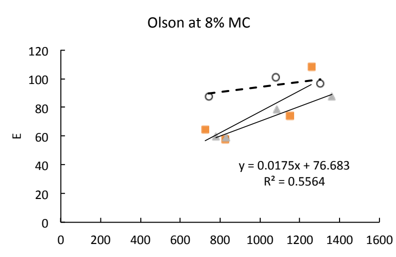
Small Scale Laboratory Experiments

Stress Dependency Olson





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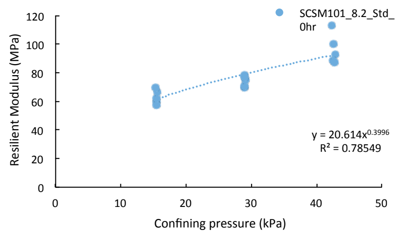
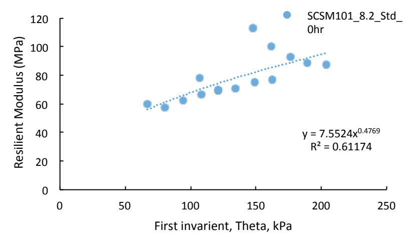
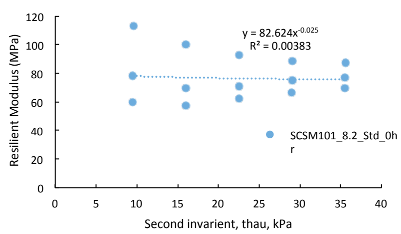
Small Scale Laboratory Experiments

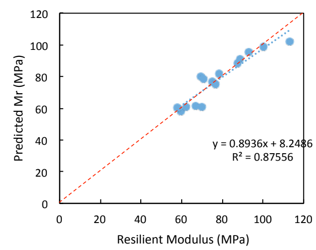
Resilient Modulus testing

SP-SM @ 8% MC









Pa	101.3
k1	909.8668569
k2	0.711232734
k3	-1.799742
SSE	437.192715
Sqr(SSE)	20.90915386
R2	0.876007705
R2_adj	0.842191624

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Small Scale Laboratory Experiments

Resilient Modulus testing

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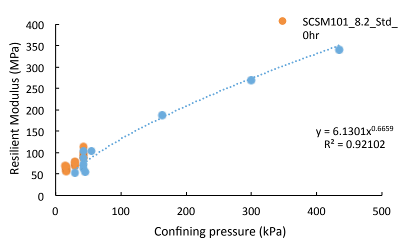

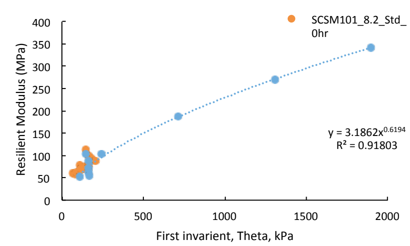

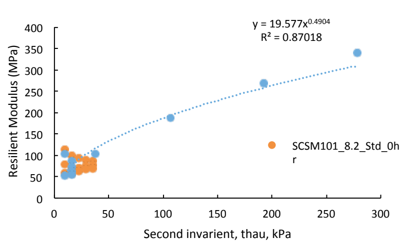

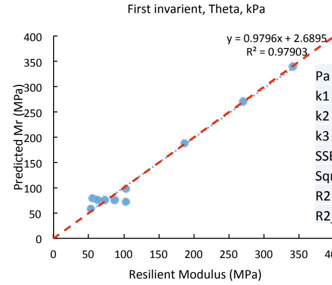

Pa	101.3
k1	564.4808614
k2	0.612606713
k3	-0.00939193
SSE	1884.326849
Sqr(SSE)	43.40883376
R2	0.979056861
R2_adj	0.968585291

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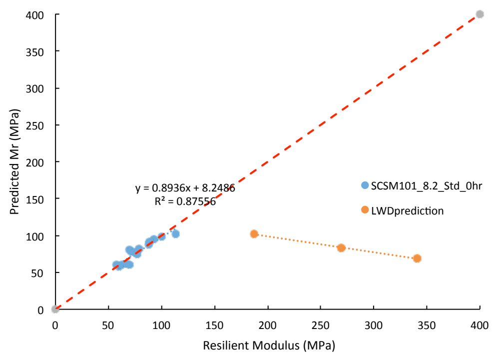
Small Scale Laboratory Experiments

Resilient Modulus testing

SP-SM @ 8% MC



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Small Scale Laboratory Experiments

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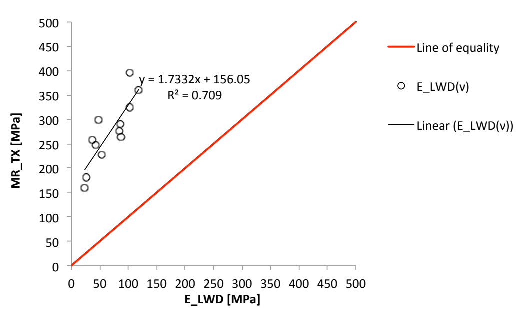

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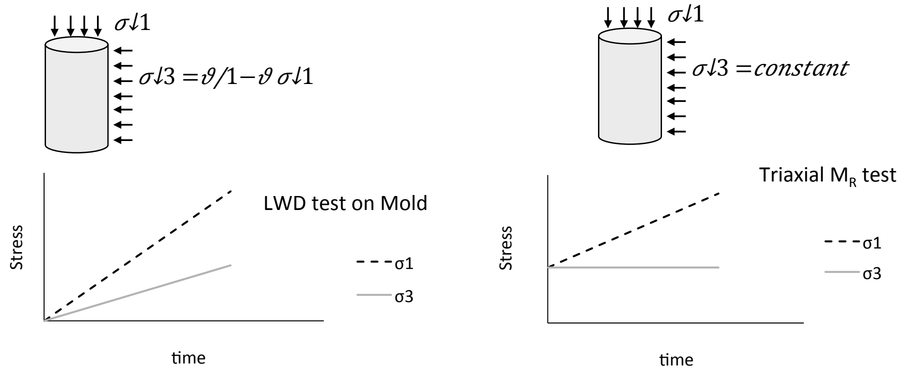
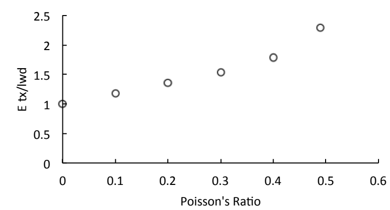
Small Scale Laboratory Experiments





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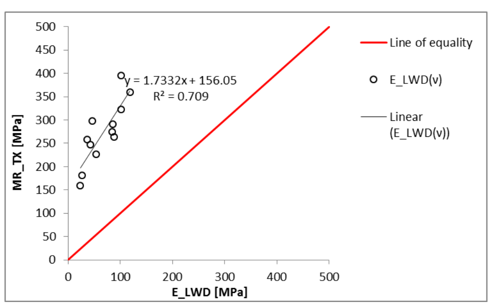
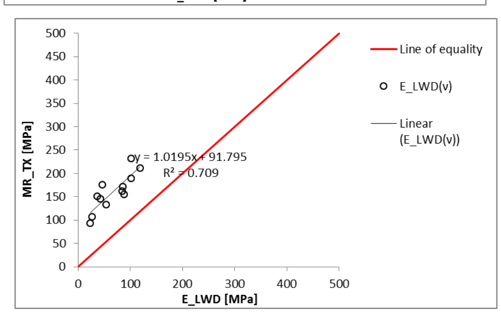
Small Scale Laboratory Experiments





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Appendix H
On-Site TAC Meeting Presentation

"Large Pit Testing" (Khosravifar)

Large Scale Test Pits

June 2nd and 3rd, 2015
University of Maryland College Park

Objective

1. Evaluation of the repeatability, reproducibility, and depth of influence of the selected LWD and moisture measurement devices.

2. Assessment of models and proposed procedures

3. Refinement of a practical testing procedure for LWD modulus based QA.

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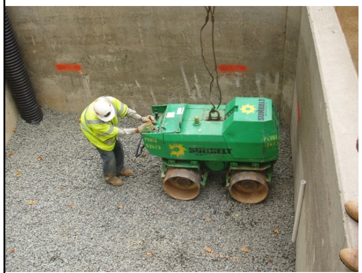
Overview

- 15' x 15' x 8'
- Equipped with reaction frame with a pneumatic pulsed loading capability
- Infrastructure to control and change the water table.
- The test pits will be instrumented with soil moisture sensors, and thermocouples. Surface deflection will be measured with Geophones.

- GS1 low cost ruggedized soil moisture sensor by Decagon Devices
- T-type thermocouples will be self fabricated
- Dynatest radial geophones. Other options are still being investigated.

Construction Schedule

Compacting the subgrade soil at the target condition in 4 inch sublayers.
Digging small holes to insert the GS1 moisture sensors and thermocouples
Backfilling the holes with material.
Testing the subgrade over the next 1 or 2 days at several time intervals.

Compact and instrument the base layer similar to the subgrade soil. Perform LWD and plate load testing.

** Priority one:
2 pits compacted at "PASS" condition, and 1 at "FAIL" condition (noncohesive subgrade).
** Priority two:
The material from one pit to be excavated and re-compacted at "FAIL" condition (cohesive SG)

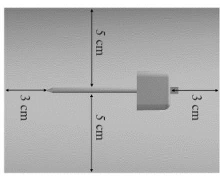
Material:
Noncohesive subgrade: ALF subgrade
Cohesive subgrade: Virginia Red Clay? Other local options
Graded Aggregate Base: Typical Maryland or Virginia Base material–
60% number 57 with 40% number 10 fine material?

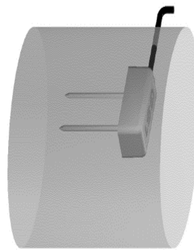
Sensor characteristics

GS1 The GS1 determines volumetric water content (VWC) by measuring the dieletric constant of the medium using capacitance and frequency domain technology.

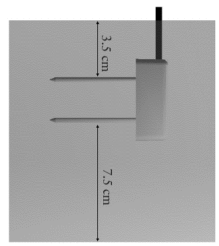
Measurement Time: 10 ms (milliseconds)
Accuracy: ± 0.03 m^3/m^3 in typical soils
Resolution: 0.001 m^3/m^3 VWC in mineral soils
Sensor dimensions: 8.9 cm x 1.8 cm x 0.7 cm

Top View





Side View



Sensor	GS1
Max Volume	1430 mL

1.4” above the upper prong- 3” beneath the lower prong

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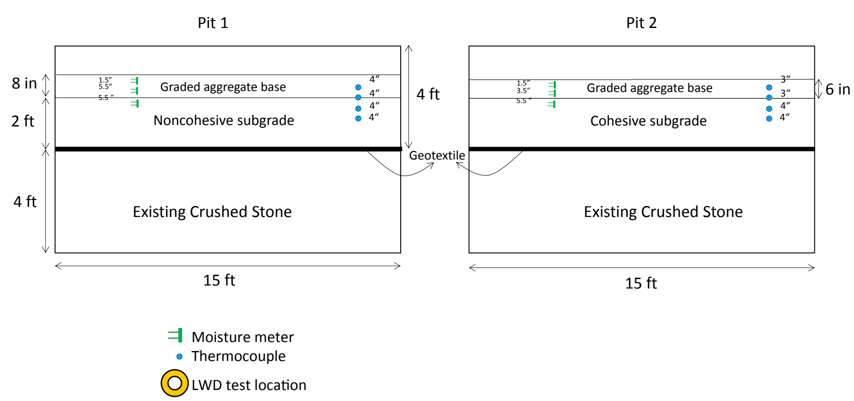
Design of the Test Pits

Front view



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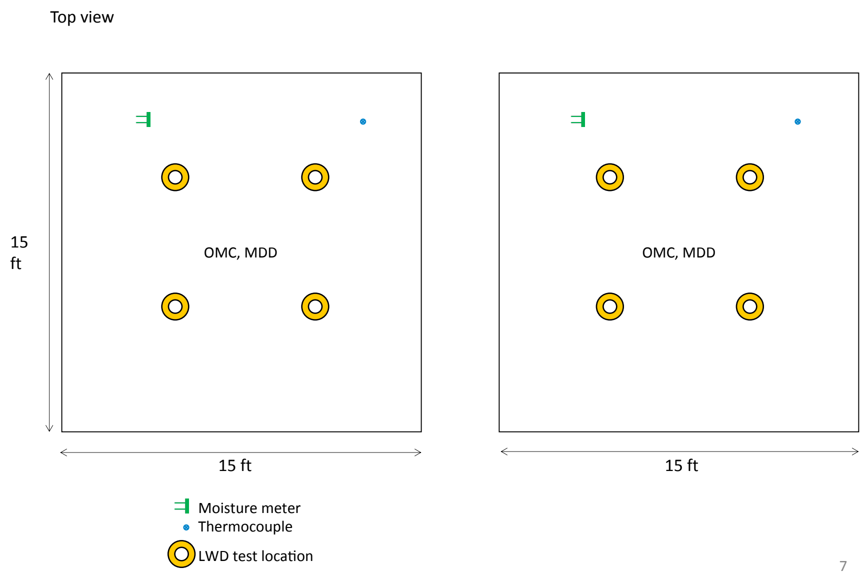
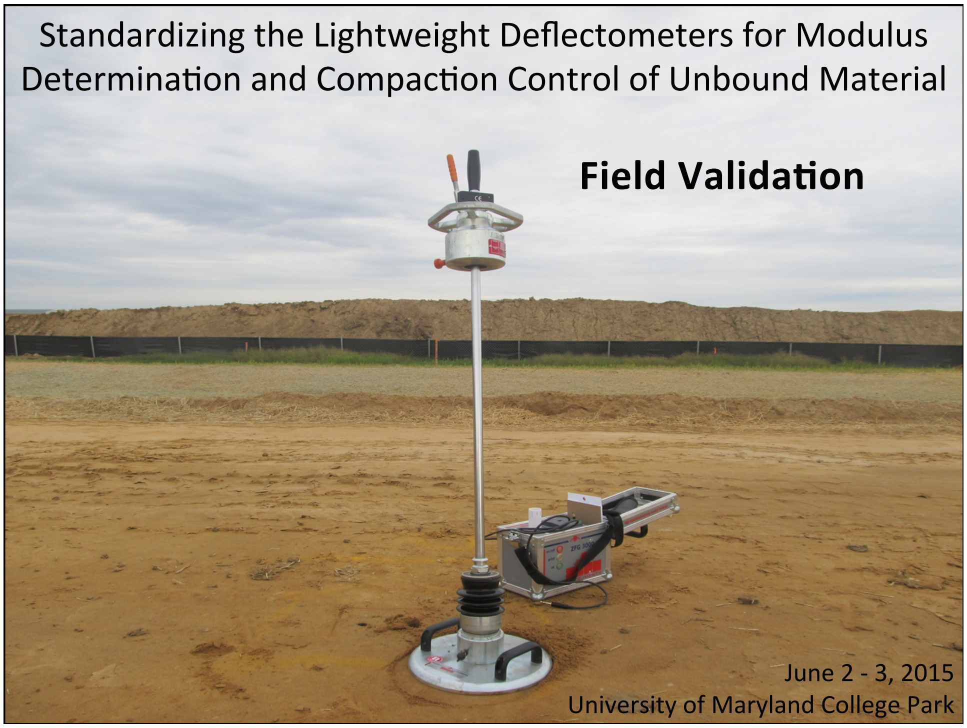
Design of the Test Pits



Design of the Test Pits

Appendix I
On-Site TAC Meeting Presentation

“Field Testing” (Afsharikia)



Objective

1. Comparison of different LWD devices measurements in the field
2. Validation of the proposed models under actual field conditions
3. Comparison of Field LWD modulus vs. Lab Mr measurements
4. Final refinement of a practical QA procedure

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Objective

For some projects:

- Assessment of the repeatability and reproducibility of the test devices in actual construction practice
- Estimation of the spatial variability of moisture, density, modulus, and layer thickness in actual construction practices
- Observing moisture content profile change after compaction under various field conditions for drying analysis purposes

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Preliminary Field Trials

US 29 NB from MD 32 to MD 175

6 inches of Granular Aggregate Base on top of Subgrade

US 404- Eastern shore Maryland

Sandy subgrade

US 424- Parking lot mbankment

Silty clay and Clay silt

Primary purposes: Material for laboratory testing, data for model evaluation
Correct comparison requires adjustment for stress state;
laboratory M_R testing currently underway

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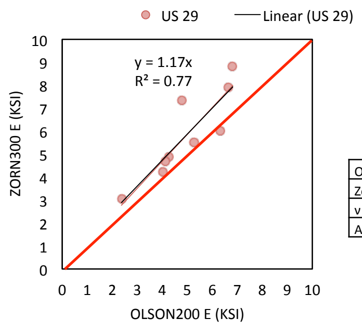
Field Trials

US 29 NB from MD 32 to MD 175

6 inches of Granular Aggregate Base on top of Subgrade



$$E = \frac{2k_s(1-\nu^2)}{Ar_0}$$

Olson	200mm/ 10 kg
Zorn	300mm/10 kg
v	0.35
A	(uniform)

Primary purposes: Material for laboratory testing, data for model evaluation

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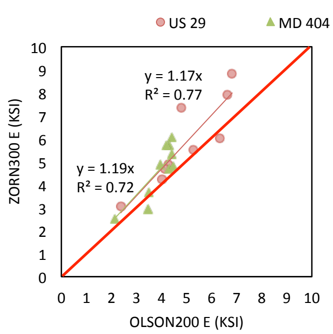
Field Trials

US 404- Eastern shore Maryland

Sandy subgrade



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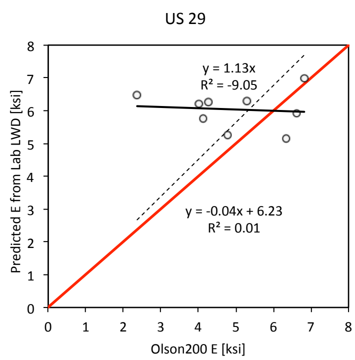
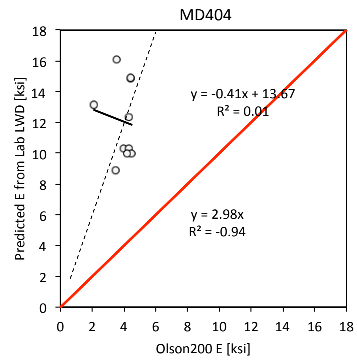
Field Trials



Granular Base



Sandy Subgrade

Correct comparison requires adjustment for stress state;
laboratory M_R testing currently underway

Field Validation Plan

- Field evaluations and associated laboratory testing will be performed at 8 to 10 individual test sites
- Each test site is expected to be approximately 200 ft long.
- The test sites should span a range of subgrade and base geomaterials having various gradations, plasticity indexes, and moisture characteristics.
- In-situ testing of the **subgrade soil** or/and **base layer** to be performed by UMD personnel prior and after compaction up to 24 hours. The respective participating agency should accommodate the testing plan.

Field Validation Schedule

Project Info	Site ID	
	Address	
	Construction Dates	
	Project Length	
	Agency Contact	
Layer thickness	Base	
	Sub-base	
Soil Classification	Base	
	Sub-base	
	Subgrade	
Local availability of test equipment	LWD-Zorn	
	LWD-Dynatest	
	Nuclear Gauge	
	Other equipment	
Comments		

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List of Field Projects Suggested

	Project Info				Layer thickness		Soil Classification		
State DOT	Site ID	Address	Date	length	Base	Subbase	Base	Subbase	Subgrade
Indiana	INDOT IR 35600	Indianapolis on U# 31, from 96 St to 136 St; added travel Lane	June to July 2015	200 ft	14 inches				Cement Modified soils
New York	D262512	Utica NY	Majority of the season	200 ft	Embankment and MSE wall 12 inches layer		SW and GM-SM		
New York	D262718	Albany NY	until early August	200 ft	Embankment		GM-SM		
Florida	Florida's typical pavement construction	Jacksonville	all year	200 ft	10-12 inches	12 inches	soft limestone with fines	sandy, granular (A-1, A-3 or A-2-4)	
Virginia	675-019-264, M501, - UPC 76170	Lynchburg, VA	May- June ends 9/28/15	0.215?	8 inch VDOT 21B				Micaceous Silty Sand SM
Virginia	0081-034-12 7,P101, R201, C501, D601, D602	Frederick County, Virginia Interstate 81 and Route 37, Interchange at Exit 310,	April 2015 to May 2018	1.06 miles	6-8 inches	10 inches	VDOT 21-A/ 21-B	Select Materials [Big size (2" to 8") rocks capped with 21B)	CL or CH

List of Field Projects Suggested

State DOT	Local availability of test equipments				Contacts
	LWD-Zorn	LWD-Dynatest	Nuclear Gauge	Others	
Indianapolis	Available	_	_	_	nsiddiki@indot.in.gov
New York	Available (300 mm plate)	_	Available	near state geotech labs	Brett.Dening@dot.ny.gov David.Patterson@dot.ny.gov
New York	Available (300 mm plate)	_	Available	Field and Lab equipments	Brett.Dening@dot.ny.gov Mike.Novak@dot.ny.gov
Florida	Available	Available	Available	DCP, Moisture	David.Horhota@dot.state.fl.us
Virginia	_	_	Available	_	Shabbir.Hossain@VDOT.Virginia.gov Don.French@VDOT.Virginia.gov
Virginia	_	_	Available	_	Shabbir.Hossain@VDOT.Virginia.gov Chaz.Weaver@VDOT.Virginia.gov

Experimental Design

- Sampling of subgrade and base materials.
- Laboratory determination of gradation, plasticity, soil classification, compaction-moisture relationship, and laboratory resilient modulus.
- Placement of **evaporation pans** to measure free water evaporation rates during construction.
- Recording of **weather history** during the construction duration.
- Measurement of in-situ density and moisture content of the subgrade at 10 foot intervals along the centerline to establish the spatial variability of the subgrade.
- LWD testing on the subgrade at 10 foot intervals to establish the spatial variability of the subgrade. For freshly placed and compacted subgrade, repeat LWD tests and moisture content at 1, 2, 4, 9, 15, and 24 hour intervals.

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Experimental Design

- Sampling of base material just prior to compaction for subsequent laboratory moisture measurement.
- In situ measurement of density and moisture content of the base layer immediately after compaction.
- LWD testing and moisture measurements on the compacted base layer at 10 foot intervals. These measurements will be repeated at 1, 2, 4, 9, 15, and 24 intervals. Moisture measurements will be accompanied by sampling from the same locations for subsequent laboratory moisture determination.

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What We Need/Want from Agencies

- Available test equipment and schedule
  - Nuclear Density Gauge and Operator
- Geological and structural information for each site
  - Layers thickness
- Base/Subbase/Subgrade Soil Properties and Classification (as much info as available)
  - Sieve Analysis
  - Saturated Hydraulic conductivity
  - Saturated Volumetric Water Content
  - Specific Gravity
- Moisture content of as-compacted material