Using Lightweight Deflectometer for Quality Control of Subbase/Base Materials

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Outline

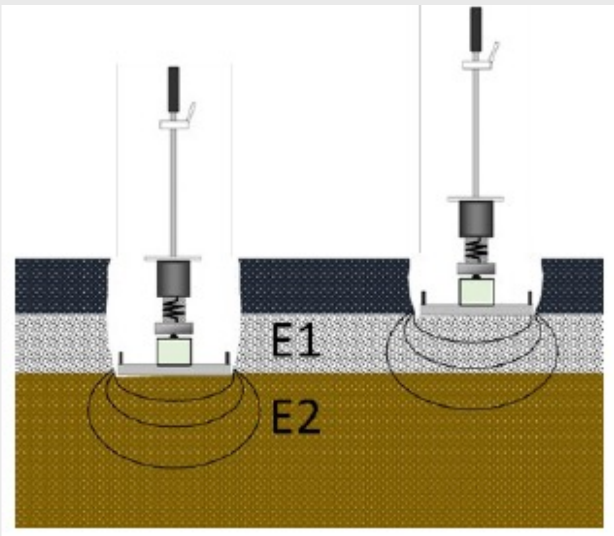
- 1. Background
- 2. Objectives
- 3. Methodology
- 4. Results
- 5. Conclusions

Background

The modulus of the soil is as follows:

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

ϑ=poison's ratio, H=height of the mold, D=the diameter of the plate or mold, and k = soil stiffness =F/δ by the LWD device.



Lightweight Deflectometer

Pit/Field Tests: $$E = \frac{2k_s(1-\vartheta^2)}{Ar_0}$$

$k_s = \left|\frac{F_{peak}}{\omega_{peak}}\right|$ calculated by the LWD device, A is the stress distribution factor, ϑ is the Poisson's ratio, and r_0 is the plate radius.

Background

Background

- LWD are convenient and cost-effective
- Compared to FWD, less manpower and faster to run
- LWD measurements influenced by soil modulus and moisture content (MC)
- Important to Understand MC and compaction effect on LWD responses

Background

State	Parameter	Coarsest	Coarser	Finer	Finest	Others
MnDOT	Material type	Base or Reclamation	Granular	Clay and Clay Loam	N/A	N/A
	Minimum Elastic Modulus (MPa)	50	40	20	N/A	N/A
INDOT	Material type	Cement Modified soil	Aggregate over Cement Modified soil	Lime Modified soil	Aggregate over Lime Modified soil	Aggregate over Untreated Soils (6 in Thick Coarse Aggregate No. 53)
	Allowable Average Deflection (mm) (Single Test)	0.30	0.30	0.27	0.27	0.51
	Allowable Single Test Deflection (mm)	0.35	0.35	0.31	0.31	0.57

Objectives

- ❖ Moisture–compaction effects on LWD
- ❖ LWD–soil property correlations
- ❖ Soil type influence on deflection
- ❖ Optimization of LWD testing protocols
- ❖ Guidance for LWD use in compaction QC

Methodology

Experimental Plan

Material Preparation
1. Obtain Materials
2. Conduct Proctor Tests

Laboratory Testing
1. Prepare Specimens at Varying Moisture Contents
2. Perform LWD and DCP Tests

Field & Test Pit Testing
1. Construct Test Pit & Place Materials
2. Vary Moisture and Compaction Levels
3. Conduct LWD and DCP Tests in Pit and Field

Data Analysis
1. Collect and Analyze All Data
2. Establish Correlations between Density, LWD, and DCP
3. Develop Quality Control Criteria

Materials

2RC (left) and 2A (Right)

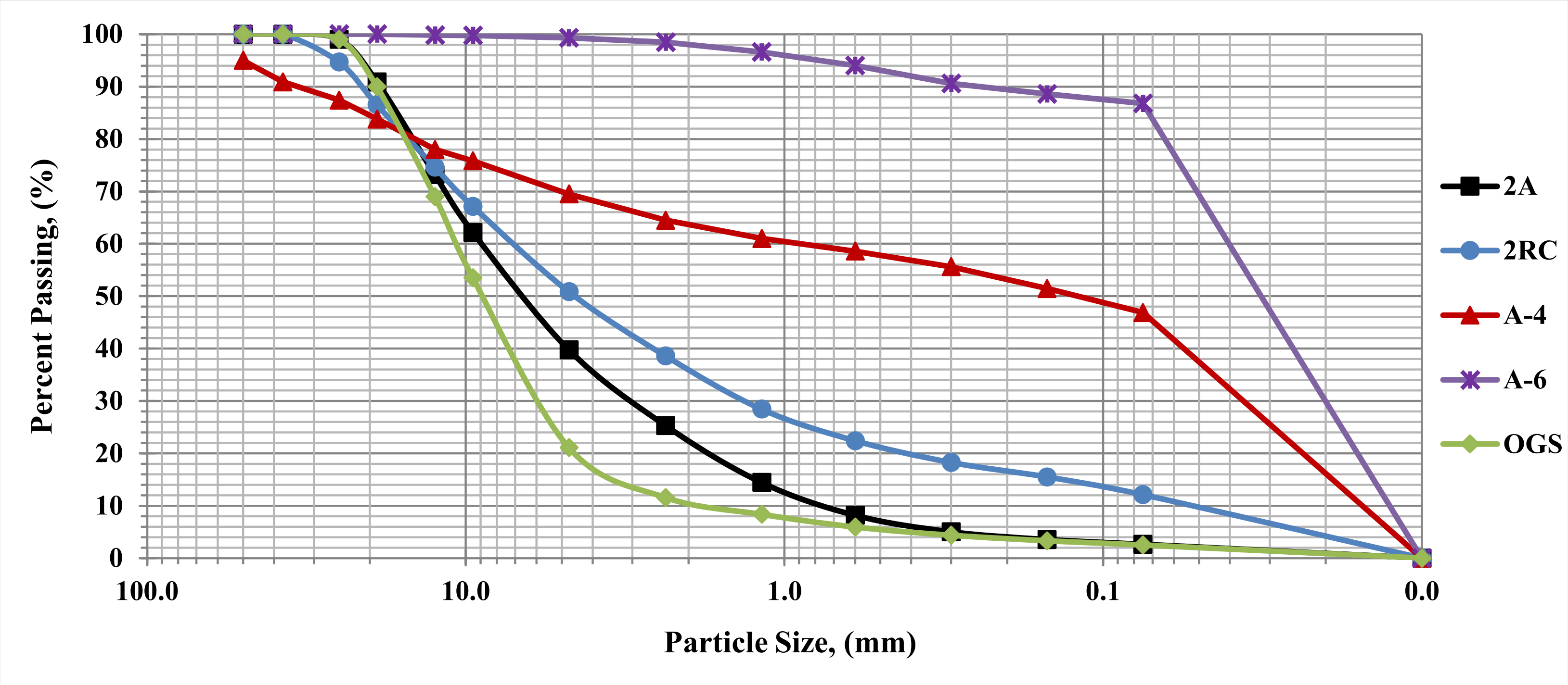
OGS

A-4

A-6

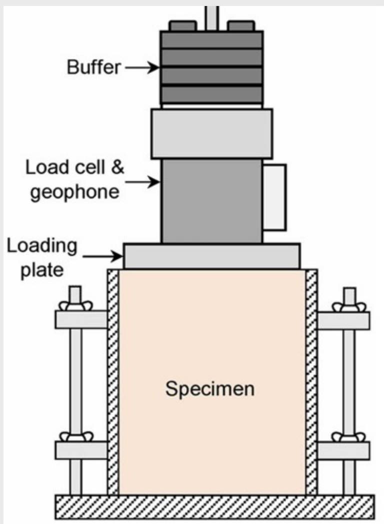
Example for OGS, 2A,2RC, A-4 and A-6 materials

Materials



Gradation for OGS, 2A,2RC, A-4 and A-6 materials

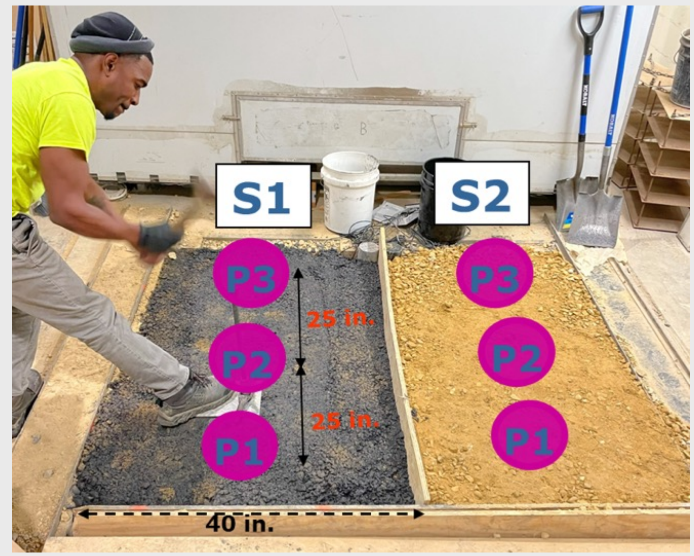
Protocol – Lab Testing



Soil compacted in the Proctor mold: (a) before the LWD test, (b) after the LWD test

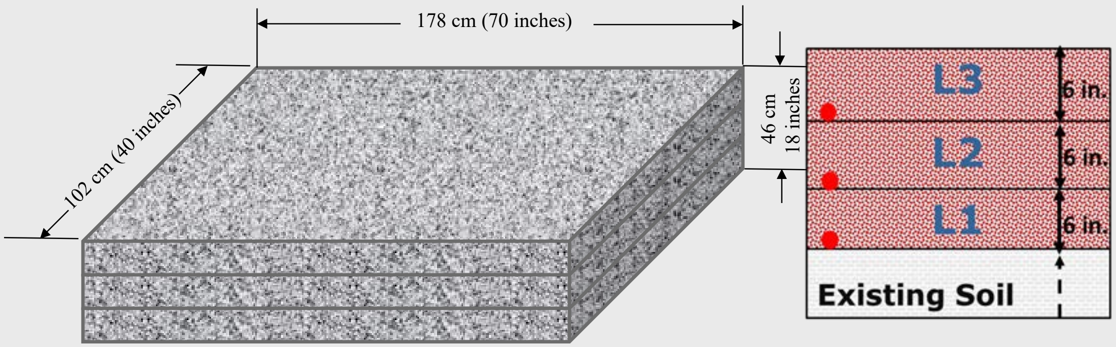
Protocol – Pit Testing

Uniform mixing and vibratory compaction in the pit

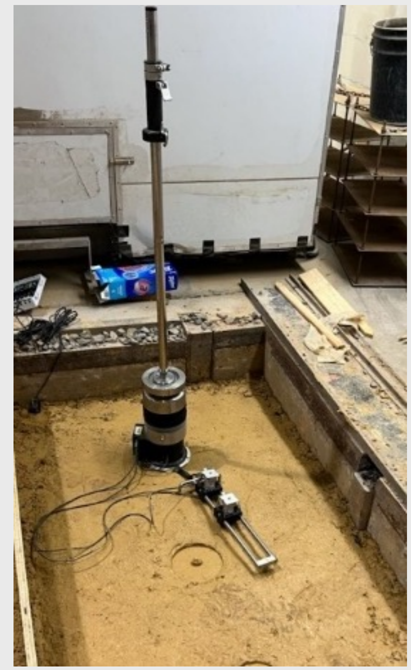


Side by Side aggregates prepared in the test pit showing LWD test locations

Protocol – Pit Testing



Dimensions of the soil after placement and compaction in the test pit



The LWD Testing at the Pit

Protocol – Field Testing

Determination of three spots 3 ft apart longitudinally and LWD Testing

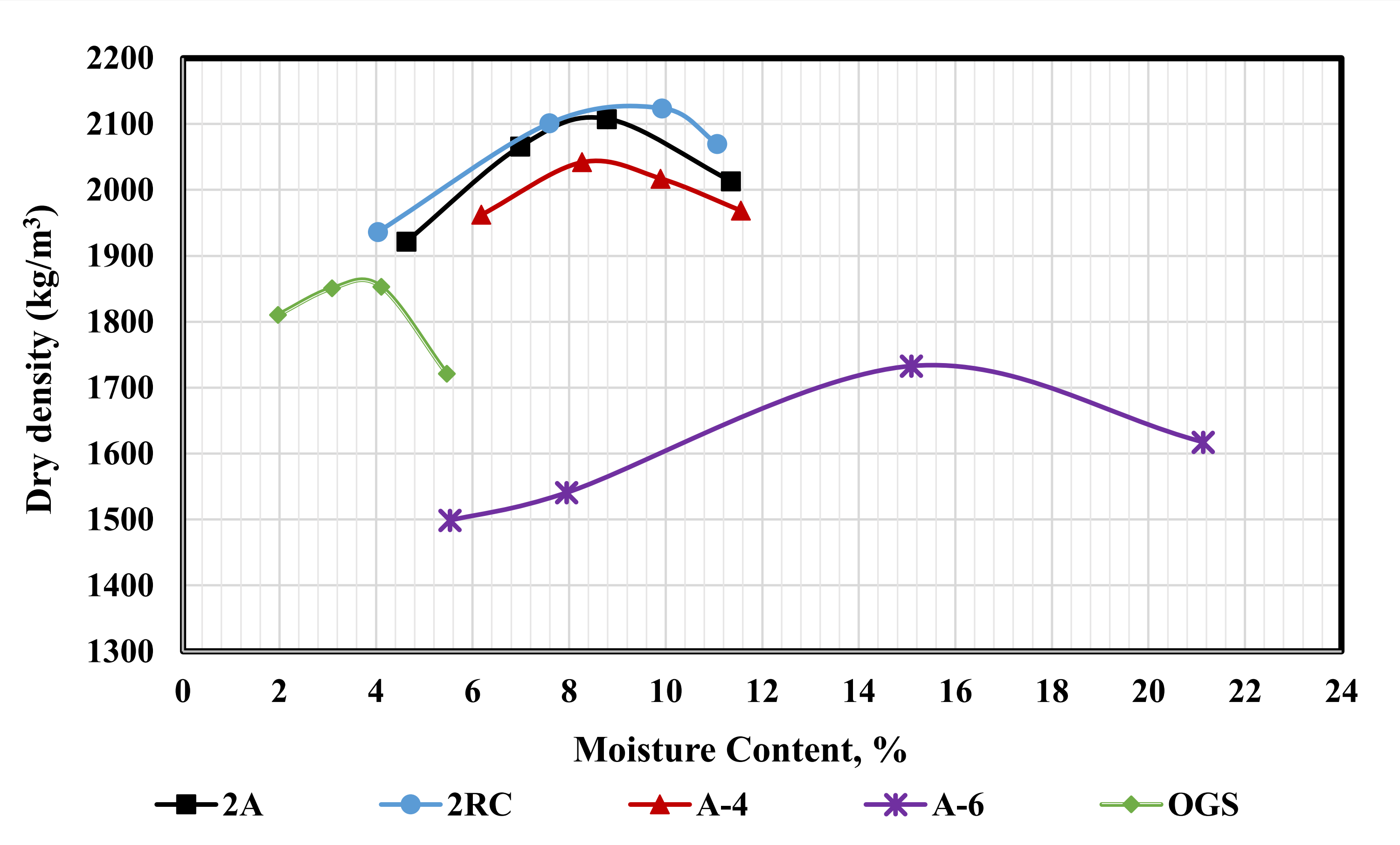
Testing Methods

Methods for this research

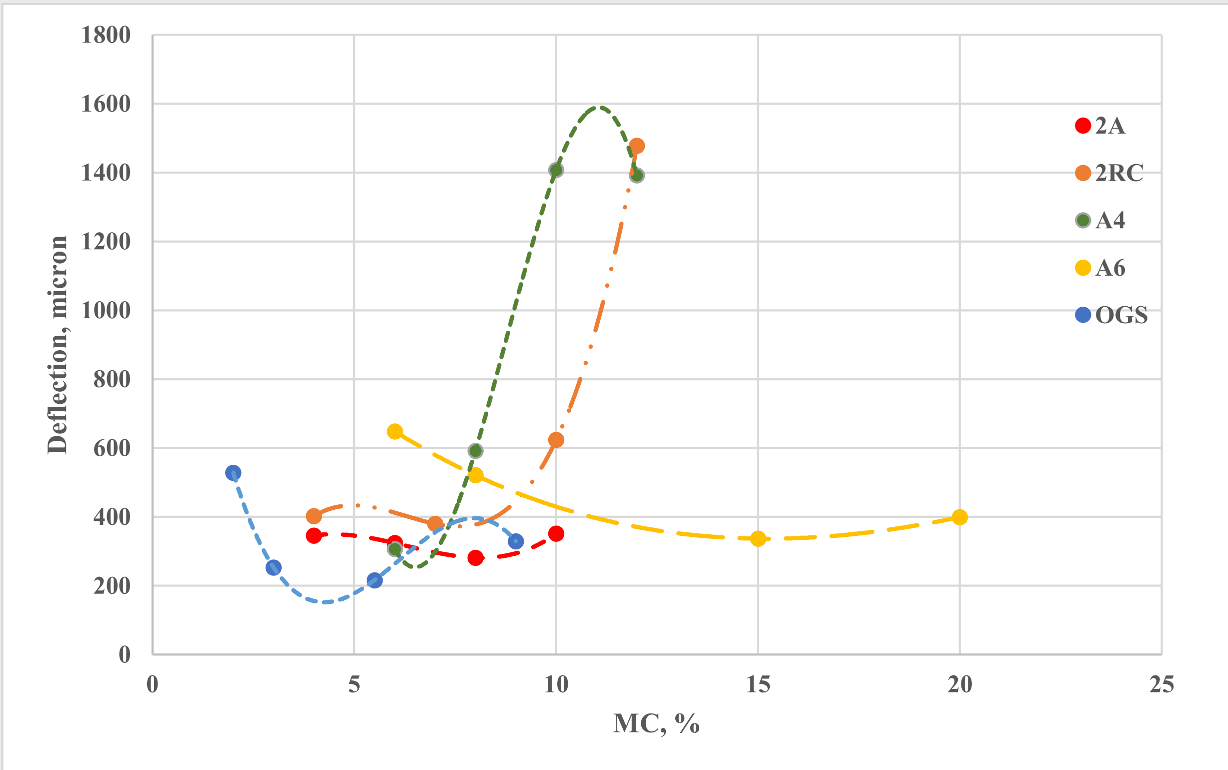
Experiment	Standard	Response
Moisture content	AASHTO T 265	Moisture content
Moisture-density relations	AASHTO T 180 and T 99, Methods B and D	Optimum moisture content and maximum dry density
LWD	ASTM E2583	Deflection and modulus
In-Place density and water content using a nuclear gauge	ASTM D6938	Moisture content and density of the aggregates at the test pit
In-place density	ASTM D1556	Verification of density measures at the test pit

Results

Optimum Moisture Content (OMC)

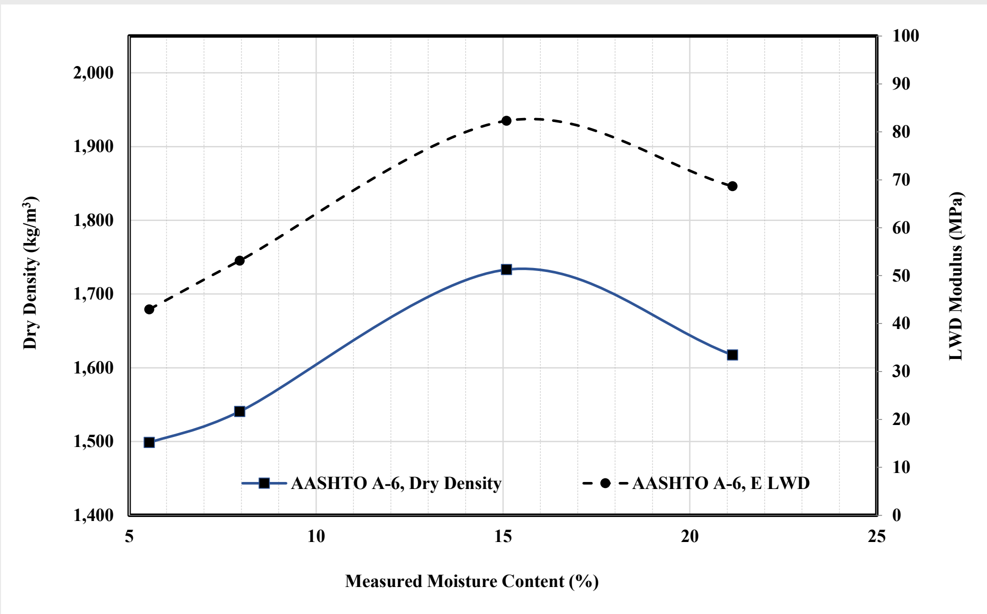


Results

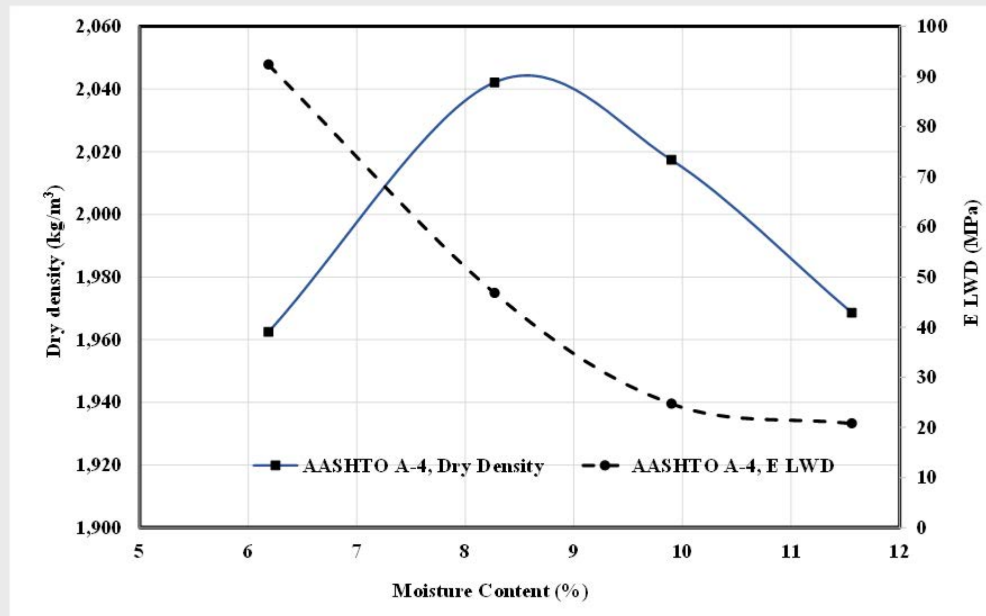


LWD Deflection Values Measured on Proctor Mold Samples at Different Moisture Contents

Dry density and LWD modulus as a function of moisture content

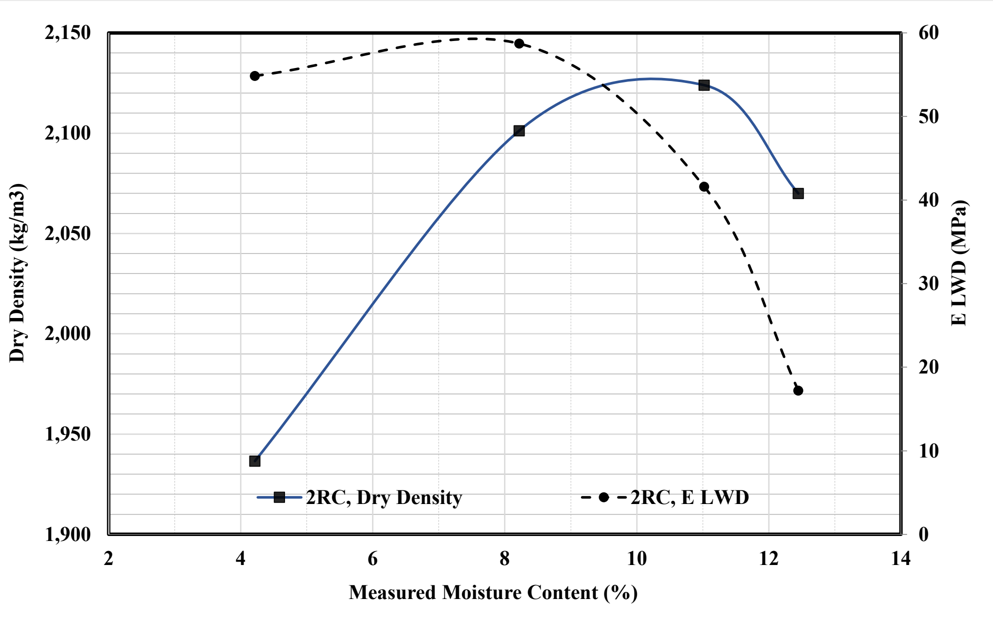


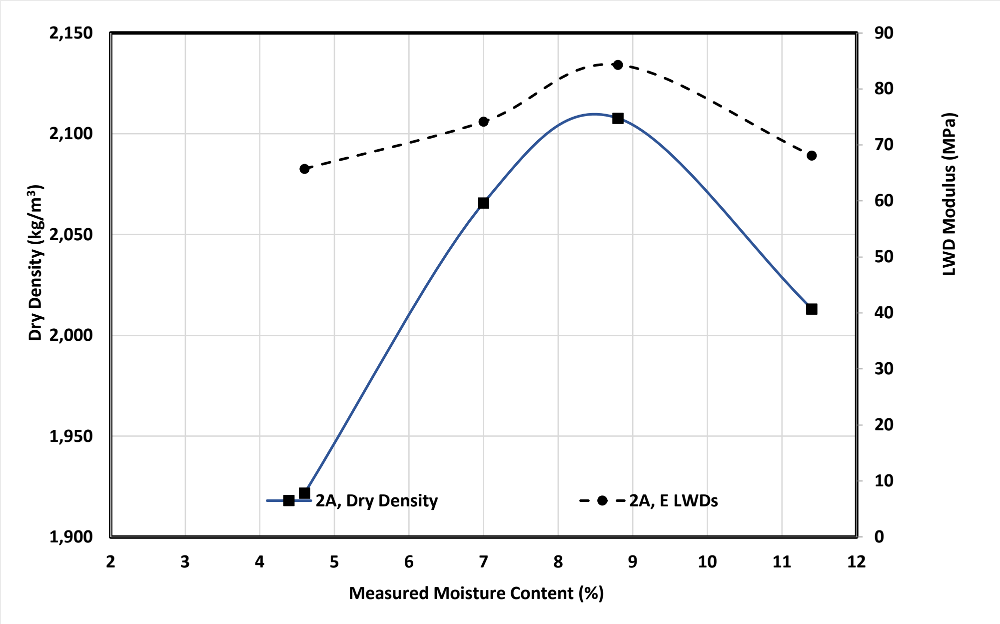
A-6



A-4

Dry density and LWD modulus as a function of moisture content

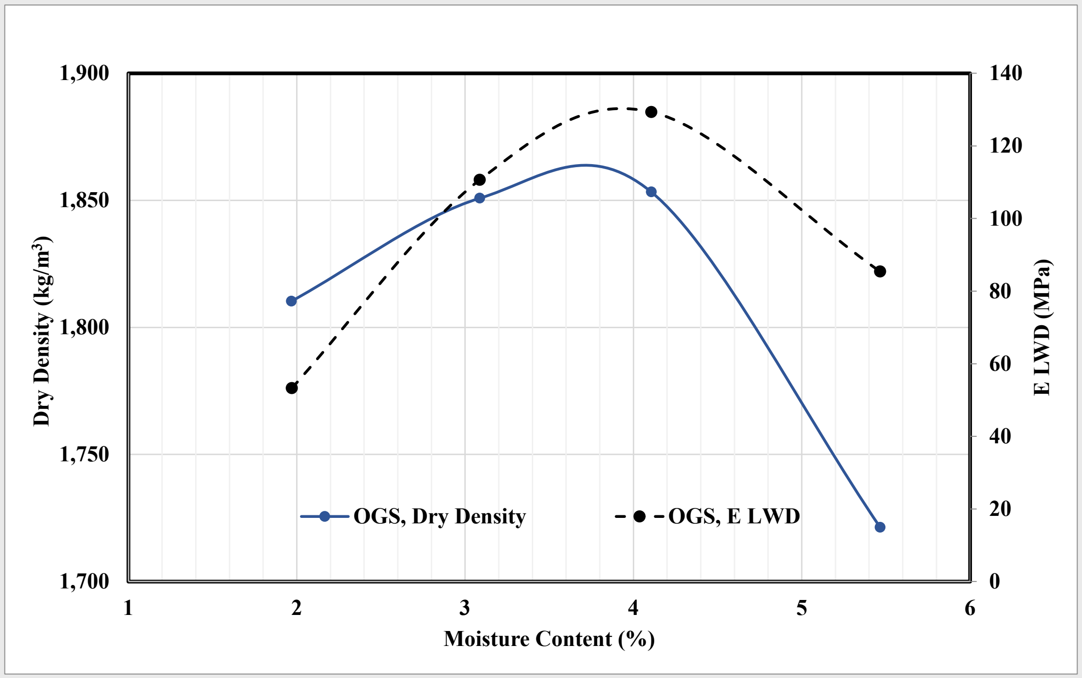




2RC

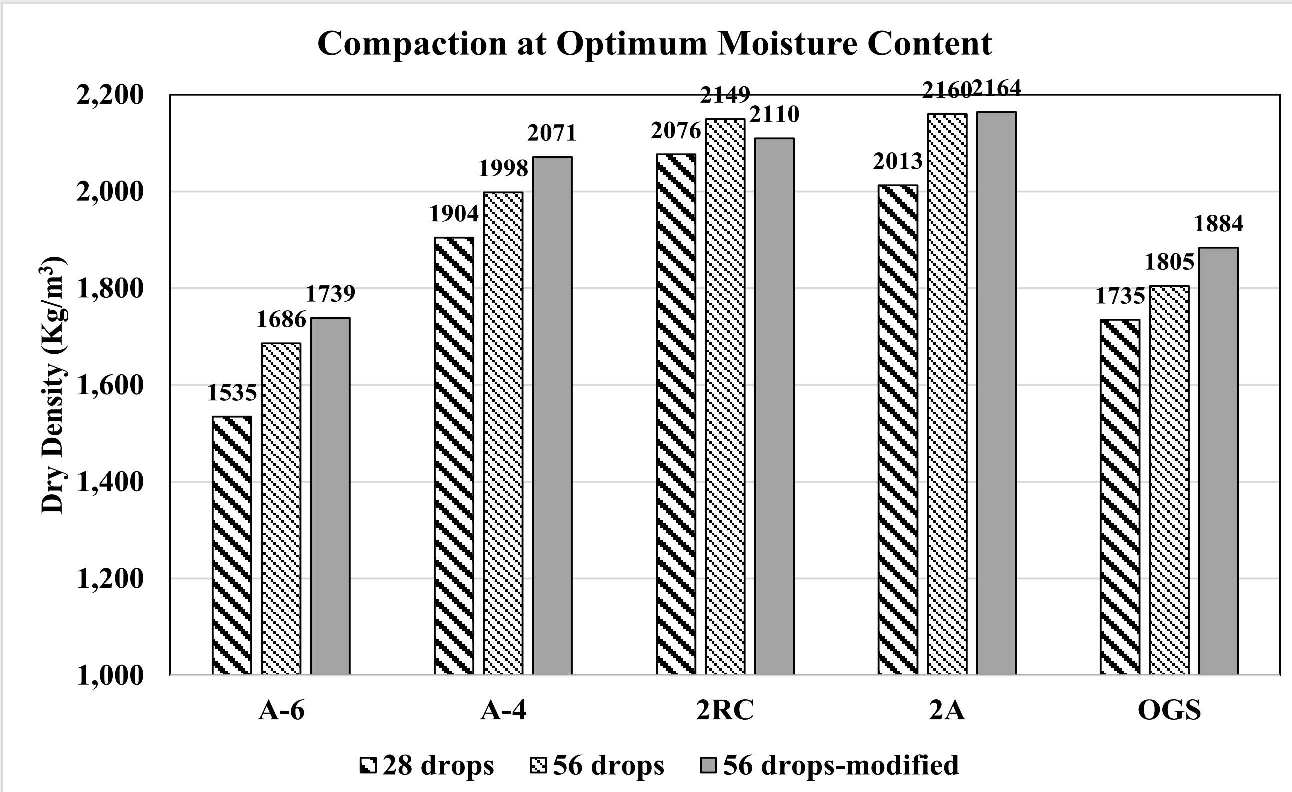
2A

Dry density and LWD modulus as a function of moisture content



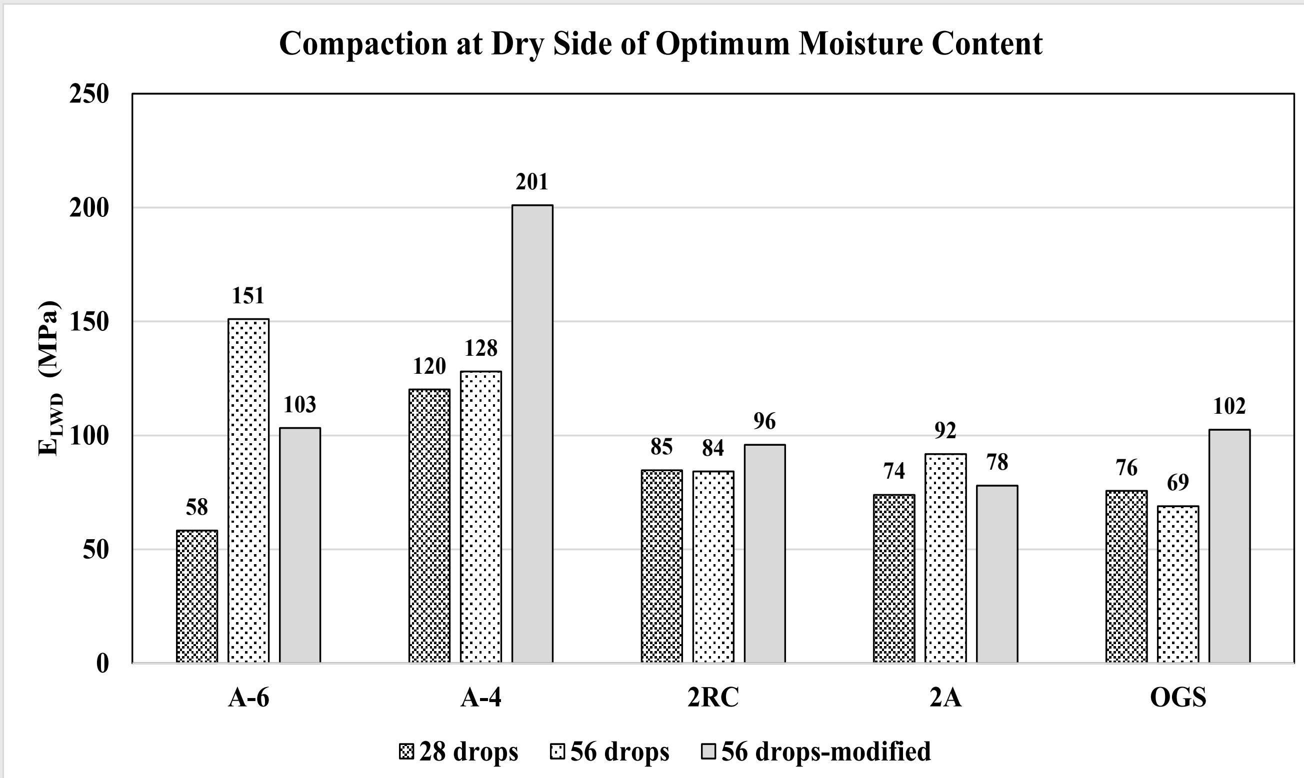
OGS

LWD Test Results: Compaction Energy Effect



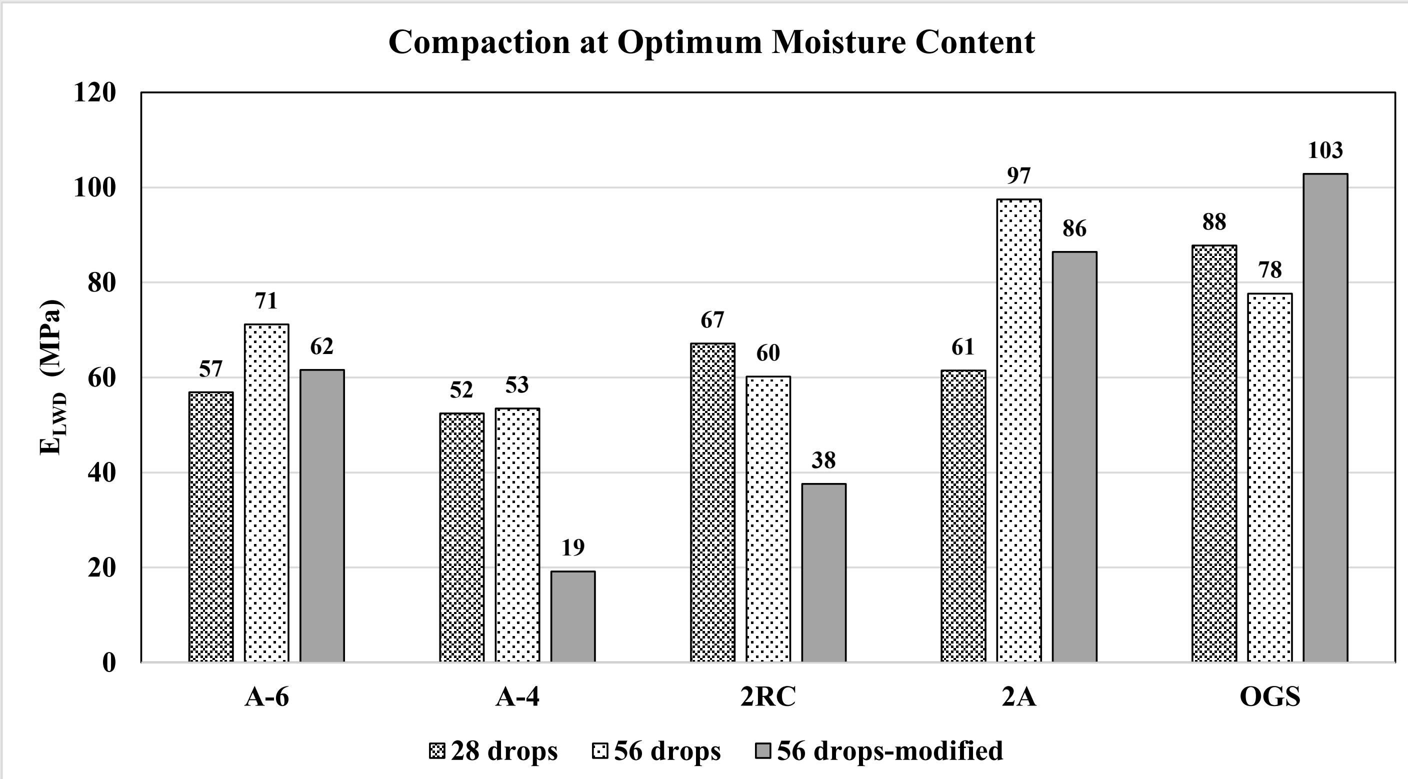
Effect of compaction on dry density at optimum moisture content

LWD Test Results: Compaction Energy Effect



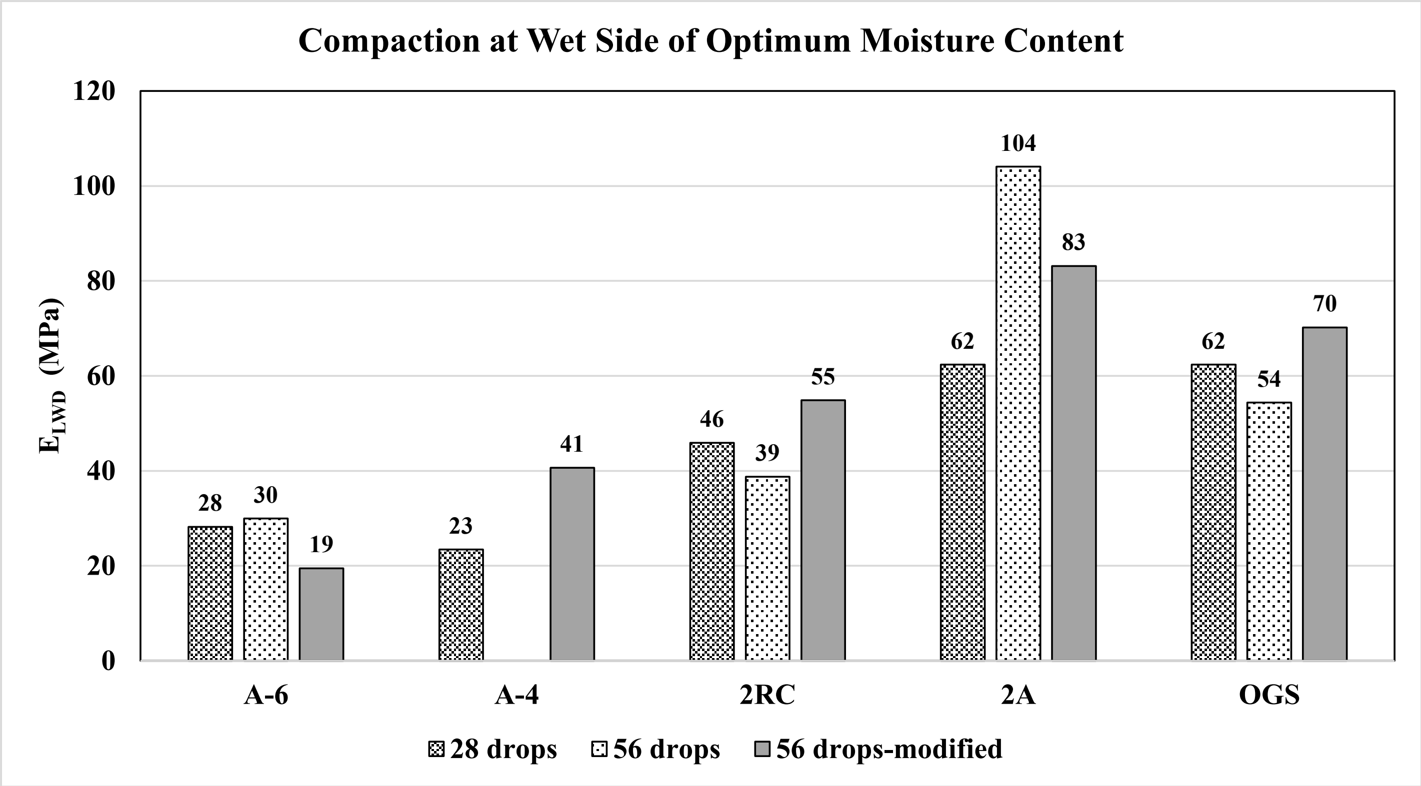
Effect of compaction on the soil LWD modulus at dry side of optimum moisture content.

LWD Test Results: Compaction Energy Effect



Effect of compaction on the soil LWD modulus at optimum moisture content

LWD Test Results: Compaction Energy Effect



Effect of compaction on the soil LWD modulus at wet side of optimum moisture content

Results from Different Test Scales

Laboratory Test Results Using Proctor Mold

Lab	Moisture Content (%)	Average ELWD (MPa)	Deflection (Micron)	Dry Density (kg/m^3)
2RC	4.0	50.7	402	1936.5
	7.6	54.7	380	2101.1
	9.9	36.3	624	2123.9
	11.1	15.7	1478	2069.9
2A	4.6	65.7	346	1921.8
	7.0	74.2	324	2065.7
	8.8	84.3	287	2107.7
	11.4	68.1	346	2013.1
A-6	5.5	43.0	648	1498.5
	8.0	53.1	521	1540.7
	15.1	82.3	337	1733.1
	21.1	68.6	399	1617.4

Results from Different Test Scales

Pit Test Results Under Varying Compaction and Moisture Conditions

Pit	Moisture Content (%)	Average ELWD (MPa)	Deflection Micron	Dry Density (kg/m^3)
2RC	5.6	72.1 (12 passes)	744	2122.6
	7.5	97.6 (12 passes)	533	1960.3
	8.2	106.7 (8 passes)	513	1953.3
2A	5.9	95.2 (12 passes)	551	1917.0
	6.8	100.3(8 passes)	504	1999.3
	8.8	87.7 (4 passes)	591	2118.7

Results from Different Test Scales

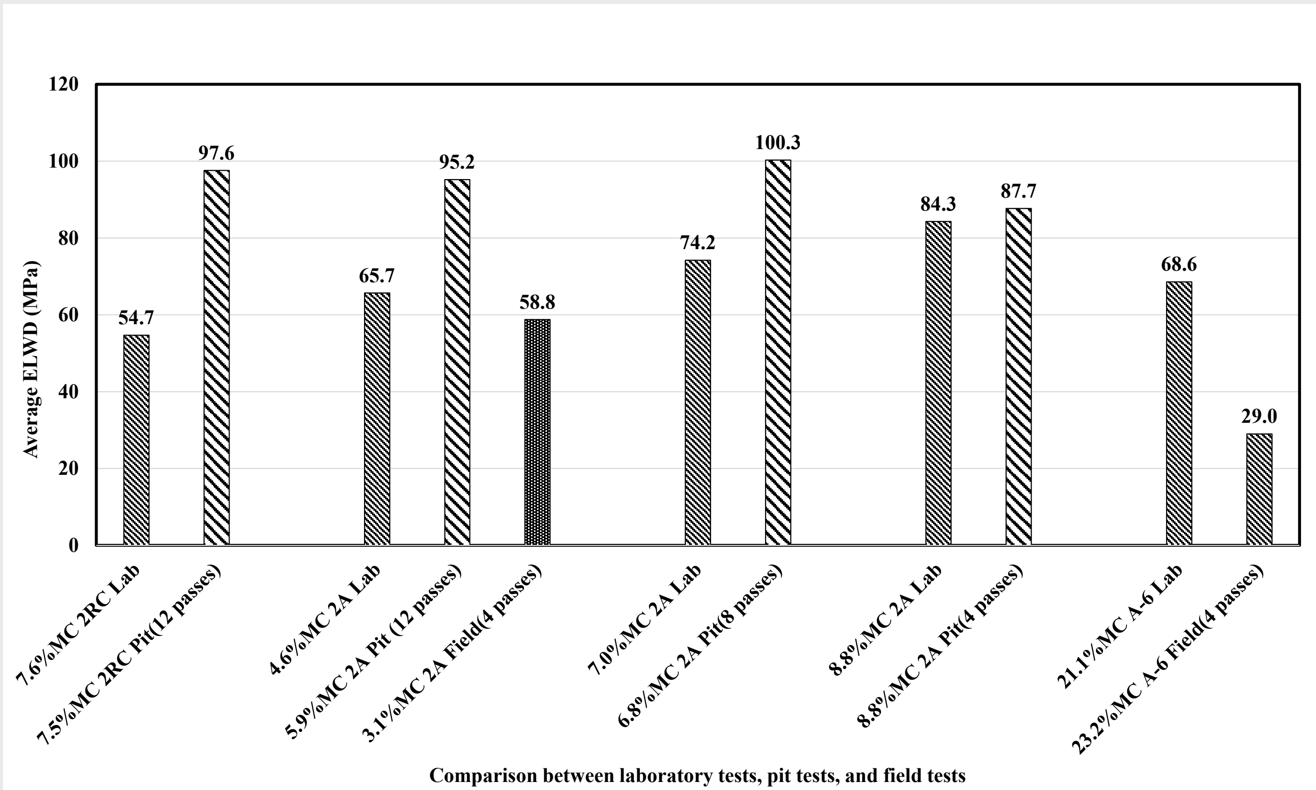
Field LWD Test Results of 2A Material with Different Compaction Passes

Number of passes	Moisture Content (%)	Average ELWD (MPa)	Deflection (Micron)	Dry Density (kg/m^3)
0	3.1	46.0	776.3	2145.9
2		39.9	730.0	2025.2
4		58.8	782.1	1992.6
6		51.1	889.8	1999.0

Field LWD Test Results of A-6 Material with Different Compaction Passes

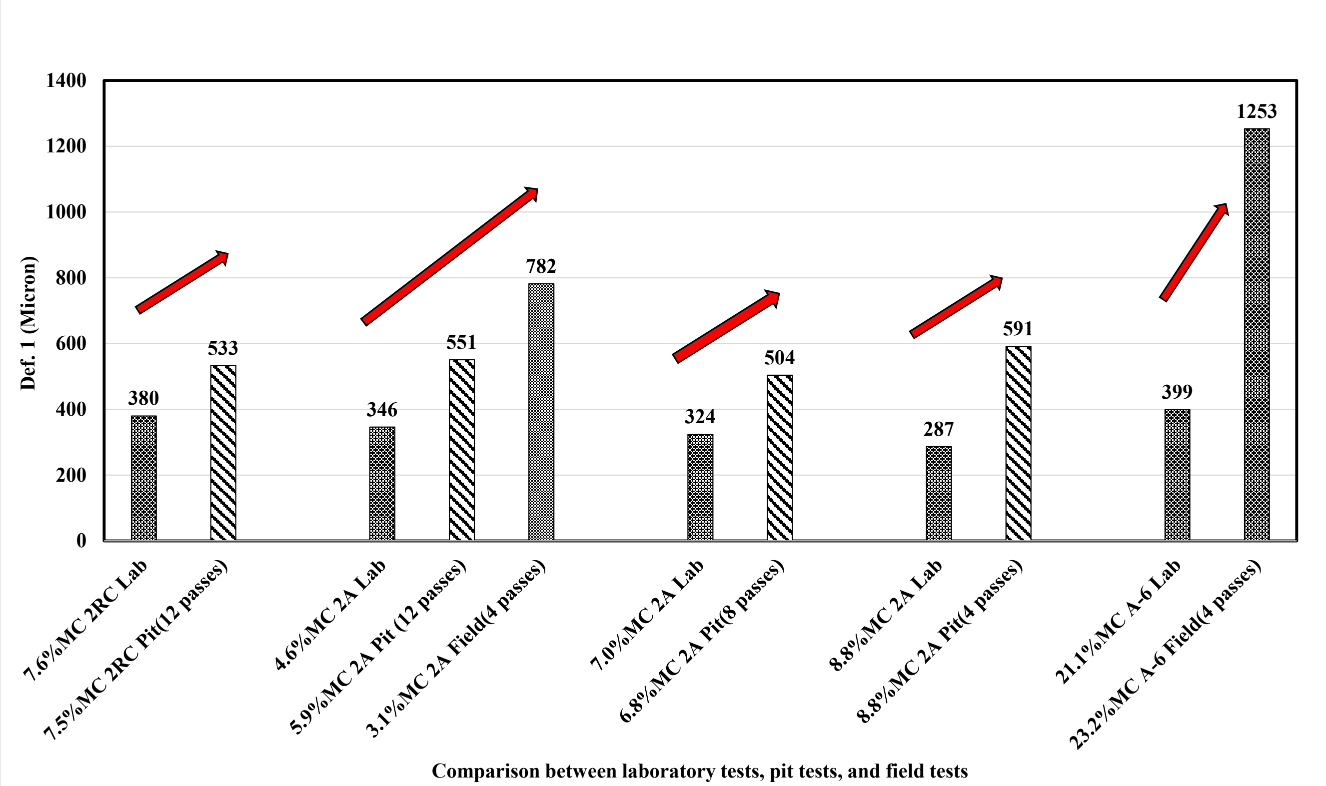
Number of passes	Moisture Content (%)	Average ELWD (MPa)	Deflection (Micron)	Dry Density (kg/m^3)
0	23.2	14.6	2504	1335.9
4		29.0	1253	1524.9
6		27.3	1336	1584.2

Results from Different Test Scales



ELWD comparison between laboratory tests, pit tests, and field tests

Results from Different Test Scales



LWD Deflections comparison between laboratory tests, pit tests, and field tests

Results from Different Test Scales

$$k_1 \times Value_{lab} \approx Value_{pit} \leq Value_{field} \approx k_2 \times Value_{lab}$$

Correction Factor k_1 (Lab → Pit):

The average correction factor was calculated as $\boldsymbol{k_1}$= 1.65

This value reflects the reduced confinement in pit conditions compared to the rigid boundary of Proctor molds and can be used to infer typical in-situ performance from lab results.

Correction Factor k_2 (Lab → Field):

The average correction factor was calculated as $\boldsymbol{k_1}$= 2.70

This value can be used to identify maximum allowable deflections under realistic field compaction conditions.

Conclusion

Key Findings from Laboratory LWD Testing:

- ❑ **Soil type affects LWD; fine soils work better when drier.**
- ❑ **No clear density–modulus link; moisture dominates effect.**
- ❑ **Lab floor makes deflection lower than field values.**
- ❑ **Lab data useful for estimating field deflection.**
- ❑ **Higher compaction lowers deflection; over-compaction may reverse it.**

Conclusion

Key Findings from Different Test Scales :

- ❑ Moisture effect: ELWD increases with moisture up to optimum, then declines.
- ❑ Material difference: 2A shows higher stiffness than 2RC.
- ❑ Scale effect: Deflection increases from lab → pit → field due to confinement differences.
- ❑ Method limitation: Simplified ELWD formula misses nonlinear/plastic soil behavior.
- ❑ Correlation & correction: Empirical factors ($k_1 \approx 1.65$, $k_2 \approx 2.7$) bridge lab–field deflection gap.

Recommendations for Future Work

- **Lab Work: Use larger molds for better test stability. Study more soil variations.**
- **Test Pits: Test more soil types in test pits to improve data reliability.**
- **Layered Systems: Study how different soil layers and geocomposite materials interact.**
- **Field Projects: Include more field projects, as this data is most critical for quality control.**

Thank you