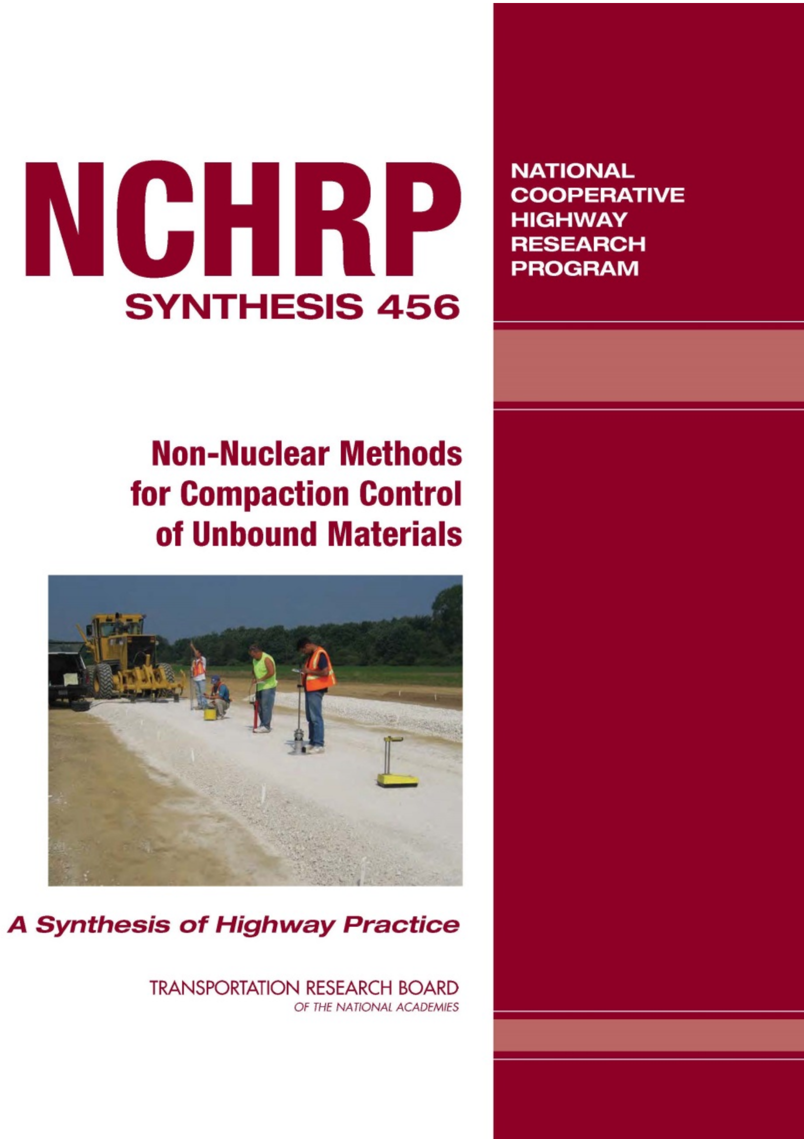
Non-Nuclear Methods for Compaction Control of Unbound Materials

- **Overview or NCHRP Synthesis 456 – Munir Nazzal**
- **Indiana Stiffness/Strength-based Compaction Control Specs – Nayyar Siddiki**
- **Compaction Control Today and Anticipating the Future – John Siekmeier**



Related Efforts

- **NCHRP Project 10-84 – Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate**
  - Research Results Digest 391

- **TPF Project 5 (285) – Standardizing LWD Measurements for QA and Modulus Determination in Unbound Bases and Subgrades**

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).

CONTENTS

INTRODUCTION

Earthwork and unbound aggregates, collectively called compacted geomaterials, are a significant portion of the construction of pavements. Much of the distress observed in pavements, particularly in flexible pavements, can be traced to problems in geomaterials. Good pavement performance can only be assured with (1) appropriate process control to ensure the geomaterials used are similar to the ones selected, (2) proper processing of the material to ensure that the material is uniformly mixed and contains an appropriate amount of moisture before compaction, and (3) adequate compaction equipment to ensure proper density and stiffness. Currently, the nuclear density gauge is the primary tool for quality management to ensure that appropriate density. Despite the importance of moisture content at the time of compaction to the quality of the final product, not all highway agencies include moisture content in their specifications. However, measurement of moisture content and dry density does not directly tie the construction quality to mechanistic-empirical (ME) design processes where stress and modulus are key input and output parameters. In-situ nondestructive testing (NDT) devices that estimate the stiffness parameters of a constructed pavement structure are now commonly available. Such stiffness parameters provide a direct link to the pavement performance predicted through a mechanistic-empirical based design process. Transformation from a density-based to a modulus-based quality assurance approach involves technical and organizational challenges that must be recognized and addressed in order to develop an efficient, practical modulus-based specification.

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Results of NCHRP Synthesis Report 456 On Compaction Control Of Geo-Materials

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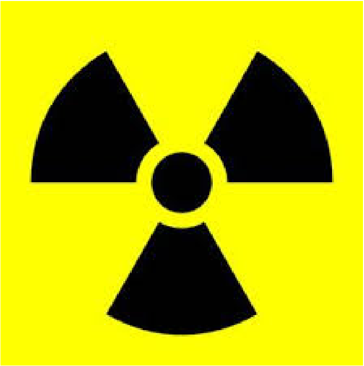
Outline

- Introduction
- Overview of NCHRP Synthesis 456
- Review of DOTs Compaction Control Specifications
- Non-nuclear Density Devices
- Devices for In Situ Stiffness/Strength Measurement
- Stiffness/Strength Based Specifications
- Conclusions

Introduction

- Compaction is the process by which soil particles are rearranged and packed together to:
  - ✓ Improve stiffness and strength
  - ✓ Reduce excessive settlement
  - ✓ Decrease the susceptibility of to environmental changes, especially those caused by frost heave, swelling, or shrinkage
- Proper compaction of unbound materials is one of the most critical components in the construction of unbound layer to ensure their adequate performance, durability, and stability.
- DOTs assess the quality of compaction by comparing their field density to a target dry density value typically determined by conducting a specified laboratory standard compaction test.

Introduction



- The nuclear density gauge (NDG) is the device used by most state DOTs for measuring the field density of compacted layers of unbound materials.
- This device contains radioactive materials that can be hazardous to the health and well-being of the operators.
- It entails intense handling, storage, calibration, maintenance, and transportation regulations.
- The costs associated with owning, operating, licensing, transporting and maintaining NDG can be also prohibitive.

Item	Cost*
Cost of nuclear gauge	$6,950
Radiation safety & Certification Class	$750
Safety training	$179
HAZMAT certification	$99
RSO training	$395
TLD Badge monitoring	$140/year
Maintenance & Recalibration	$500/year
Leak test	$15
Shipping	$120
Radioactive Materials License	$1,600
License Renewal	$1500/year
Reciprocity	$750

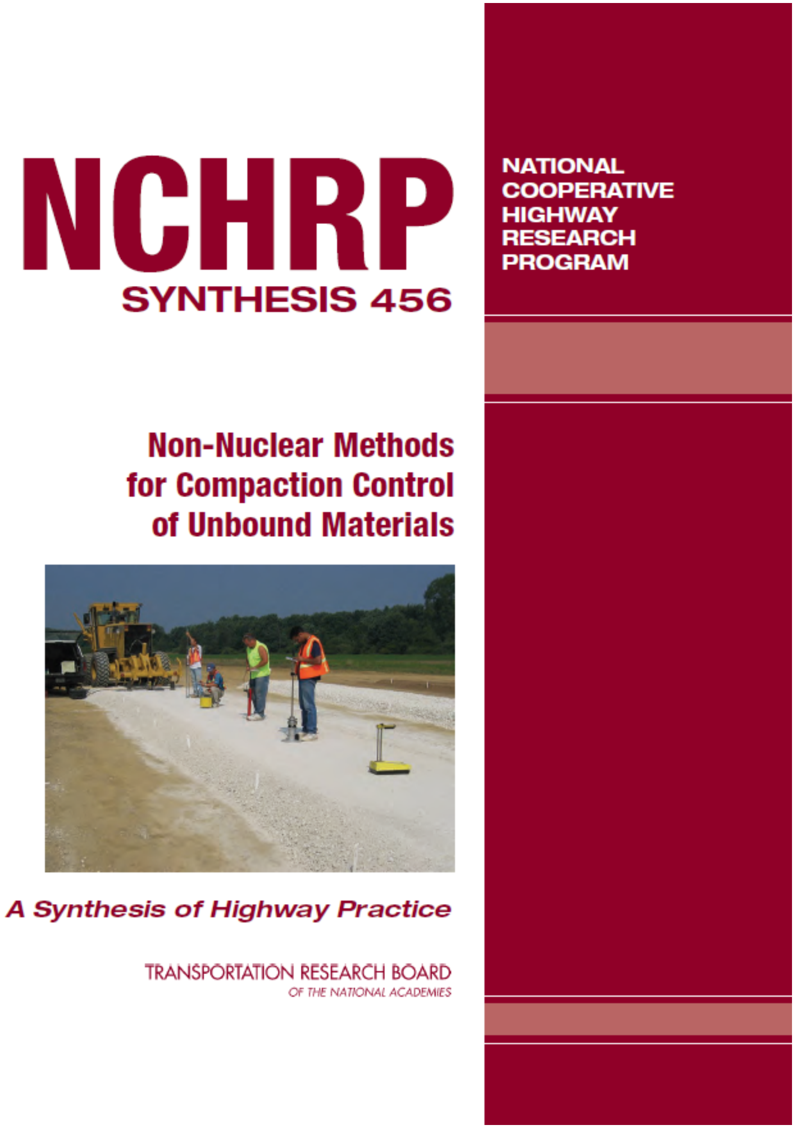
***Cho et al. (2011)**

Introduction

- Compaction control based on density presents several challenges:
- **From inspectors perspective :**
  - ✓ Target density value is determined using a very small sample
  - ✓ Test methods to determine target density do not accurately represent the compaction energy levels applied in the field
- **From the design and performance perspective:**
  - ✓ The main purpose of compaction is to improve their engineering properties, not only their density.
  - ✓ The key functional properties of unbound layers are their stiffness and strength, which are typically used in the design of different transportation structures

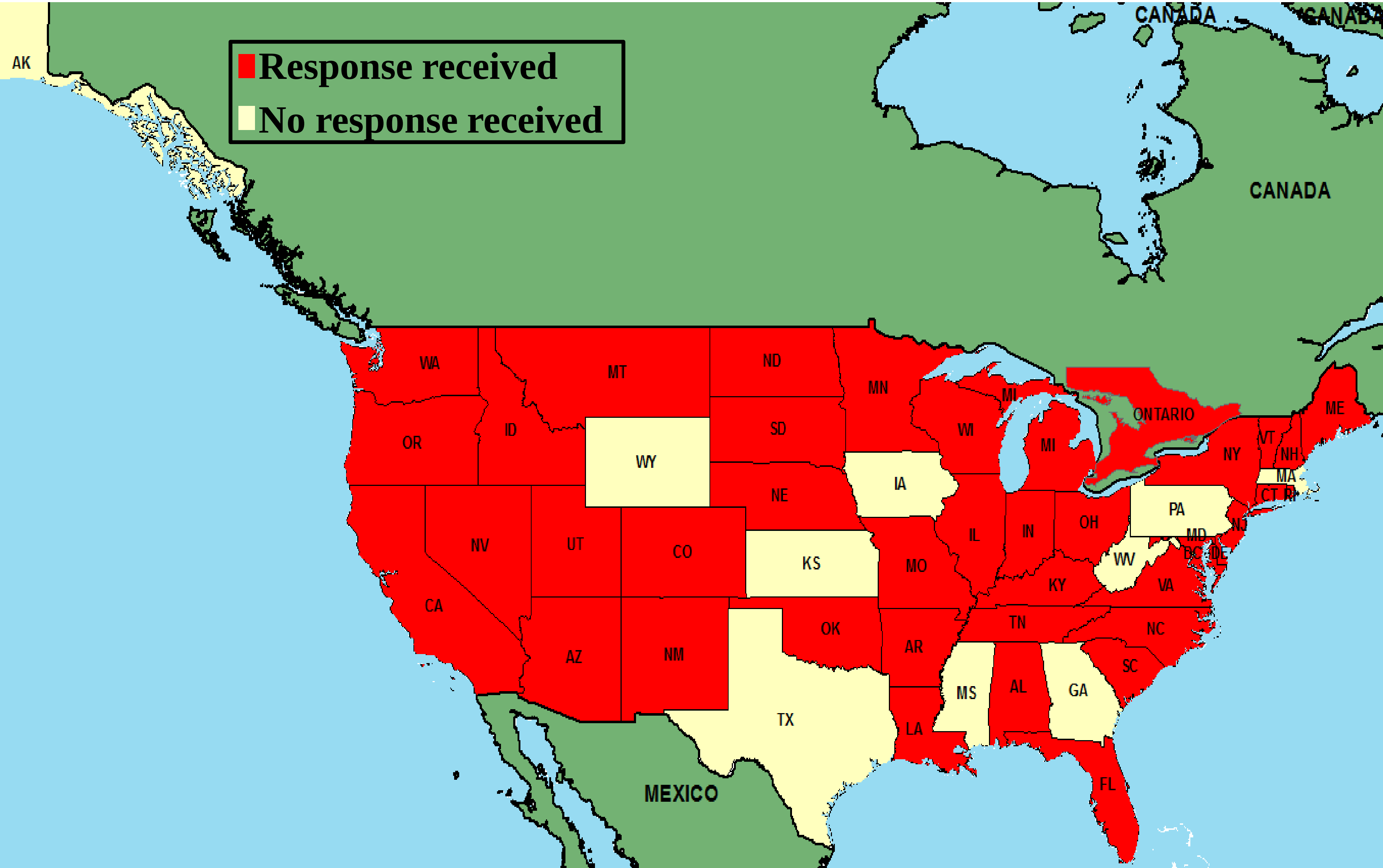
Consequently, there is currently a missing link between the design and compaction quality control processes.

NCHRP Synthesis 456 Overview



- Review current state of practice for compaction control of geo-materials.
- Summarize all information on the various non-nuclear devices and methods used for compaction control of geo-materials based on:
  - ✓ Density measurement
  - ✓ stiffness/strength-related properties
- Review of stiffness/strength-based specifications that have been developed and implemented by state DOTs for compaction control to geo-materials

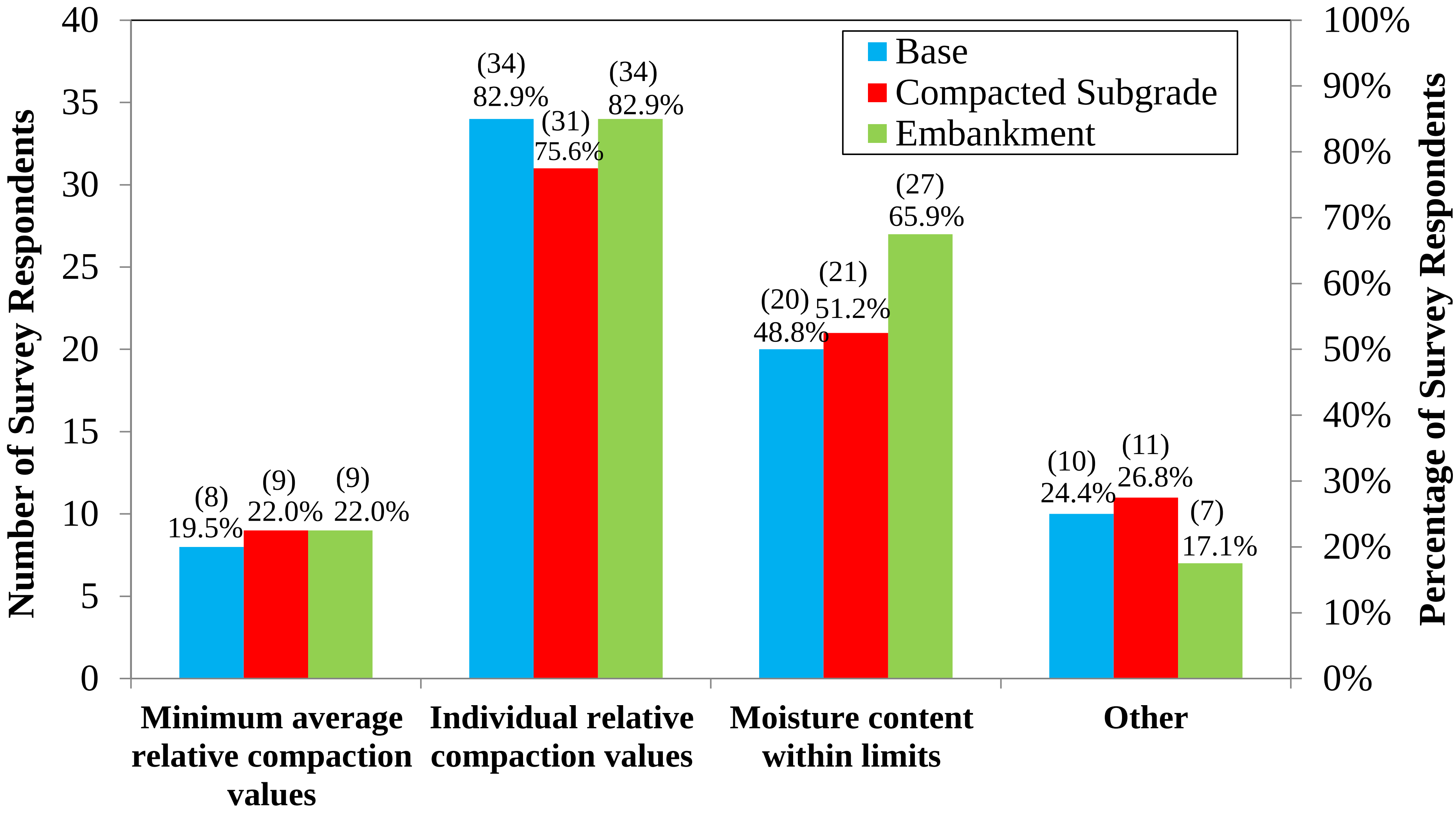
NCHRP Synthesis 456 Overview



Review of DOTs Compaction Control Specifications

Compaction Control Specifications

Review of DOTs Compaction Control Practices of Geo-Materials



Target Density Value Selection

1. Impact Compaction Laboratory Methods

- ✓ Are the most commonly used to determine the target field density value.
  - ASTM D 698 or AASHTO T 99 (standard effort)&ASTM D 1557 or AASHTO T 180 (modified effort)
- ✓ Do not accurately represent the compaction energy levels currently applied in the field
- ✓ Can only be conducted on materials below grain size 3/4 inch
- ✓ If the particles in excess of this size is included, corrections need to be applied using AASHTO T224.
- ✓ This correction cannot be applied if the tested materials have more than 30% by mass of its particles larger than 3/4 inch.

Target Density Value Selection

2. Static Compaction Laboratory Method

- ✓ Has not been widely used since static pressure was not found to be effective in compacting granular materials
- ✓ Currently there is no standard procedure

3. Vibratory Compaction Laboratory Method

- ✓ This method was reported to produce consistently higher maximum densities for granular materials than the impact compaction method and also better replicates of field.
- ✓ Some studies indicated that it can be effective in cohesive soils if compacted at low frequencies.
- ✓ Only two state DOTs (Kansas and Alabama) reported the use of this method for unbound aggregate materials.

Target Density Value Selection

4. Gyratory Compaction Laboratory Method

- ✓ Introduced by the U.S. Army Corps of Engineers.
- ✓ Involves applying a controlled normal force to both the top and bottom of the sample at a constant gyration rate.
- ✓ Currently, there are no standard values available
- ✓ Different gyratory compaction parameters were used in previous studies.

Study	Vertical Stress (kPa)	Gyration angle	No. of Gyrations	Soil type
Smith (2000)	1380	1.0	30-40	Crushed stone
Ping (2003)	2000	1.25	90	Fine sand
Kim and Labuz (2006)	6000	1.25	50	Recycled material
White et al. (2007)	6000	1.25	50	Granular and cohesive soils

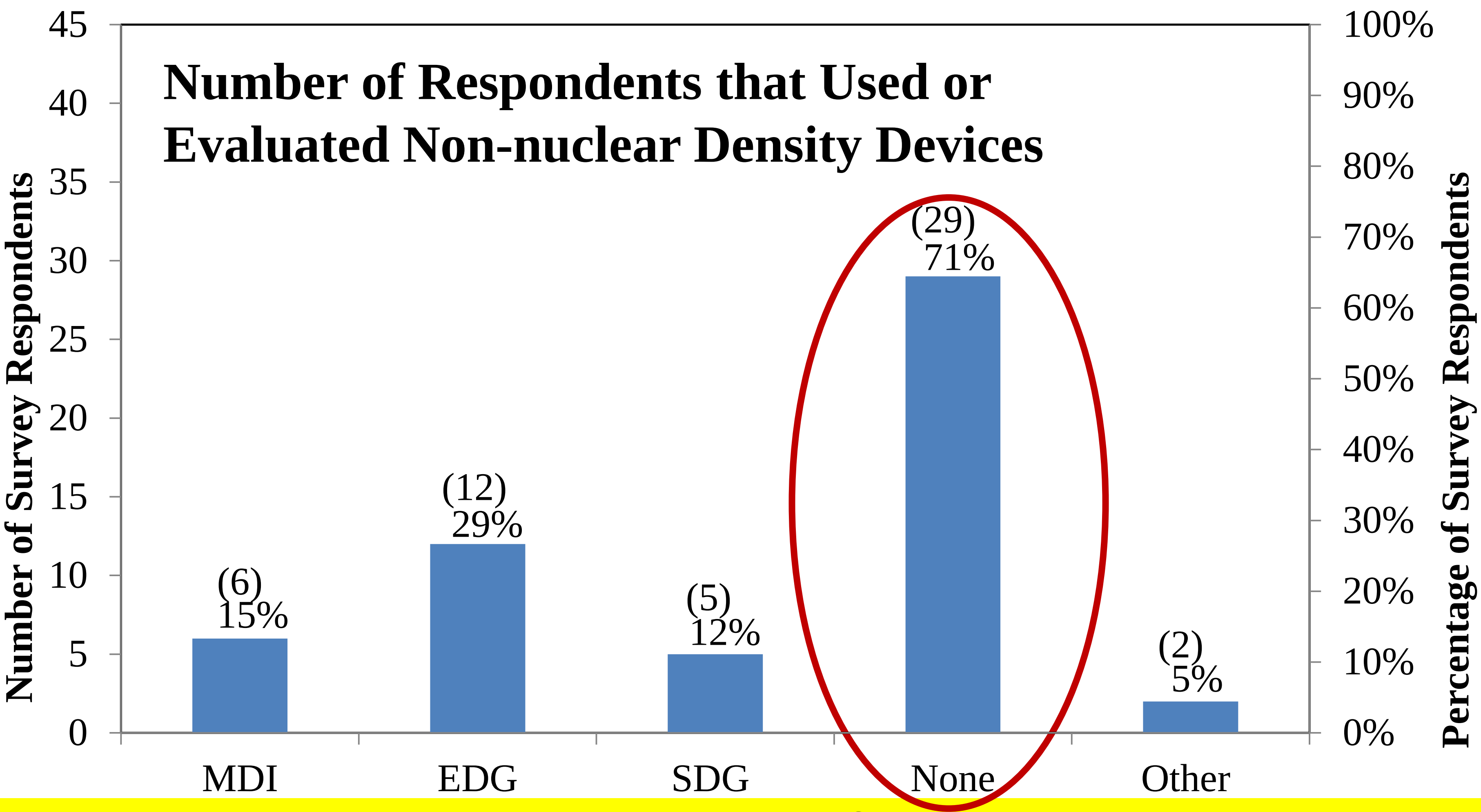
Target Density Value Selection

5. Test Strip Method

- ✓ Used to determine the maximum target density value as well as the roller type, pattern, and number of passes.
- ✓ Test sections are typically constructed every 1500 to 4000 yd^3 or where the compacted material changes significantly.
- ✓ Field density and moisture measurements are obtained at three or more randomly selected locations after each pass until no significant increase in density is observed. The average final density is used as the maximum target density.
- ✓ Usually agencies specify that lifts must be compacted to a certain percentage of this maximum density.
- ✓ Several DOTs have specifications for using control strips in their compaction control procedures for geo-materials.

NON- NUCLEAR DEVICES FOR DENSITY MEASUREMENTS OF GEO-MATERIALS

Non-Nuclear Density Devices



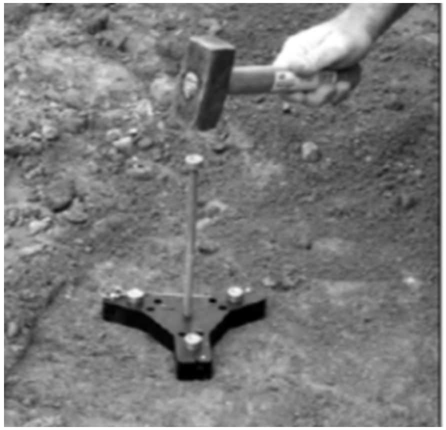
There is consensus among respondents for not recommending using any of the available non-nuclear density devices

Electrical Density Gauge (EDG)

Test Method	Electrical
Standard	None
Measurement	γd, w
Calibration of Device	Field calibration using direct measurement of γd, w
Portability	Medium
Durability	Good
Operator skill	Moderate
Ease of use-Training	Difficult
Initial Cost	$9,300
Data Storage	Yes
Repeatability	Mixed Results
Accuracy	Mixed Results
Main Limitations	-Complex and time consuming -NDG is required for calibration -Cannot test highly plastic clay

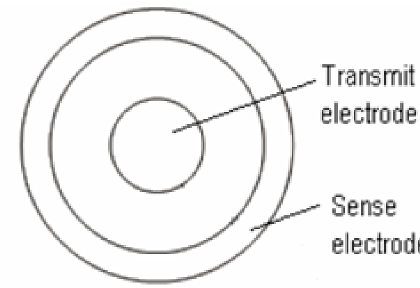
Moisture Density Indicator (MDI)

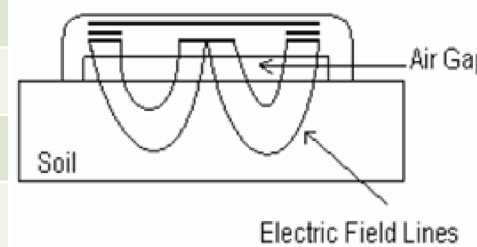
Test Method	Electrical
Standard	D 6780
Measurement	γd, w
Calibration of Device	Laboratory testing in Proctor mold
Portability	Medium
Durability	Good
Operator skill	Moderate
Ease of use-Training	Difficult
Initial Cost	$6,000
Data Storage	Yes
Repeatability	Good
Accuracy	Mixed Results
GPS	No
Main Limitations	-Complex and time consuming -Cannot test highly plastic clay.



Soil Density Gauge (SDG)

Test Method	Electrical
Standard	None
Measurement	γd, w
Calibration of Device	Field calibration using direct measurement of γd, w
Portability	Good
Durability	Good
Operator skill	Extensive
Ease of use-Training	Difficult
Initial Cost	$10,000
Data Storage	Yes
Repeatability	*
Accuracy	*
GPS	Yes
Main Limitations	-Extensive operator training



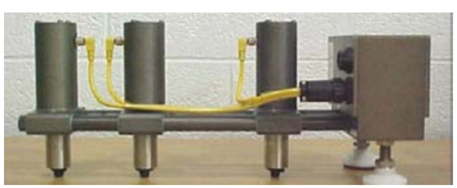


Methods for
In Situ Stiffness/Strength Measurement

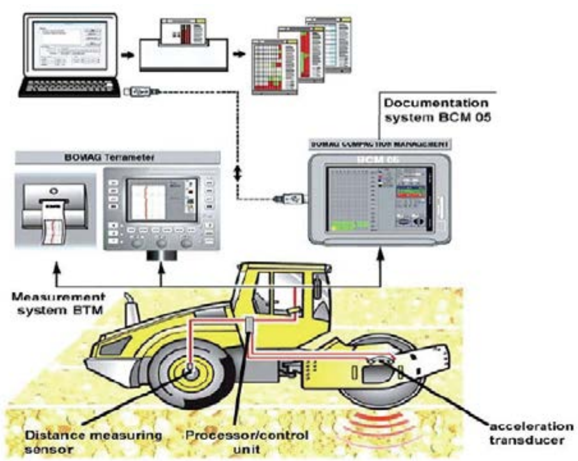
In Situ Stiffness/Strength Devices

In Situ Stiffness/Strength Devices

Spot In-situ Tests



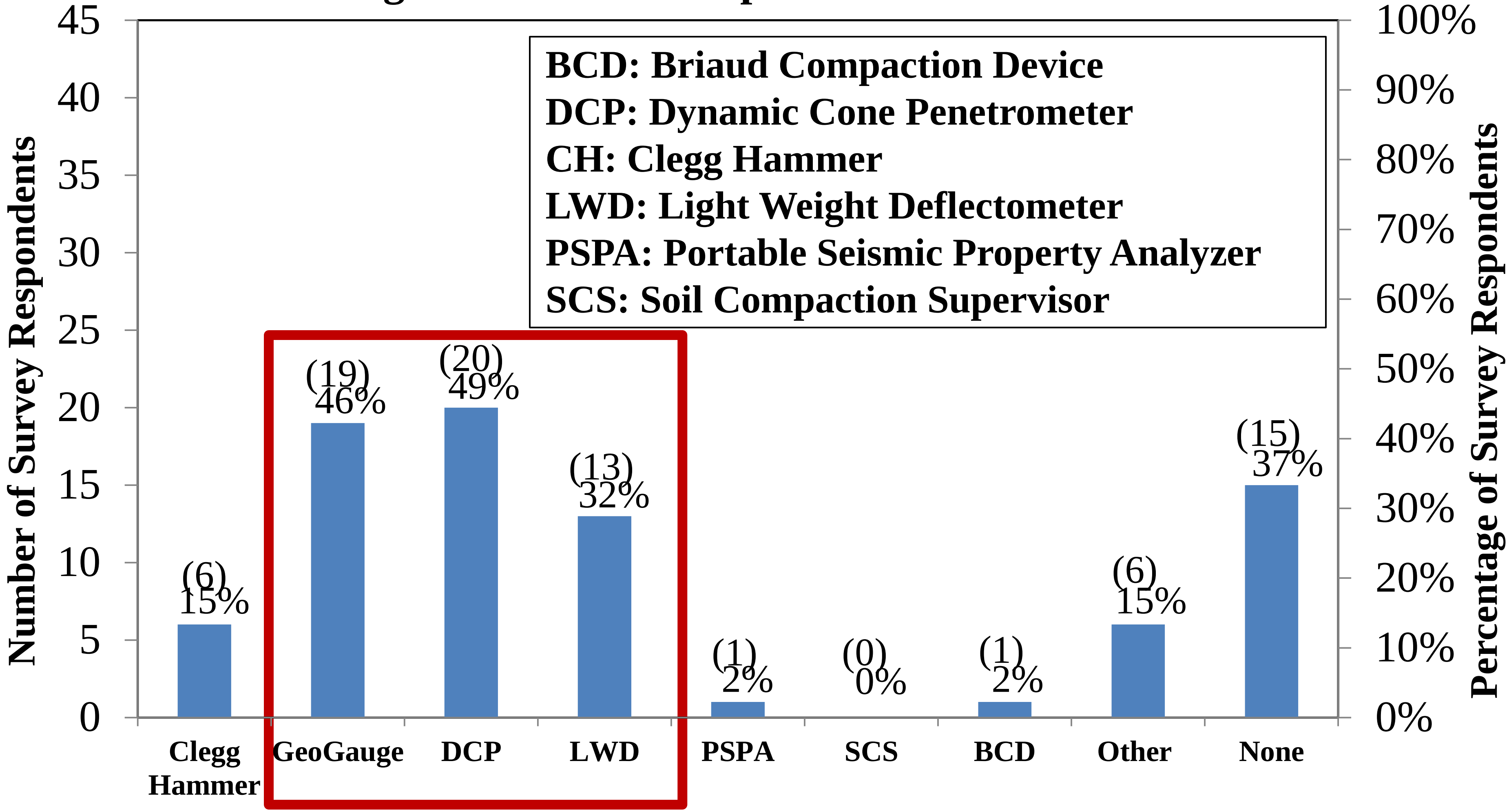
Continuous compaction control Intelligent compaction



(Courtesy of Bomag)

In Situ Stiffness/Strength Devices

Number of respondents that used or evaluated in situ stiffness/strength devices for compaction control



Dynamic Cone Penetrometer (DCP)

ASTM Standard	D6951
Measurement	DPI
Moisture Measurement	No
Calibration of Device	None
Portability	Good
Durability	Good
Ease of use/Training	Easy-minimal
Initial Cost	$1,000
Influence Depth (inch)	48
Repeatability	Good
Main Strengths	- Simple, quick for shallow depth - Economical -Assess up to 4ft thick layers -Strong correlation with CBR & M_r -Used in Many DOTs
Main Limitations	-May require 2 persons -Max. allowed particle size is 2 in. -Deeper testing can take up to 15 min

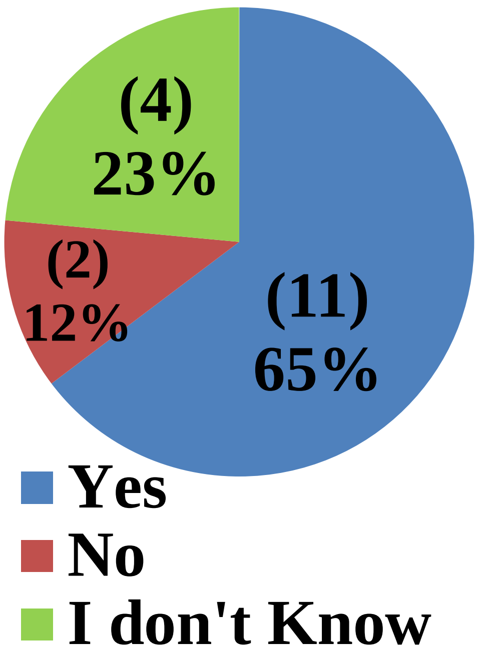
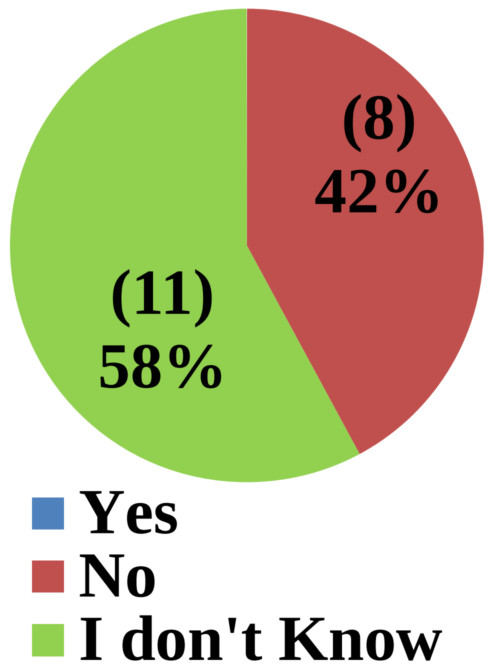
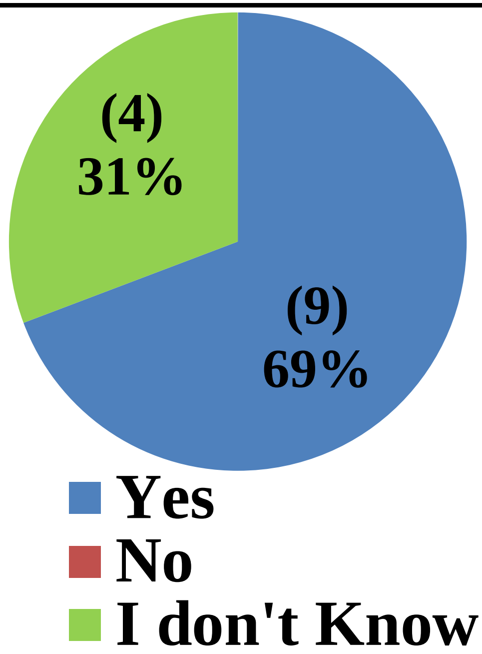
GeoGauge

ASTM Standard	D6758
Measurement	Modulus
Moisture Measurement	No
Calibration of Device	Calibration plate
Portability	Good
Durability	Good
Ease of use/Training	Easy-minimal
Initial Cost	$5,000 - $5,500
Data Storage	Yes
Influence Depth (inch)	5-8
Repeatability	Fair
GPS	Yes
Main Strengths	-Simple, quick and non-intrusive - good portability and durability
Main Limitations	-Extremely sensitive to seating conditions -Inconsistencies in testing data -Unfavorable findings by several DOT’s

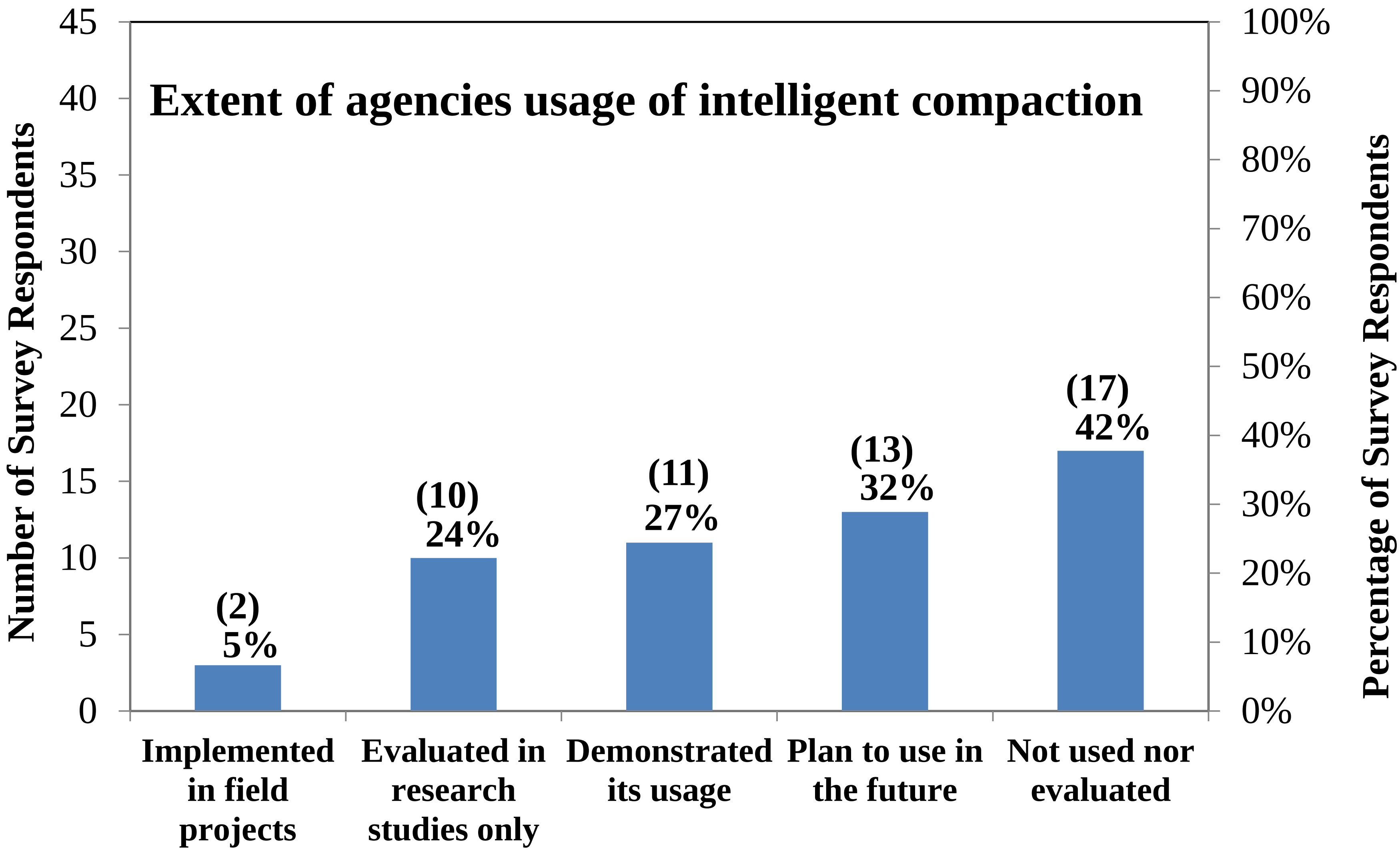
Light Falling Weight Deflectometer (LWD)

ASTM Standard	E2583
Measurement	Modulus
Moisture Measurement	No
Calibration of Device	Required
Portability	Medium
Durability	Good
Ease of use/Training	Moderate
Initial Cost	$8,000 - $15,000
Data Storage	Yes
Influence Depth (inch)	11 (1-1.5D)*
Repeatability	Fair
GPS	No
Main Strengths	-Quick - Measure wide range modulus values -Not influenced by aggregate size
Main Limitations	- High variability in weak soft soils -May require 2 persons

Agencies Experience with Devices

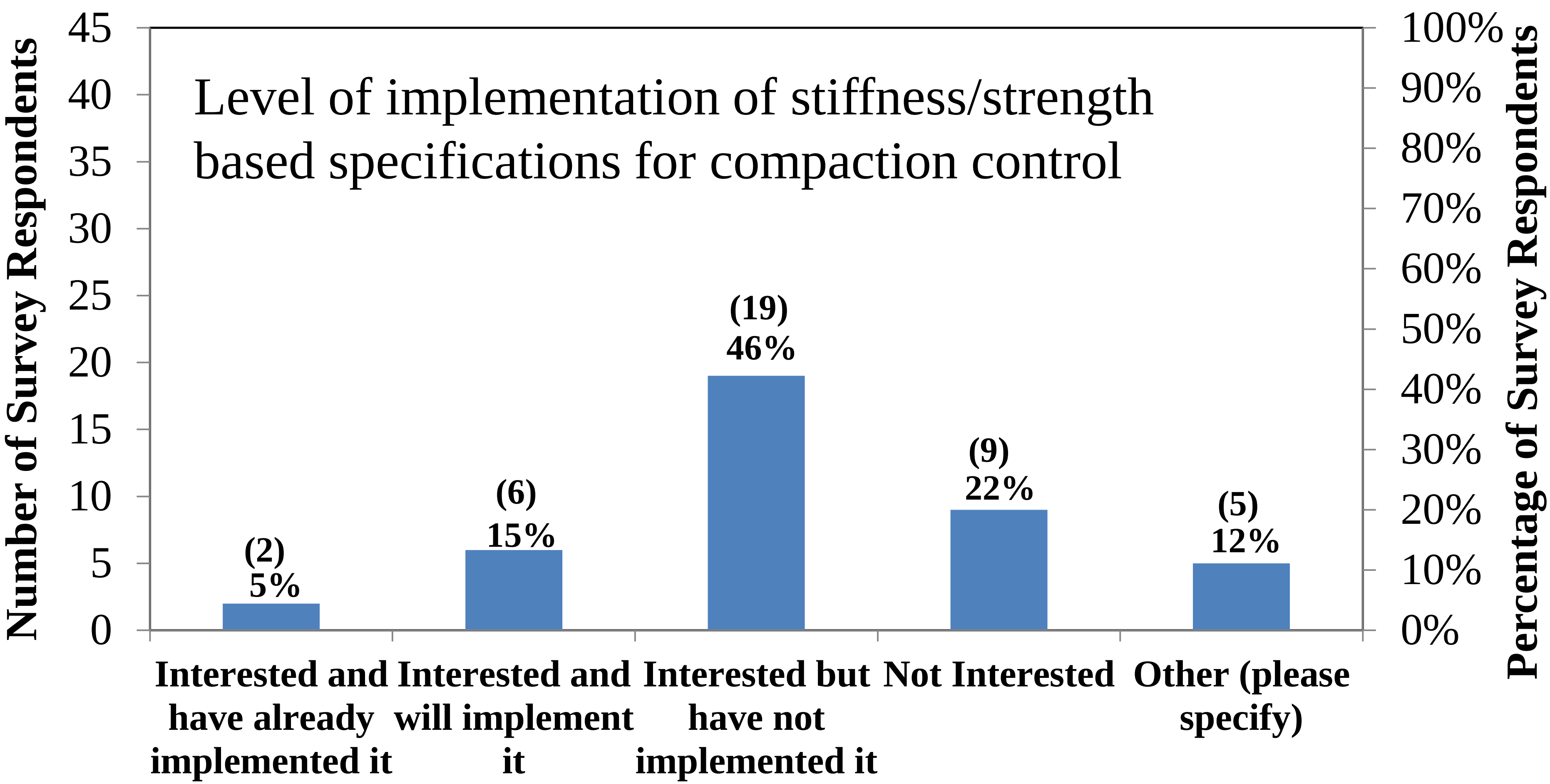
	DCP	GeoGauge	LWD
Recommendation			

Intelligent Compaction



Stiffness/Strength Based Specifications

Stiffness/Strength Based Specifications



Stiffness/Strength Based Specifications

- Only a few state DOTs have developed compaction control specifications for unbound materials that are based on in situ stiffness/strength measurements

State DOT	Specifications links
Minnesota	DCP specification: http://www.dot.state.mn.us/materials/gbmodpi.html LWD specification: http://www.dot.state.mn.us/materials/gblwd.html
Indiana	DCP specification: http://www.state.in.us/indot/files/Fieldtesting.pdf LWD specification: http://www.in.gov/indot/div/mt/itm/pubs/508_testing.pdf
Missouri	http://www.modot.org/business/standards_and_specs/Sec0304.pdf
Illinois	http://www.dot.il.gov/bridges/pdf/S-33%20Class%20Reference%20Guide.pdf

MnDOT Stiffness/Strength Based Specifications

- DCP is used for base aggregates, granular subgrade, and edge drain trench filter aggregates.
- Maximum allowable DCP penetration is found using:

$$\mathbf{DPI_{max}(mm/blow)=4.76xGN+1.68MC-14.4}$$

MC: the moisture content at the time of testing,

GN: Grading Number, calculated

GN = [25 mm+19mm+9.5mm+4.75mm+ 2.00mm+425μm +75μm]/100

GN	In Situ Moisture (% by dry weight)	Maximum Allowable Seating (mm)	Maximum Allowable DPI (mm/blow)
3.1-3.5	< 4.0	40	10
	4.1-6.0	40	10
	6.1-8.0	40	13
	8.1-10.0	40	16
3.6-4.0	< 4.0	40	10

MnDOT Stiffness/Strength Based Specifications

- LWD is used for granular as well as fine grained soils

Granular Soils

Grading Number GN	Moisture Content (%)	Estimated LWD Modulus: Keros/Dynatest (MPa)	Estimated LWD Modulus: Zorn (MPa)	Estimated LWD Deflection Zorn (mm)
3.1 – 3.5	5 -7	120	80	0.38
	100	100	67	0.45
	75	75	50	0.6
3.6 – 4.0	5 -7	120	80	0.38
	80	80	53	0.56
	63	63	42	0.71

Fine grained Soil

Plastic Limit	Estimated Optimum Moisture	Field Moisture as a Percent of Optimum Moisture	DCP Estimated DPI at Field Moisture	Zorn Deflection Estimated at Field Moisture minimum	Zorn Deflection Estimated at Field Moisture maximum
15-19	10-14	70-74	12	0.5	1.1
		75-79	14	0.6	1.2
		80-84	16	0.7	1.3
		85-89	18	0.8	1.4
		90-94	22	1	1.6

INDOT Stiffness/Strength Based Specifications

Specifications

DCP

clay, silt, or sand

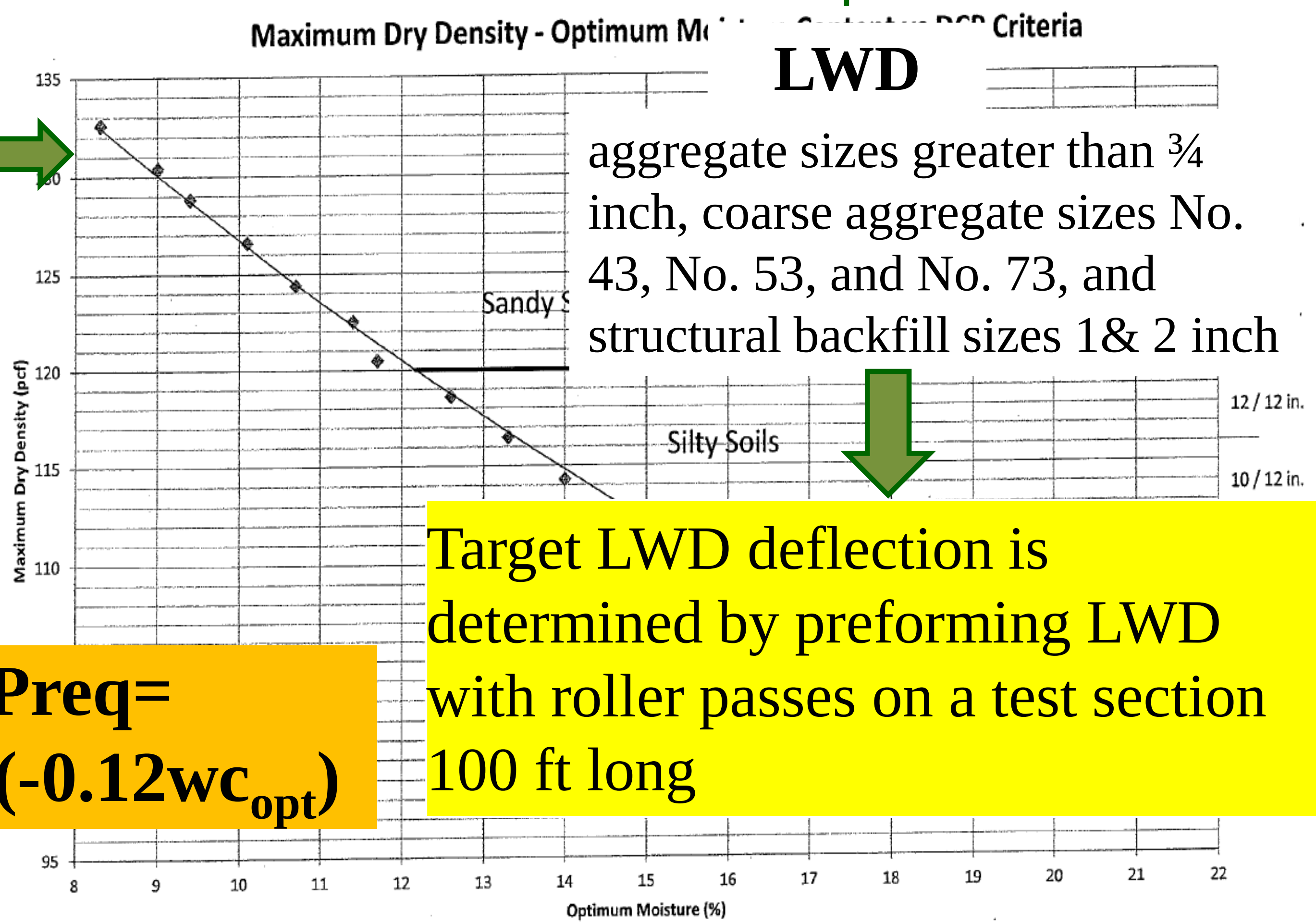
granular soils with aggregate sizes smaller than ¾ inch, and structural backfill sizes 1 inch, 1/2 inch, No. 4 and No. 30.

NDCPreq= 59exp(-0.12wc$_{opt}$)

LWD

aggregate sizes greater than ¾ inch, coarse aggregate sizes No. 43, No. 53, and No. 73, and structural backfill sizes 1& 2 inch

Target LWD deflection is determined by preforming LWD with roller passes on a test section 100 ft long



Conclusions

- The majority of DOTs use field density measurements obtained by the nuclear density gauge for compaction control of various types of geo-materials.
- DOTs overall satisfaction with non-nuclear density devices is so low that none of them recommended their use.
  - ✓ More difficult to operate and require longer testing time than nuclear density gauge
- DCP, GeoGauge, and LWD are the most evaluated devices by DOTs among all in situ tests stiffness/strength devices.
- The DCP and LWD have been implemented by some DOTs in the field for compaction control of geo-materials.
- GeoGauge measurement was found to be very sensitive to the seating procedure and to the stiffness of the top two inches of the tested soil layer, which significantly affected its reliability.

Conclusions

- The influence depth differs between the various in situ devices.
  - ✓ Some devices have shallow depths that may not allow them to assess the properties of the entire lift.
  - ✓ The zone of influence of some devices might exceed the lift thickness and it, thus providing a composite value of two layers rather than solely the tested layer.
- There is not one single in situ test device that can assess all types of geo-materials.
  - The BCD, DCP, LWD and SCS may not be suitable for very soft, fine-grained soils.
- In general, no strong correlation was found between in situ stiffness/strength measurements and in-place density, as this relationship continuously changes with moisture content.

Conclusions

- The majority of transportation agencies are interested in implementing stiffness/strength based specifications for compaction control of geo-materials.
- Only Indiana and Minnesota have widely implemented stiffness/strength based specifications, and both states use the DCP and LWD in those specifications
- Most research and implementation projects that were conducted on the use of continuous and intelligent compaction reported considerable success with and numerous benefits of these technologies.
- However, currently, only three state DOTs (Indiana, Minnesota, and Texas), have IC specifications.

Non-Nuclear Methods for Compaction Control of Unbound Materials

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Outline

- Historical Background

  Use of Resilient Modulus in lieu of CBR in subgrade design

- Motivation Behind the change in Construction Specifications

  - Light Weight Deflectometer

    - Device and Test Method
    - Construction Specifications
    - Limitations and Repeatability

Outline (Cont'd.)

- Dynamic Cone Penetrometer
  - Device and Test Method
  - Construction Specifications
  - Limitations
- Indiana Test Methods
- Questions

Joint Transportation Research Projects, JTRP Studies

FHWA/IN/JHRP-92/23, Subgrade Resilient Modulus for Pavement Design and Evaluation, Woojin Lee, Nihal C. Bohra, Adolph G. Altschaeffl, and Thomas D. White, HPR-2032

FHWA/IN/JTRP-98/02-1, Implementation of Subgrade Resilient Modulus for Pavement: Laboratory Procedures Manual (2 volumes), A. G. Altschaeffl, Ross A. Duckworth, and M. K. Clough, SPR-2134

FHWA/IN/JTRP-98/02-2, Implementation of Subgrade Resilient Modulus for Pavement (2 volumes), A. G. Altschaeffl, Ross A. Duckworth, and M. K. Clough, SPR-2134

FHWA/IN/JTRP-2004/35, Non-Destructive Estimation of Pavement Thickness, Structural Number and Subgrade Resilience along INDOT Highways, Samy Noureldin, Karen Zhu, Dwayne Authur Harris, and Shuo Li, SPR-2408

FHWA/IN/JTRP-2005/23, Simplification of Resilient Modulus Testing for Subgrades, Daehyeon Kim and Nayyar Zia Siddiki, SPR-2633

Research Studies Completed to Improve the Construction

JTRP & In-House Research

1998, JTRP Technical Report Series
Cone Penetration Test to Assess the Mechanical Properties of Subgrade Soils

2010, FHWA/IN/JTRP-2010/27 SPR- 3009
Use of Dynamic Cone Penetration And Clegg Hammer Tests For Quality Control of Roadway Compaction and Construction
JTRP & In-House Research

2014, FHWA/IN/JTRP   SPR-3537
QA/QC of Subgrade and Embankment Construction

2014, JTRP SPR#3651
Developing Statistical Limits for using the Light Weight Deflectometer, LWD in Construction Quality Assurance

Subgrade Type and Mr Recommendations During Design Phase

Type of Work	Traffic	Subgrade Length	Subgrade Type and Description	M_r Value 1.25 times M_r @ σ_1=6psi and σ_3=2psi at OMC
New Road, Road Reconstruction and >8 feet Widening	*VPD ≥ 1,000 or Truck ≥ 5 %	> 800 feet	**Type-IB** 14 inches-chemical Soil Modification Granular Soils- Clay < 20%, PI < 10 - **Cement** Cohesive Soils- Clay > 20 %, PI > 10 -**Lime**	Up to M_r - 9,500 psi
New Road, Road Reconstruction and <8 feet Widening	•VPD ≥ 1,000 or Truck ≥ 5 %	–	**Type IC** Excavation and replacement with 12 inches Aggregates	Up to M_r - 9,500 psi
New Pavement or Reconstruction	High water/ urban area, shallow utilities or others	–	**Type IV** 12 inches Aggregates w/Geogrid Type IB & woven Geotextile if needed	Up to M_r - 9,500 psi
New Road, Road Reconstruction	*VPD ≤ 1,000 or Truck ≤ 5 %	–	**Type I** 24 inches Strength/density and Moisture Control	Up to M_r - 7500 psi

* Vehicle per day

INDOT adopted Resilient Modulus (Mr) since 2002 and following recommendations are included in Geotechnical Report for designing the pavement.

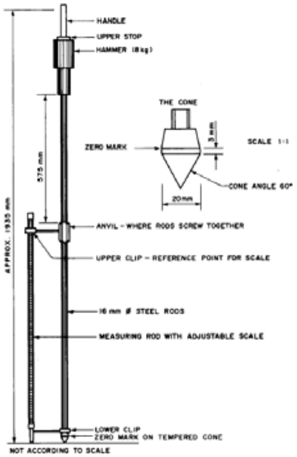
- Subgrade Type
- Resilient Modulus of prepared subgrade
- Resilient Modulus of foundation soils
- AASHTO Classification
- Water Table

Motivation Behind the Change in Construction Specifications

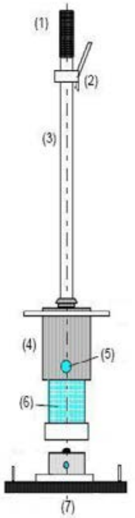
- Measure fundamental properties of material (strength, modulus, etc.)
- Delineate the poor to good compaction in short time
- Simple enough to train and easy to perform with no electronics
- Precise enough to accept with confidence
- Safety issues (nuclear gauge handling)

Devices Evaluated

Clegg Hammer
(Hammer weight, 10kg).

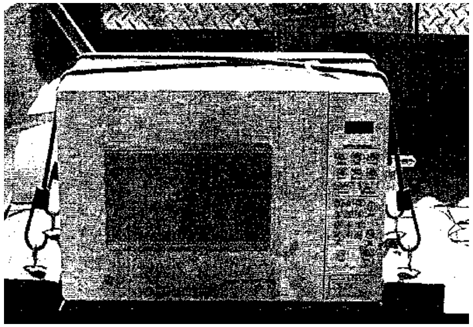


Dynamic Cone Penetrometer



Light Weight Deflectometer

Moisture Probe



Microwave Oven

Moisture Analyzer

Light Weight Deflectometer - LWD

Indiana
Test
Method
ITM-508

LWD Test Procedure, ITM 508

- Select site and prepare surface.
- LWD plate should not translate laterally.
- Perform three seating (1st, 2nd and 3rd) drops from the fixed height
- Record the average of 4th, 5th and 6th drops and the test is complete.
- Deflection > 0.03 mm for any two consecutive drops warrants compaction.

Compaction Acceptance with LWD 203-R-628

The maximum allowable deflection for #53 aggregate will be as follows or determined by the test section.

Material Type	Maximum Allowable Deflection (mm)
Lime Modified Soil	0.30
Cement Modified Soil	0.27
Aggregates over Lime Modified Soil	0.30
Aggregates over Cement Modified Soil	0.27

Materials not included in the table need a test section.

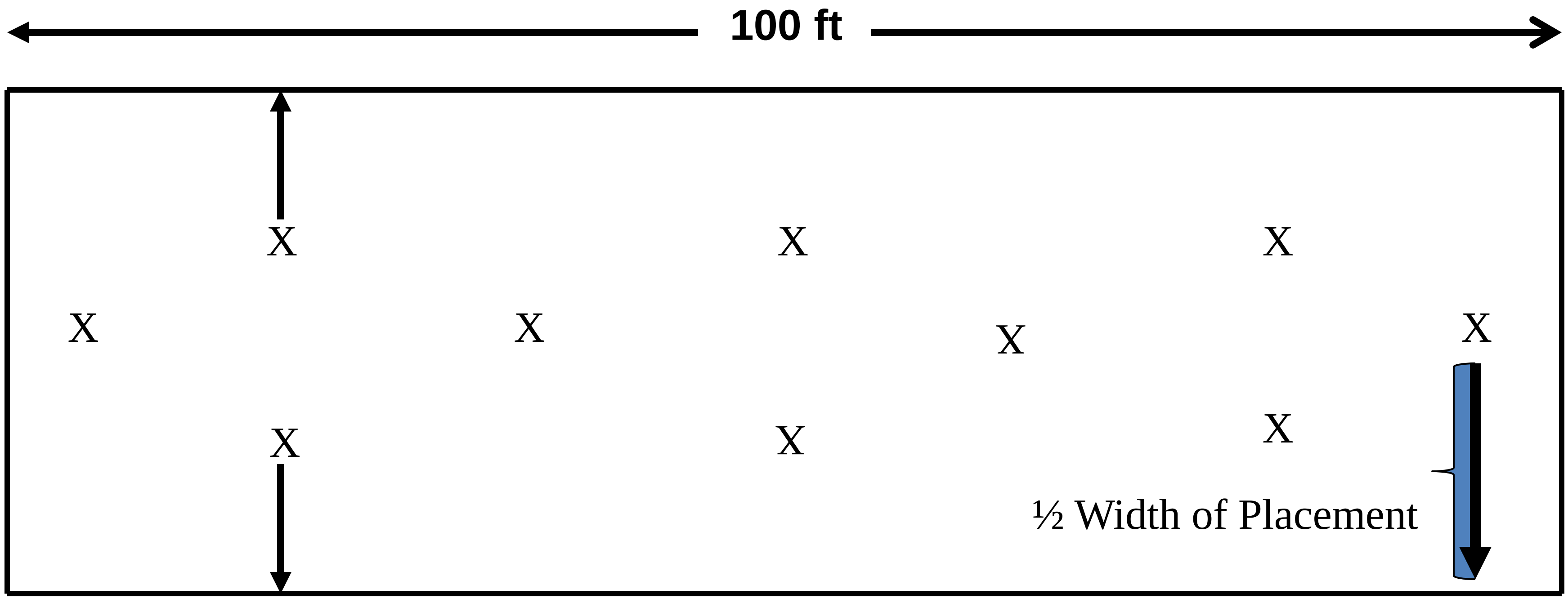
Proofrolling of Chemically Modified Soil

A fully legally loaded tri-axle dump truck. (About 70,000 lbs.)

Sec. 207 and 300 requires proofrolling prior to placing next layer

Compaction Acceptance with LWD, 203-R-628

A Test Section Layout



Test sections shall be constructed in accordance with ITM 514.

Test Section

Size: 100 X 20 feet

Aggregate Moisture: -3% of OMC and OMC

Compacted Lift Thickness: 6 inches

Test Section Requirements, ITM-514

1. Proofroll and construct a lift.

2. Test 10 random locations and take the average.

3. Perform additional compaction. Retest previous test locations and take the average.

4. Subtract the average deflection of step 3 from step 2.

5. If the difference in step 4 is <0.02 mm. Test section is complete

ITM-514 Cont'd.

6. If the difference is >0.02 mm, additional compaction is required.

7. Step 3 is the maximum allowable deflection and used for the remaining project.

Compaction Acceptance with LWD, 203-R-628

- Gradation and OMC on aggregates by (AASHTO T11,T27 and T99).

- Moisture: -3% of OMC and OMC

- Testing Frequency

  - 3 Tests/1,400 cyd of chemically modified soils.

  - 3 Tests/800 t for compacted aggregates at random station.

  - One moisture test / day in accordance with AASHTO T 255.

Limitation

- The aggregates larger than 1.5 in. shall not be *over* 15% in testing location.

- The testing location shall not exceed 5% inclination.

- The testing location shall not be frozen.

- Test shall not be executed when deflection measurements are less than 0.2 mm.

- LWD test is questionable in case of shallow ground water (2 feet) or soil with high moisture content.

LWD Repeatability Procedure

The Office of Material Management will establish the repeatability of lightweight Deflectometer (LWD) deflection measurements under defined conditions.

Repeatability testing will be performed:

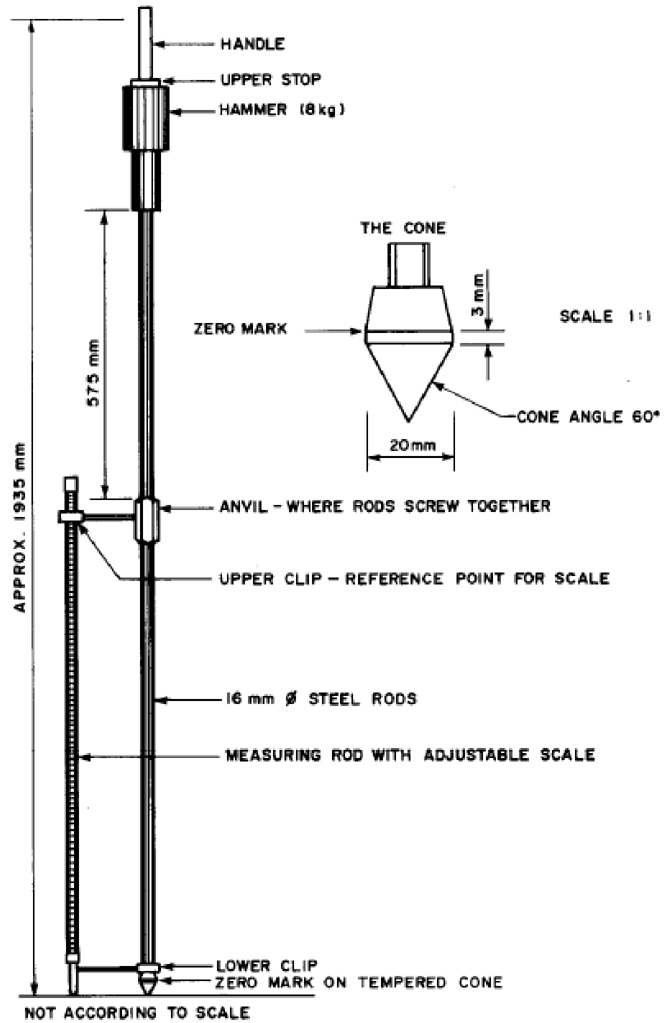
- Immediately upon receipt of a newly purchased device
- Immediately after full calibration
- After significant repair
- Annually
- When measurements are no longer repeatable or questionable

Projects and Tests Completed in 2014

Projects completed	**118**
Test Performed	**2011**

Dynamic Cone Penetrometer

Indiana
Test
Method
ITM-509



Section 203.23

Based on the research (QA/QC of Subgrade and Embankment Construction) the following relationships were developed

Soil type		Correlation	R^2	Penetration depth (inches)	Range of applicability
Coarse- grained soils	Natural	Blow Count= $0.17 \times OMC^2 - 5.94 \times OMC + 60$	0.95	0-to-12	$8<OMC\%<13$
	Manufactured	Blow Count= $4.03 \times \ln (C_u) + 2.64$	0.99	0-to-12	$3.0<C_u<6.0$
Fine-grained soils		Blow Count= $13.03 \times e^{-23 \times PI} + 8.05 \times e^{-0.005 \times PI}$	0.99	0-to-6	$8 \geq PI\%$
		Blow Count= $22.11 \times e^{-0.23 \times PI} + 13.04 \times e^{-0.012 \times PI}$	0.98	6-to-12	

Section 203.23 Cont'd.

The following laboratory tests are required during construction:

- Sieve Analysis.........AASHTO T-88, T-89/or ASTM D-1140
- Atterberg Limits .... AASHTO T-90
- Moisture –Density .... AASHTO T-99
- Loss on Ignition..............AASHTO T-267
- Ca/Mg Carbonate........... ITM-507*
- Sulfate test ITM 510

*Not required when presence of shells in soil or density <105 lbs.

Soil Types

More than 1800 tests performed in the laboratory, grouped in three categories on the basis of Maximum Dry Density and other parameters.

Cohesive Soil: Soil is cohesive when >35% passing No.200 sieve and categorize as:

- Clay -   Max. dry density ≤ 114 pcf
- Silty -   Max. dry density ≥ 114 pcf and ≤ 120 pcf
- Sandy- Max. dry density > 120 pcf

Granular Soil: Soil is non cohesive when <35 % passing No. 200 sieve.

Embankment other than Rock, with Strength or Density Control, Sec. 203.23

Textural Classification	Maximum Dry Density (pcf)	Optimum Moisture Content Range (%)	Acceptable Minimum DCP value for 6 in.	Acceptable Minimum DCP value for 12 in.
CLAY SOILS				
Clay	< 105	19 - 24	6	
Clay	105 - 110	16 - 18	7	
Clay	111 - 114	14 - 15	8	
SILTY SOILS				
Silty	115 - 116	13 - 14		9
Silty	117 - 120			11
SANDY SOILS				
Sandy	121 - 125	8 - 12		12
Sandy	> 125			15
GRANULAR SOILS - STRUCTURE BACKFILL AND A-1, A-2, A-3 SOILS				
No. 30				6
No. 4				7
1/2 in.				11
1 in.				16

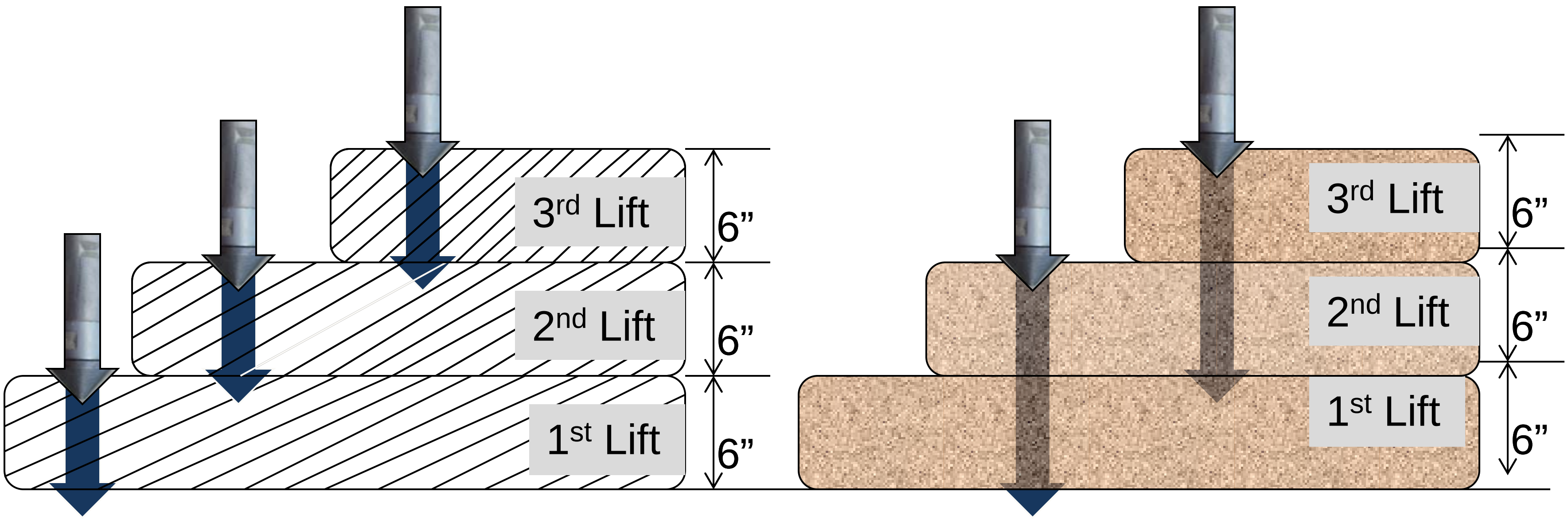
Section 203.23 Cont'd.

Moisture Range for Compaction

Moisture range for all soil types are as follows:

Soil Type	Moisture Compaction Range
Clay (<105 lb/cu ft)	-2 to + 2% of optimum moisture content
Clay (105-114 lb/cu ft)	-2 to + 1% of optimum moisture content
Silty and Sandy (>114 lb/cu ft)	-3% of optimum moisture content and optimum
Granular	5 to 8%

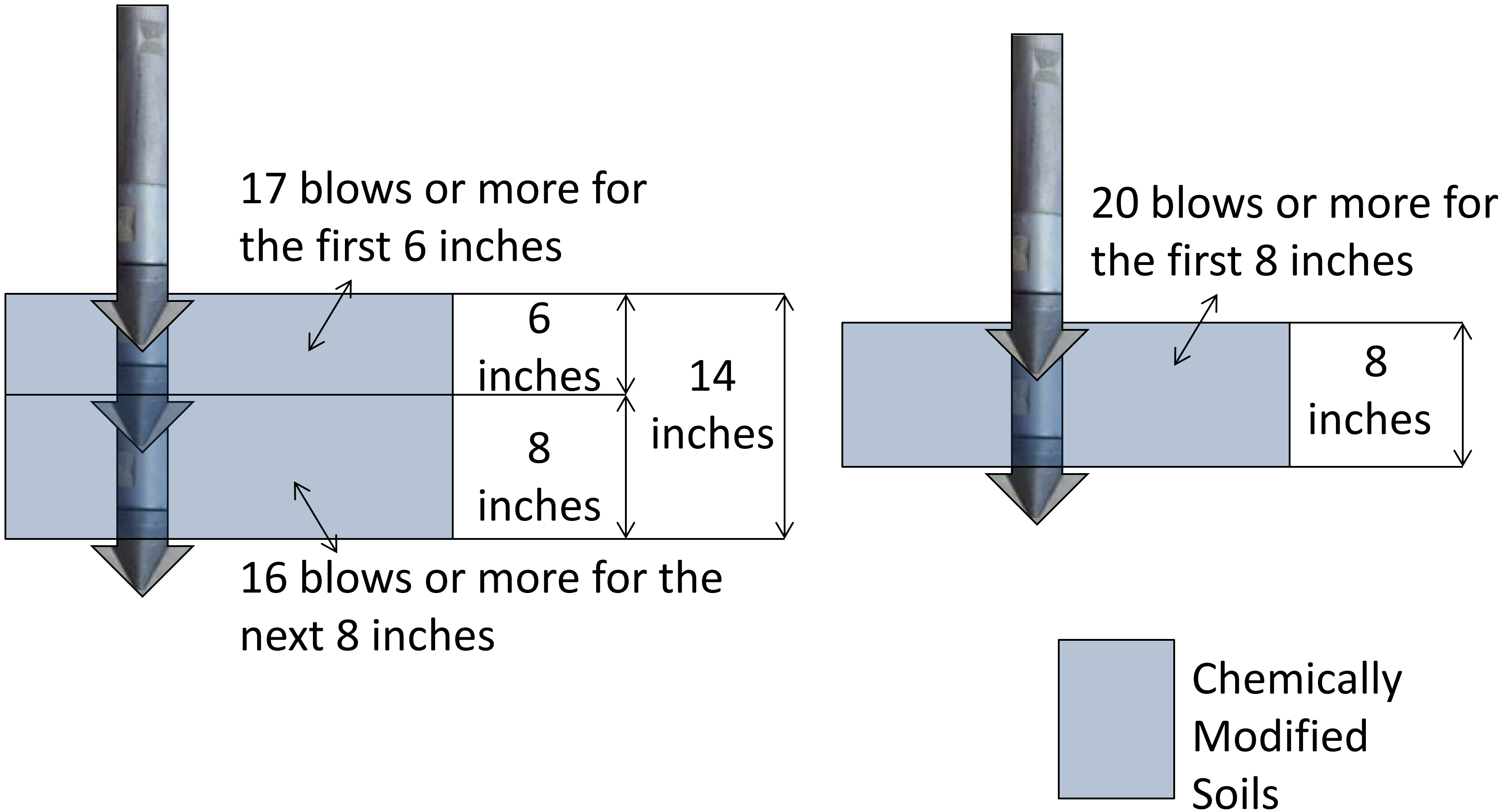
Dynamic Cone Penetrometer Testing



Clayey Soils

Silty , Sandy & Granular Soils

DCP blow counts for the chemically modified soils



Section 203.23 Cont'd.

Frequency of Testing

- 3 Random test / 2000 cyd of compacted soil.
- Moisture test at every 4 hrs for clayey soils.
- Moisture test once per day for other type of soils.

Note:

The moisture sample should represent the entire lift.

Additional moisture tests may be required if there is an obvious visual change in moisture

When the soil type changes during construction:

One Point Proctor shall be performed to identify the soil type and revised DCP blow counts in accordance with the ITM 512-15T

Motive behind performing One Point Proctor

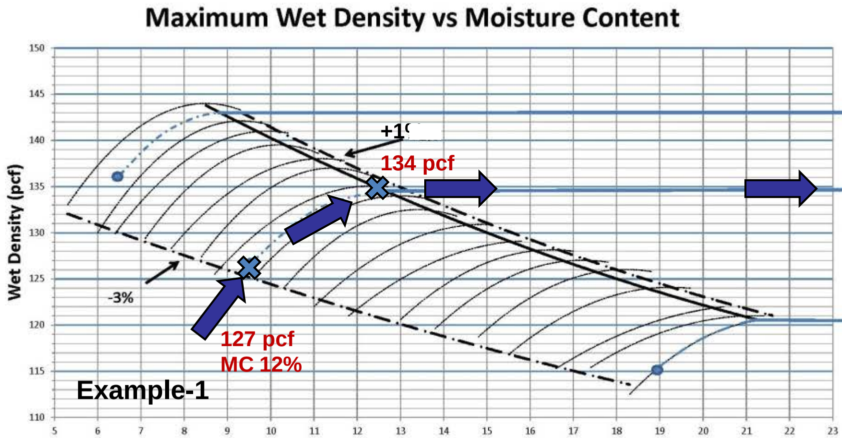
To determine the following properties at the project:

- Optimum Moisture Content of the blended soils
- Maximum Dry Density and the use of ITM 512 Charts
- Density based soils classification
- Adjusted Optimum Moisture and DCP blow counts

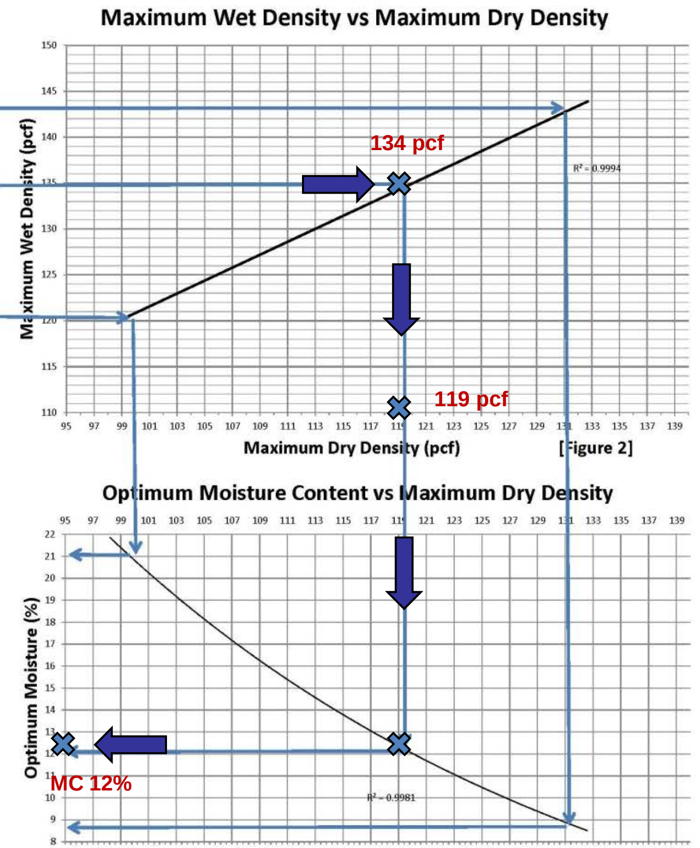
One Point Proctor

ITM - 512

EXAMPLE



[Figure 1]



[Figure 2]

[Figure 3]

-Data not to be used with Granular Soils.

-Plot based on data acquired from July 1965 to January 1969 by Soils Department .

-Moisture must be between -3% and +1% for a valid Maximum Wet Density

-These charts are an alternative to the Family of Curves and may be used in accordance with ITM-512

-Revised 4/4/14

Conclusion

- The DCP is portable, easy to operate, and requires no electronics. It takes couple of minutes to learn the test.
- It is an effective tool to identify weak layers when penetration rates are plotted vs. depth.
- Improve inspector safety.
- Directly related to design.
- Increase compaction uniformity.
- Increase productivity due to less time per test.
- Improve documentation and reporting.

INDOT Strength / Stiffness Specifications

	Design Phase	Construction Phase			
		DCP		LWD	
Soils	M_r psi	Blow Counts/ inch	M_r psi	Max. Allowable Deflection (mm)	M_r psi
Chemically Modified Soils	Up to 9,500 →	29/ 12	14,000 →	0.27 - 0.3	13,000 to 15,000
Aggregates Over Chemically Modified Soils	Up to 9,500 →	→	NA →	0.27 - 0.3	13,000 to 15,000
Compacted Soils	Up to 7,500 →	7/6 to 14/12	upto 12,000	← NA	→

NA= Not Applicable

Equipment Inventory

INDOT Inventory of LWD and DCP Devices		
LWD (ZORN) & DCP (KESSLER)		
Available With	No's of LWD	No's of DCP
INDOT	60	200 +
CONSULTANTS	10	30

Comparison Cost / Test With Different Devices

Device	Estimated Tests Per 8-hr Day	Daily Employee Rate	Daily Equipment Rate	Daily Charge	Cost Per Test (Approx.)	Est. Device Price
NDG including 1-Point Proctor	18	$336.00	$35.00	$371.00	$20.60	$ 8,000.00- $12,000.00
DCP	32	$336.00	$ 3.00	$339.00	$10.00	$ 1,000.00- $ 1,300.00
LWD	72	$336.00	$14.00	$350.00	$ 5.00	$ 7,500.00- $ 1,2000.00

Other Costs:
NDG - Training: Safety and Maintenance
DCP - None
LWD- Calibration and Verification

INDOT Compaction Requirements

Material Types	Lab. Testing	Field Testing					
		Max. DD & OMC (ITM 512)	DCP (ITM 509)	Sand Cone (AASHTO T191)	Moisture Test (ITM 506)	Moisture Test AASHTO T255	LWD (ITM 508)
Cohesive Soils	AASHTO T 99 (Method A)	X	X	X	X	N/A	N/A
Granular Soils (Soils with aggregate retained on the 3/4 in., structural backfill size 2 in. and 1 1/2 in., and b borrow with a similar gradation)	AASHTO T 99 (Method A or C)	N/A	N/A	X	X	N/A	X
Granular Soils (Soils with 100% passing 3/4 in., structural backfill sizes 1 in., 1/2 in. No 4, No. 30, and b borrow with a similar gradation)	AASHTO T 99 (Method A or C)	N/A	X	X	X	N/A	N/A
Coarse Aggregates (No. 43, 53, and 73)	AASHTO T 99 (Method A or C)	N/A	N/A	X	N/A	X	X
Coarse Aggregates (No. 5, 8, 9, 11 or 12)	Field Testing is not required. Compaction in accordance with applicable specification.						
Chemical Modified Soils	AASHTO T 99 Performed by the Contractor	N/A	X	N/A	*X	N/A	X

N/A Not Applicable
*X No Microwave Testing
No Probe Testing

ITM for Compaction Acceptance

ITM No. 506-15T
Field Determination of Moisture Content of Soil

ITM No. 508-12T
Field Determination of Deflection Using Light Weight Deflectometer

ITM No. 509-15P
Field Determination of Strength Using Dynamic Cone Penetrometer

ITM No. 512-15T
Field Determination of Maximum Dry Density and Optimum Moisture Content of Soil (AASHTO T272)

ITM No. 514-15T
Test Sections for Aggregates and Recycled Materials

QUESTIONS

Compaction Control Today and Anticipating the Future

NCHRP Synthesis 456

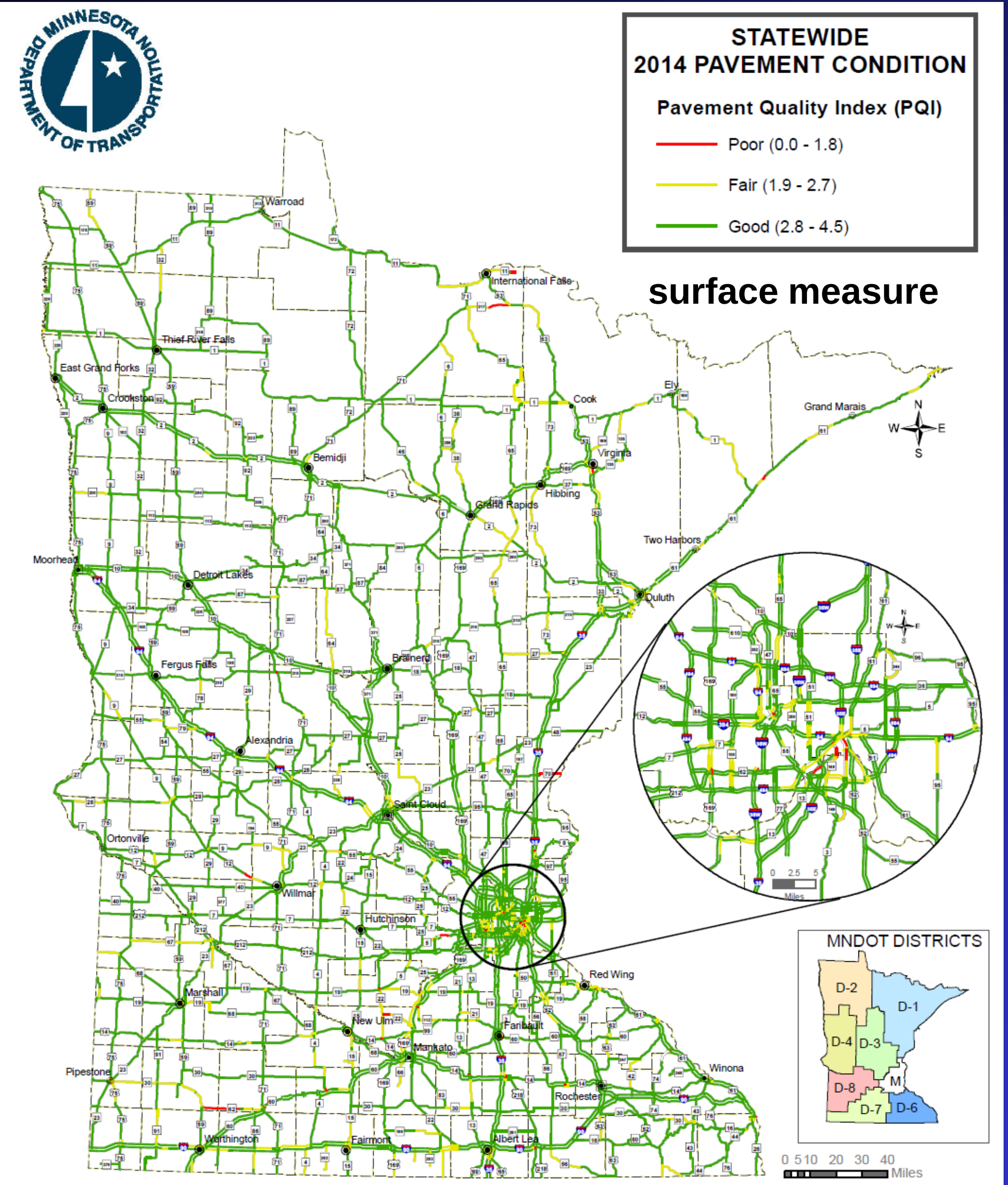
“Non-Nuclear Methods for Compaction Control of Unbound Materials”

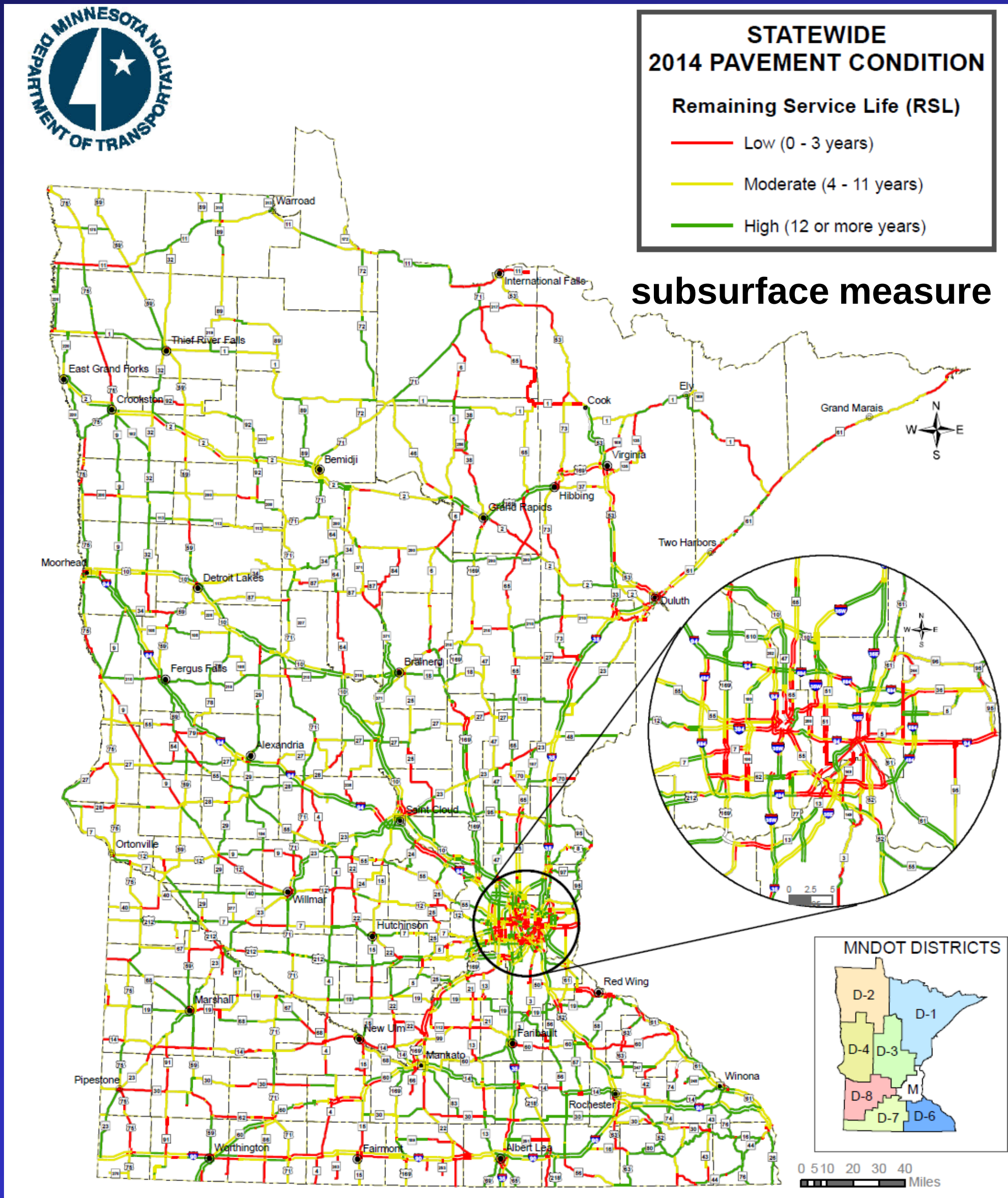
John Siekmeier P.E. M.ASCE

Why would we replace a density-based specification with a modulus-based specification?

- Road foundations are important.
- Poor performance has consequences.
- Testing has NOT "always been done this way."
- Building financially effective highways for the 21st century requires 21st century technology.

Road Foundations are Important





Poor Performance has Consequences

- Unable to maintain our public assets.
- Waste labor, energy, and natural resources.
- Public confidence reduced.
- New investments (higher gas tax) difficult.

Ralph Proctor reminds us.

- Strength is not achieved by density alone.
- Optimum moisture is for compaction.
- Need to avoid rutting during construction.

photo courtesy of Dr. J. David Rogers
University of Missouri-Rolla

Ralph Proctor, 1945, Trans 110, ASCE

- “Methods for hand compaction, such as dropping various weight tampers from different heights and mechanical tampers, were tried and discarded.”
- “No use is made of the actual peak dry weight.”
- “The measure of soil compaction used is the indicated saturation penetration resistance.”

Proctor Penetrometer

Photo courtesy of Humboldt

Minnesota Department of Transportation
Office of Materials & Road Research
1400 Gervais Avenue, MS 645
Maplewood, MN 55109

Memo

TO: PCMG, CMG, MnDOT Districts, Materials Engineers, Soils Engineers, State Aid

FROM: Glenn M. Engstrom, Director
Office of Materials & Road Research

DATE: October 31, 2014

SUBJECT: Pavement Design Manual Publication

I am pleased to announce the publication of the MnDOT Pavement Design Manual.

This publication represents a significant effort to update pavement design procedures and codify existing documents into a single point of reference. As of November 1, 2014, all MnDOT pavement designs shall follow the pavement design, pavement-type selection, LCCA, and alternate bidding as laid out in the Pavement Design Manual. To view the manual, please follow http://www.dot.state.mn.us/materials/pvmtdesign/newmanual.html

Mechanistic Empirical Pavement Design

- Provides the framework for using performance based material properties
- Free design software available http://www.dot.state.mn.us/app/mnpave/index.html
- Just Google “MnPAVE”

MnPAVE - Deflection Test Simulation

Edit | Print Window | Help

Plate Diameter 200 mm LWD Resistance Factor 0.67

Applied Load 6.3 kN

Restore Default Values

Units
- English
- SI

Input Data

Exit

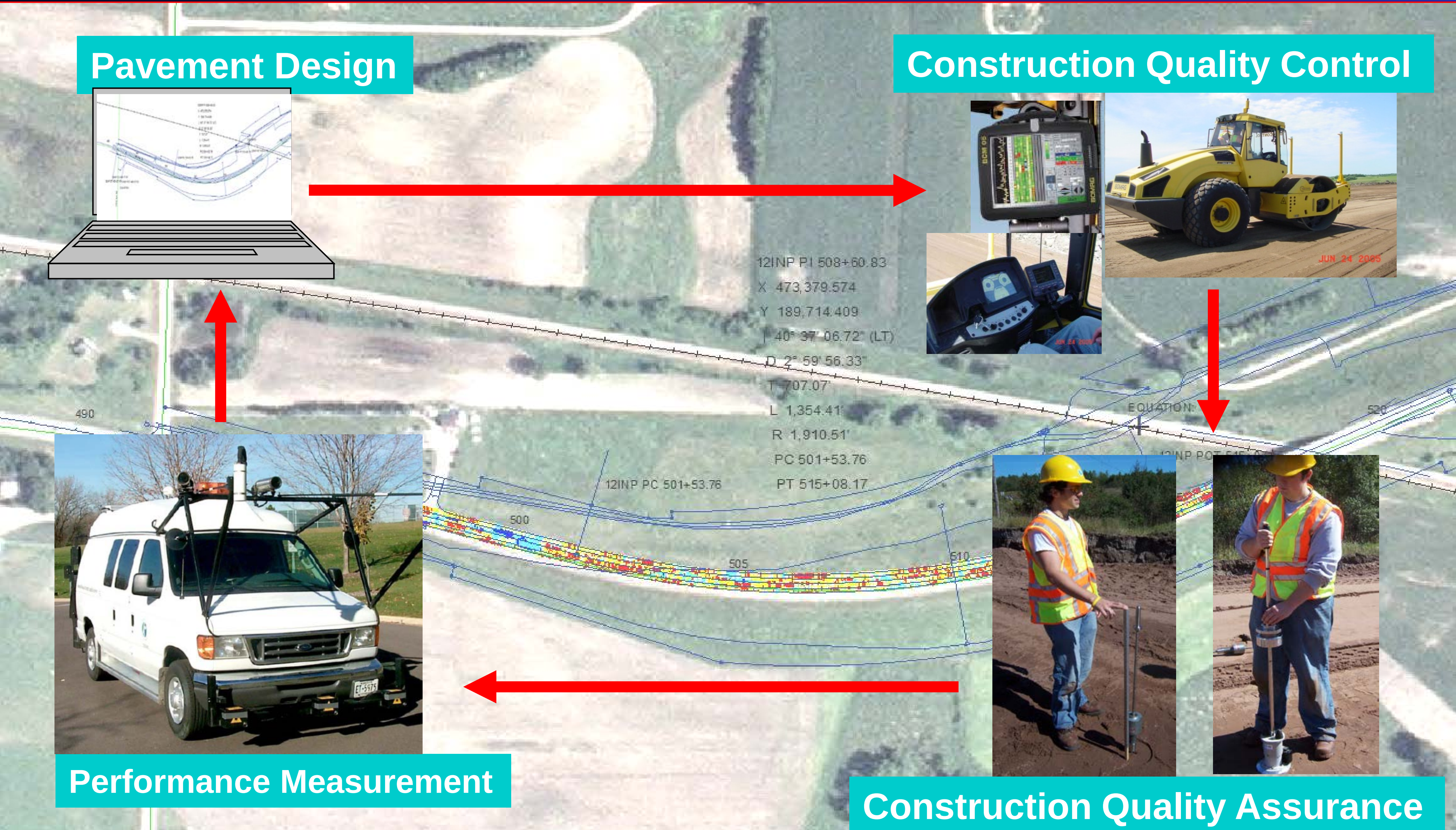
Surface Material	Field Modulus (MPa)	Field Resistance Factor	LWD Deflection (mm) at top of Surface Material				
			Degree of Saturation				
			Opt.-20%	Opt.-10%	Optimum	Opt.+10%	Opt.+20%
				Estimated Target Values			
AggBase	180.5	1.15	0.52	0.55	0.60	0.66	0.71
EngSoil	29.98	0.96				X	
UndSoil	19.23	0.75			X		

Simulated using material properties from Intermediate design level.

Light Weight Deflectometer Links Design to Construction

- Verifies pavement design inputs
- Empowers inspector with useful measures
- Creates as-built construction record

Design, Construction and Performance



Action Items and Future Work

- **Continue participation on national project teams.**
  - TPF (5)285 Standardized LWD Measurements for QA
- **Inspector certification training includes LWD.**
- **Educate designers, opportunity to optimize design.**
- **Enhance LWD and DCP target value prediction.**
- **Specification to include design-based LWD targets.**
- **Further development of moisture/suction field test.**

Thank you. Questions?