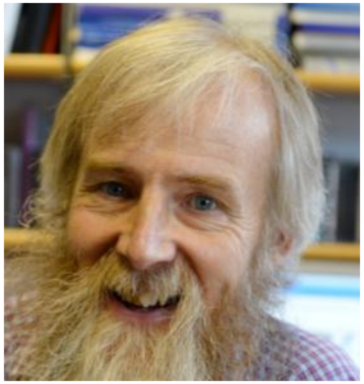
Construction, Quality Control & Performance of Unbound Granular Layers

Hosted by
Andrew Dawson
University of Nottingham, UK



chair, TRB Committee AFP70 "Aggregates"

Your presenters

- Debakanta Mishra
  - Boise State University
- Rick Boudreau
  - Boudreau Engineering
- George Chang
  - Transtec Group

Today's Content on Granular Bases/Subbases

- Brief review of construction practices
- Compaction
- Quality control
- Field performance
- Continuous and intelligent compaction
- Summary and conclusion

NCHRP
SYNTHESIS 445

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Practices for Unbound Aggregate Pavement Layers

A Synthesis of Highway Practice

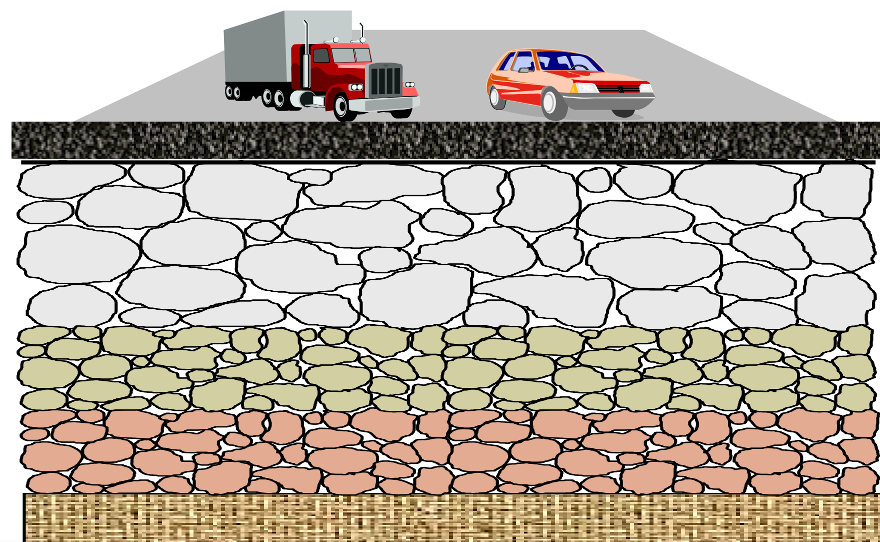
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NCHRP Synthesis 445

(Tutumluer, 2013)

Download from the TRB Website:

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_445.pdf



NCHRP is...

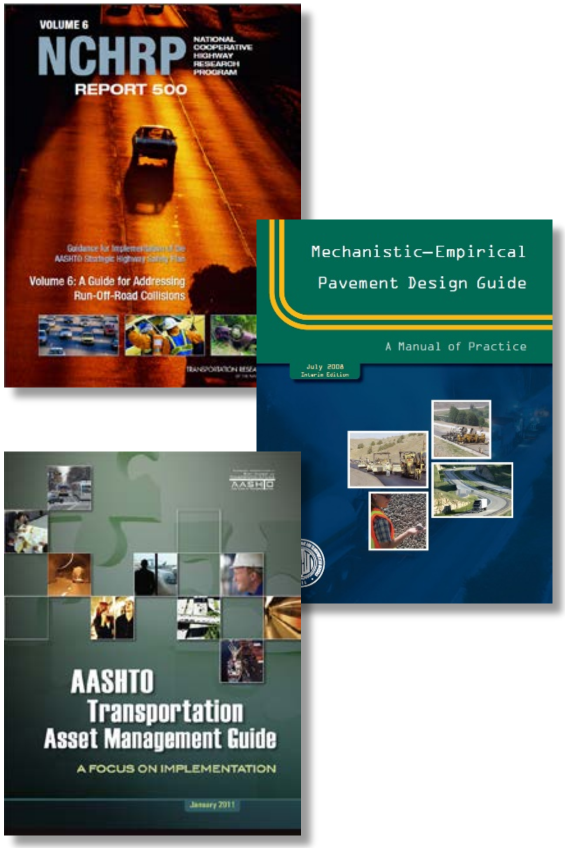
A state-driven national program

- The state DOTs, through AASHTO's Standing Committee on Research...
  - Are core sponsors of NCHRP
  - Suggest research topics and select final projects
  - Help select investigators and guide their work through oversight panels

NCHRP delivers...

Practical, ready-to-use results

- Applied research aimed at state DOT practitioners
- Often become AASHTO standards, specifications, guides, manuals
- Can be directly applied across the spectrum of highway concerns: planning, design, construction, operation, maintenance, safety



A range of approaches and products

- Traditional NCHRP reports
- Syntheses of highway practice
- IDEA Program
- Domestic Scan Program
- Quick-Response Research for AASHTO
- Other products to foster implementation:
  - *Research Results Digests*
  - *Legal Research Digests*
  - *Web-Only Documents and CD-ROMs*

Review of granular base/subbase construction practices

Rick Boudreau
Boudreau Engineering

Granular Base/Subbase

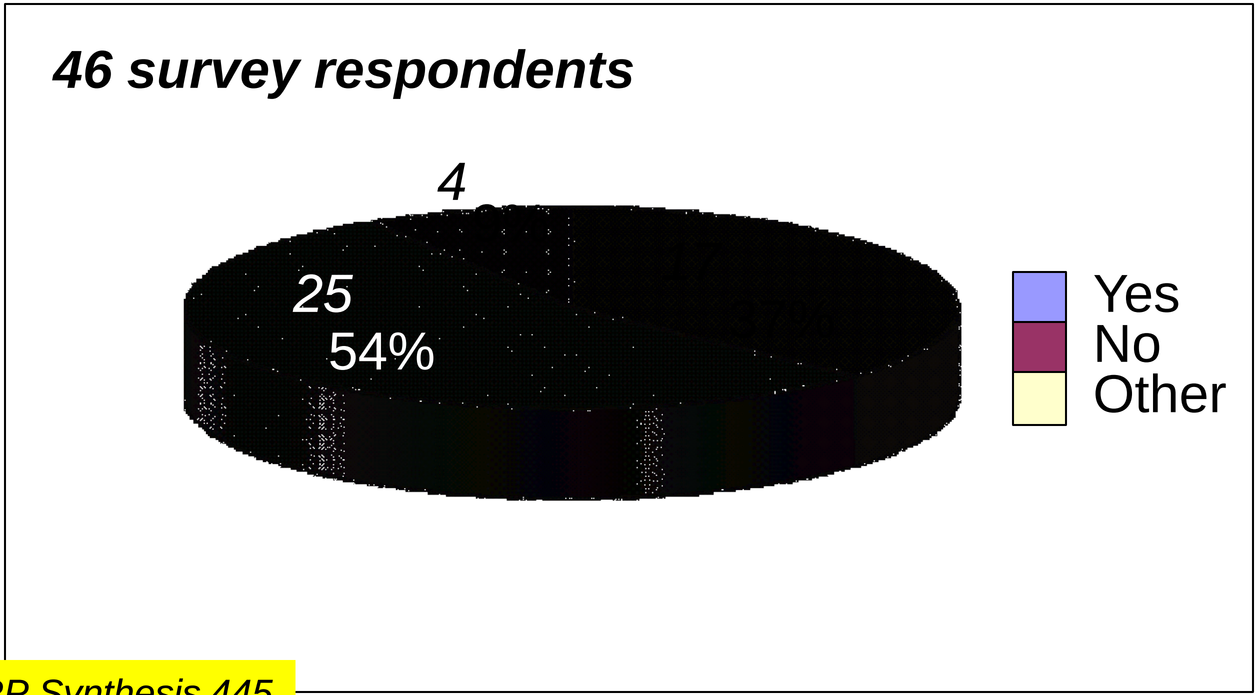
Brief Overview

- Granular Base Defined
- Composition
- Segregation and Degradation
  - Stockpiling
  - Transporting
  - Spreading
  - Compacting

Brief Overview

- Granular Base Defined
- Composition
- Segregation and Degradation
  - Stockpiling
  - Transporting
  - Spreading
  - Compacting

Does your agency have specific guidelines regarding the transportation and storage (stockpiling) of aggregate materials for base and subbase construction?



NCHRP Synthesis 445

Granular Base/Subbase

Granular Base/Subbase

What is it?

Granular Base/Subbase

“granular materials of mineral composition such as sand, shell, slag, or crushed stone, used with a cementing medium to form mortars or concrete, or alone as in base courses, railroad ballasts, etc.” - ASTM

Natural extraction from: Stone Deposits or Sand and Gravel Deposits –Barksdale 1991

Composition

- Mineralogy (igneous, metamorphic, sedimentary origin)
- Particle shape and texture (angularity, crushed faces, elongation, rough, smooth)
- Gradation – grain size distribution, fines and property of fines

is every base layer a 0.14?

Blast and Load

Blast and Load

Haul
to
Crusher

Load Primary Crusher

Primary Crusher

Secondary Crusher

Size Separation

Sizing Stockpiles

Sizing Stockpiles

Segregation?

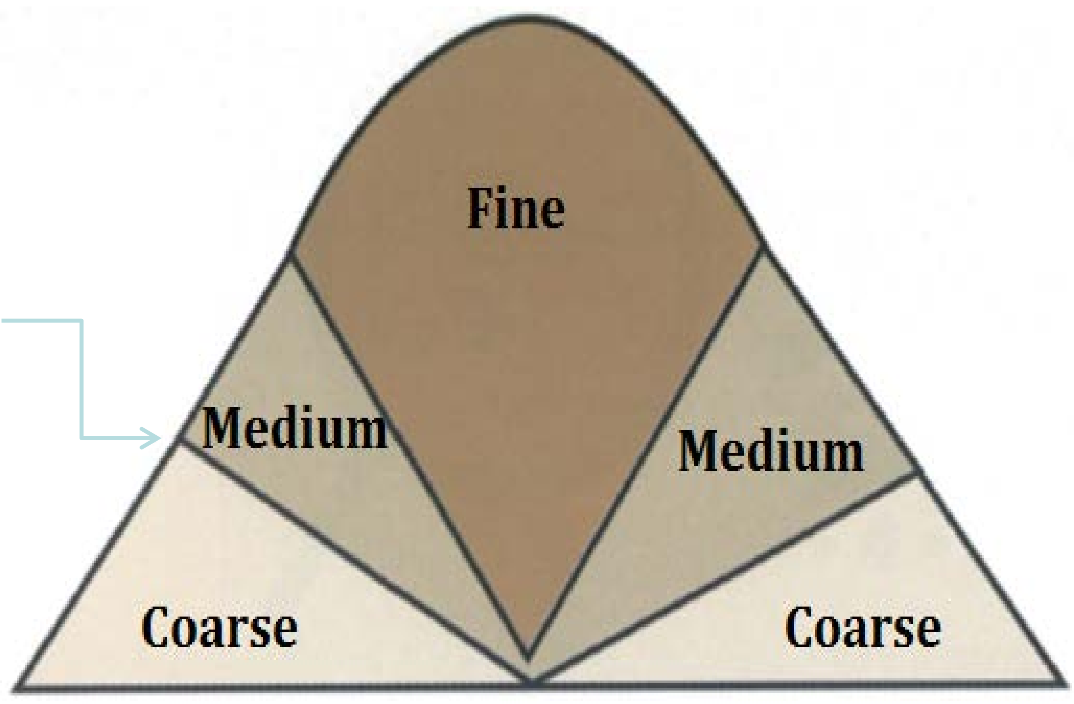
Aggregate Segregation – the separation of one size of particles from a mass of particles of different sizes, caused by the methods used to mix, transport or store aggregate.

- Barksdale 1991

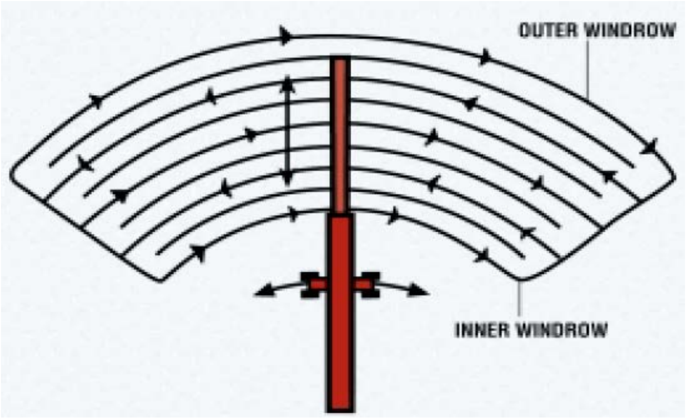
Segregation?

Stockpile Segregation

material overrun

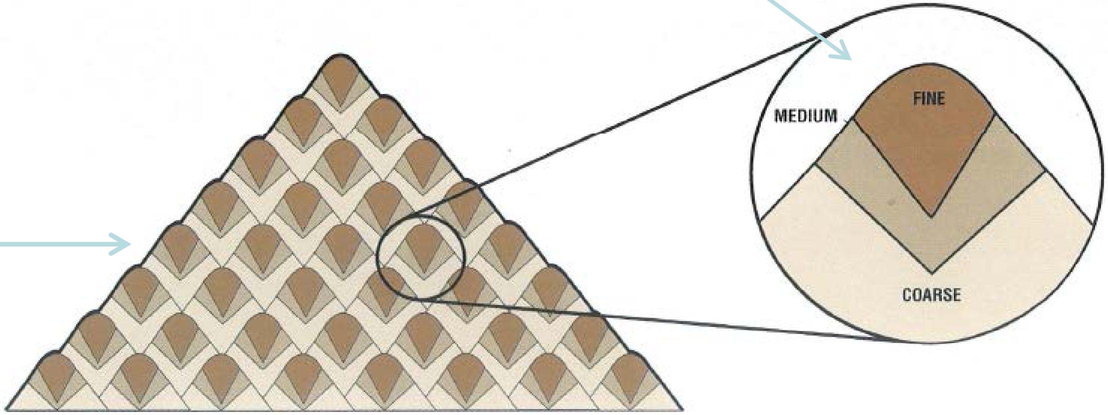


Stockpile Segregation



radial telescoping stacker

miniature stockpile

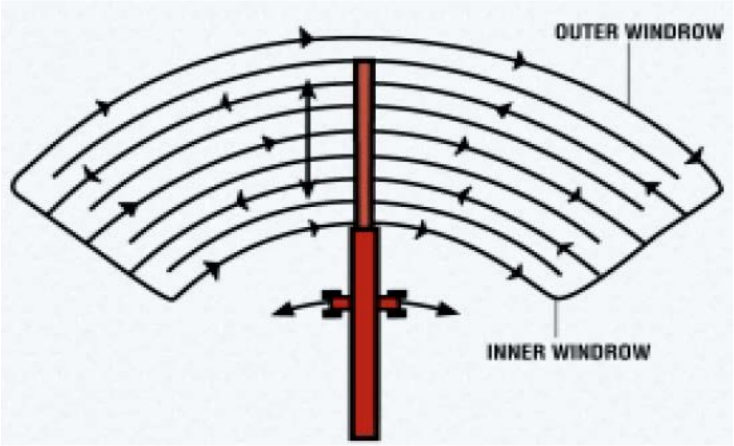


results in a more uniform stockpile

GAB Stockpile – formed with…

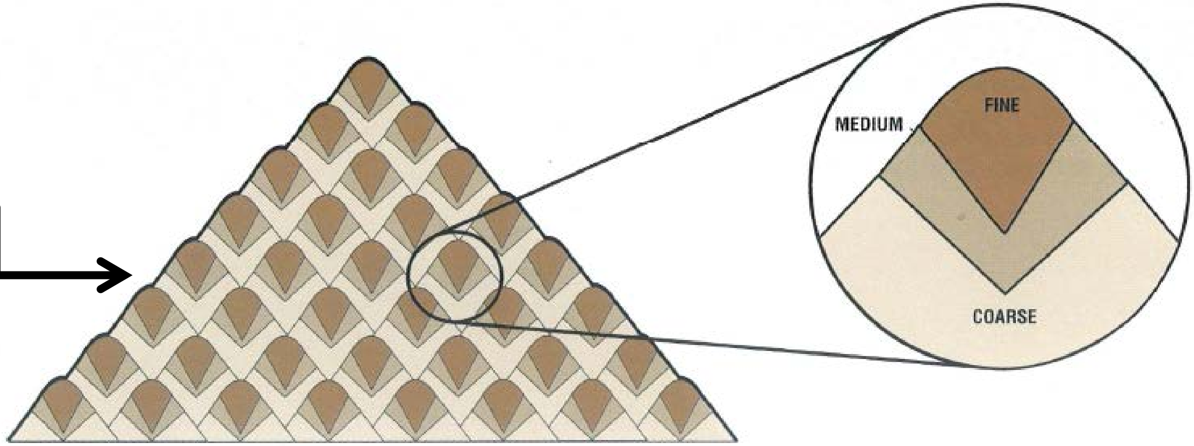
GAB Stockpile – formed with a radial telescoping stacker

Stockpile Segregation



radial telescoping stacker

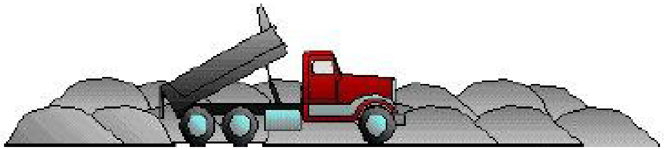
results in a more uniform stockpile



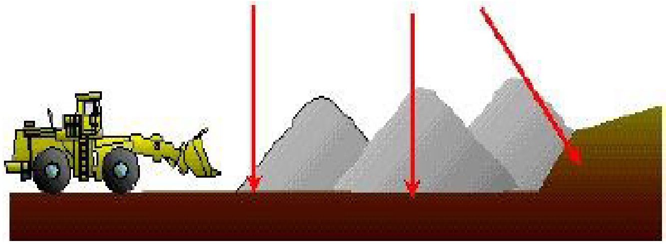
Good Practices

DON'T CONE UP

DO DUMP TIGHTLY IN SINGLE PILES

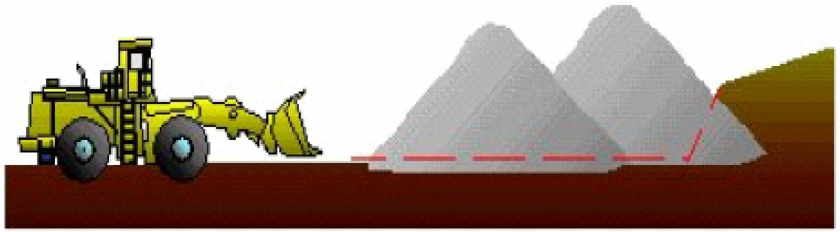


DON'T DIG UP THE MAT

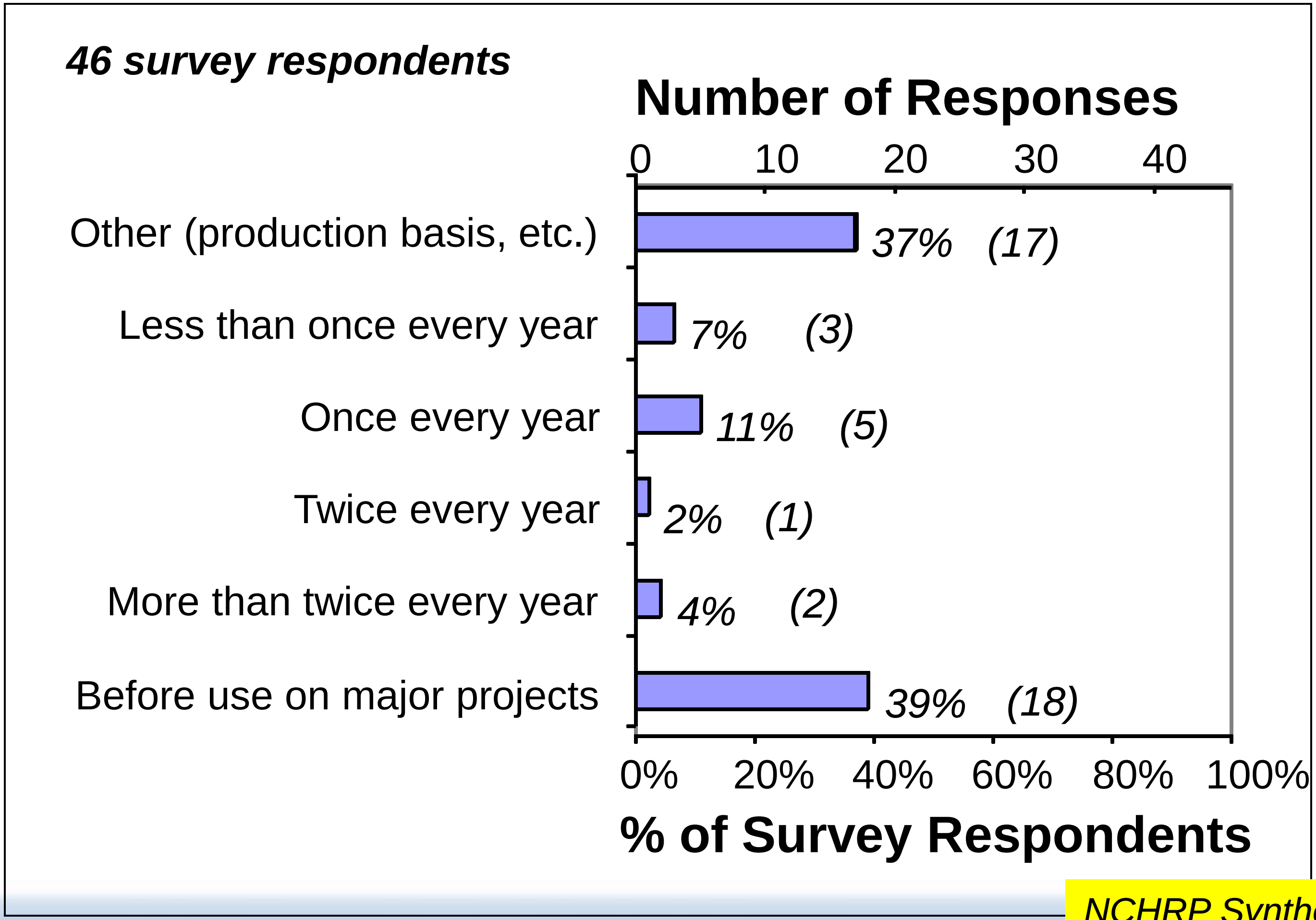


CONTAMINATION

DO KEEP THE BUCKET UP



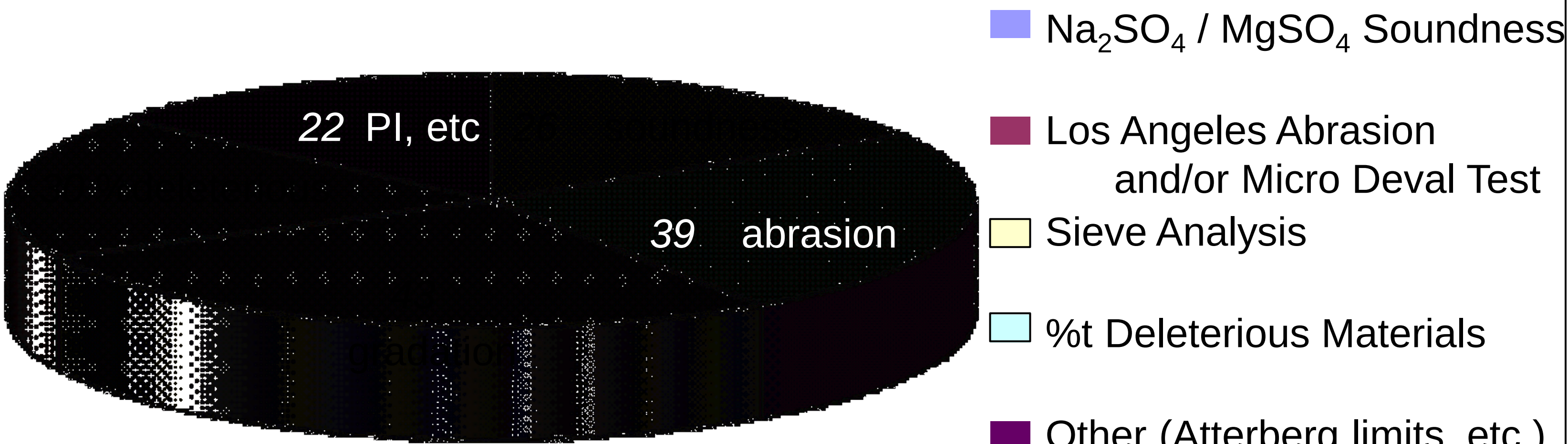
How frequently does your agency check the acceptance of materials obtained from commonly used and/or approved aggregate sources?



NCHRP Synthesis 446

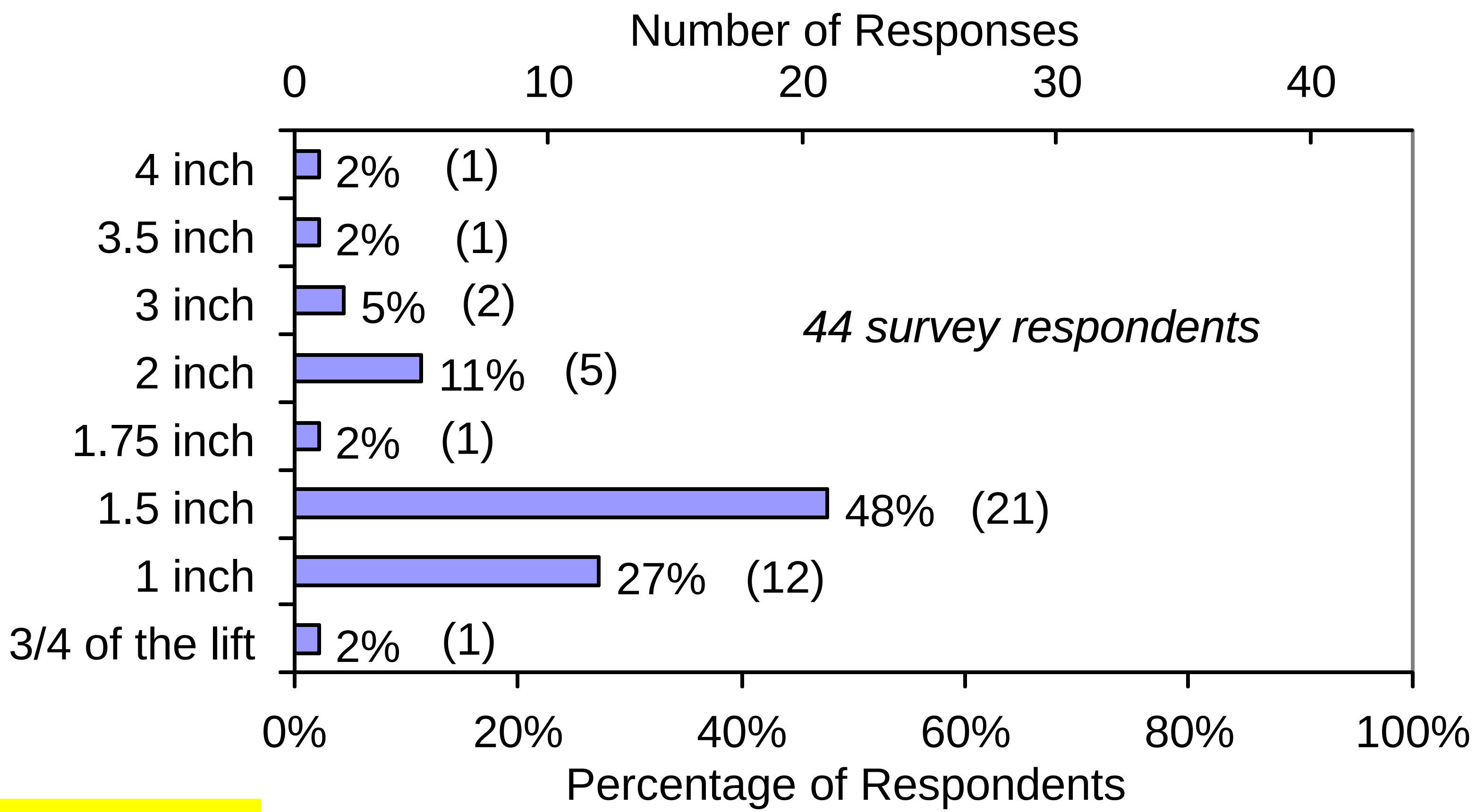
What tests are used by your agency for evaluating quality aspects of virgin aggregate materials for pavement base and subbase applications?

46 survey respondents



NCHRP Synthesis 446

What is the maximum aggregate particle size (D_{max}) in inches allowed by your agency in the following constructed unbound aggregate layers?



NCHRP Synthesis 446

Transport to Jobsite

- End Dump Truck (typical)

- Belly Dump (preferred to minimize segregation)

Shaping and Compacting

1. Spread

2. Grade

3. Compact

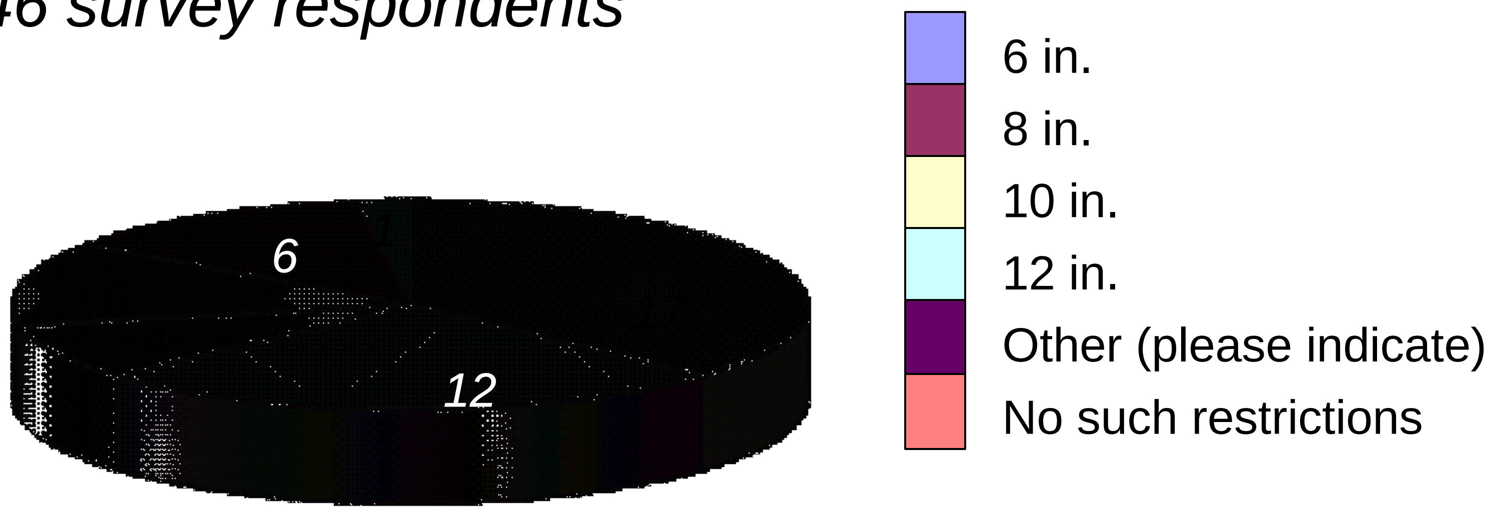
or ....

Place and Shape with Paving Equipment

Can Minimize Segregation

Allowable Max. Lift Thickness

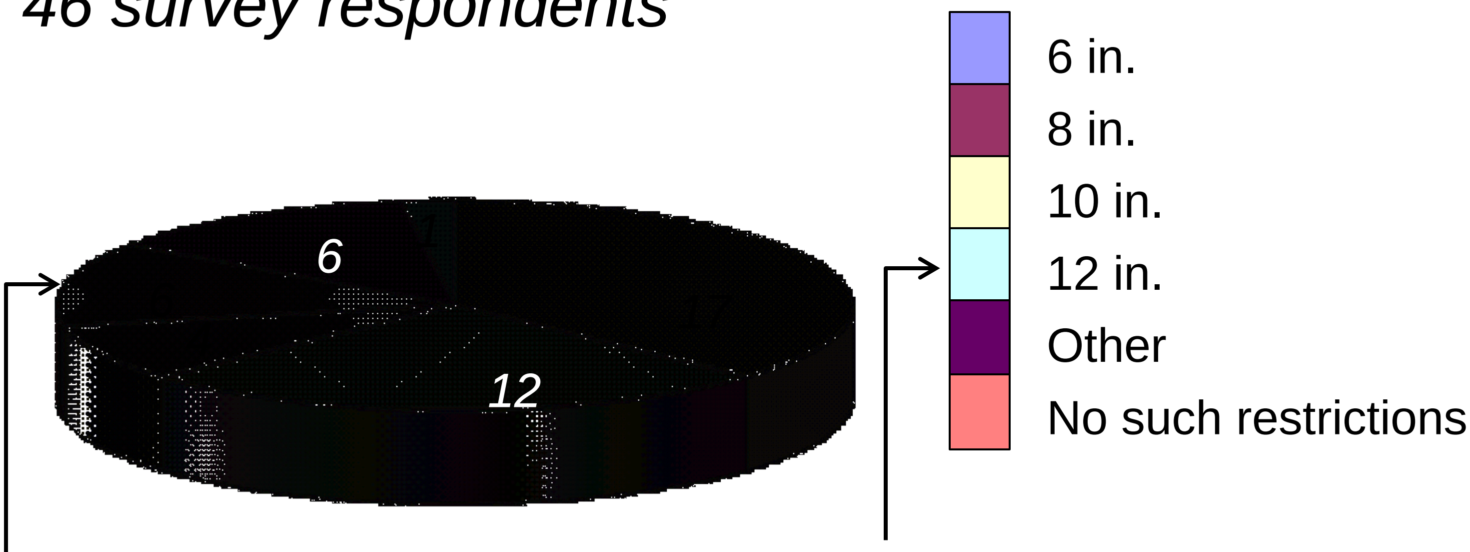
46 survey respondents



NCHRP Synthesis 446

Allowable Max. Lift Thickness

46 survey respondents



Studies indicate uniform compaction possible for 12 inch lift thickness (over “firm” prepared subgrade soils, i.e. CBR > 8)

NCHRP Synthesis 446

Compacting

textured/sheepsfoot

smooth drum/vibratory

Improving the Chance of Success

- **Equipment:** Mixing should be accomplished by stationary plant such as a pugmill or by road mixing using a pugmill or rotary mixer. Mechanical spreaders should be utilized to avoid segregation and to achieve grade control. Suitable vibratory compaction equipment should be employed.
- **Mixing and Transporting:** The aggregates and water should be plant mixed (stationary or roadway) to the range of optimum moisture plus 1% or minus 2% and transported to the job site so as to avoid segregation and loss of moisture.
- **Spreading:** The material should be placed at the specified moisture content to the required thickness and cross section by an approved mechanical spreader. At the engineer's discretion, the contractor may choose to construct a 500-ft long test section to demonstrate achieving adequate compaction without particle degradation for lift thicknesses in excess of 13 in. The engineer may allow thicker lifts on the basis of the test section results.

Allen, et al. ICAR 501-5 (1998)

Granular Base/Subbase Compaction, Quality Control and Field Performance

Debakanta Mishra
Boise State University

Outline

- Compaction Testing of Laboratory Samples
- Field Compaction
- Quality Control and Quality Assurance
- Field Performance Evaluations of Constructed Unbound Aggregate Base/Subbase Layers

Purpose of Compaction

- ✓ Reduce / Prevent Settlement
- ✓ Increase Strength – Improve Slope Stability
- ✓ Improve Subgrade Bearing Capacity
- ✓ Control Volume Change
  - Frost Action – surcharge
  - Swell – Shrinkage

Note: Attainment of High Density is NOT included!!!

Establishing Target Density for Field Compaction Control

Drop Hammer Methods

- Also known as Proctor Methods

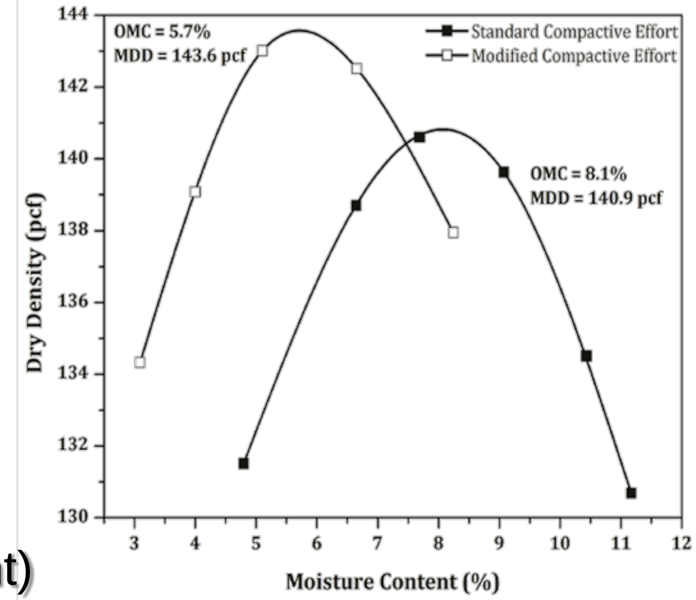
Standard Compaction (AASHTO T-99)

- 5.5-lb hammer
- 12-in. drop height
- 25 blows/lift (4-in. diameter mold)

Modified Compaction (AASHTO T-180)

- 10-lb hammer
- 18-in. drop height
- 25 blows/lift (4-in. diameter mold)
- Higher Energy!.. (mass × g × drop height)

Using molds of fixed volume

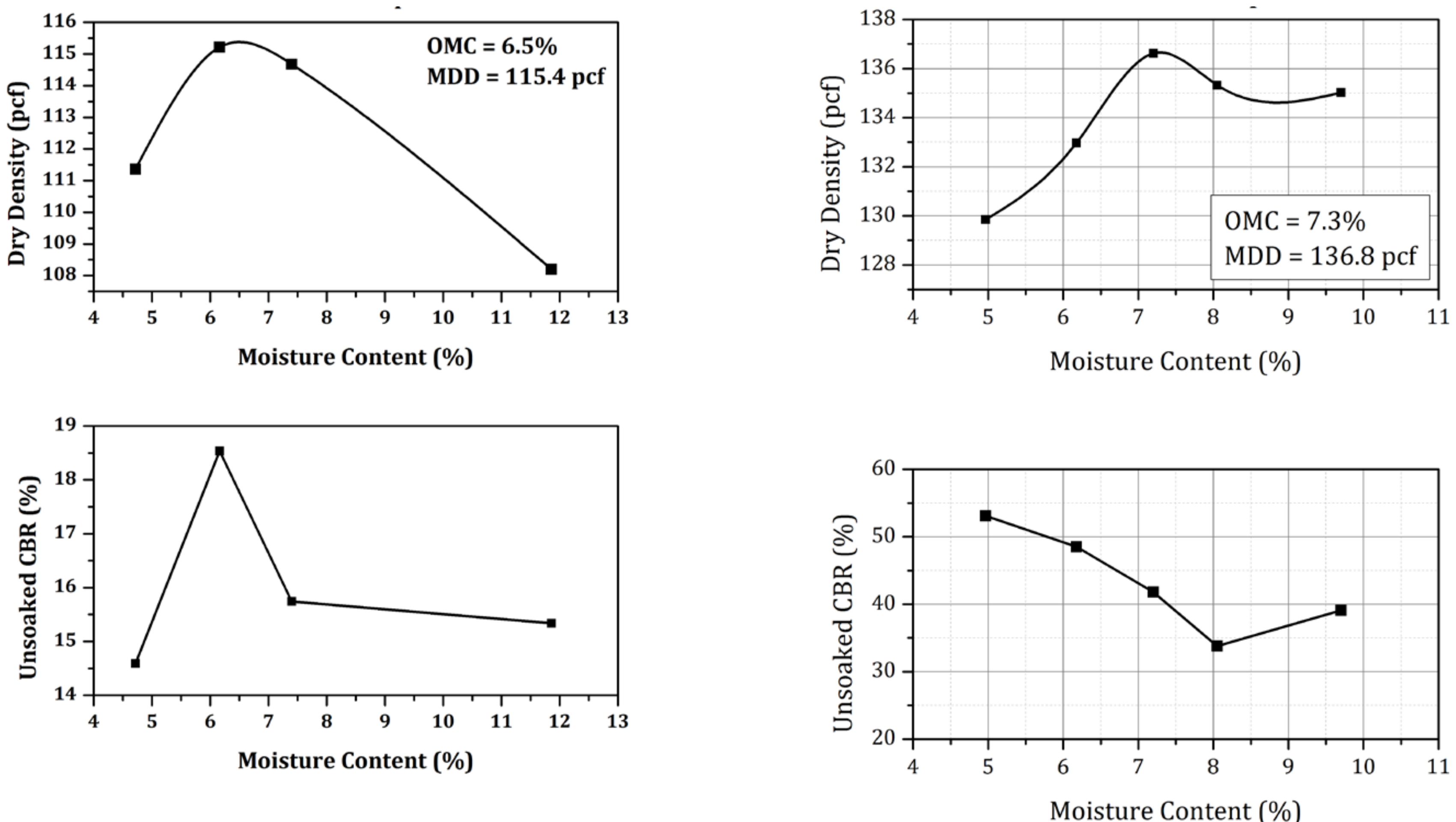


Typical Compaction Curve

Procedure:

- Prepare 4 to 5 soil samples by increasing w(%)
- Compute dry density from wet density for the known volume and plot (γ_{dry} vs. w)

May NOT Always be Adequate !



Standard Compaction

Modified Compaction

Crushed Limestone with 5% Fines

Control Strip or Test Strip Methods

- ✓ Construct a “test strip” using the same material
- ✓ Compacted through repeated rolling and vibration
  - ✓ Achieved density checked after each pass
  - ✓ Compaction stopped when no further increase in density with increasing number of passes
- ✓ Average final density of the control strip is used as the “maximum density” for the particular aggregate type
- ✓ Target density is specified as a certain percentage of the maximum density

28% (13) survey respondents currently use Test Strip Method

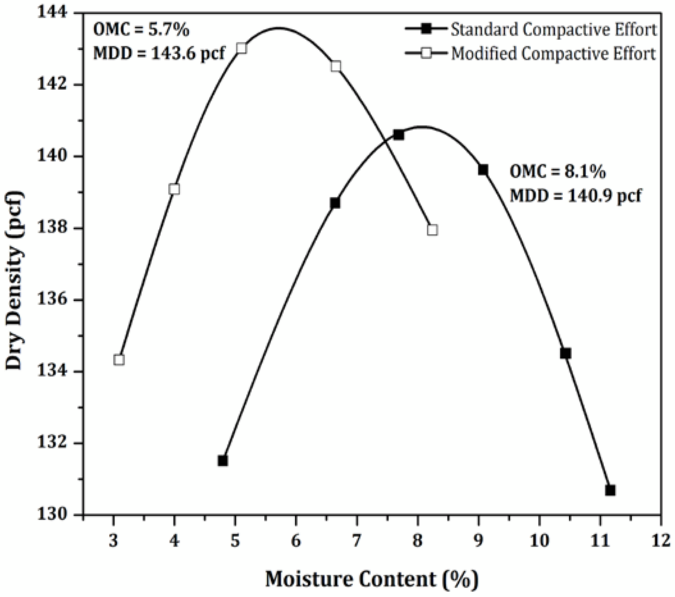
Solid Volume Density Method

- ✓ Specific Gravity x Density of Water
- ✓ Target density specified as a percentage of solid volume density
- ✓ Correlation between achieved density in the field, and "void-less" density needs to be known
- ✓ Example application: South African G1 Base

Unbound Aggregates Compaction Variables

Aggregate Material and Layer Characteristics

1. Type of parent rock (in terms of the hardness and durability of individual particles)
2. Particle shape and surface texture
3. Gradation or particle size distribution
4. Construction lift thickness
5. Moisture content
6. Layer support conditions

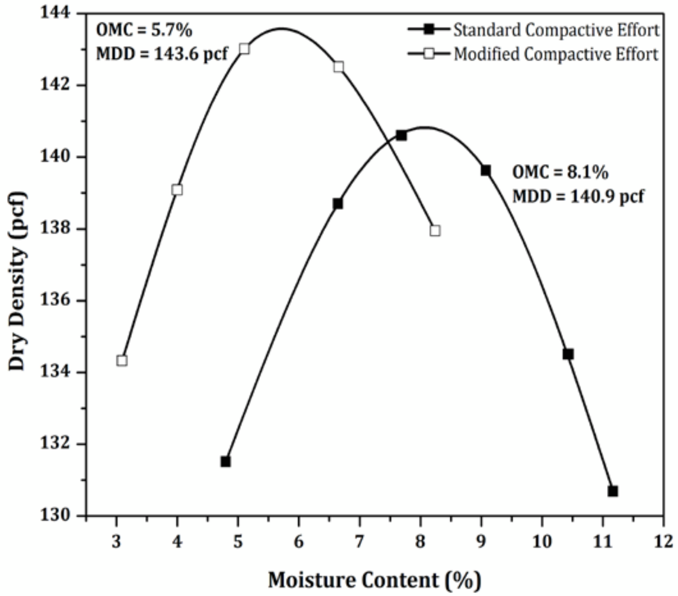


Typical Compaction Curve

Unbound Aggregates Compaction Variables (2)

Compaction Equipment and Operating Characteristics

1. Roller Type
2. Roller Weight / Energy
3. Roller Speed or Dwell Time
4. Number of Passes or Coverages
5. Rolling Zone
6. Rolling Pattern



Typical Compaction Curve

Types of Compaction Equipment

Smooth Drum Vibratory Roller

Sheepsfoot Roller

Most common for unbound aggregate layers	*Typically used for cohesive soils*
Single or dual drums	*"Bottom up" Compaction*
Static or Virbratory	*Kneading action maximizes shear strength*
Sometimes used to finish subgrade layers	*Roller "walks out" after compaction*

Types of Compaction Equipment (2)

(Photo source: http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/08.cfm)

Impact Roller

Triangular ellipsoids or hexagonal drums

Greater zone of influence compared to conventional rollers

Up to 11 g's

Commonly used in Europe and South Africa

Pneumatic or Rubber-Tire Rollers

Generally two tandem axles

3-6 wheels each (70-80% coverage)

Particularly effective for non-cohesive silty soils

Top-Down compaction

Relatively shallow depth of influence

Grid Rollers

Cylindrical heavy steel surface with a network of steel bars forming a grid

High contact pressure, but little kneading action

Suitable for most coarse-grained soils (breaks lumps)

Recommended Field Compaction Equipment for Different Soil Types

Soil Type	First Choice	Second Choice	Comment
Rock Fill	Vibratory	Pneumatic	-
Plastic Soils, CH-MH (A-7, A-5)	Sheepsfoot or pad foot	Pneumatic	Thin lifts usually needed
Low-plasticity soils, CL, ML (A-6, A-4)	Sheepsfoot or pad foot	Pneumatic, vibratory	Moisture control often critical for silty soils
Plastic sands and gravels, GC, SC (A-2-6, A-2-7)	Vibratory, Pneumatic	Pad foot	-
Silty Sands and Gravels SM, GM (A-3, A-2-4, A-2-5)	Vibratory	Pneumatic, Pad foot	Moisture Control often critical
Clean Sand, SW, SP (A-1-b)	Vibratory	Impact, pneumatic	-
Clean Gravels, GW, GP (A-1-a)	Vibratory	Pneumatic, Impact, Grid	Grid useful for over-sized particles

Christopher et al. (2010)
Rollings and Rollings (1996)

Methods to Measure the Moisture-Density of Constructed Unbound Aggregate Layers

Parameter to be Determined	Name of Method	ASTM	AASHTO
Moisture Content	Gravimetric Method	D 2216	T 265
	Microwave Method	D 4643	*N/A
	Calcium Carbide Gas Pressure Test	D 4944	T 217
Density	Sand Cone Method	D 1556	T 191
	Sand Replacement Method	D4914	*N/A
	Balloon Method	D 2167	T 205**
	Oil or Water		
	Drive Cylinder	D 2937	T 204**
Moisture and Density	Rapid Method	D 5080	*N/A
	Nuclear – Moisture	D 3017	T 310
	Nuclear – Density	D 2922	T 310
	Time Domain Reflectometry	D 6780	*N/A

*N/A: Not available
**: Withdrawn from latest standards

Methods for Moisture Measurement

Desirable Characteristics

- ✓ Accurate
- ✓ Durable
- ✓ Reasonably fast
- ✓ Easy to use

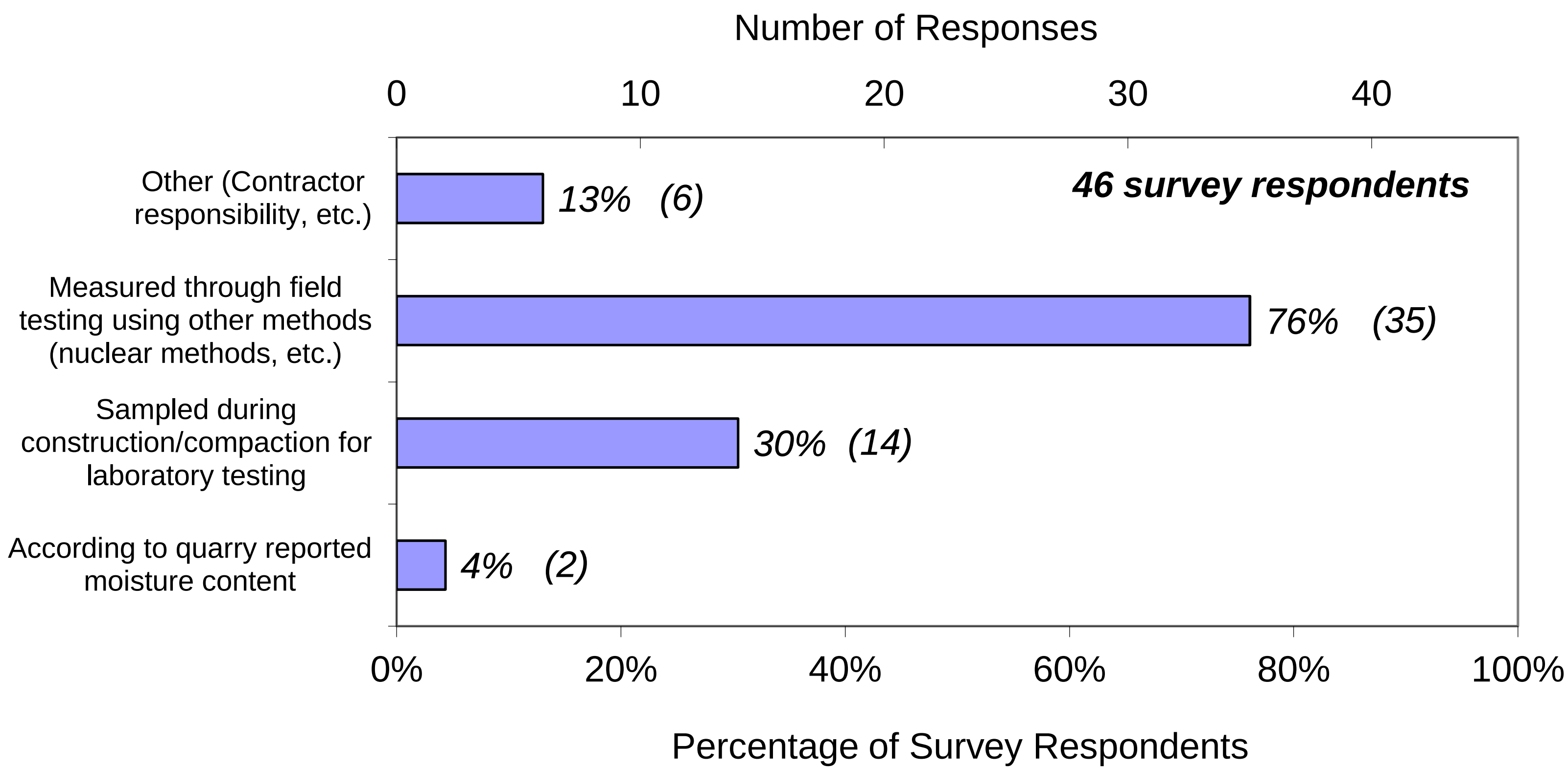
Direct Methods

- ✓ Oven Dry Method
- ✓ Direct Heating Method
- ✓ Calcium Carbide Gas Pressure Tester Method

Indirect Methods

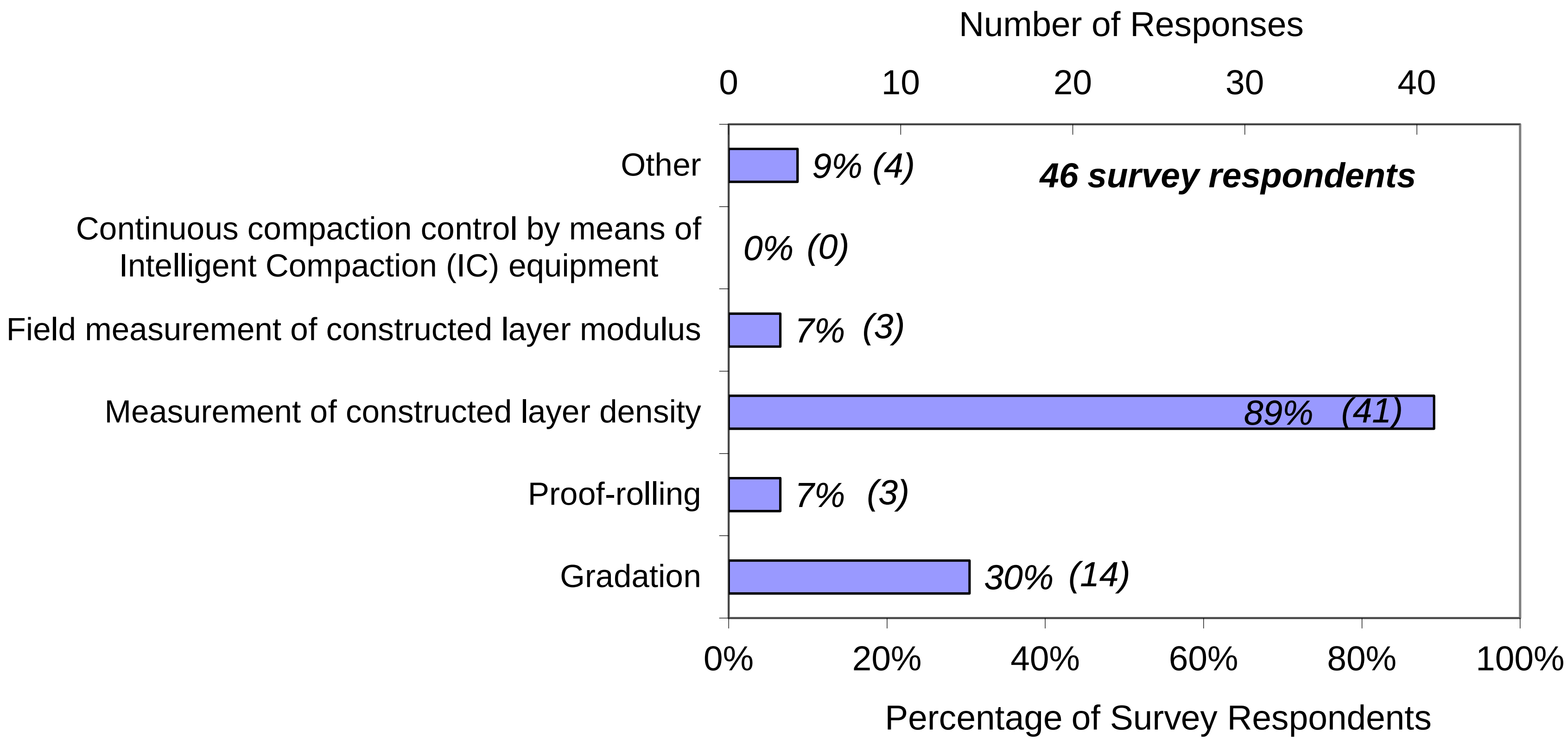
- ✓ Nuclear Gauge Method
- ✓ Time-Domain Reflectometers
- ✓ Frequency-Domain Reflectometers
- ✓ Capacitance Probes

Methods to Control the Moisture Content of Unbound Aggregate Base/Subbase Layers



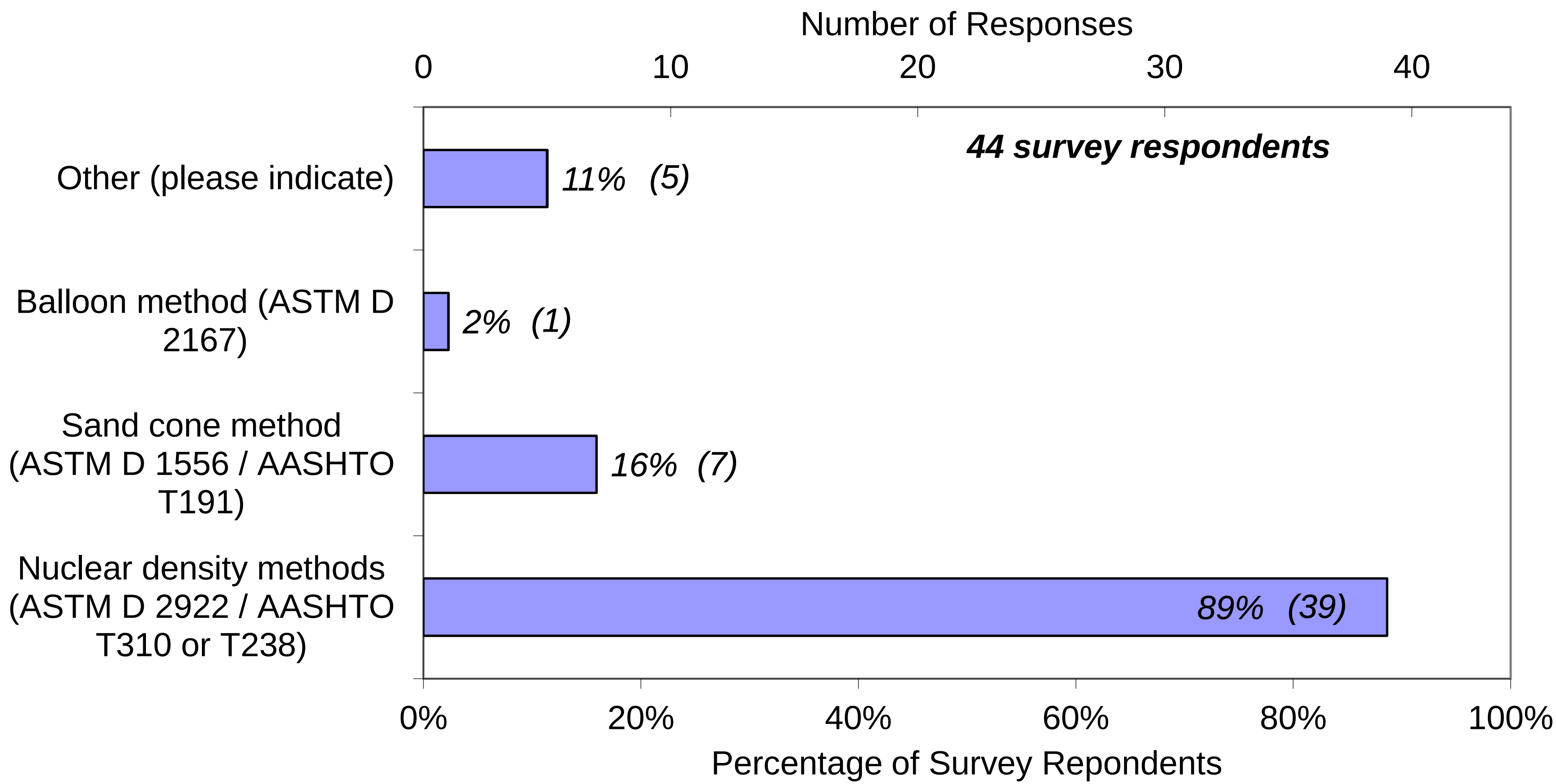
Unbound Aggregate Pavement Base / Subbase Applications (46 respondents – NCHRP Synthesis 43-03 -2012)

Approaches for Evaluating Degree of Compaction and Construction Quality Control



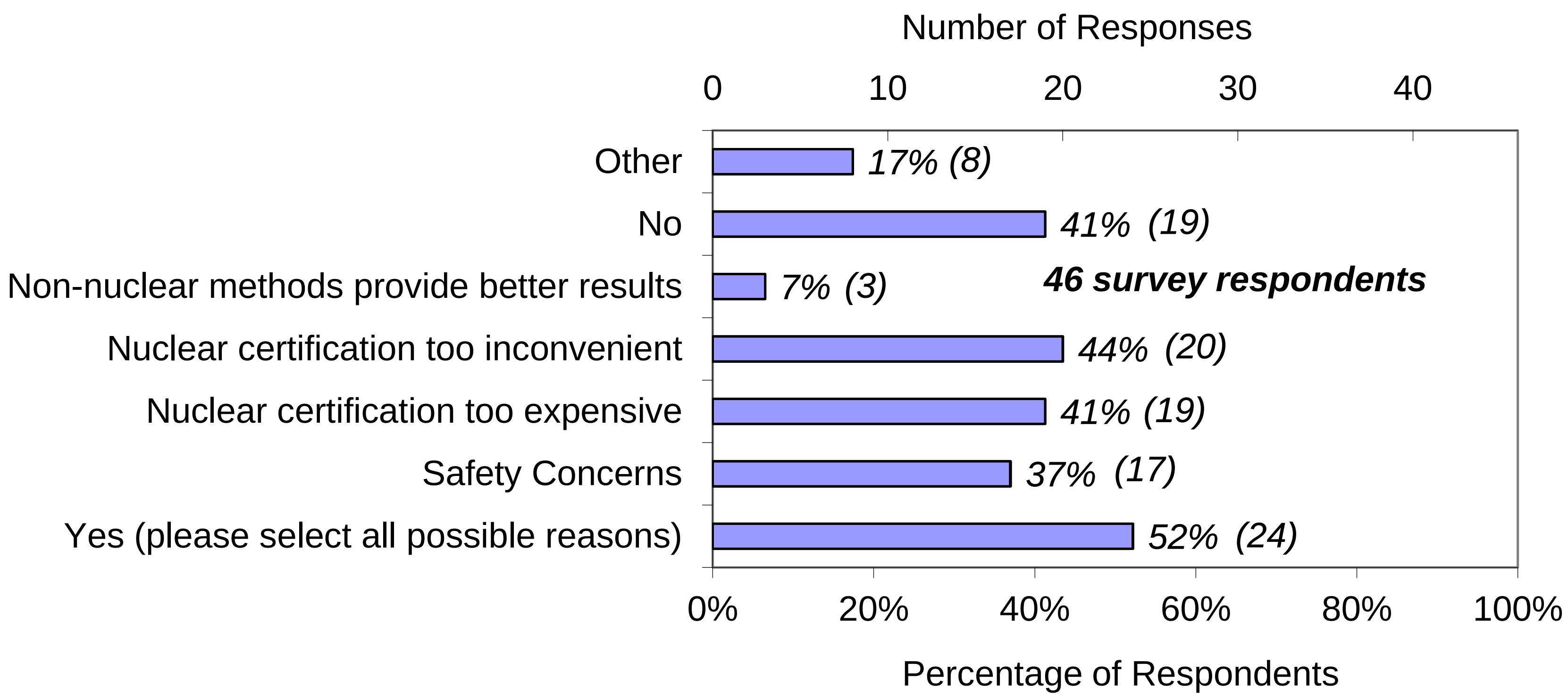
Unbound Aggregate Pavement Base / Subbase Applications (46 respondents – NCHRP Synthesis 43-03 -2012)

Methods to Measure Constructed Base/Subbase Layer Densities in the Field



Unbound Aggregate Pavement Base / Subbase Applications (46 respondents – NCHRP Synthesis 43-03 -2012)

Response to Whether there is Interest to Implement Non-Nuclear Density Measurement Methods



Unbound Aggregate Pavement Base / Subbase Applications (46 respondents – NCHRP Synthesis 43-03 -2012)

Several survey respondents indicated "lack of confidence" in non-nuclear methods

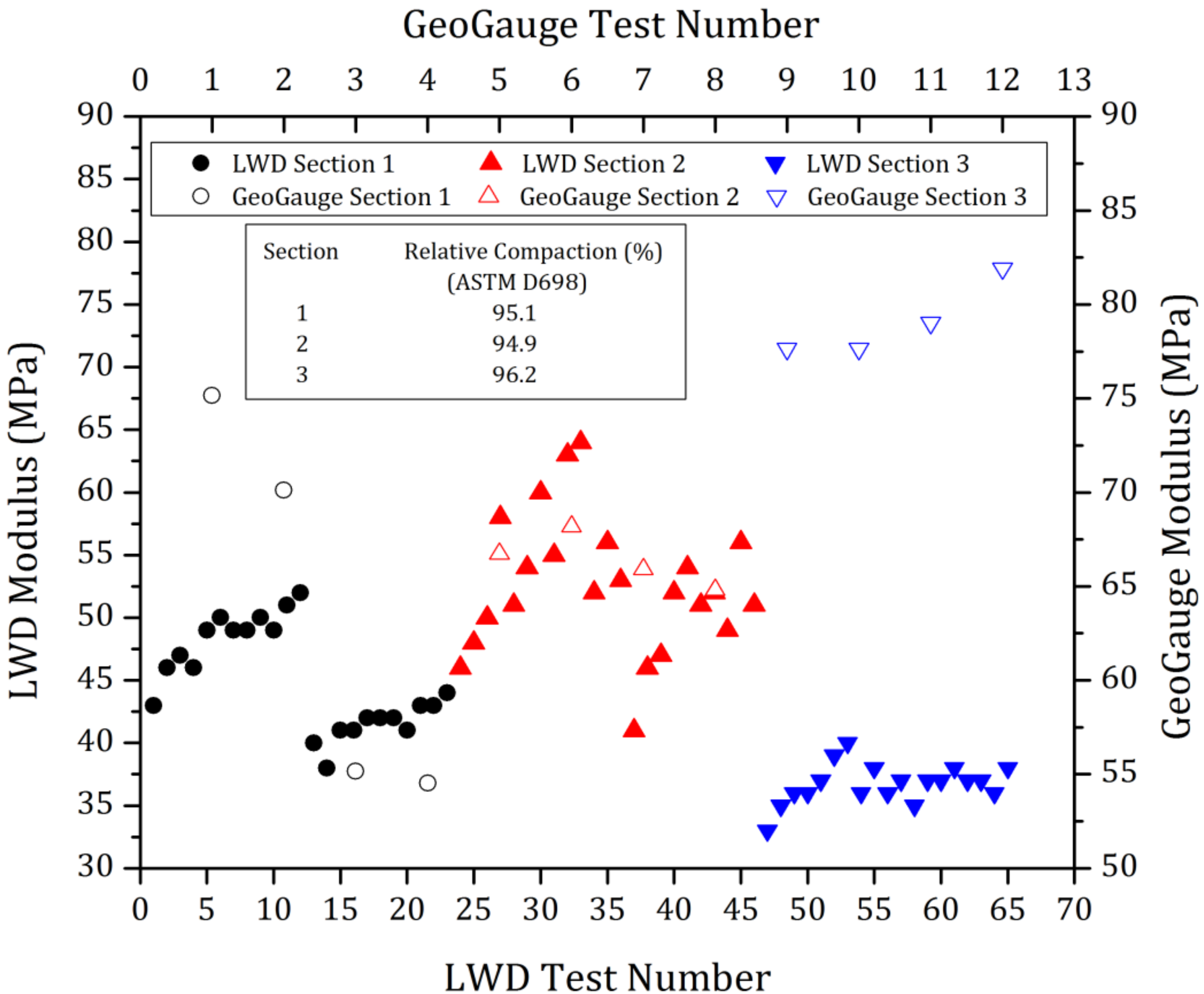
In-Place Modulus Measurement of Constructed Aggregate Layers

- ✓ Density is not a required input for Mechanistic-Empirical pavement design methods
- ✓ Resilient modulus (M_R) is used as a key input
  - ✓ Using M_R for construction quality control may facilitate linkage with design methods

Different Methods for In-Situ Modulus Measurement

Test Category	Underlying Principle	Corresponding Devices
Surface Deformation	**Static Load**	• Benkelman Beam • Briaud Compaction Device (BCD, based on measuring the bending strain on a loading plate in contact with the ground)
	Steady State Vibratory	• Soil Stiffness Gauge (e.g. Humboldt GeoGauge™)
	Impact Load	• Falling Weight Deflectometer (FWD) • Portable Falling Weight Deflectometer (PFWD) or Light Weight Deflectometer (LWD)
	Sinusoidal Load	• Dynaflect • Road Rater
	Continuous Load	• Rolling Wheel Deflectometer (RWD)
Geophysical	**Wave Propagation**	• Ultrasonic Body Waves • Ultrasonic Surface Waves • Spectral Analysis of Surface Waves (SASW) • Multi-channel analysis of surface waves • Free-Free Resonant Column Tests • Seismic Pavement Analyzer (SPA) • Portable Seismic Pavement Analyzer (PSPA)

Need to know what we are measuring !!



Mishra et al. (2011)

Modulus-Based Compaction Control

- ✓ Combine the aspects of in-place modulus measurement and construction quality control

- ✓ Key issues to consider
  - ✓ Measurement Depth
  - ✓ Induced Stress State (In Relation to Strength)
  - ✓ Proper Algorithms for Layer Modulus Estimation

- ✓ Ideal approach (Do not base on any one measurement!)
  - ✓ Density: Target Value ± Tolerance
  - ✓ Moisture Content: Target Value ± Tolerance
  - ✓ Layer Modulus: Target Value ± Tolerance

Compaction control using modulus only may not be feasible !

Development of Modulus-Based Compaction Control Specifications

NCHRP Project 10-84

Requirements:

1. Should be based on field measures of the stiffness or modulus and moisture content
2. Should provide a single, straightforward, and well-defined method for determining stiffness or modulus that is compatible with a variety of earthwork and unbound aggregate design methodologies

Development of Modulus-Based Compaction Control Specifications (2)

NCHRP Project 10-84

Requirements:

3. Should directly account for the seasonal variation of the modulus of the compacted earthwork or unbound aggregate

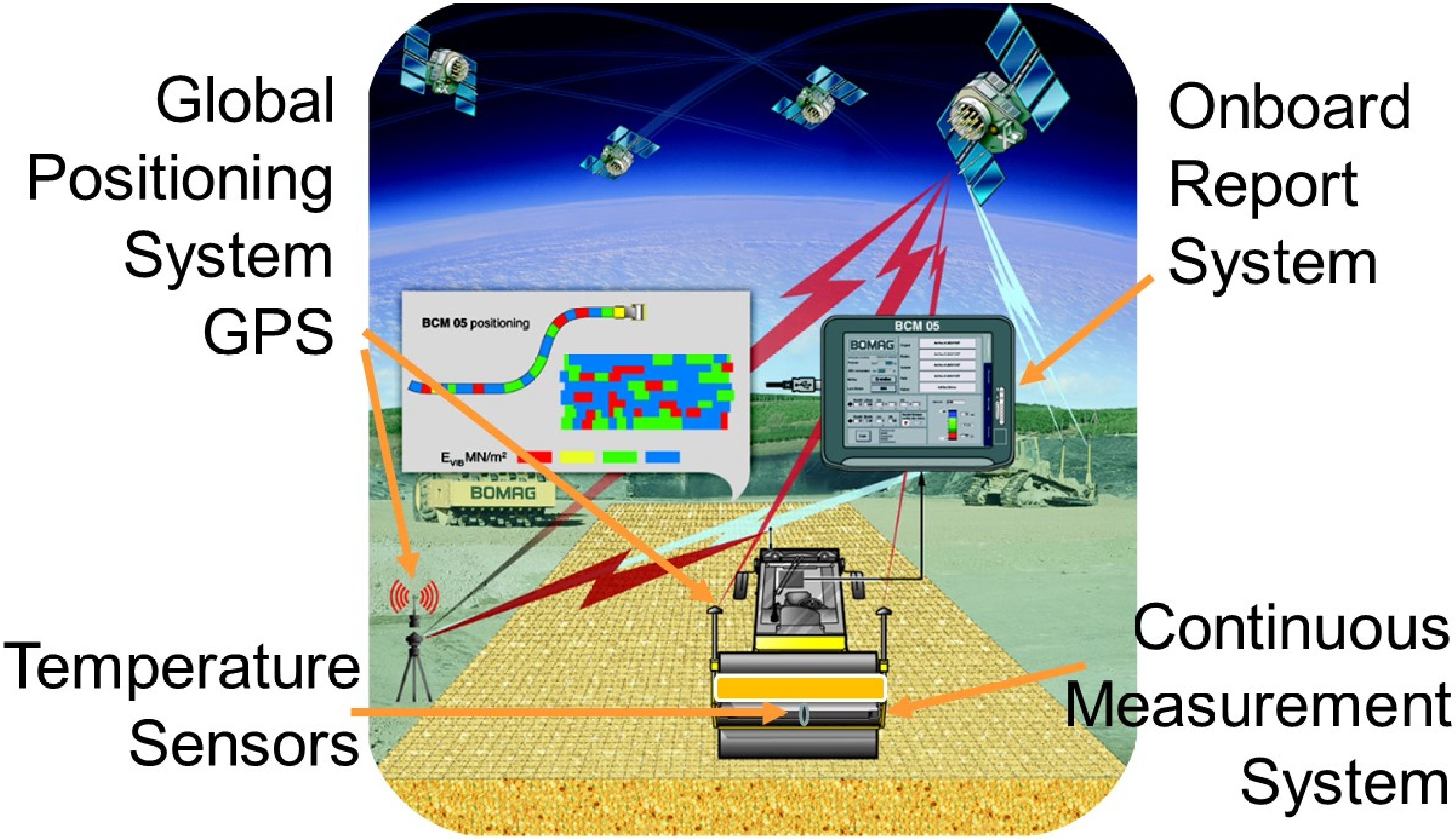
4. Should use available models, devices, and methods

5. Should be founded on a comprehensive review of the current literature on the long-term behavior of various soils and unbound aggregates in terms of the principles of unsaturated soil mechanics

Continuous & Intelligent Compaction of Granular Bases/Subbases

George Chang
The Transtec Group

Continuous Compaction Control (CCC) & Intelligent Compaction (IC)



Courtesy of Bomag


Traditional Compaction Testing Method
1 / 1,000,000
Compaction Testing and Coverage Mapping with AccuGrade
100 %
Coverage

Single Drum IC Rollers

Ammann-Case

Caterpillar

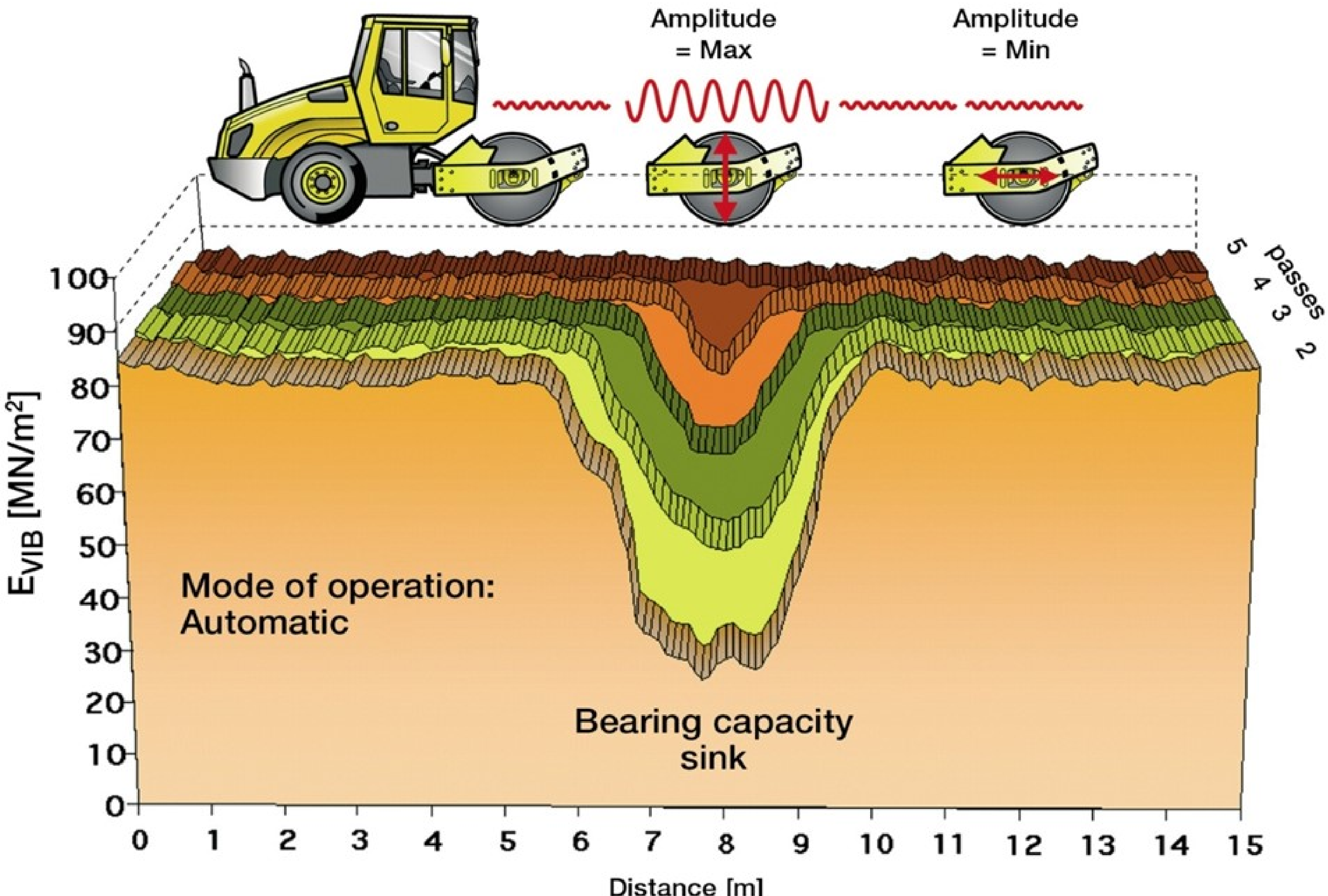
HAMM-Wirtgen

BOMAG

Dynapac-Atlas Copco

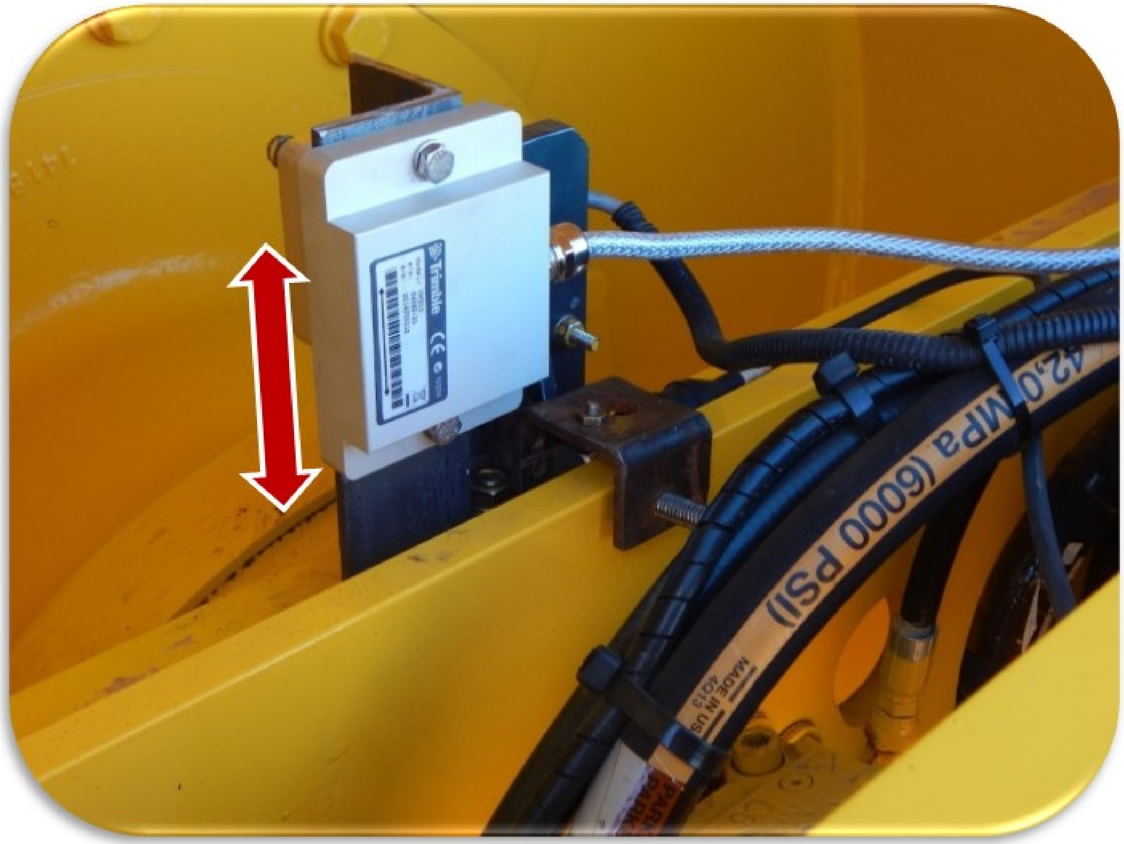
Sakai

Auto-Feedback Control - AFC



Courtesy of Bomag

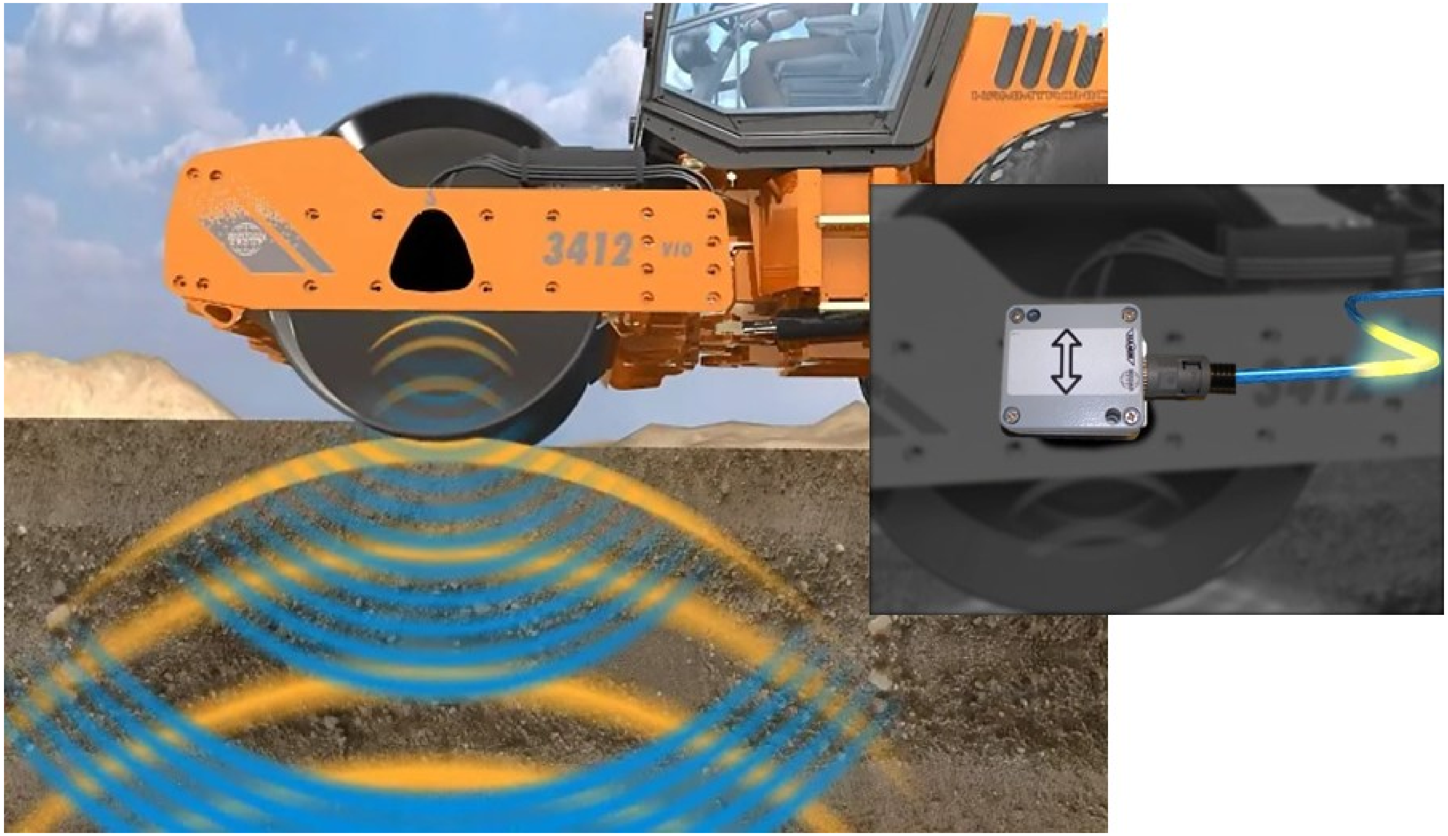
Accelerometer Installation



ICMV

Intelligent **C**ompaction **M**easurement **V**alue

Accelerometer-Based ICMV



Various ICMVs

Responses Measured

- Level 1 – Frequency response
  - Compaction Meter Value (CMV)
  - Stiffness increase causes increased vdrum vibration frequency
- Level 2 – Energy & Rolling Resistance
  - Machine Drive Power (MDP)
  - As layer becomes compacted less power is needed to move roller forward

Responses Measured

- Level 3 – Static Mechanistic Solutions
  - Vibration Modulus (E_{vib})
  - More compacted layer absorbs more compaction energy
- Level 4 – Layer Mechanical Properties
  - work in progress!

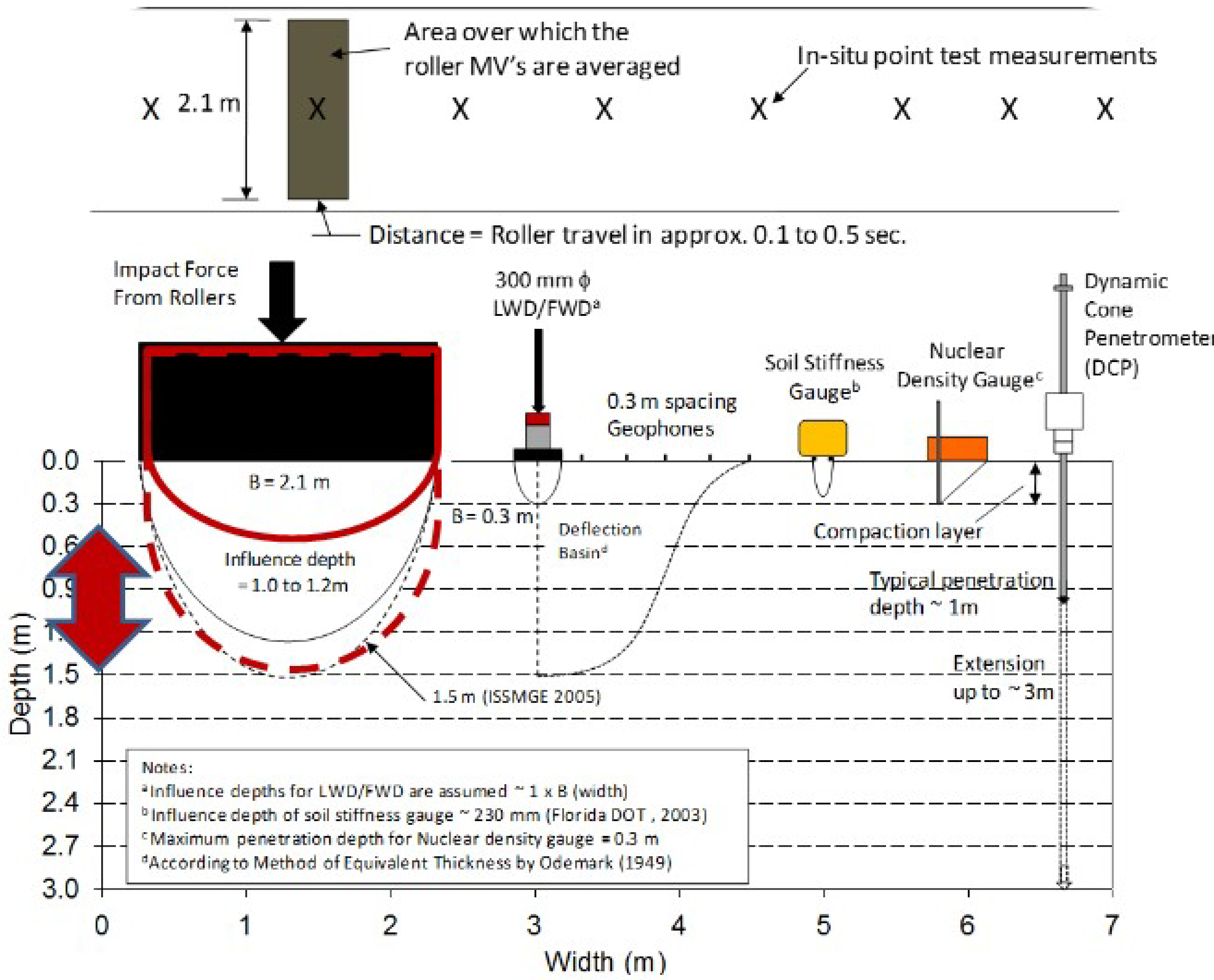
Factors that Influence Correlation

Footprint

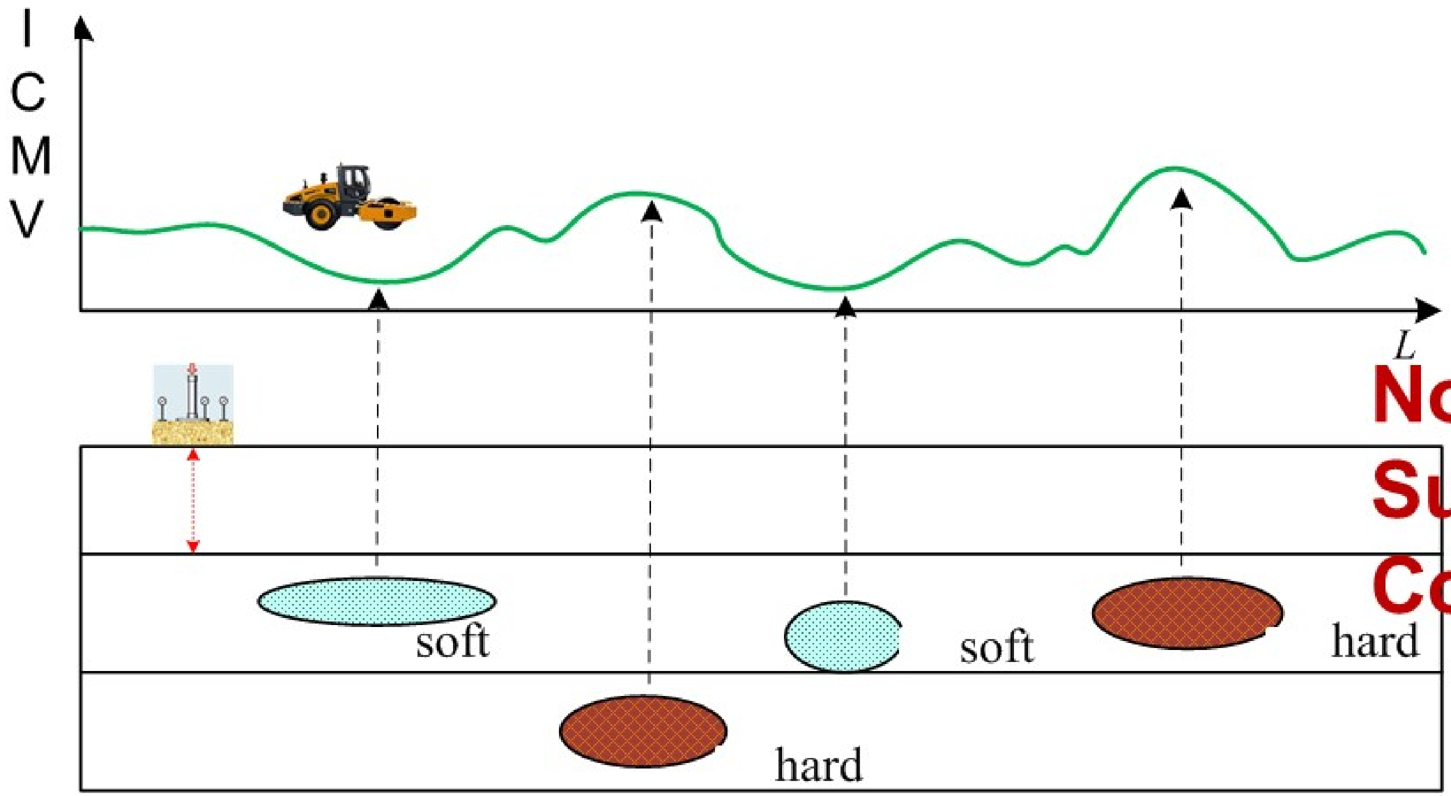
Depth

0.5 m 20 in.

1.2 m 5 ft

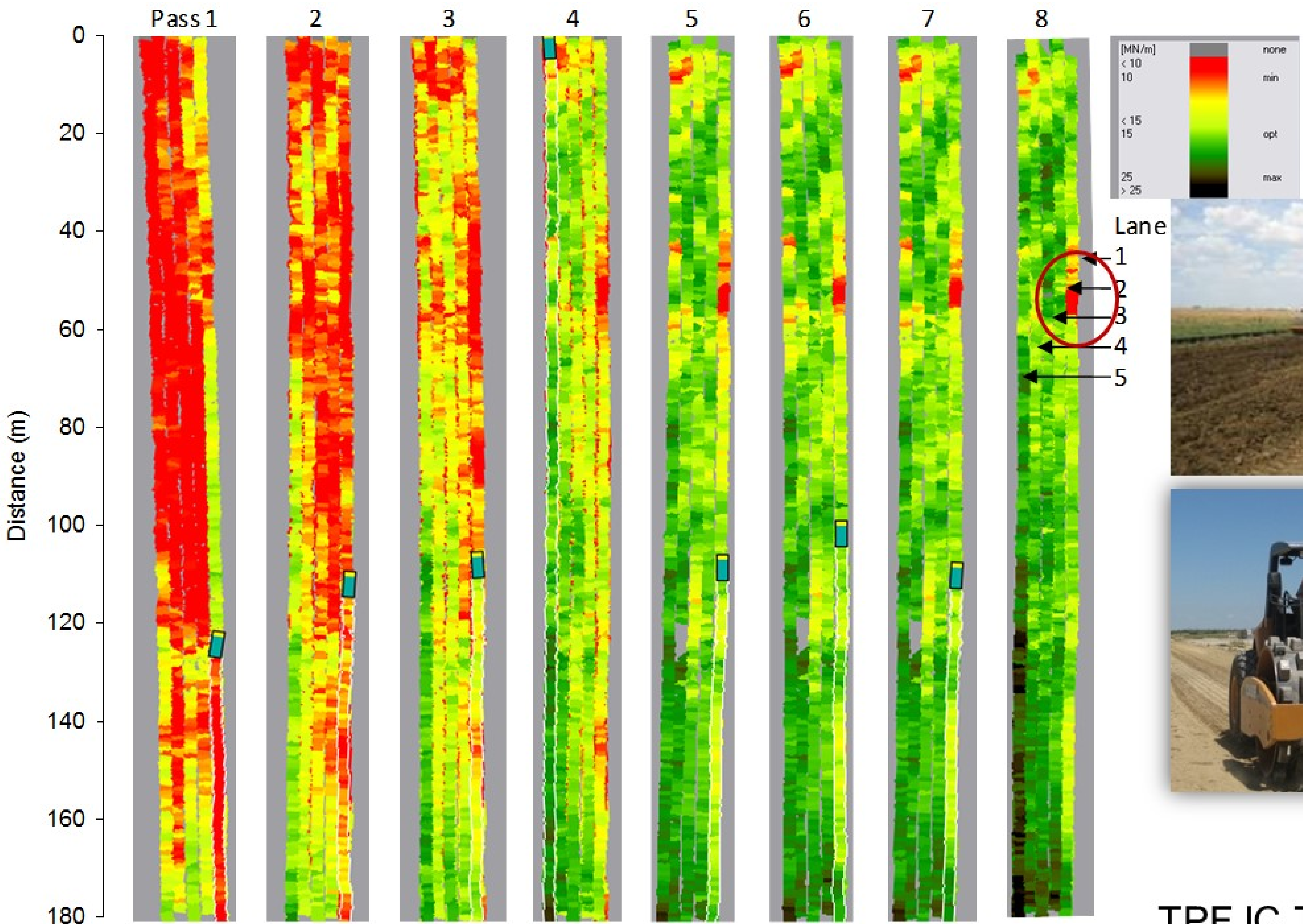


Factors that Influence Correlation (cont'd)



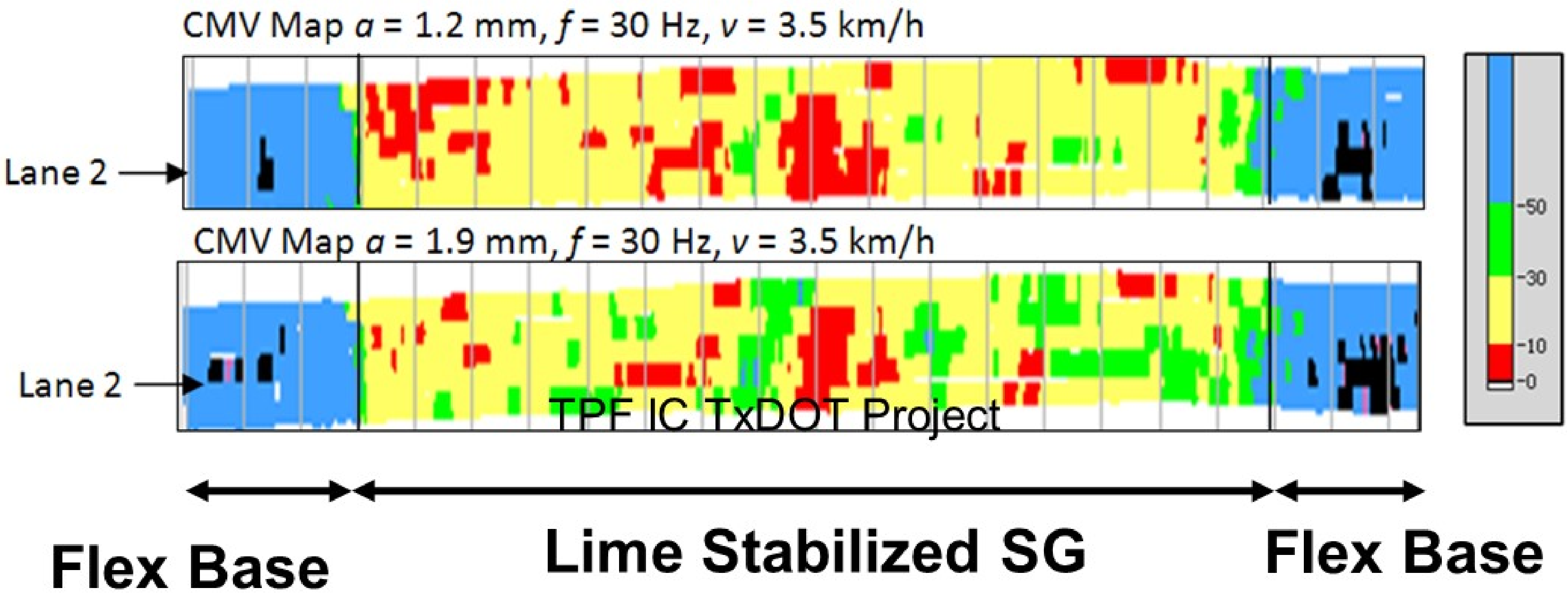
Non-uniform Support Condition

Identify Weak Areas

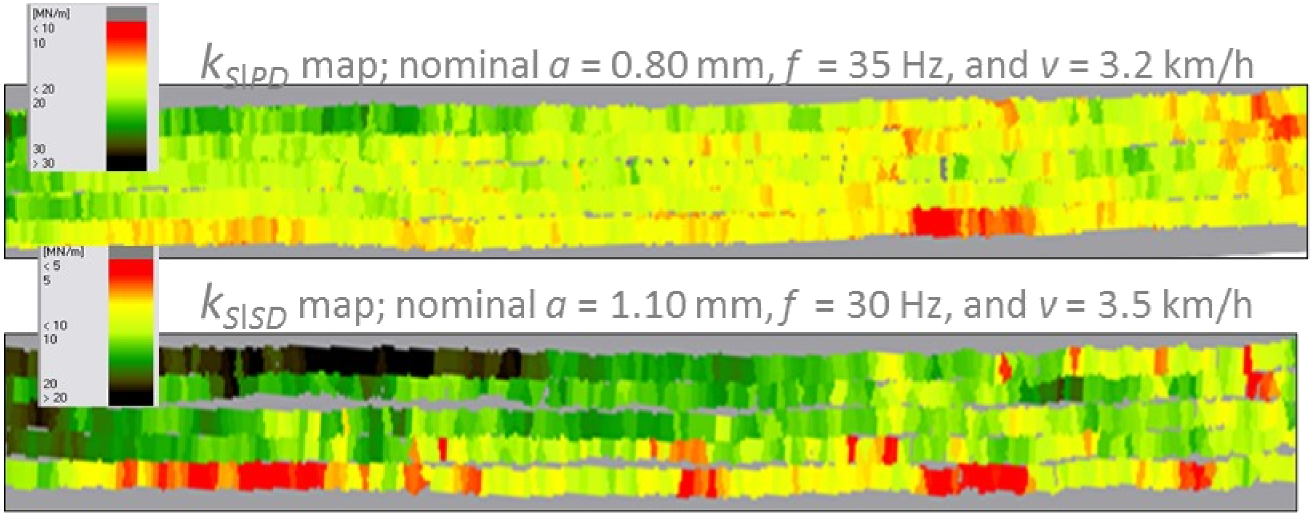


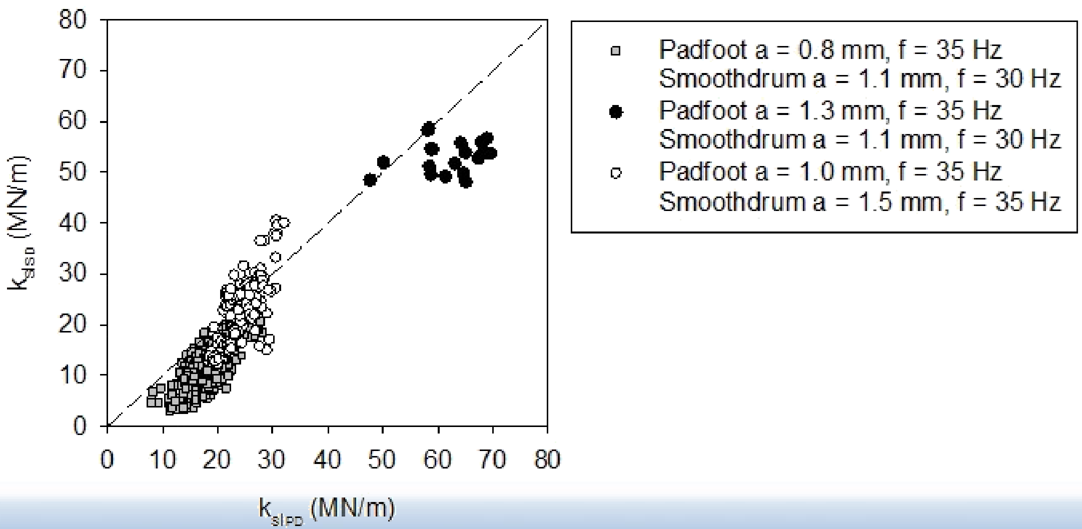
TPF IC TxDOT Project

Differentiate Materials



Padfoot vs. Smooth Drum

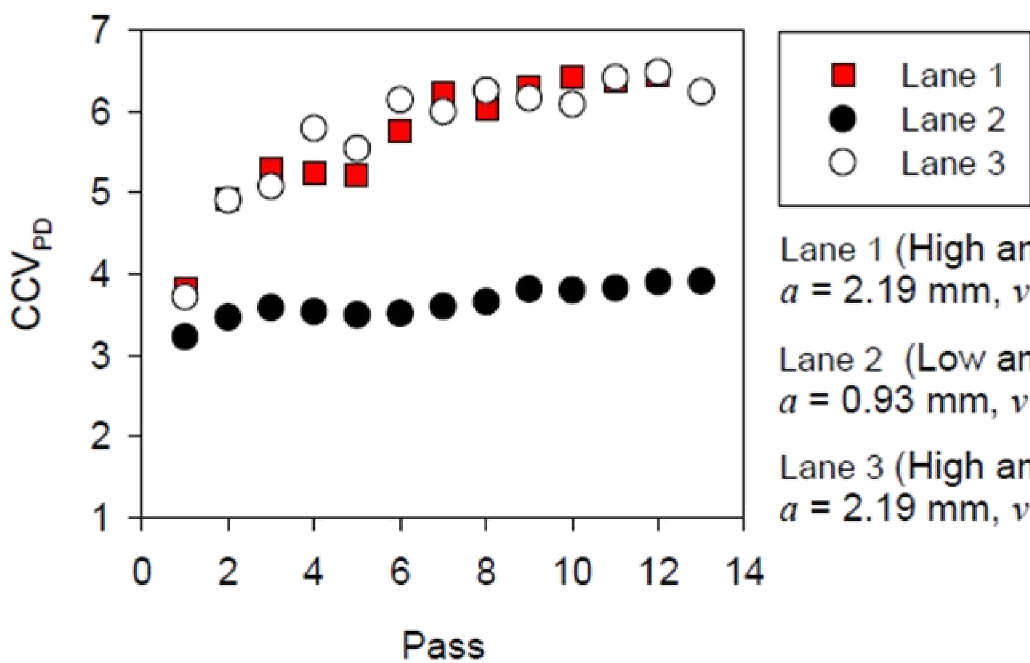




Courtesy of Dr. David White

TPF IC TxDOT Project

Compaction Curves



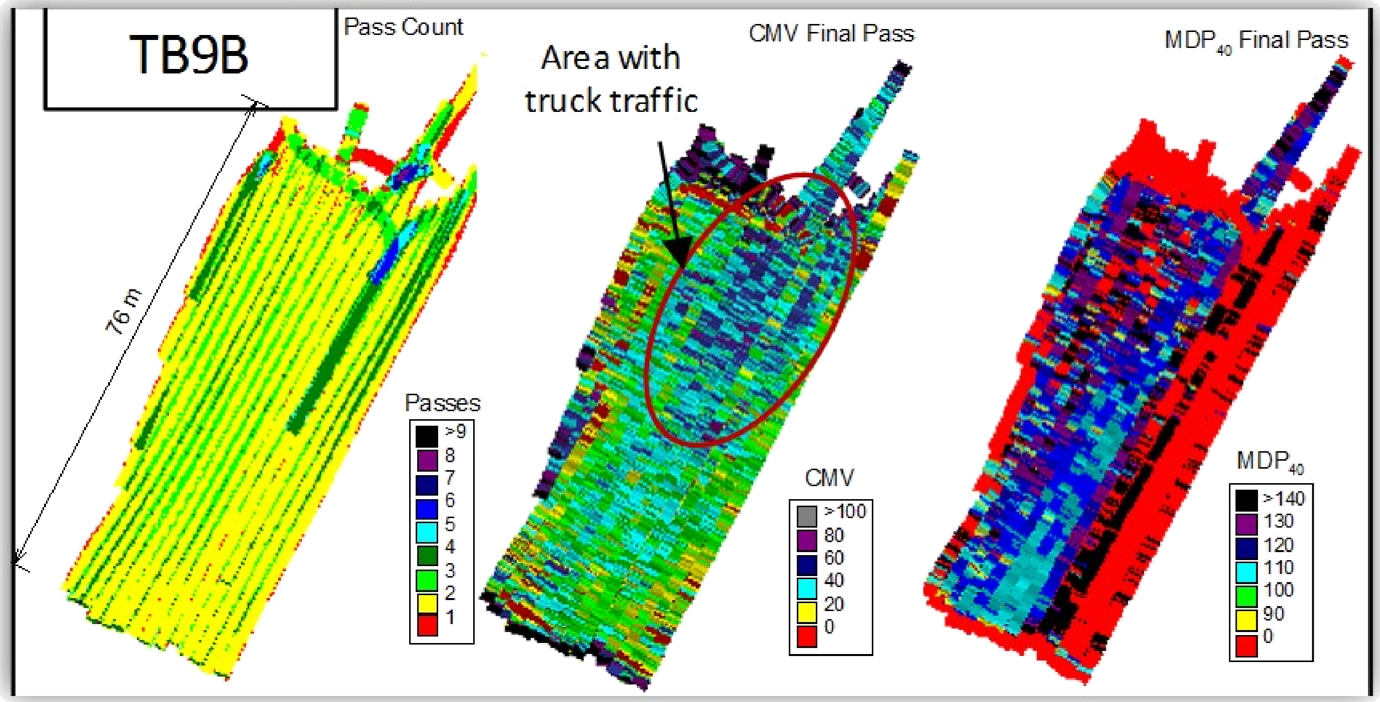
Lane 1 (High amp setting):
a = 2.19 mm, v = 6 km/h, f = 26 Hz

Lane 2 (Low amp setting):
a = 0.93 mm, v = 6 km/h, f = 33 Hz

Lane 3 (High amp setting):
a = 2.19 mm, v = 6 km/h, f = 26 Hz

TPF IC KSDOT Project

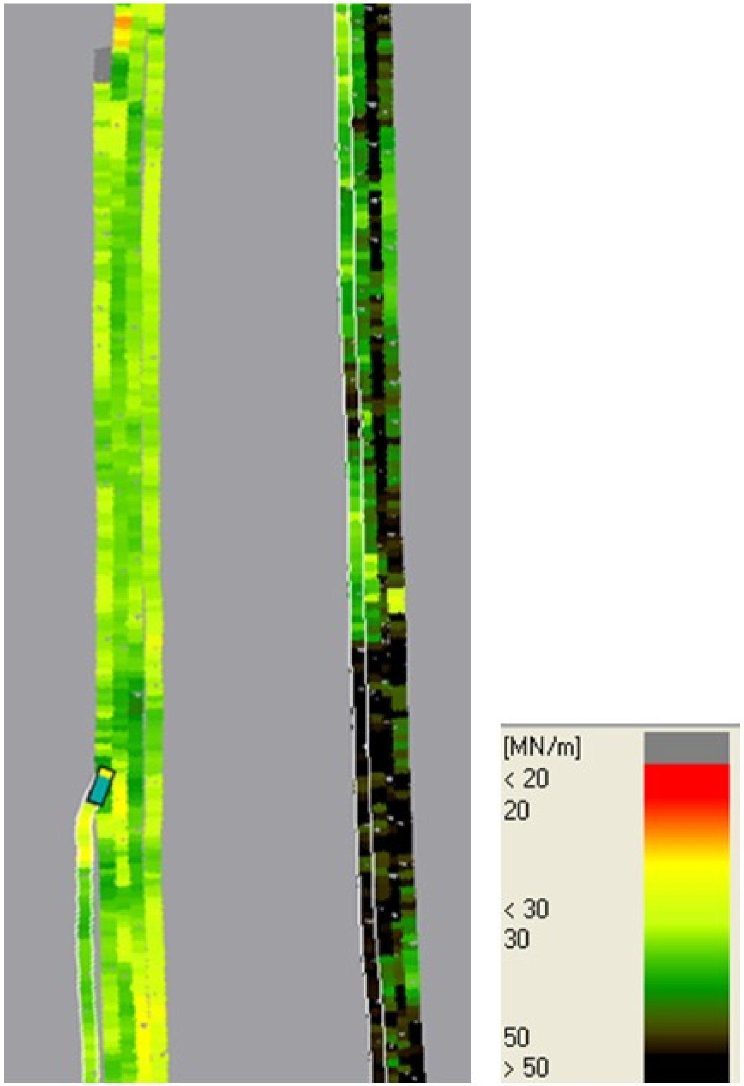
Compaction due to Truck Traffic



Courtesy of Dr. David White

TPF IC NYSDOT Project

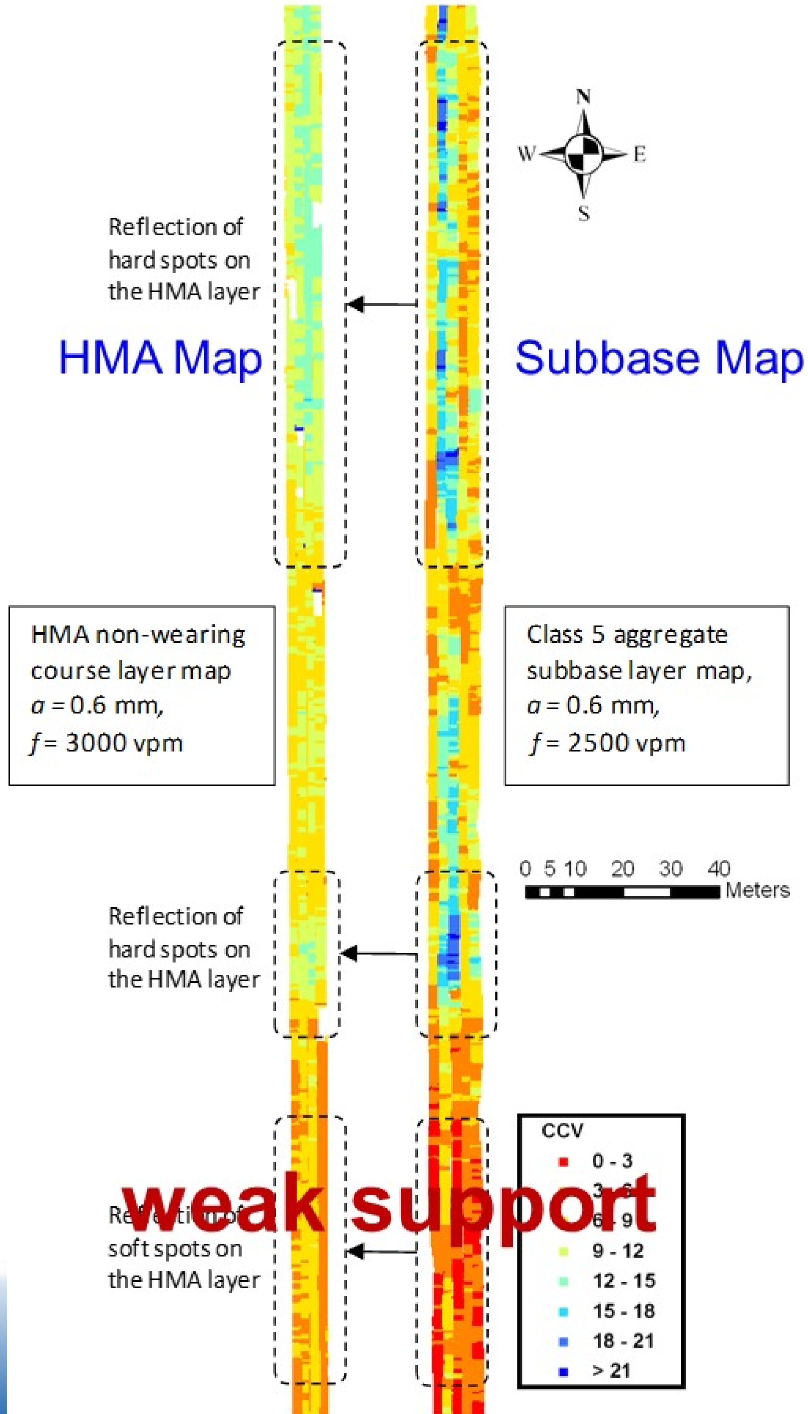
Age Effects on Stabilized Base



Courtesy of Dr. David White

5 hours 2 days

TPF IC MSDOT Project

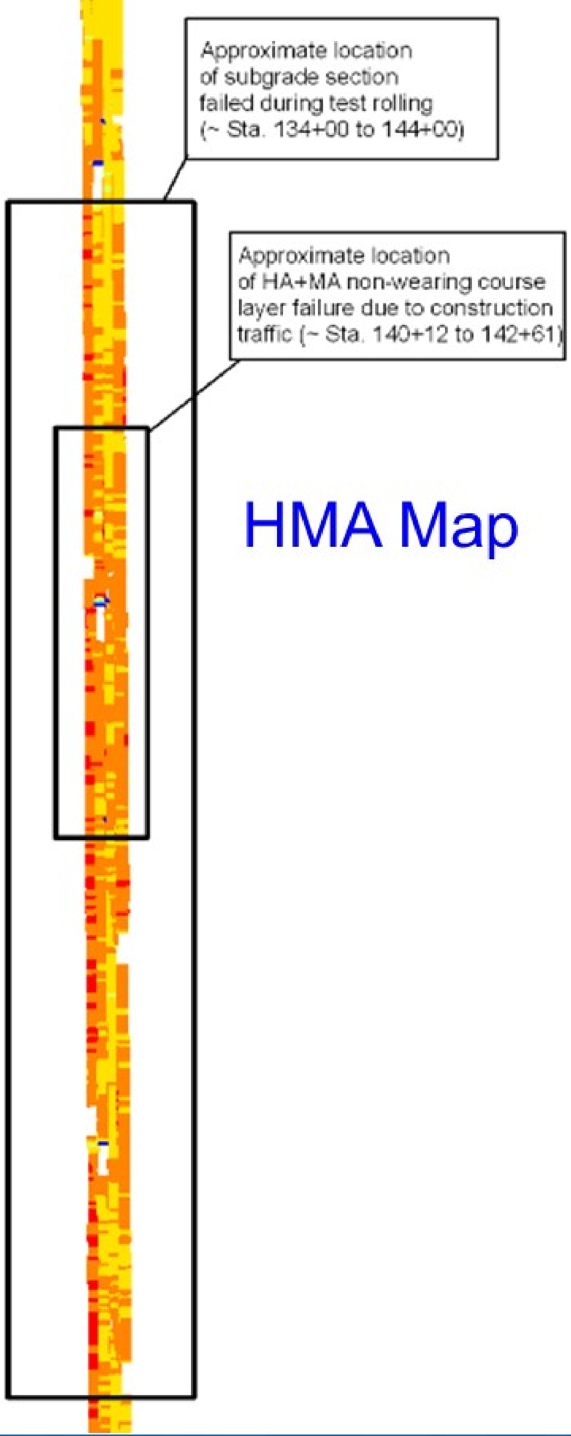


Pre-Mapping Subbase

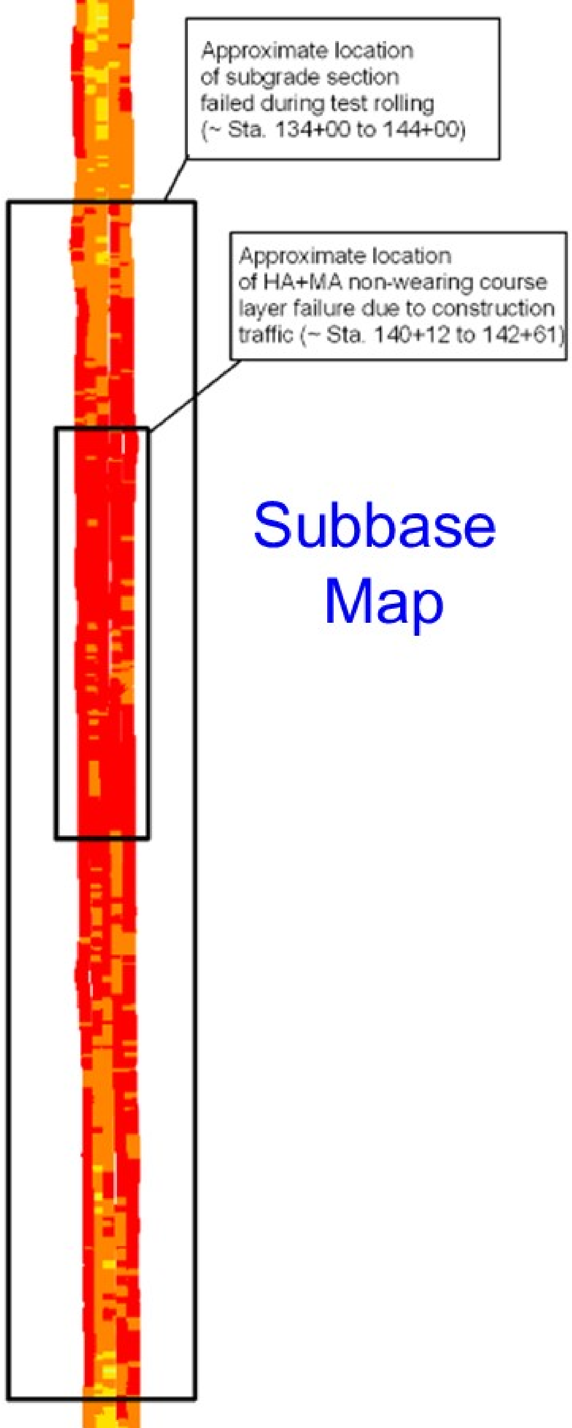
Asphalt Compaction

TPF IC MNDOT Project

Premature Failure

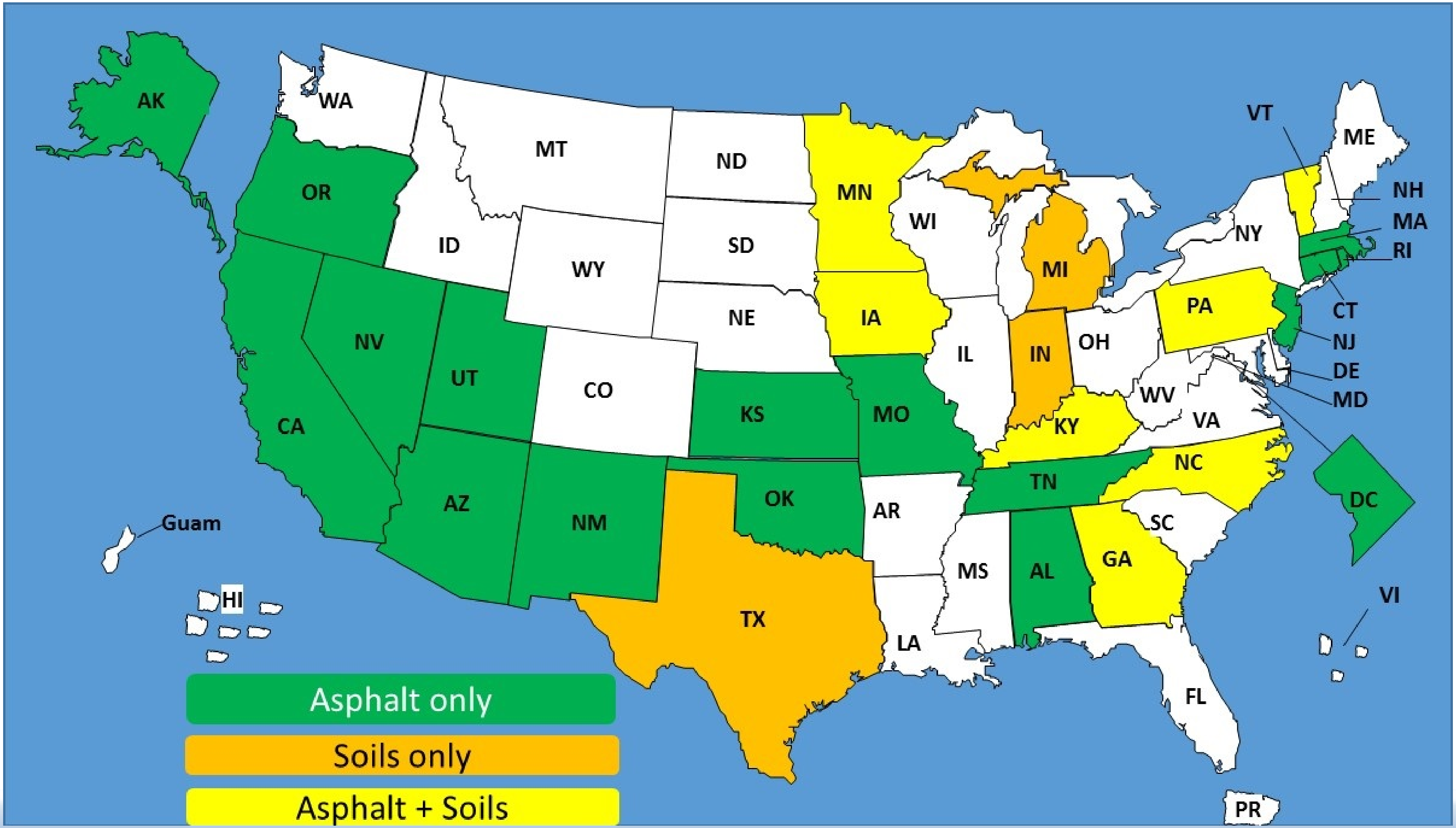


HMA Map

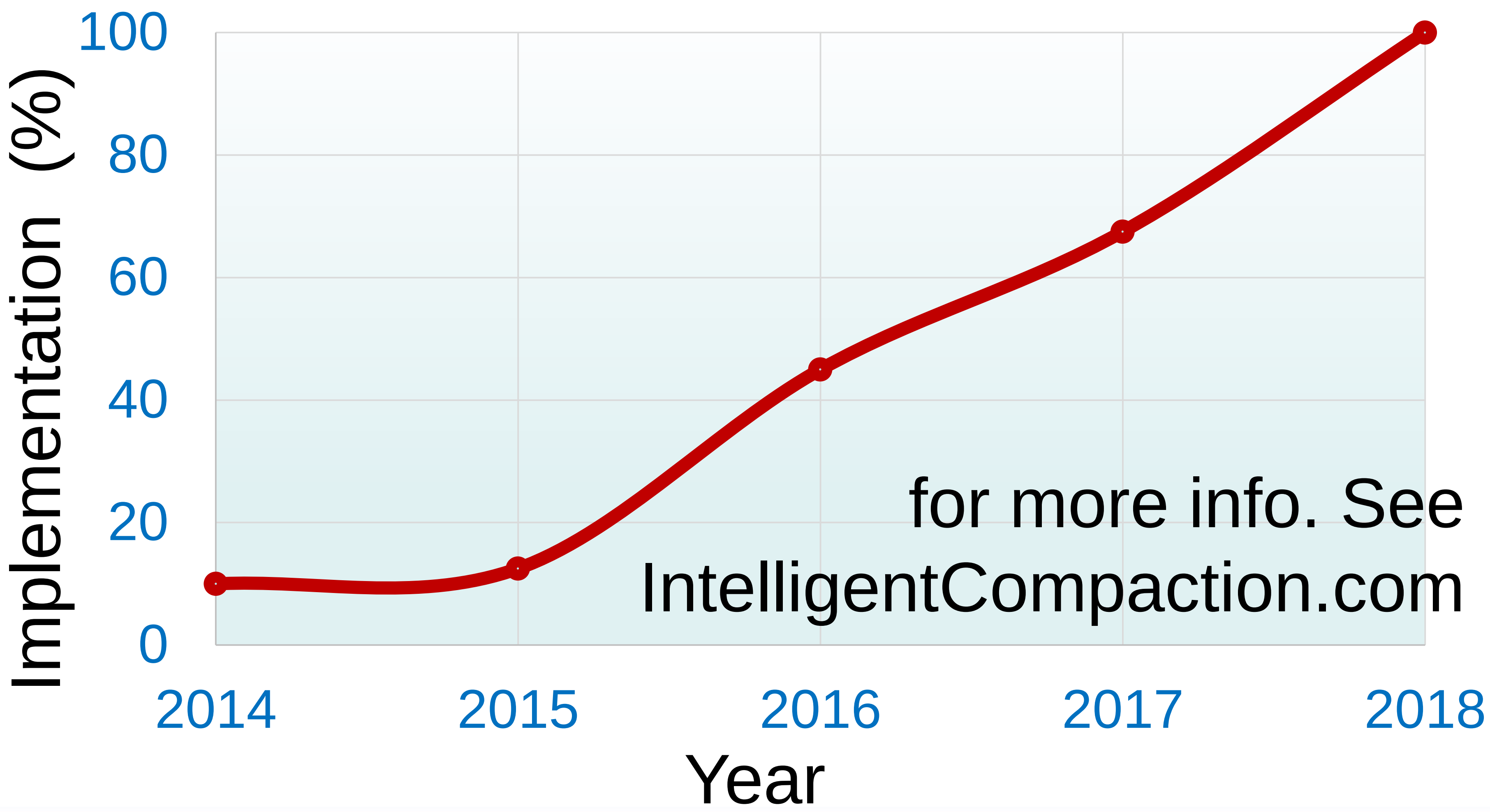


Subbase Map

US DOT IC Specification



MnDOT's Implementation of ICC



Question Time