Intelligent Soil Compaction

Technology, Results and a Roadmap toward Widespread Use

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#Minnesota Department of Transportation

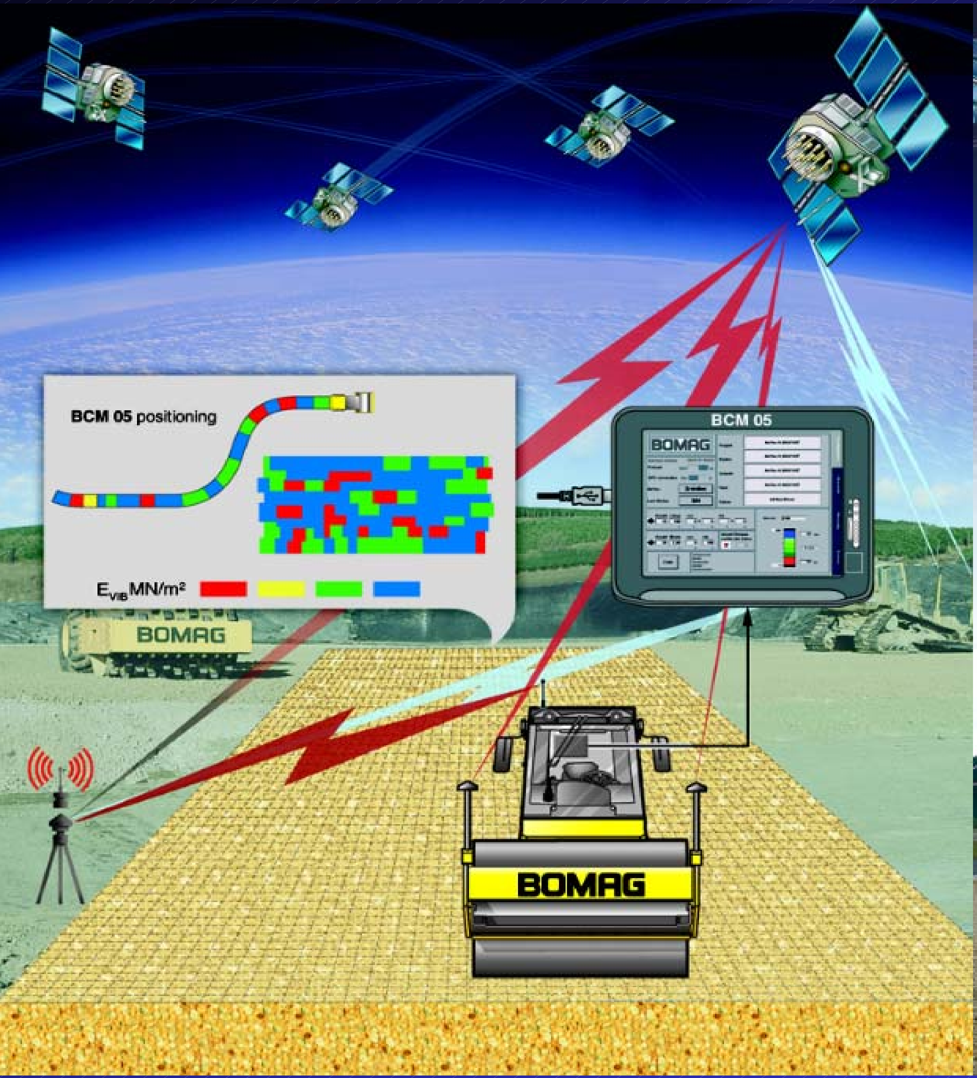
Topics

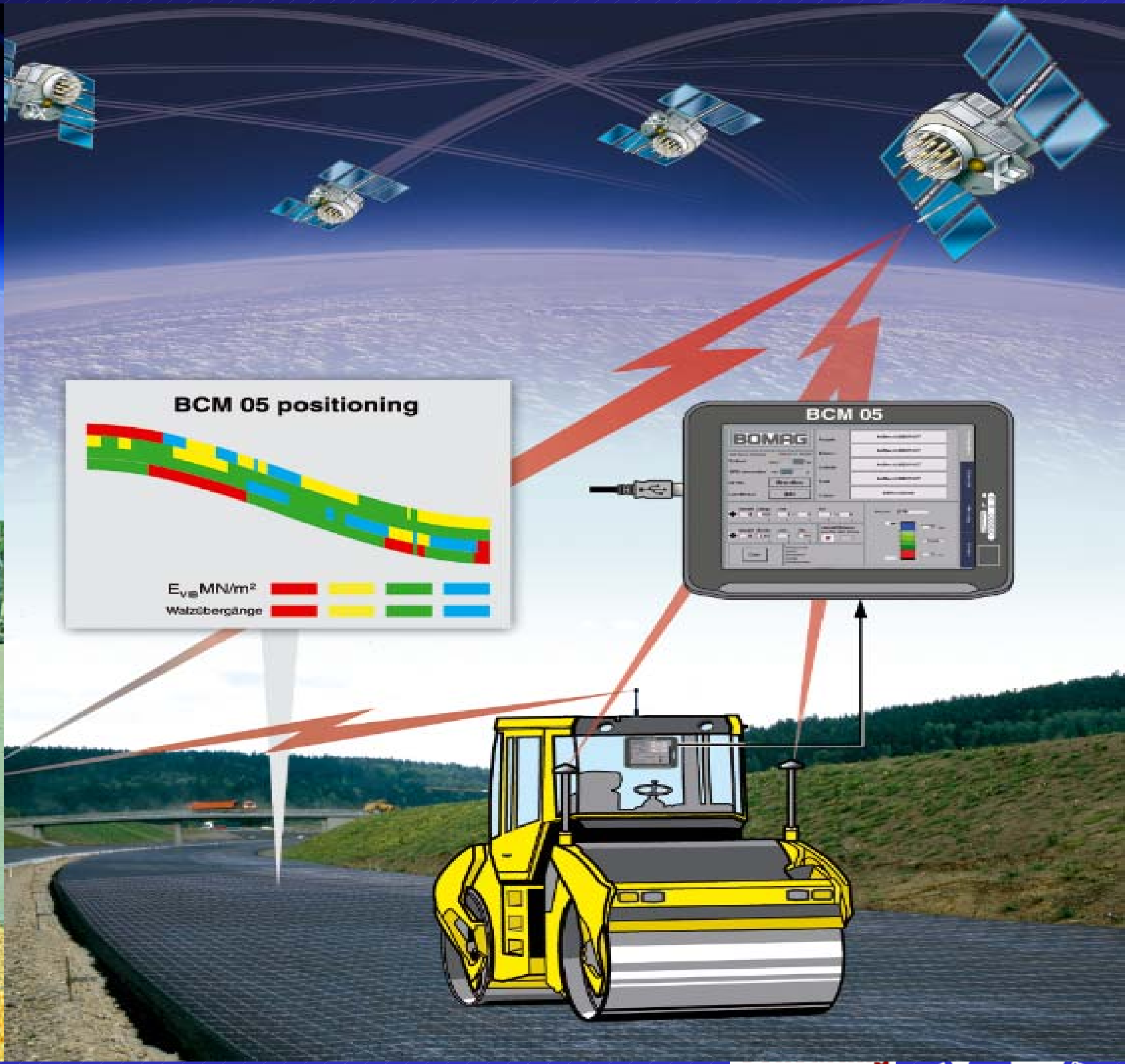
- Introduction to Intelligent Compaction Technology
- Potential Benefits
- Technology & Validation
- Demonstration Projects
- Roadmap for Widespread Use
- Questions?
- Concluding remarks

Definition

- Intelligent compaction equipment measures and records the quality of compaction during the compaction process. The compactor's force changes in real time to increase compaction where needed, while preventing over compaction. The equipment uses a global positioning system to create a map that shows the quality of compaction across the entire surface of each lift.

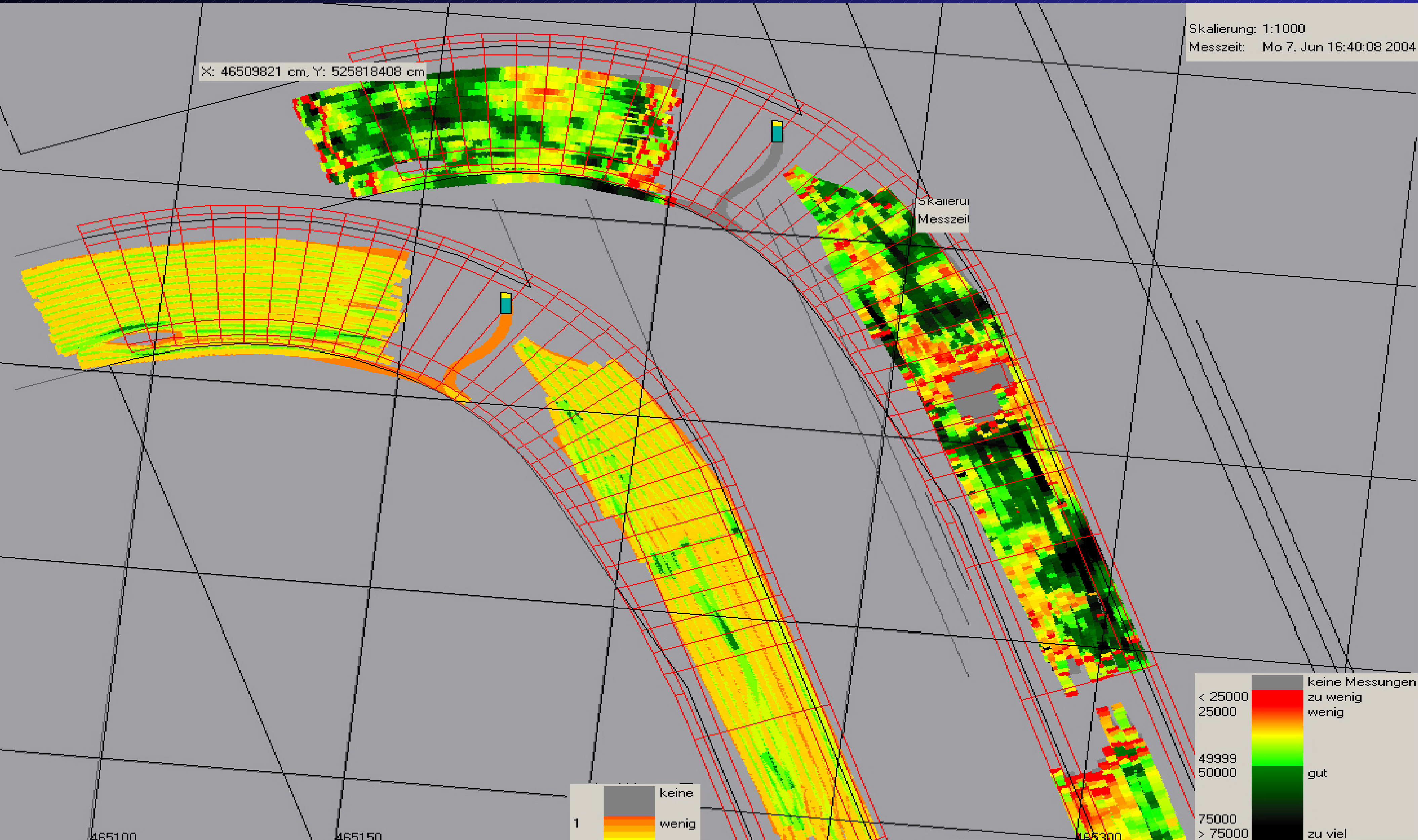
Bomag Soil and Asphalt IC Systems





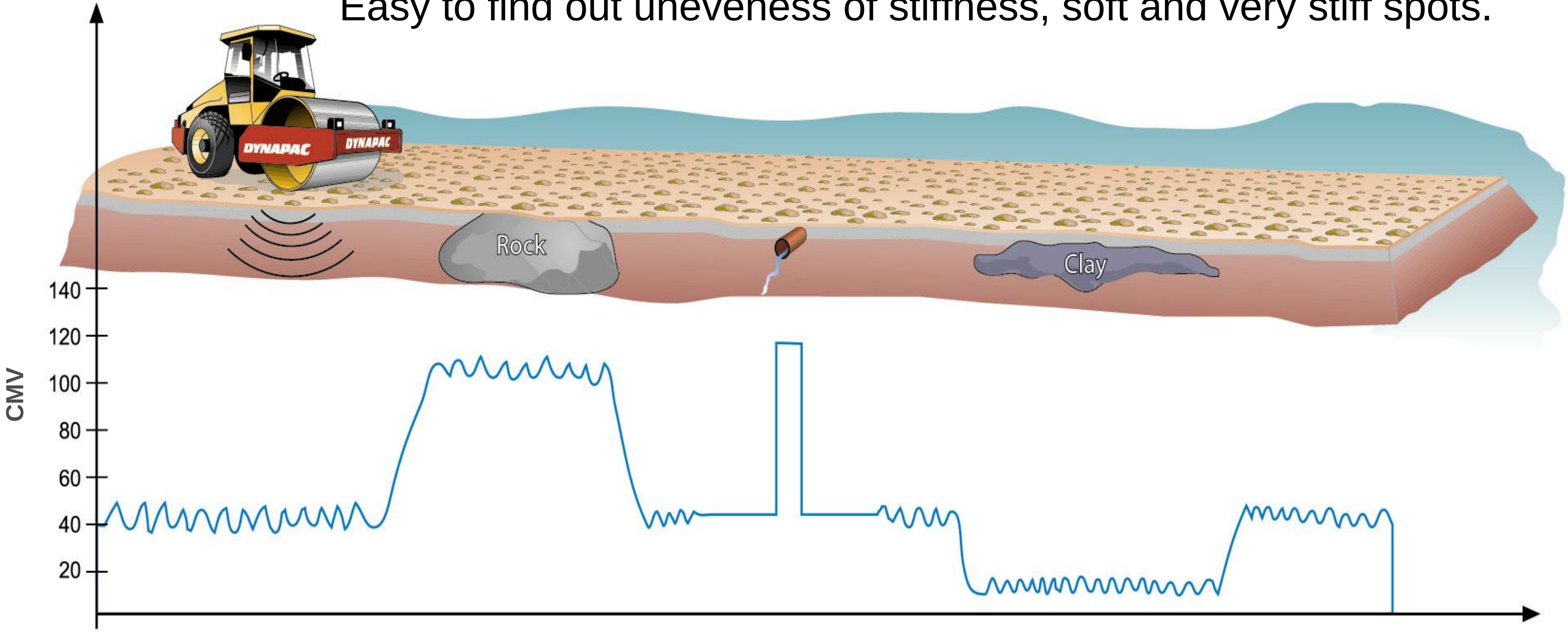
Engineers

AMMANN Compaction Expert (ACE)

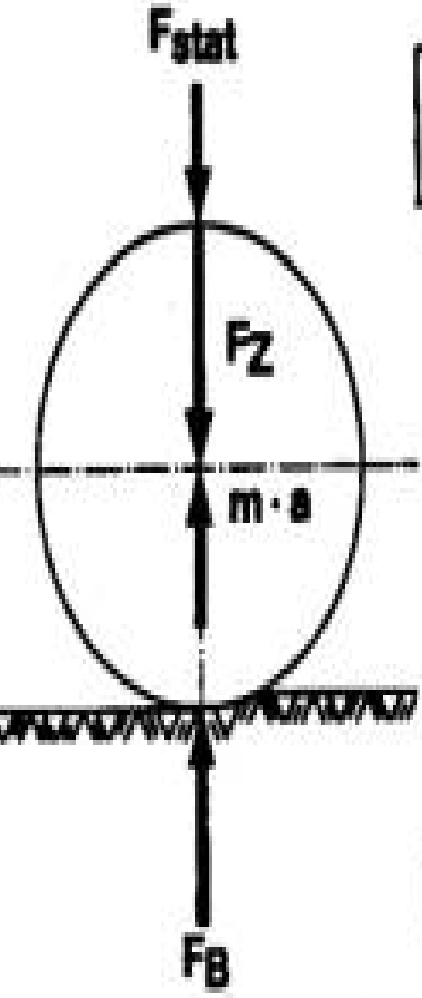


Dynapac Continuous Compaction Control

Easy to find out uneveness of stiffness, soft and very stiff spots.

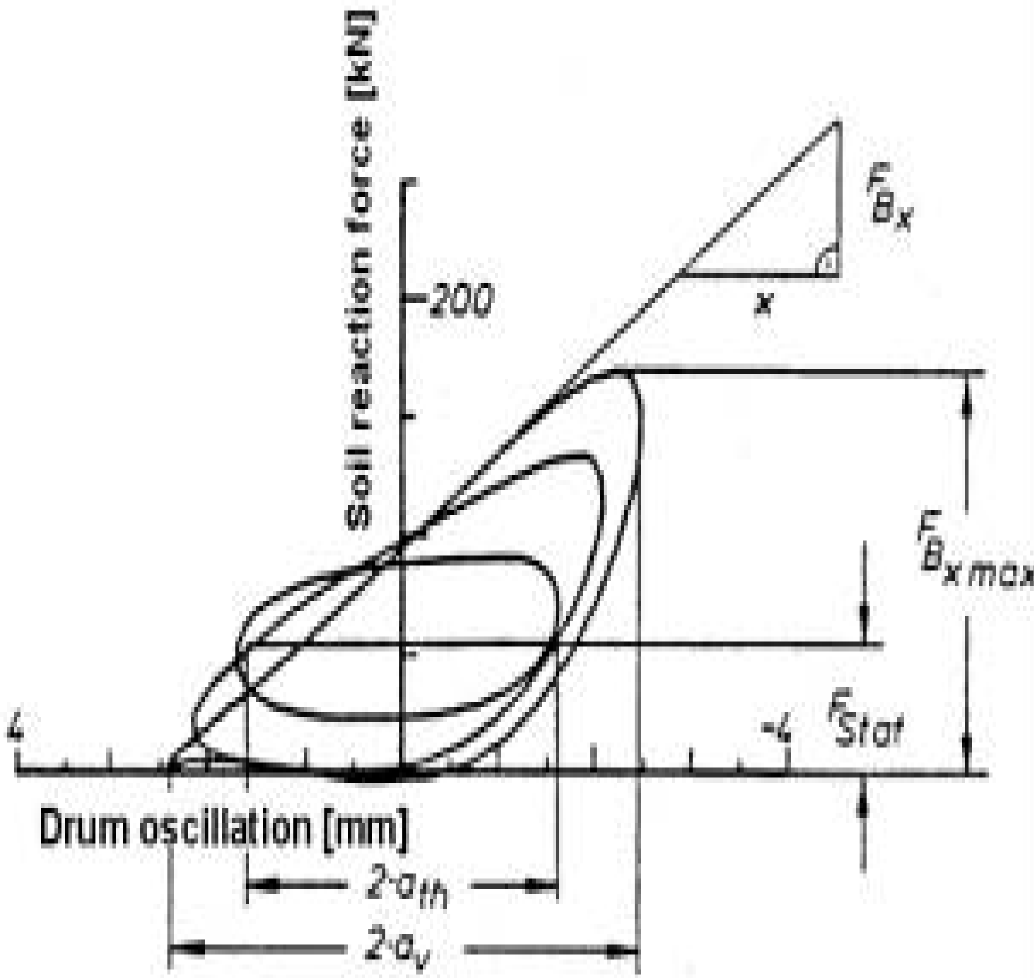


Intelligent Compaction Technology



$$F_B = F_{stat} + F_Z - m \cdot a$$

- F_B : soil reaction force
- m : vibrating mass of the drum
- a : acceleration
- F_Z : centrifugal force
- F_{stat} : static axle load



Potential Benefits of Intelligent Compaction

- Improved quality
- Reduced compaction costs
- Reduced life cycle cost
- Integration of design, construction, and performance

Testing for Compaction

- **Uniformity is the Priority**
- **Currently (Empirical Pavement Design, R-Value)**
  - Specify Relative Density (Proctor Test)
  - Specify Moisture Limits (Proctor Test)
  - Test Rolling (optional)
- **Future (Mechanistic Pavement Design, Modulus)**
  - QC: Intelligent Compaction Equipment
  - QC/QA: Continue to Specify Moisture
  - QA: Specify Modulus and Strength

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Changing from Density to Modulus

- **We Still Need Moisture Control**
- **Density**
  - Mass / Volume
  - Proctor Test is NOT the Maximum
- **Modulus (Stiffness or Strength)**
  - All Are Mechanical Properties
- **We Just Need Two of the Three**
  - Moisture and Modulus

Test Type and Equipment

- **Elastic Modulus**
  - Intelligent Compactor (IC)
  - Falling Weight Deflectometer (FWD)
  - Light Weight Deflectometer (LWD)
  - Soil Stiffness Gauge
  - Quasi-static Plate Load Test
- **Shear Strength**
  - Dynamic Cone Penetrometer (DCP)
- **Density**
  - Sand Cone, Nuclear Gauge
- **Moisture**
  - Sand Cone, Nuclear Gauge
  - Camp Stove with Scale, Kessler FMO
  - Trident and Percometer


keros

Materials QC/QA Compliance

Materials database

- Test requirements known
- Field samples taken
- Field test results recorded
- Pass / fail in real time

2005 Intelligent Compaction Projects

- **District 8**
  - TH12 near Atwater
  - June 2005
  - 1 mile of bridge approaches
  - 10” HMA, 6” Class 5, 14” Select Granular, 6” R-Value 12
- **District 7**
  - TH14 near Janesville
  - July and October 2005
  - Length 12.4 miles
  - 8.5” PCC, 4” Open-graded Base, 4” Class 5, 42” Select Grading Material
- **District 1**
  - TH53 near Duluth
  - September 2005
  - Length 2.25 miles
  - 8” HMA, 6” Class 6, 36” Select Granular

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VARIOCONTROL
BOMAG


BW 213 DH

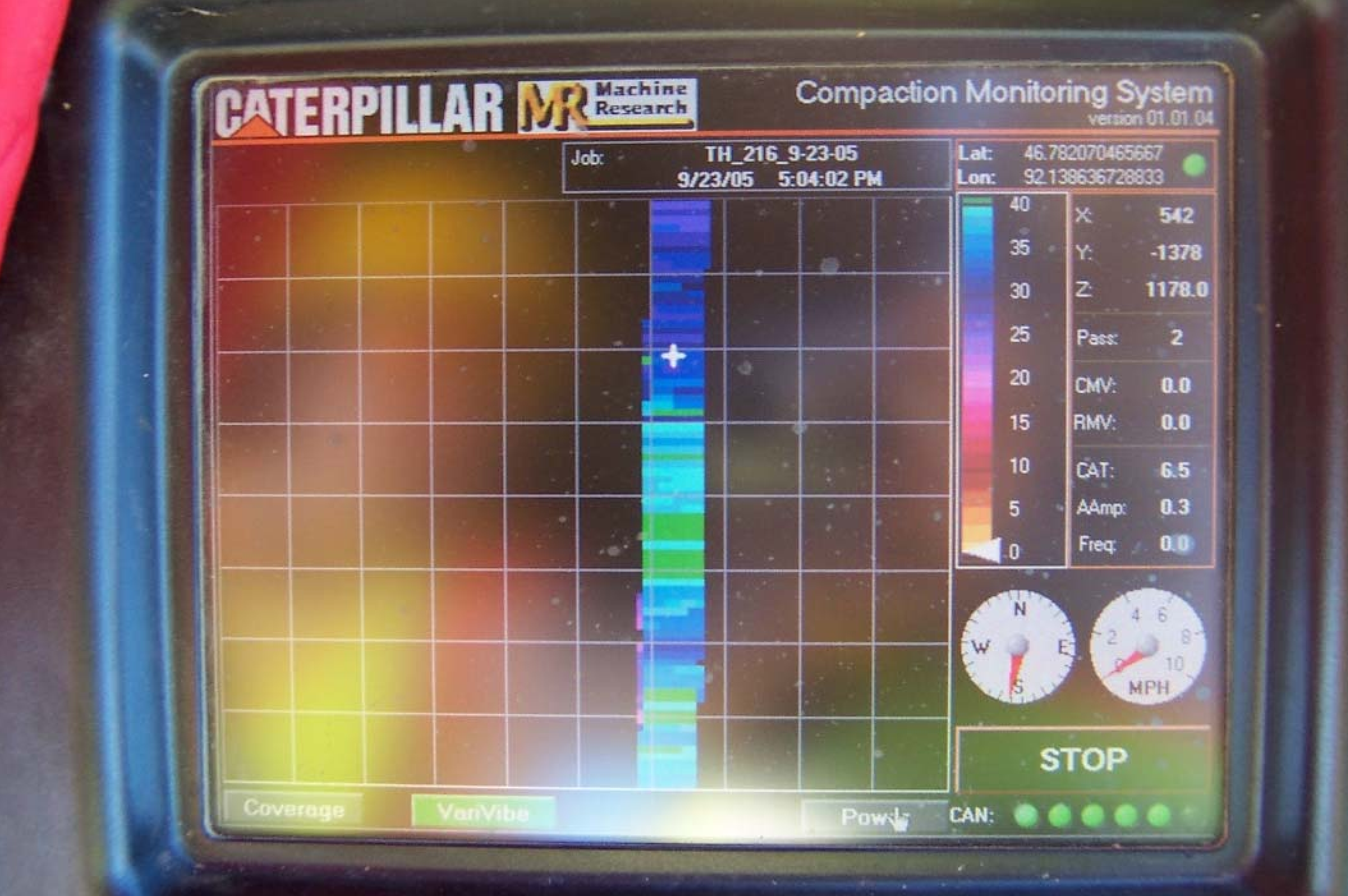


CATERPILLAR


AMMANN
ACE


TRACK
PRINT


CATERPILLAR


CATERPILLAR
Machine Research
Compaction Monitoring System
version 01.01.04
Job: TH_216_9-23-05
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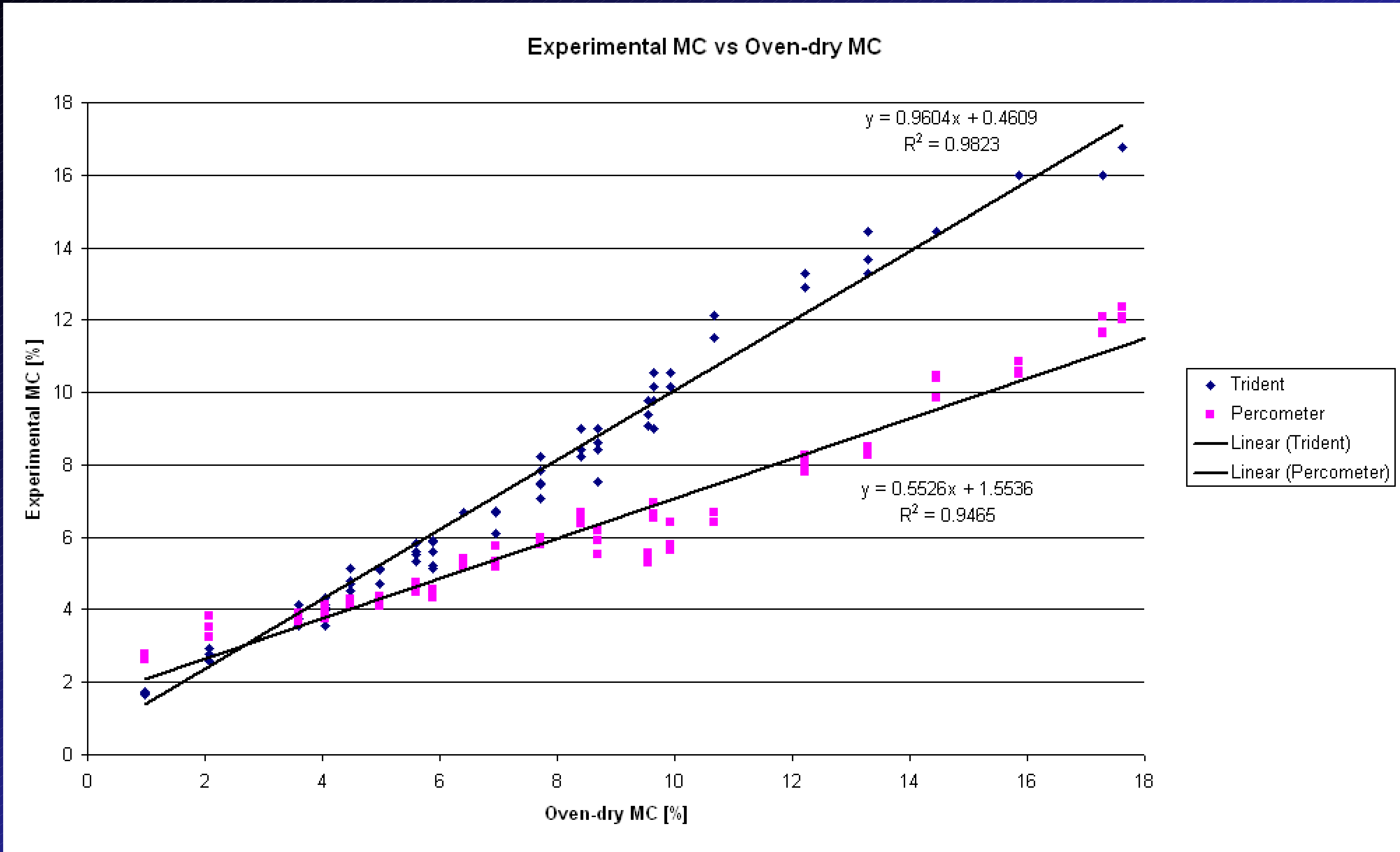
40
35
30
25
20
15
10
5
0
X: 542
Y: -1378
Z: 1178.0
Pass: 2
CMV: 0.0
RMV: 0.0
CAT: 6.5
AAmp: 0.3
Freq: 0.0
N
W
E
S
MPH
STOP
Coverage
VariVibe
CAN:

Trident T-90 Moisture Meter

- **Volumetric Moisture Meter**
  - Utilizes Frequency Domain Reflectometry to estimate volumetric moisture content
  - The calibration procedure for the instrument allows for estimation of the gravimetric moisture content
  - Calibration is required for each different soil type


PERCOMETER

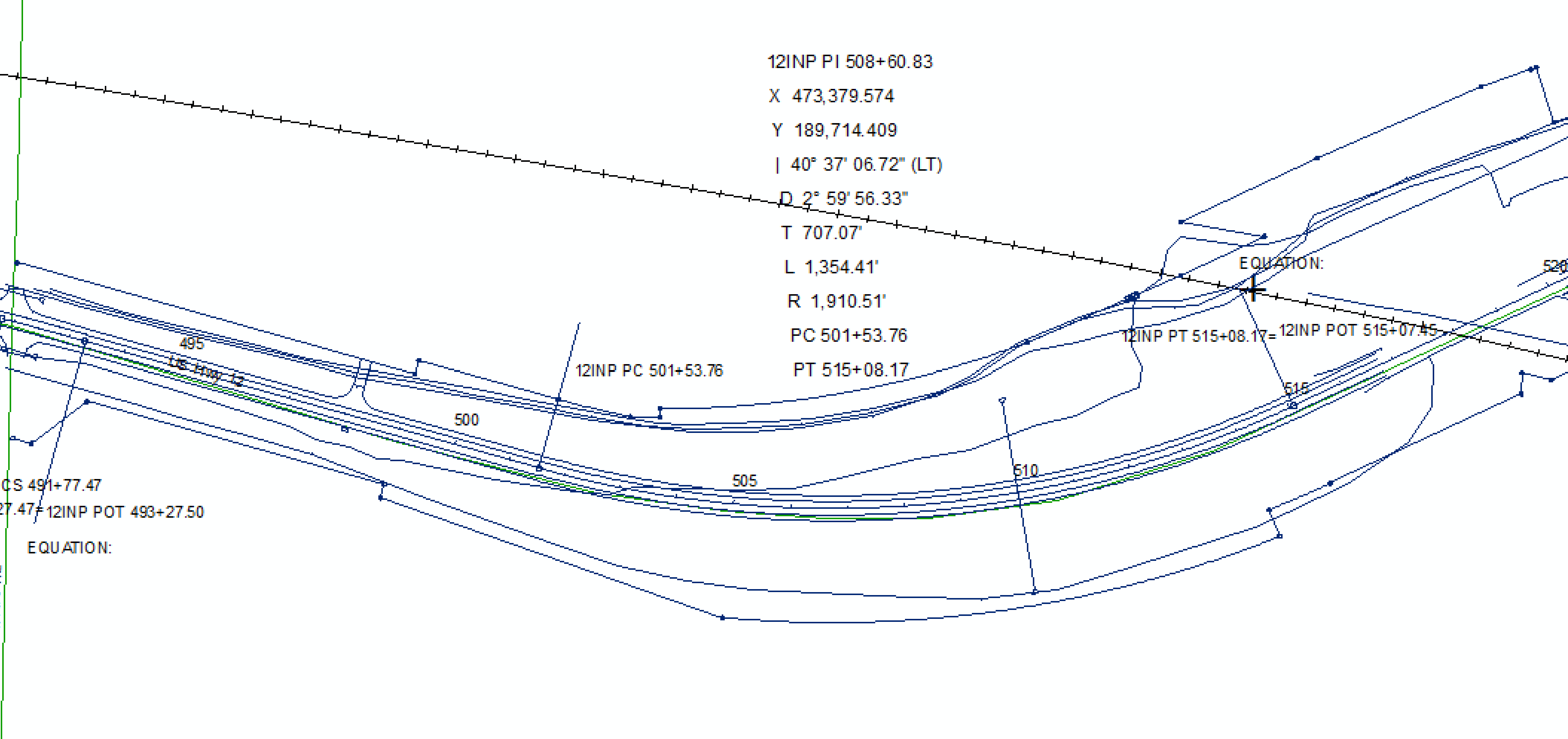


Experimental MC vs Oven-dry MC
y = 0.9604x + 0.4609
R2 = 0.9823
y = 0.5526x + 1.5536
R2 = 0.9465
Experimental MC [%]
Oven-dry MC [%]
0
2
4
6
8
10
12
14
16
18
Trident
Percometer
Linear (Trident)
Linear (Percometer)

ICTGI Team

- Ruth Roberson
- Bruce Chadbourn
- John Siekmeier

- Felipe Camargo
- Brett Larsen
- Cassie O'Neal
- Peter Davich
- Agueda Guerra



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12INP PI 508+60.83
X 473,379.574
Y 189,714.409
I 40° 37' 06.72" (LT)
D 2° 59' 56.33"
T 707.07'
L 1,354.41'
R 1,910.51'
PC 501+53.76
PT 515+08.17
EQUATION:
12INP PT 515+08.17=
495
500
505
510
515
12INP PC 501+53.76
CS 491+77.47
12INP POT 493+27.50
EQUATION:

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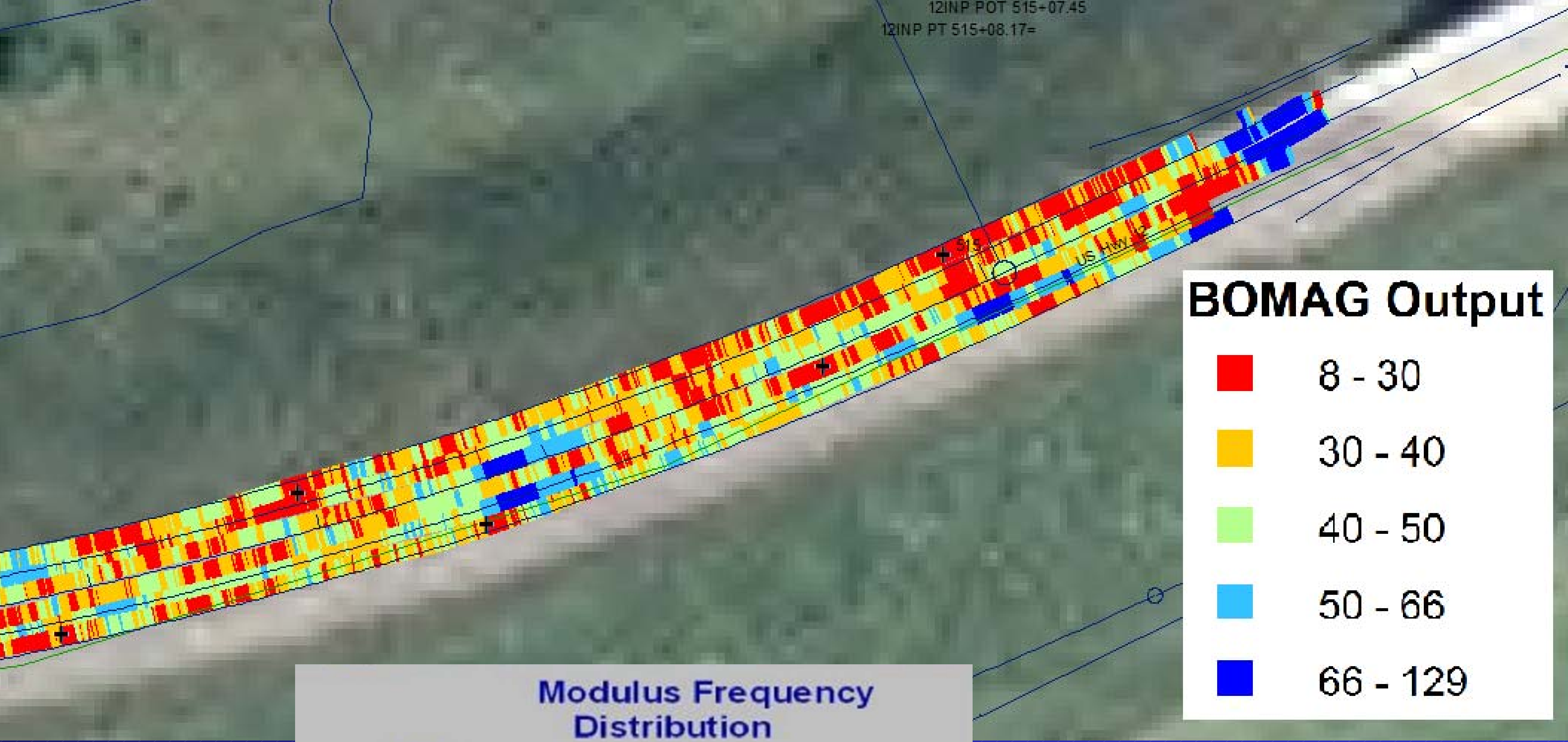

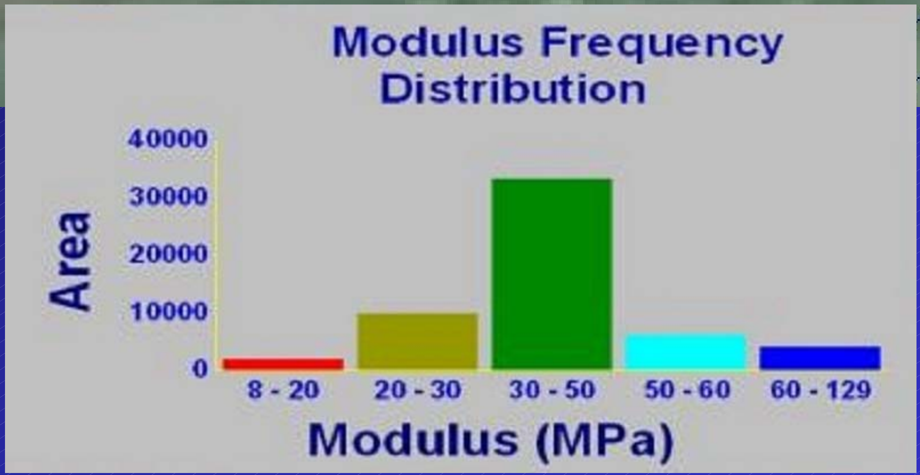

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What's Next in Minnesota 2006

- **Intelligent Compaction in Several TH Contracts**
  - Grading Projects with Resident Engineer Interest Identified
    - S.P. 2903-10 T.H. 64 Hubbard County, District 2
    - S.P. 8285-88 I-494 Valley Creek Road, Metro Twin Cities
  - TH212 Meeting with Contractor and IC Manufacturers
  - HMA Projects are also Possible with Iowa State Testing
- **Open House/Demonstration at MnROAD TS 27-28**
- **Continued Technology Transfer at Conferences**
- **Mn/DOT Participation with Other DOTs**
  - FHWA-led Intelligent Compaction Pooled Fund
  - NCHRP 21-09 Intelligent Compaction Specifications

Roadmap for Widespread Use

- **Potential Roadblocks**
  - Technological
  - Cultural & Institutional
- **Roadmap**
  - Material Behavior
  - Technology
  - Standards & procedures
  - Education

Potential Roadblocks

- **Technological**
  - Strike a balance between standardization & innovation
    - The marketplace includes about a half-dozen compactor technologies & more than a half-dozen companion test technologies
    - The "best" technologies, the ones that will provide the desired end product at the right price, may be all, some or none of the current ones
    - Manufacturers must be allowed to innovate
    - Agencies must resist the temptation to standardize on one or two technologies at the expense of the others
    - Supporting technologies like global positioning systems, wireless communications and data storage methods must also be encouraged!

Potential Roadblocks

- **Technological**
  - The complexity of soil behavior, soil modulus depends upon:
    - Moisture content
    - Stress level
    - Loading rate
    - Stress history
    - Soil "age."
  - Hence, soil modulus measured by one method with characteristic size, stress level and depth of measurement may be different than the value measured by another method
  - Soil behavior during compaction is highly non-linear, and it may be necessary to consider such behavior in evaluating and establishing compaction target values.

Potential Roadblocks

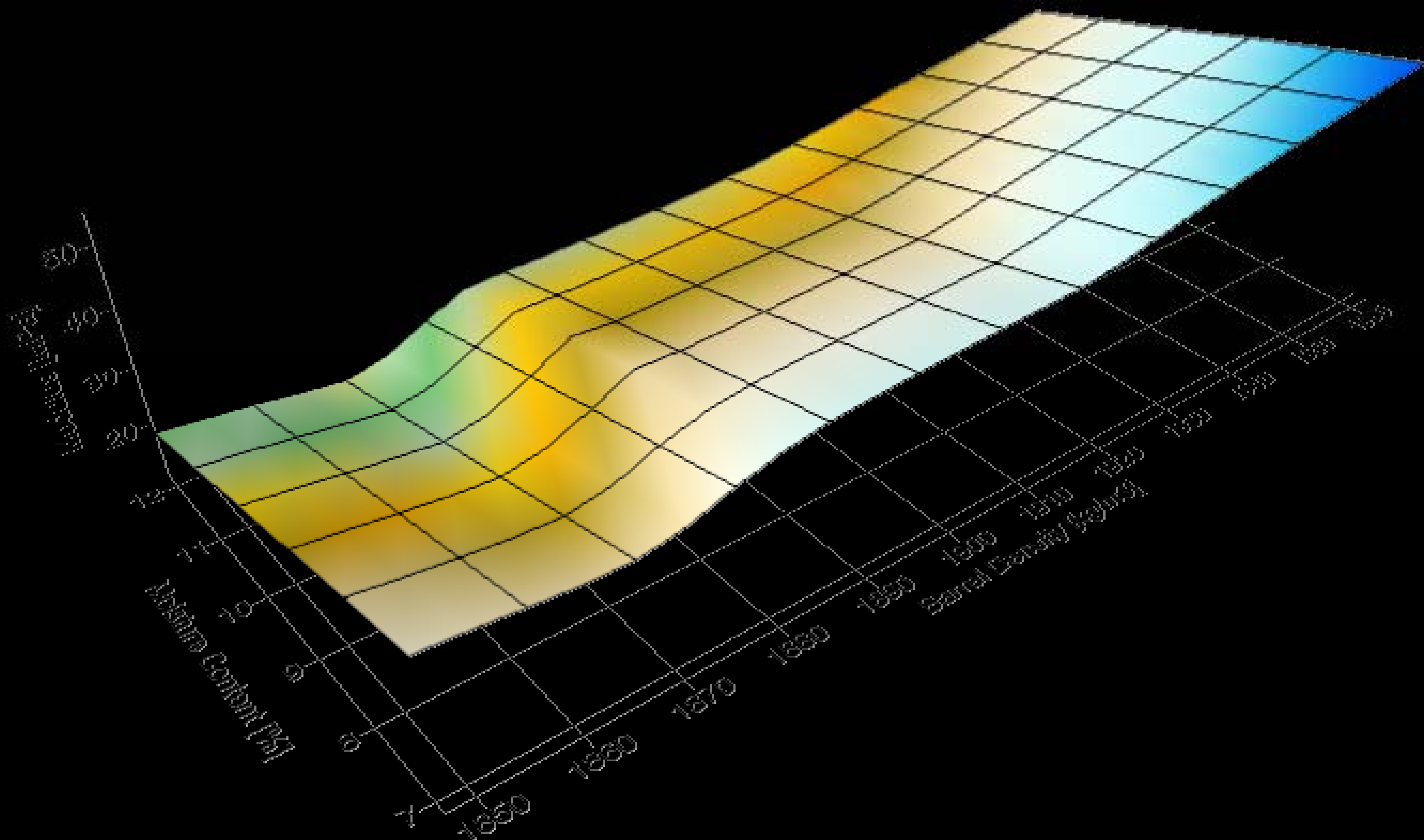
- **Technological**
  - The complexity of soil loadings associated with compaction, laboratory testing and field-testing
  - Because of the dependencies listed in the previous slide, different soil loadings produce different soil responses.

Potential Roadblocks

- **Cultural & Institutional**
  - Stakeholders and their attitudes
  - Potts (2005) identifies some of the critical “disablers” in his discussion of the jobsite of the future. These include:
    - Those who say it can’t be done
    - Those who say we don’t need it to be done
    - Those who say we can’t afford the risk
    - Manufacturers that won’t develop new products when there isn’t a proven market
    - Political in-fighting and (regressive) agendas

Roadmap—Material Behavior

- **Sponsor and conduct focused research on:**
  - Investigate modulus—density—moisture—compactive effort relationships
  - Determine the depth, shape and volume of soil sensed by IC compactors
  - Determine the effect of compactor speed, travel direction, vibration direction, amplitude and frequency on reported values, and verify the precision and repeatability



1870
20
40
50
10

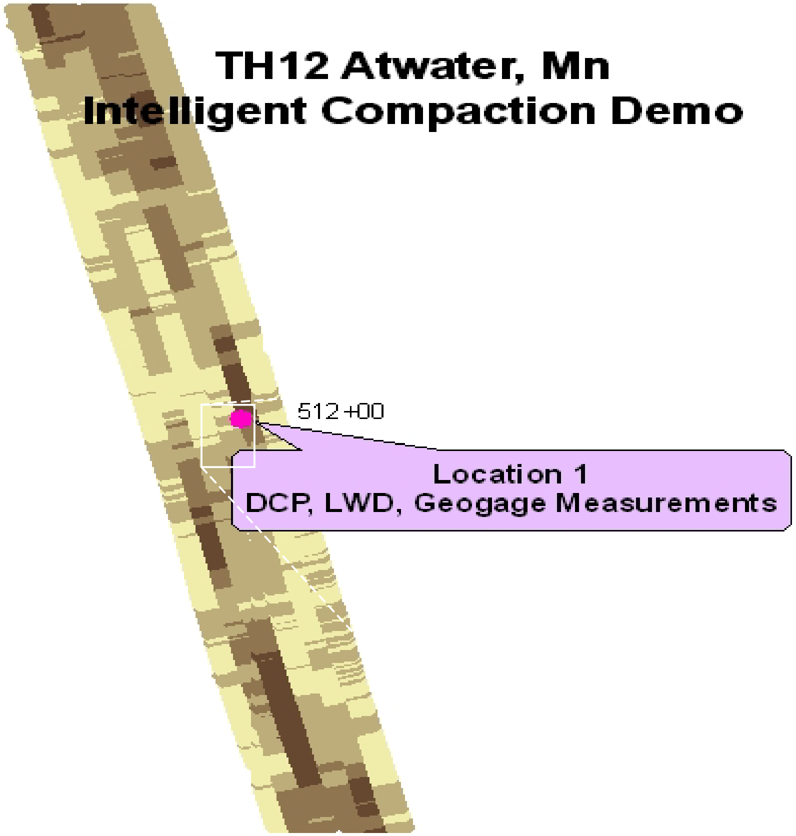
Roadmap—Material Behavior

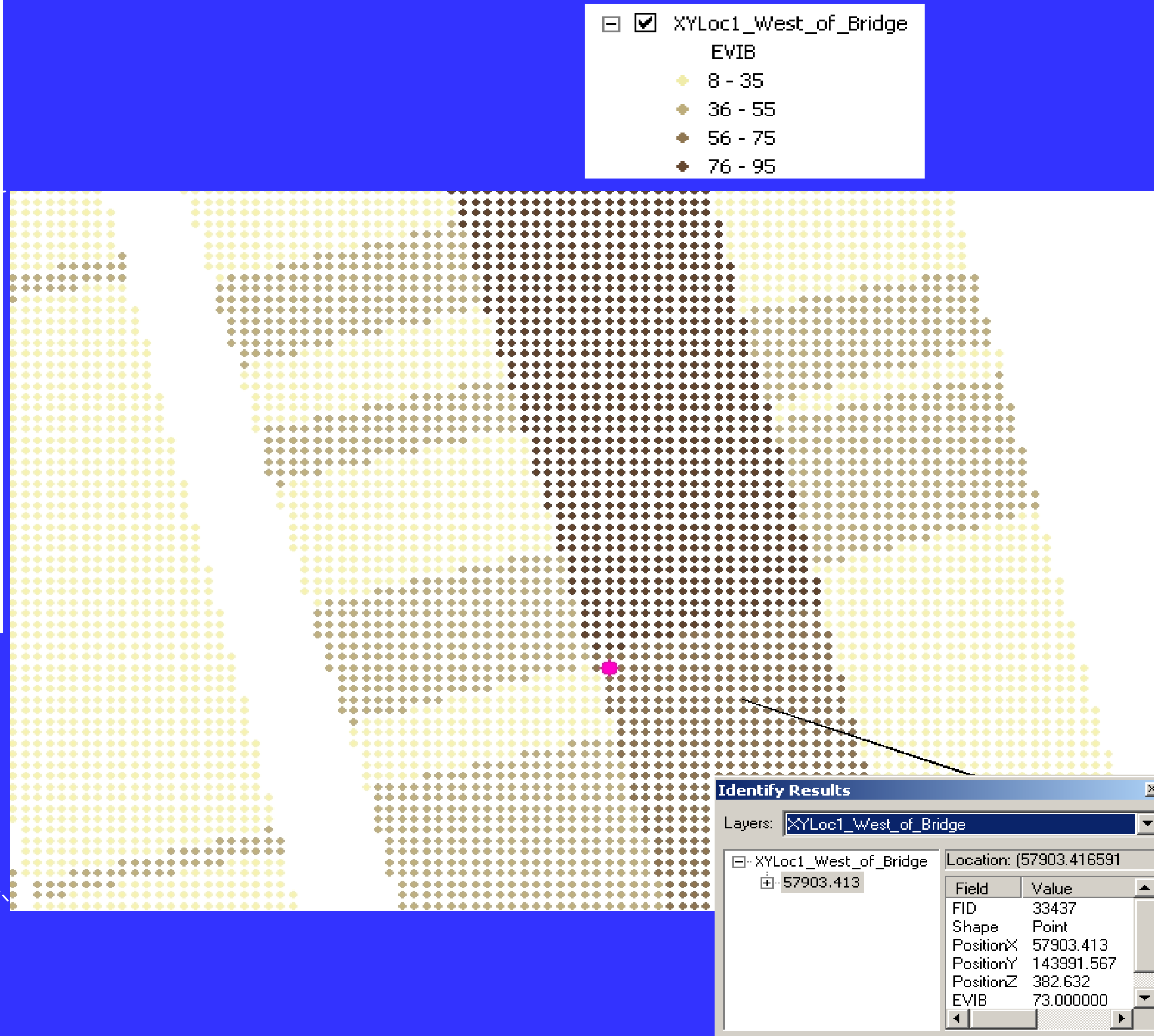
- **Sponsor and conduct focused research on:**
  - Encourage manufacturers to develop rational or empirical relationships between their reported values and soil properties
  - Develop rational or empirical relationships between companion test methods
  - Develop adequate material property relationships to establish target values
  - Identify unbound materials commonly used in roadway construction that represent special problems in for Intelligent Compaction

Roadmap—Technology

- **Maintain flexibility regarding specific equipment for compaction and companion testing**
- **Develop methods to rapidly determine soil moisture content, because of the significant effect of moisture on deformational properties**
- **Develop forward-thinking geotechnical data management practices**
  - Encourage machine manufacturers to implement GPS-based location documentation
  - Encourage companion test equipment manufacturers to also implement GPS-based location documentation
  - Develop and implement geotechnical data management standards and practices
  - Integrate Intelligent Compaction into the facility performance and design cycle
  - Encourage industry-wide data exchange standards

TH12 Atwater, Mn
Intelligent Compaction Demo





Engineers

Roadmap—Standards & Procedures

- **Experiment with compaction process control, quality control and quality assurance practice with demonstrations that:**
  - Show Intelligent Compaction is an acceptable Quality Control procedure
  - Identify Quality Assurance procedures necessary when Intelligent Compaction is used for Quality Control
- **Develop draft specifications, starting with European practice and modifying as necessary**

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Roadmap—Education

- **Document & distribute**
  - The benefits of Intelligent Compaction must be documented using established metrics, and then widely distributed to the stakeholder communities.
- **Create a culture of innovation**
  - Continuous feedback and readjustment is necessary to produce an optimized Intelligent Compaction system, including specification, implementation and quality control.
- **Sponsor and conduct demonstration tests**
  - The industry must see proof that new technologies work

Current/Future Standards

- EU Performance Related Specifications
- Mn/DOT DCP Specifications Aggregate and Granular
- ASTM DCP Test Method
- ASTM LWD Test Method
- ASTM GeoGauge Test Method
- FHWA GeoGauge Pooled Fund
- FHWA CRREL Subgrade Performance Pooled Fund
- NCHRP 10-65 NDT QC/QA for Flexible Pavements
- NCHRP 21-09 Intelligent Compaction Specifications
- FHWA-led Intelligent Compaction Pooled Fund
- AASHTO M-E Pavement Design

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National Initiatives

- **NCHRP 21-09**
  - Determine the Reliability of IC Equipment
  - Develop Construction Specifications
  - Soils and Aggregate Base Materials
  - Five States, Three IC Roller Types
- **FWHA-led Pooled Fund 954**
  - Develop Construction Specifications
  - Soils, Aggregate Base, HMA Materials
  - More States Will Have Projects Included
  - Increase DOT Experience Though Participation
  - Identify and Prioritize Improvements
    - IC Equipment
    - In Situ Test Equipment Used for QC/QA

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Conclusions

- **We believe that substantial potential benefits exist:**
  - Lower compaction cost
  - Improved quality and uniformity
  - Improved safety
  - Reduced life-cycle costs
  - Integration of design, construction and facility management.
- **These benefits arise from:**
  - The surface-covering documentation provided
  - Identification of problem areas
  - Elimination of under- and overcompaction.

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  - Minnesota Department of Transportation
  - CNA Consulting Engineers

Thank you.

- Questions?

- http://mnroad.dot.state.mn.us
  - Research Products
  - Mechanistic Empirical Resources

Concluding Remarks