Intelligent Compaction
Mn/DOT Demonstrations 2005

Iowa Geotechnical Workshop
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Ames, IA

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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
AMMANN Compaction Expert (ACE)
Dynapac Continuous Compaction Control

Easy to find out uneveness of stiffness, soft and very stiff spots.
Intelligent Compaction Task Force

- District 1
- District 7
- District 8
- Office of Construction
- Office of Investment Management
- Office of Materials
- Office of Technical Support
- Federal Highway Administration
Task Force Objective

- Begin the process of determining whether to change the Mn/DOT compaction acceptance criteria and quality control / quality assurance (QC / QA) procedures for soils and aggregate bases from density to modulus by using emerging technologies that include intelligent compaction.
Benefits to Mn/DOT

- Increased Compaction Uniformity
- Complete Documentation of Every Lift
- Better Record Keeping and Reporting
- Automation and Higher Productivity
- Improved Inspector Safety
- No More Sand Cone Testing
QA During Bomag Dam Construction
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
In-Situ Non-Destructive Tests Exist

- Achieve agreement between construction quality assurance and pavement design.

- Quantify alternative materials and construction practices. Show economic benefit of improved materials. Reward good construction.

- This requires new specifications and new tools. Tools must be quantitative, portable, and accurate in the field.
Structure

Check box to enter test data. Uncheck to use Basic defaults.

HMA Modulus
- Edit HMA Properties

Agg. Test Type
- Modulus, psi
- R-Value
- DCP, mm/blow
- CBR

Soil Test Type
- Modulus, psi
- R-Value
- DCP, mm/blow
- CBR

Other
- All others require Modulus, psi

Edit Structure

Layers | Material | Thickness (in.)
--- | --- | ---
1 | HMA | 4
2 | AggBase | 12
3 | EngSoil | infinite
4 |  |
5 |  |

Design Mode: Intermediate

Units
- English
- SI

Finished Structure
Go to Control Panel

Agg. Base Moisture Condition
- Optimum
- Wet

Soil Moisture Condition
- Optimum
- Wet

Optimum = Fall conditions, Wet = Late Spring conditions
Density Testing Issues

- Proctor had a Different Idea
- Optimum Moisture for Compaction
- Strength May Not be Achieved
- Rutting Due to Moisture and Construction Traffic
- Is Not Necessarily Consistent with the Moisture and Density of the R-Value Test Specimens
“Originally published objective of compaction in earth fills was a saturated penetration resistance of 300 lb per sq in.”

“Soil would then have twice the penetration resistance required to permit loaded truck travel when fully saturated.”
PERCENTAGES APPEARING BELOW CURVES SHOW THE COMPACTIVE EFFORTS REQUIRED TO SECURE FROM 80% TO 100% OF THE SOIL DRY WEIGHT SECURED BY 12,375 FT. LB. PER CU. FT. COMPACTIVE EFFORT AND THE CORRESPONDING SHEAR STRENGTHS.
Nuclear vs Sandcone Densities

- Investigation 622, U of M, LRRB, Mn/DOT, 1966
- Sandcone results have appreciable errors
- Greatest errors in high density granular soils
- More than 5 lbs per cubic foot
- Due to inherent errors in the sandcone procedure
Nuclear Density vs Sandcone Density
Mn/ROAD Aggregate Base

\[ y = 1.0x - 5.0 \]
\[ R^2 = 0.7 \]
Nuclear Compaction vs Sandcone Compaction
Mn/ROAD Aggregate Base
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
PERCENTAGES APPEARING ABOVE AND BELOW CURVES SHOW THE COMPACTIVE EFFORTS REQUIRED TO SECURE FROM 90% TO 100% OF THE SOIL DRY WEIGHT SECURED BY 67.250 AND 123.75 FT. LBS. PER. CU. FT., RESPECTIVELY.
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
Field Testing Equipment
Humboldt GeoGauge
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
TH12 District 8 Atwater

- June 22 to June 28
- Bomag Intelligent Compaction Equipment
- Mn/DOT Materials Testing and Report
TH14 District 7 Janesville

- July 18 to July 22
- CAT Intelligent Compaction Equipment
- Iowa State University Testing
- FHWA Funding
Back to TH14 at Janesville

- October 27 to November 11
- Ammann Intelligent Compaction Equipment
- Iowa State University, Mn/DOT FHWA Funding
- Colorado School of Mines, NSF Funding
TH53 District 1 Duluth

- September 19 to October 6
- CAT Intelligent Compaction Equipment
- CNA Consulting Engineers Testing and Report
- Mn/DOT Implementation Funding
- Mn/DOT Materials Testing and Conference Paper
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
Field Moisture Oven

- **Gravimetric Moisture Meter**
  - Heats 200-250g soil sample on dual thermostatically controlled platens at 200°C
  - Tests take approximately 8-12 minutes for granular samples
  - Best suited for:
    - Fine and coarse grained soils
    - Fine gravels

Please Note: Newer models may include additional features (i.e., USB/Serial Port, On/Off Switch)
Experimental MC vs Oven-dry MC

- Trident: $y = 0.9604x + 0.4609$, $R^2 = 0.9823$
- Percometer: $y = 0.5525x + 1.5536$, $R^2 = 0.9485$
Density vs Moisture
Median of Dielectric Repetitions Taken Near Edge and Center
Sample SS02263

Density vs Moisture Standard Proctor (lb/ft³)
Gravimetric Moisture Standard Proctor (percent)

- Density Dry
- Dielectric Moisture Only
- Zero Air Voids Dry Density SG = 2.65
- Poly. (Dielectric Moisture Only)
- Poly. (Density Dry)
Standard Proctor Density vs Optimum Dielectric
Mn/DOT Textural "Clay Loam" Classification
Minnesota Statewide (not Mn/ROAD)

\[ y = -34.30 \ln(x) + 219.29 \]

\[ R^2 = 0.90 \]
How We Handle the IC Roller Data
ICTGI Team

- Ruth Roberson
- Bruce Chadbourn
- John Siekmeier

- Felipe Camargo
- Brett Larsen
- Cassie O’Neal
- Peter Davich
- Agueda Guerra
LWD, DCP, GeoGauge Modulus vs DCP800 Modulus
TH12 Atwater CCC Demonstration, June 28, 2005
Sand with Silt and Gravel, Poisson’s Ratio = 0.35
LWD Mean of Drops 3 to 5 from 50 cm Drop Height
FWD Moduli vs Peak Stress
MnROAD CCC Demonstration, October 21, 2004
Class 6 Prior to Paving, Three Drop Heights Shown, Mean of Three Repetitions Shown
Poisson's Ratio = 0.35, Plate Radius = 150 mm, Rigid Plate Factor = 0.79

\[ y = 0.07x + 98.07 \]
\[ R^2 = 0.57 \]
TH12 Atwater CCC Demonstration, June 28, 2005
Sand with Silt and Gravel, Poisson’s Ratio = 0.35
Mean of Drops 3 to 5, EnAdj = 0.5, a=2, b=-0.6

LWD and DCP Modulus and Vertical Stress vs Unique Number

- DCP200topDeBeer
- DCP800topDeBeer
- PRIMA
- GeoGauge at 0.024 MPa
- Bomag ave
- Bomag high
- LWD EA only
- LWDwithAB
- LWDwithABstr
- PRIMA stress
- LWD EA str
What We Learned

- The compactors were well made and easy to operate.
- Intelligent compactors can measure the stiffness of the ground and adjust their compactive force as needed.
- Surface covering documentation can be produced.
- Data transfer was functional.
Conclusions

- Density testing has been useful, but is not time efficient, does not verify design properties, and should be replaced.
- Construction equipment and field tests are now available that can measure the mechanistic properties used to design pavements.
- Field data acquisition and materials reporting using global positioning systems (GPS) and geographic information systems (GIS) are available.
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
### German Design Standards

<table>
<thead>
<tr>
<th>Road classification</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
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<tr>
<td>Equiv. 10 t axle loads</td>
<td>&gt;10–32</td>
<td>&gt;3–10</td>
<td>&lt;0,8–3</td>
<td>&gt;0,3–0,8</td>
<td>0,1–0,3</td>
<td>&lt;0,1</td>
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<tr>
<td>Thickn. of frostres. pavement</td>
<td>50 60 70 80</td>
<td>50 60 70 80</td>
<td>50 60 70 80</td>
<td>50 60 70 80</td>
<td>40 50 60 70</td>
<td>40 50 60 70</td>
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</table>

#### Asphalt base on subbase

- **Surface course**
- **Binder course**
- **Asphalt base**
- **Subbase** (frost resistant material)

| Thickness of subbase | - 30 40 50 | - 34 44 54 | 28 38 48 58 | 32 42 52 62 | 26 36 46 56 | 30 40 50 60 |

Thickness in cm, modulus of deformation $E_{V_2}$ in MN/m²

Equivalent 10 axle loads on one lane during road (according to German specifications)
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
Mn/DOT Research Projects

- Mechanistic Empirical Design 1999
- Seasonal Properties 2000
- Dynamic Analysis of FWD 2001
- MnROAD TDR Data Analysis 2002
- LWD Enhancement and Verification 2003
- Moisture Retention Characteristics 2004
- Modulus of Select Granular 2004
- Moisture Effects on DCP/LWD 2005
- Unsaturated Material Resistance Factors 2005
- Implementation of LWD Dynamic Analysis 2006
- Implementation of Intelligent Compaction 2006
What’s Next in Minnesota 2006

- **Intelligent Compaction in Several TH Contracts**
  - Grading Projects with Resident Engineer Interest Identified
  - 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
<table>
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<th>Force (kN)</th>
<th>Press (kPa)</th>
<th>Pulse (ms)</th>
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<td>2.3</td>
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<td>Defl. (µm)</td>
<td>E-mod (MPa)</td>
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</table>

Location: st-1241
Elephant vs Intelligent Compaction
Thank you.

Questions?

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