LWD Fundamentals

12th Annual Minnesota Paving Conference
February 14, 2008
St. Paul, Minnesota

Rebecca Embacher
Topics

- Testing for Compaction
- LWD Operation
- LWD Calibration
- 2105 Excavation and Embankment – LWD Quality Compaction
- LWD Technology Transfer Workshop
Testing for Compaction

- **Uniformity is the Priority**

- **Traditionally (Empirical Design, Trial/Error Based)**
  - Specify Relative Density
  - Specify Moisture Limits
  - Test Rolling for some projects

- **Future (Mechanistic Design, Stiffness Based)**
  - Intelligent Compaction Equipment
  - Moisture Limits
  - DCP Strength, LWD Stiffness, or Test Rolling

*Uniformity is the goal*
Why Use Mechanistic Field Tests?

- Achieve agreement between construction quality assurance and pavement design.
- Quantify alternative materials and innovative construction practices.
- Show economic benefit of improved materials in terms of longer pavement life.
- Reward good construction practices.
Density Testing Issues

- Small Sample that is Labor Intensive
- Significant Lab Time
- Optimum Moisture for Compaction
- Strength May Not be Achieved
- Rutting Due to Moisture and Construction Traffic
LWD Operation
Summary of Test Method

(ASTM E2583-07)

- Type of plate-bearing test.
- Load: Force pulse
- Vertical movement (deflection) is measured.
- The peak deflection and estimated elastic modulus is recorded.
Mn/DOT Standard LWD Configuration

Mn/DOT currently supports the Zorn, ZFG2000 model.

- **Drop Height**: See Calibration Certificate/Plate
- **Falling Weight**: 10 kg (22 lb)
- **Loading Plate Diameter**: 200 mm (8 in)

Schematic Courtesy of Zorn
Light Weight Deflectometer Video

~ 4 minutes in length
LWD Calibration
Calibration by Test Institute

- **Recommended Intervals:**
  - Annually
  - 10,000 measurement, but at least in every 2\textsuperscript{nd} yr.

- **Measure stress under the load plate**
  - Standard Pressure = 0.20 MPa
  - Force = 6.28 kN
  - Drop Height = 54 cm
  - Load / Plate = 10 kg / 200 mm
On-Site Verification Testing

Objective:
To determine the **repeatability** of deflection measurements under defined conditions.
On-Site Verification Testing (cont.)

- **Frequency**
  - (Re-) Commissioning
  - Annually
  - Not repeatable

- **Environment**
  - Room temperature
  - Batteries fully charged.

- **On-Site Verification Facility**
  - Unaltered over time
  - Concrete Foundation
  - Verification Pads
## General Testing Protocol
- Preload / Seat
- Unaltered Load Plates
- 9 load pulses

## Acceptance
- $S_{max} - S_{min} \leq 0.04 \text{ mm}$
- $|S_{mean} - | \leq 0.02 \text{ mm}$
- $|S_i - S_{mean @ \text{calibration}}| \leq 0.02 \text{ mm}$
- Calibration considered when above criteria not met.

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### ON-SITE ZORN LWD VERIFICATION TESTING

<table>
<thead>
<tr>
<th>Variable</th>
<th>Drop #</th>
<th>Output Designation</th>
<th>#1</th>
<th>#4</th>
<th>#4 / #3</th>
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<tbody>
<tr>
<td>Temperature (°C)</td>
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<td></td>
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<tr>
<td>Relative Humidity (%)</td>
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<tr>
<td>3 Seating Drops Completed (✓)</td>
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<td>S1</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>S2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td>S3</td>
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<tr>
<td></td>
<td></td>
<td>Average (S)</td>
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</tr>
<tr>
<td>Modulus (Evd)</td>
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<td>5</td>
<td>S2</td>
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<td></td>
<td>6</td>
<td>S3</td>
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<tr>
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<tr>
<td></td>
<td>9</td>
<td>S3</td>
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<td>Average (S)</td>
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<tr>
<td>Modulus (Evd)</td>
<td>Average (Evd)</td>
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<tr>
<td>Deflection (mm)</td>
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<td></td>
<td>12</td>
<td>S3</td>
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<td>Average (S)</td>
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<tr>
<td>Modulus (Evd)</td>
<td>Average (Evd)</td>
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</tbody>
</table>

Extra measurements if problems encountered during a previous set of measurements.
2105 Excavation and Embankment – LWD Quality Compaction

Performance Based Specifications

- Mn/DOT Specification 2105 Excavation & Embankment
- Duluth and Bemidji Districts
  - Support from Mn/DOT IC Task Force
- Implemented in 2006
- [http://www.mrr.dot.state.mn.us/pavement/GradingandBase](http://www.mrr.dot.state.mn.us/pavement/GradingandBase)
Control Strip (Roadbed Embankment)

- **Objective:** LWD compaction target value

- **Constructed for each:**
  - Type and/or source of soil
  - Observable variations
    - Not-Limited to: gradation, texture, silt & clay content, moisture content

- **Incorporated into final embankment.**

- **300 ft long and 32 ft wide**

- **Total Thickness**
  - Planned thickness
  - 4 ft maximum

(Roadbed Embankment)
Control Strip (cont.)

- 65 and 95% of OMC or EOMC

- LWD Testing
  - 6 drops without moving plate.
  - LWD-TV = \( \frac{E_4 + E_5 + E_6}{3} \)

- Testing Frequency
  - Between each compaction pass
  - Minimum of 3 locations
  - 25 ft spacing

(Roadbed Embankment)
Control Strip (cont.)

- **LWD-TV**
  - Optimum Modulus Value
  - 1 ft increments to 4 ft.
  - Value at 4 ft used for portions in excess of 4 ft.
Acceptance

- **Testing Lot**
  - 1000 ft length
  - Embankment Width
  - 1 ft increments
  - Minimum 3 / nominal vertical increment / testing lot

- **Acceptance**
  - $E_i \geq 0.90 \times \text{LWD-TV}$
    - Corrections as needed
    - Re-test
  - $E_i > 1.20 \times \text{LWD-TV}$
    - Re-evaluate LWD-TV selection
    - Construct new control strip

(Roadbed Embankment)
## 2007 Deflection Testing

<table>
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<tr>
<th>SP Number</th>
<th>District</th>
<th>Route</th>
<th>Location</th>
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<tbody>
<tr>
<td>6211-11</td>
<td>METRO</td>
<td>TH36</td>
<td>Maplewood</td>
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<tr>
<td>3104-51</td>
<td>1</td>
<td>TH2</td>
<td>Grand Rapids</td>
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<td>3801-13</td>
<td>1</td>
<td>TH1</td>
<td>Ely</td>
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<td>3609-25</td>
<td>1</td>
<td>TH65</td>
<td>Silverdale Bridge Replacement</td>
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<td>0916-16</td>
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<td>TH210</td>
<td>Jay Cooke State Park</td>
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<td>0301-47</td>
<td>4</td>
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<tr>
<td>5305-55</td>
<td>7B</td>
<td>TH60</td>
<td>Bigelow</td>
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9 Projects
## 2008 Deflection Testing Projects

<table>
<thead>
<tr>
<th>SP Number</th>
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<th>Route</th>
<th>Location</th>
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<tr>
<td>3104-51</td>
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<td>Grand Rapids</td>
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<td>6915-129</td>
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<td>6916-99</td>
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<td>Cty 8 to Pike Lake</td>
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<td>1604-40</td>
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<td>Grand Portage Rest Area</td>
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<td>1105-08</td>
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<td>TH34</td>
<td>Akeley to Walker</td>
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<td>3604-71</td>
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<td>Canadian Border</td>
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<td>TH197</td>
<td>Bemidji</td>
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<tr>
<td>7702-42</td>
<td>3A</td>
<td>TH10</td>
<td>Staples</td>
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<tr>
<td>8680-157*</td>
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<td>TH94</td>
<td>Mn/ROAD, Albertville</td>
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<tr>
<td>0301-47</td>
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<td>8103-49</td>
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<td>Waseca County</td>
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<tr>
<td>5305-55</td>
<td>7B</td>
<td>TH60</td>
<td>Bigelow</td>
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~ 17 Projects
Light Weight Deflectometer Technology Transfer Workshop

Baxter, Minnesota (November 14, 2007)

Attendees: Project & Resident Engineers, Inspectors, Materials Engineer
Positive Characteristics

- Quick and Easy
- Inspector Remains on Grade
- Made Contractor more aware of what is needed for acceptance
- Better understanding of water content and processes.
- Improved Uniformity
- Improved over DCP
  - Quicker
  - Contractor better understands results
- Reliable Measurements
  - (e.g., 199 LWD tests out of ~ 200 matched those of the DCP)
Troubles / Concerns

- Difficult portability in utility trenches.
- Can be a 2 person job.
- Not “light” weight.
- Water table can be drawn up and affect results.
- Set up of soil (soil curing) / bridging. Need to remove crust on clay prior to testing.
- LWD will move if sand is too wet and sloped.
- Need to level plate.
- Unable to obtain consistent LWD results with only 1 ft of sand above grade.
Quantitative Results

- Able to find deeper soft layers.
- Able to obtain better results near structures.
- Did not notice significant effect from mild skew of testing surface.
- Achieved similar modulus values after 3 ft and up.
Moisture Effects

- Need to obtain relatively uniform moisture.

- Variable soils change optimum moisture content.

- First control moisture then establish LWD target value.

- Need adequate moisture content to get passing LWD readings.

- Moisture tested with both the Speedy and Burn Method. Results within 1 percent.
Moisture testing and control was a continual battle.

Contractor personnel are interested and asking for LWD values.

Contractor is learning that scrapers should be run in different spots to achieve passing values compaction.
Testing Procedures

- **LWD to determine rolling pattern in trenches.**
  - Difficult to carry LWD in trenches.
  - Used LWD for spot checks.
  - Focus more on moisture content and lift thicknesses.
  - Ensured that moisture content remained the same after determination of rolling pattern.

- **QA Procedure:**
  - 1st test moisture
  - Moisture Fails ⇒ Inspector does not “waste time” performing LWD testing.
  - Full scrapers often run over site to help achieve density.

- **Testing at “time of compaction”** – Contractor should not be delayed.

- **Test soft areas every 300 to 400 ft.**
Changes Next Year

- Procedures need to be flexible, but balanced with the ability to enforce.
- Test on “surface” of aggregate base.
- Control strips need to be eliminated.
- Better if “over-built” and then dug down for testing with some confinement.
Questions?
Scope of Discussions

- Positive Characteristics
- Troubles/Concerns
- Quantitative Results
- Moisture Effects
- QC Contractor Responsibility
- Testing Procedures
- Changes for Next Year
Scope of Discussions

- **Presentation:** Dr. Fleming
  “Experience with LWD for Routine In Situ Assessment of Foundation Stiffness”

- **Presentation:** Dr. White
  “Mn/DOT Intelligent Compaction Implementation Seminar #4: Lessons Learned from IC and LWD Testing”
## Typical Zorn LWD Values

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>LWD Modulus (MPa)</th>
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<tbody>
<tr>
<td>Sand w/ Silt</td>
<td>20-30</td>
</tr>
<tr>
<td>Silty gravel w/ sand</td>
<td>30-35</td>
</tr>
<tr>
<td>Silty sand w/ gravel</td>
<td>30-35</td>
</tr>
<tr>
<td>Poorly graded gravel</td>
<td>40-45</td>
</tr>
<tr>
<td>Silty sand</td>
<td>15-20</td>
</tr>
<tr>
<td>Clayey gravel</td>
<td>30-40</td>
</tr>
<tr>
<td>Well graded sand w/ silt</td>
<td>25-35</td>
</tr>
</tbody>
</table>