Determining Frost Depth in Pavement Systems Using a Multi-Segment Time Domain Reflectometry Probe

Ruth Roberson
John Siekmeier

Minnesota Department of Transportation
Office of Materials and Road Research
Applications in Pavement Research and Engineering

• **Seasonal Load Limit**
  – Optimize timing of:
    • Winter load increase
    • Spring load decrease

• **Mechanistic Empirical Design**
  – Seasonal Changes in Strength Properties
    • Material properties database
Objectives

• Evaluate Mult-Segment TDR probe for improved frost depth measurements within pavement structures.

• Implement field testing at designated Road and Weather Information (R/WIS) System sites.
## Summary of Methods

<table>
<thead>
<tr>
<th></th>
<th>Frost Tube</th>
<th>Resistivity Probe</th>
<th>Moisture Block</th>
<th>TDR Probe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Collection</strong></td>
<td>Manual</td>
<td>Primarily Manual</td>
<td>Automated</td>
<td>Automated</td>
</tr>
<tr>
<td><strong>Data Interpretation</strong></td>
<td>Subjective</td>
<td>Subjective, requiring temperature data.</td>
<td>Subjective, requiring temperature data.</td>
<td>Potential for developing algorithm for automated analysis.</td>
</tr>
</tbody>
</table>
Using TDR to Estimate Frost Depth

- Significant decrease in dielectric constant (Ka) when water freezes.
- Result is abrupt decrease in the propagation time (Δt) measured by the TDR probe.
Multi-Segment TDR Probe

Type K Probe:

- Four segment Probe
- Each segment 15 cm
- Two stainless steel rails separated by an epoxy and high density plastic.
- Segment boundaries defined by switching diodes.
Laboratory Experiment

- **Frozen Soil Core**
  - PVC column packed with Class 5 Special resting on heater core base.
  - **Instrumentation**
    - MP Probe
    - Thermocouples
  - **Automated Data collection**
    - MP917
    - Campbell Scientific CR10X and AM416
    - Dell PC (Procomm script file)
Confine Freezing to the Surface of the Soil Column

Heater Core

Switching Diodes

3" R13 Unfaced Fiberglass Insulation

Thermocouples
Frost Depth
(Step-wise freezing)
Frost Depth
(Rapid freezing)

Temperature (°C)

Time (doy)

Dielectric

Air_T  Soil_T  Ka

Freeze

Thaw

Segment 3
Frost Depth

(Resolution)

Segment 1

Temperature (°C)

Dielectric

Time (doy)

Air_T

Soil_T (2 cm)

Soilt_T (13 cm)

Ka

Segment 1
RESULTS

• Measured decrease in Ka near 0° C for each segment.

• Estimated frost depths agree with temperature measurements and physical test.

• Rate of freeze/thaw and initial moisture content affect magnitude of change in Ka near 0° C.

• Resolution is limited to the length of the segment.
Road and Weather Information System (R/WIS)

- Main elements of RWIS are
  - environmental sensor system (ESS)
  - advanced processing systems to develop forecasts and tailor the information into an easily understood format
  - dissemination platforms on which to display the tailored information.
Road and Weather Information System (R/WIS) cont’d

• Specific to Minnesota
  – Implementation of a system that is able to accommodate various types of instruments.
  – Portion of the R/WIS project is dedicated to testing the system's communication architecture.

• Specific to Minnesota Road Research
  – Investigate new methods for determining frost depth as well as looking for improved data transfer protocols.
STATE-WIDE INSTALLATIONS

- Rochester
- Marshall Solar Powered
- Effel R/WIS Site
- Jacobson R/WIS Site
- Minnesota Road
- Rochester Solar Powered
R/WIS SITES:
EFFE and JACOBSON, MN
R/WIS SITE: 52
EFFE, MN
Spring Thaw 2001

Ka (dielectric constant)

15 - 21 inches

21 - 27 inches

27 - 33 inches
CONCLUSIONS

• Multi-segment TDR probe shows promise as instrument for measuring frost depth within pavement structures.
• TDR methods provide a means for validating air temperature based models.
• Increase the number of field sites.
• Continue research into TDR methods.
Continuing Research

• Temperature Effects on Dielectric Constant
  – Evidence of significant temperature effect on measured Ka.
  – Temperature correction for moisture content measurements.

• Calibration for Moisture Content

• Automation of data interpretation
  – Ka and raw waveform interpretation
Acknowledgements

• Minnesota Local Road Research Board
• Mn/DOT Engineering Services
• Mn/DOT Maintenance Division (Ed Fleedge)
• Office of Materials and Road Research
• Environmental Sensors Inc.
• Chad Millner