OUTLINE

- Introduction to Non-Destructive Pavement Testing (NDT)
- Description of Falling Weight Deflectometer (FWD)
- Overview of Data Analysis Methods
- Example Projects
- Brief overview of MEPDG and Darwin ME pavement design software
What is NDT?

- As the name implies, it is nondestructive testing of pavement
  - Fast when compared to standard pavement sampling
  - Mobile
  - Allows greater coverage (i.e. more test locations)

- Simulates traffic loading
  - Measures pavement response at or near design loads
  - Allows changes in load magnitude
  - Records pavement surface deflections

- Measures in-situ conditions
  - Takes into account impact of pavement distress
  - Measures response of deeper / wider area compared to a core sample
Why do we need NDT?

- Pavement design methods are moving from Empirical to Mechanistic-Empirical methods with the introduction of the new AASHTO MEPDG

- Need to model pavement structures as multi-layer systems and evaluate the pavement response to traffic loads and changes in environmental conditions
  - Need Layer Moduli
  - Field conditions are different from lab conditions
Elastic Modulus vs. Resilient Modulus

\[ M_r = \frac{\sigma_d}{\varepsilon_r} \]

The recoverable portion of the plot is used to determine the elastic modulus.

Stress \( \sigma \)

STRESS

STRAIN

ELASTIC RANGE

Strength

\( \sigma_d \)

\( \varepsilon_r \)

\( \varepsilon_p \)

\( \varepsilon_r \)
<table>
<thead>
<tr>
<th>Material</th>
<th>E (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber</td>
<td>1,000</td>
</tr>
<tr>
<td>Wood</td>
<td>1,000,000-2,000,000</td>
</tr>
<tr>
<td>Aluminum</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Steel</td>
<td>30,000,000</td>
</tr>
<tr>
<td>Diamond</td>
<td>170,000,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>E (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Concrete (32°F)</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Asphalt Concrete (70°F)</td>
<td>500,000</td>
</tr>
<tr>
<td>Asphalt Concrete (120°F)</td>
<td>50,000</td>
</tr>
<tr>
<td>Crushed Stone</td>
<td>20,000-100,000</td>
</tr>
<tr>
<td>Soils</td>
<td>5,000-30,000</td>
</tr>
<tr>
<td>PCC</td>
<td>3-8,000,000</td>
</tr>
</tbody>
</table>
MECHANISTIC vs EMPIRICAL

- **EMPIRICAL** - BASED ON OBSERVATION
  - AASHTO
  - CBR
  - R-VALUE

- **MECHANISTIC** - BASED ON MECHANICS
  - Load
  - Material response
  - Stress or strain
  - Performance (e.g. Fatigue)
MECHANISTIC ADVANTAGES

- Changing loads
- Changing materials
- Better utilization of materials
- More reliable design predictions
- Evaluate construction effects
- Evaluate environmental effects
- Better understanding of behavior
Falling Weight Deflectometer

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FWD Testing

Load

9 Geophones (e.g.)

Surface
Base
Subbase
Subgrade
FWD Testing

- FWD Plate Diameter: try to match stress level (tire pressure)

Small Plate (12”): Highways

- Geophones spacing
  7 geophones: 0, 8, 12, 18, 24, 36 and 60” (minimum)

8” and 12” behind/side of plate are also typical for joint testing
Concrete Joint Testing

- Load Transfer Efficiency at Longitudinal, Transverse Joints or Corners
Deflection Measurements
TYPICAL DEFLECTION BASIN

LOAD (kN or LBF.)

DEFLECTION (microns or mils)

OUTER DEFLECTIONS (SUBGRADE)

INNER DEFLECTIONS (PAVEMENT + SUBGRADE)

RADIAL DISTANCE (mm or inches)
DATA ANALYSIS

- **DIRECT METHOD**
  - Subgrade Resilient Modulus
  - Treat pavement as two layer system
  - Calculate pavement modulus
  - Estimate SNeff

- **BACKCALCULATION**
  - Iterative process
  - Uses deflection basin
  - Outer sensor(s) reflect $E_{SG}$
  - Layer thicknesses known
  - Assume moduli (“seed” values)
  - Calculate deflections
  - Measured vs. calculated?
  - Adjust moduli and repeat
TEST EVERY 100 FEET IN EACH LANE
OFFSET TEST LOCATION
TEST AT MULTIPLE LOAD LEVELS
ESTIMATE
- EFFECTIVE STRUCTURAL NUMBER (SN Effective)
- ESTIMATE SUBGRADE RESILIENT MODULUS (Mr)
- OVERLAY THICKNESS
- POTENTIAL UNDERCUTTING
- DETERIORATED CONCRETE IN COMPOSITE PAVEMENTS
OTHER USES OF FWD

- LOAD CARRYING CAPACITY
- OVERLOAD PERMITS
- SEASONAL LOAD LIMITS
- ACCEPTANCE OF NEW SUBDIVISIONS
- UTILITY CUTS
Coolidge Rd

- Located in the City of Oak Park, MI.
- Five lane road, two northbound and southbound lanes, and center turning lane.
- Asphalt concrete overlay of concrete pavement (composite pavement).
- Condition of concrete layer unknown.
- Pavement exhibiting low to medium severity distress on the asphalt surface.
- FWD testing performed to evaluate the condition of the concrete layer and subsurface conditions.
Falling Weight Deflectometer

Test Spacing = 100 ft on each lane
Deflection Basin Recorded at a Test Location

Deflections for 9,000 lb Load

Deflection (mils)

Distance to Sensor from Center of Load Plate (in)
Backcalculation of Layer Moduli

- Assume elastic moduli for pavement layers, calculate theoretical deflections.
- Vary layer moduli until theoretical deflections match measured deflections within a specified tolerance.

<table>
<thead>
<tr>
<th>Pavement Structure</th>
<th>0&quot;</th>
<th>8&quot;</th>
<th>12&quot;</th>
<th>18&quot;</th>
<th>24&quot;</th>
<th>36&quot;</th>
<th>60&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>4.55</td>
<td>4.14</td>
<td>3.92</td>
<td>3.59</td>
<td>3.35</td>
<td>2.58</td>
<td>1.56</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigid Layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Measured Deflection | 4.55 | 4.14 | 3.92 | 3.59 | 3.35 | 2.58 | 1.56 |
| Computed Deflections| 4.64 | 4.11 | 3.9  | 3.59 | 3.26 | 2.61 | 1.57 |
### Preliminary Backcalculation

- Pavement thickness measured during soil borings performed by others
- No cores were obtained during geotechnical evaluation.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Thickness (in)</th>
<th>D0 (mils)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC</td>
<td>PCC</td>
</tr>
<tr>
<td>NB - Outside</td>
<td>5.8</td>
<td>8.1</td>
</tr>
<tr>
<td>NB - Inside</td>
<td>5.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Center</td>
<td>7.6</td>
<td>12.1</td>
</tr>
<tr>
<td>SB - Inside</td>
<td>4.7</td>
<td>12.4</td>
</tr>
<tr>
<td>SB - Outside</td>
<td>2.8</td>
<td>7.8</td>
</tr>
</tbody>
</table>
## Preliminary Backcalculation Results

<table>
<thead>
<tr>
<th>Lane</th>
<th>Estimated Percent Test Locations Deteriorated/Cracked Concrete (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB - Outside</td>
<td>18</td>
</tr>
<tr>
<td>NB - Inside</td>
<td>7</td>
</tr>
<tr>
<td>Center</td>
<td>70</td>
</tr>
<tr>
<td>SB - Inside</td>
<td>81</td>
</tr>
<tr>
<td>SB - Outside</td>
<td>5</td>
</tr>
</tbody>
</table>
Core Locations (Based on NDT Data)
PROJECT LEVEL – CORES / SOIL BORINGS

- Dynamic Cone Penetrometer
- Geoprobe
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Pavement History Records
ORIGINAL PAVEMENT – TWO CONCRETE LAYERS

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CORES CONFIRMED NDT RESULTS
Cornell (Grand River to Orlando)
Deflection Below Load for 9000 lb

Deflection [mils]

Distance (ft)

Lane 1
Lane 2
Deflection at 60" for 9000 lb

Deflection (mils)

Distance (ft)

Lane 1
Lane 2
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CONCLUSIONS

- Optimizing pavement performance requires use of advanced pavement evaluation techniques.
- Condition assessments based on visual condition survey and cores do not provide a complete picture.
- NDT can provide cost effective solutions to shrinking funds and increased maintenance backlog.
- Reduce change orders by reducing the unknowns (undercutting, deteriorated concrete, etc..)
CLOSING REMARKS

- **NDT**
  - **FAST (< 2 MINUTES PER TEST)**
  - **RELIABLE**
  - **REDUCES RISK (IDENTIFY PROBLEMS IN DESIGN PHASE)**
  - **PROVIDE NECESSARY DATA FOR MECHANISTIC-EMPIRICAL DESIGN**