The INDOT Friction Testing Program: Calibration, Testing, Data Management, and Application

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1. Purposes of Pavement Friction Testing Program

- To identify possible slick pavements and monitor network pavement friction conditions
- To provide pavement surface condition data for planning pavement resurfacing projects
- To provide performance evaluation for pavement preservation projects
- To measure the friction performance of pavement warranty projects
- To investigate the skid resistance of new pavements and materials
- To provide evidences for INDOT’s legal defenses
2. Friction Testing Resources

- The team
  - Main persons
    1 pavement friction engineer
    1 system analyst
    1 testing coordinator
    1 testing technician
  - Supporting persons
    Electrical technician
    Mechanical technician
The testing system

2 ASTM E-274 locked wheel testers

Fig. 1 ASTM E-274 Locked-Wheel Tester
• The system calibration facilities

Fig. 2(a) In-House Transducer Calibration Platform
Fig. 2(b) Friction test Track: Testing System Calibration
3. Testing System Calibration

3.1 Types of Calibration

- Monthly calibration and checking
  - Force transducer calibration
  - Water flow, brake, speed, mileage …
  - Verification testing on the friction test track

- Weekly verification and checking
  - Temperature sensor, wiring, plumbing, nozzle …
  - Verification testing on the friction test track

- Others
  - Annual calibration (force plate …)
  - Daily checking (tire …)
3.2 Surface Characteristics of the Friction Test Track

• Slick concrete pavement
  Normal cement concrete mix
  Surface finishing: steel floating

• HMA pavement
  9.5 mm hot mix asphalt (asphalt binder PG 76-22)
  Coarse aggregates: 27% slag/dolomite

• Transversely tined concrete pavement
  Normal cement concrete mix
  Surface texturing (transverse tining):
  3-mm wide, 3-mm deep, 18~20-mm spacing

• Advantages
  Safety, accuracy, and convenience
TABLE 1 Friction test track surface characteristics

<table>
<thead>
<tr>
<th>Section</th>
<th>MPD (mm)</th>
<th>DFT20</th>
<th>F60</th>
<th>FN40 (Smooth tire)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slick Concrete</td>
<td>0.04</td>
<td>0.58</td>
<td>0.08</td>
<td>&lt; 10.0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.45</td>
<td>0.75</td>
<td>0.33</td>
<td>35.0 ~ 50.0</td>
</tr>
<tr>
<td>Tined Concrete</td>
<td>1.35</td>
<td>0.86</td>
<td>0.56</td>
<td>&gt;60.0</td>
</tr>
</tbody>
</table>

MPD = surface texture depth (circular texture meter)
DFT20 = friction value (dynamic friction tester at 20 km/h)
F60 = friction value at 60 km/h computed from MPD and DFT20
FN40 = friction number at 40 mph measured (ASTM E 274)
3.3 System Calibration Testing

- Minimum Sample Size Requirements

![Graph showing standard deviations versus sample size](image)

**Fig. 3 Standard deviations versus sample size**
• Significant errors arising when sample size <3
• Standard deviations utilized to measure the potential errors

\[ N = \left( \frac{1.96\sigma}{\varepsilon} \right)^2 + 3 \]

in which,

\( N = \) minimum sample size
\( \sigma = \) population standard deviation of the friction test results
\( \varepsilon = \) allowable error for verification testing
### TABLE 2 Friction Test Results and 95% Confidence Intervals

<table>
<thead>
<tr>
<th>Tester</th>
<th>Test Section</th>
<th>Smooth Tire</th>
<th>Ribbed Tire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Interval</td>
</tr>
<tr>
<td>300-4</td>
<td>Slick</td>
<td>8.3</td>
<td>(7.8, 8.8)</td>
</tr>
<tr>
<td></td>
<td>Asphalt</td>
<td>51.8</td>
<td>(49.8, 53.8)</td>
</tr>
<tr>
<td></td>
<td>Tined</td>
<td>71.6</td>
<td>(70.5, 72.7)</td>
</tr>
<tr>
<td>379-6</td>
<td>Slick</td>
<td>8.3</td>
<td>(7.9, 8.7)</td>
</tr>
<tr>
<td></td>
<td>Asphalt</td>
<td>54.2</td>
<td>(52.1, 56.3)</td>
</tr>
<tr>
<td></td>
<td>Tined</td>
<td>71.3</td>
<td>(70.6, 72.0)</td>
</tr>
</tbody>
</table>
3.4 Friction Variations due to System Anomalies

- **Standard Deviations**

**Fig. 4(a) Standard deviations with smooth tire**
Fig. 4(b) Standard deviations with smooth tire
Fig. 4(c) Standard deviations with ribbed tire
Fig. 4(d) Standard deviations with ribbed tire
Fig. 5(a) Coefficients of variations with smooth tire
Fig. 5(b) Coefficients of variations with smooth tire
Fig. 5(c) Coefficients of variations with ribbed tire
Fig. 5(d) Coefficients of variations with ribbed tire
**TABLE 3 Average Friction Numbers, Standard Deviations, and Coefficients of Variation**

<table>
<thead>
<tr>
<th>Trailer</th>
<th>Statistics</th>
<th>Slick Concrete</th>
<th>Asphalt</th>
<th>Tined Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-4</td>
<td>Average</td>
<td>8.3</td>
<td>50.2</td>
<td>70.5</td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>1.2</td>
<td>3.8</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>COV</td>
<td>14.7</td>
<td>7.3</td>
<td>2.2</td>
</tr>
<tr>
<td>379-6</td>
<td>Average</td>
<td>8.2</td>
<td>53.3</td>
<td>72.4</td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>1.3</td>
<td>3.3</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>COV</td>
<td>15.6</td>
<td>6.1</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Observations

- Standard deviations:
  - Smooth tire: Largest in the asphalt section
    Lowest in the slick concrete section
  - Ribbed tire: Largest in the asphalt section
    Lowest in the tined concrete section

- Coefficients of variations:
  - Both tires: Largest in the slick concrete section
    Lowest in the tined concrete section

- Coefficients of variations more consistent than standard deviations

- Variations by the smooth tire greater than the ribbed tire
3.5 Multi-Parameter Assessment of System Performance

• Step 1: Examine mean values

  \[(\text{Current mean} - \text{Reference mean}) \leq \text{Allowable error}\]

• Step 2: Examine standard deviations or coefficients of variations

  \[
  \text{Current standard deviation} \leq \text{Allowable value} \\
  \text{or} \\
  \text{Current coefficient of variations} \leq \text{Allowable value}
  \]
TABLE 4 Requirements for system verification testing

<table>
<thead>
<tr>
<th>Test Section</th>
<th>Min. No. of Tests</th>
<th>Test Speed</th>
<th>Allowable Errors for Friction Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Slick Concrete</td>
<td>4</td>
<td>±1 mph</td>
<td>±3</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4</td>
<td>±1 mph</td>
<td>±5</td>
</tr>
<tr>
<td>Tined Concrete</td>
<td>4</td>
<td>±1 mph</td>
<td>±4</td>
</tr>
</tbody>
</table>

S.D. = standard deviation  
COV = coefficient of variations
4. Test Tires and Speeds

4.1 Test Tires

- ASTM E-274 standard tires
  Rib tire (ASTM E-501)
  Smooth tire (ASTM E-524)
- INDOT
  Before 1997: rib tire
  Since 1997: smooth tire
- Friction measurement

\[ \mu = \frac{F}{N} \times 100 \]

where \( \mu \) = friction number;
\( F \) = tractive force or friction force; and
\( N \) = normal force on the test wheel.

Fig. 6 Test tires
• Smooth Tire versus Rib Tire

![Diagram showing friction measurements on slick concrete surface.](image)

**Fig. 7(a)** Friction measurements on slick concrete surface

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Fig. 7(b) Friction measurements on asphalt surface
Fig. 7(c) Friction measurements on tined concrete surface
Fig. 7(d) Friction differences on SR-37
Fig. 7(e) Friction differences in the network
• Summary of Friction Differences between the 2 Tires

- On INDOT friction test track

  Slick concrete surface: 17

  Asphalt surface: 12

  Transversely tined concrete surface: 0

- On real-life pavements

  Interstates: 23

  US and State roads: 20
4.2 Test Speeds

- ASTM E-274 standard test speed
  40 miles per hour

- INDOT friction test speed
  - Warranty pavement friction test
  - Special friction test
  - Network inventory friction test

Interstates: 50 mph

US and State roads: 50 mph (30 or 40 mph)
• Speed gradients

Fig. 8(a) Speed gradients by smooth tire
Fig. 8(b) Speed gradients by rib tire
- Conversion constants

- System 300-4

Smooth tire:

\[ FN_{40} = 0.898418 \times FN_{30} \]

\[ FN_{40} = 1.168647 \times FN_{50} \]

Rib tire:

\[ FN_{40} = 0.951607 \times FN_{30} \]

\[ FN_{40} = 1.045475 \times FN_{50} \]
5. Variations of Pavement Friction

5.1 Effects of Air and Pavement Temperatures

Fig. 9(a) Friction number vs. air temperature
Fig. 9(b) Friction number vs. pavement surface temperature
• Variations due to seasonal effects equivalent to those due to system errors

• Effects of air and pavement surface temperatures not significant

• No seasonal or temperature corrections for INDOT network pavement inventory friction testing
5.2 Spatial Variations of Pavement Friction

- Lateral friction variations

Fig. 10(a) Directional friction variations
**Fig. 10(b) Lane friction variations**
• Directional friction variation up to 16
• Friction variation up to 13 between passing and driving lanes
• Friction variation up to 16 in the wheel track and outside the wheel track
• INDOT network pavement inventory friction testing conducted
  - In both directions
  - In driving lane
  - Inside the wheel track
• **Longitudinal friction variations**

![Friction variations on asphalt and concrete pavements](image)

**Fig. 11(a)** Friction variations on asphalt and concrete pavements
Fig. 11(b) Longitudinal friction variations on interstate highway
FIG. 11(C) Longitudinal friction variations on US highway
Fig. 11(d) Standard deviations vs. pavement segment length
• A linear relationship between the standard deviation and log of pavement section length

• The standard deviation

  - Stdev = 3.4 when section length = 1 mile
    Close to the stdev at 0.1 mile spacing in Fig. 9(a)
  - Stdev = 1.3 when section length very small
    Close to those due to system errors in Table 3

• INDOT network pavement inventory friction testing conducted at 1-mile spacing
5.3 Temporal Variations of Pavement Friction

- Asphalt Pavements

Fig. 12(a) Friction variations with time in new HMA pavements
Fig. 12(b) Friction variations with time in rutted HMA pavements
Fig. 12(c) Friction variations with time in cracked HMA pavements
Fig. 13 Friction variations with time in concrete pavements
Fig. 14 Friction variations with time in pavement network
• Friction fluctuated over time depending on surface conditions; but decreasing overall

• Largest average annual friction decrease of up to 7 observed on interstates

• Largest average annual friction decrease of 4 observed on US and State highways

• INDOT network pavement friction testing conducted on all interstates every year and on US and State highways every three years
6. The Friction Flag Value

• Factors

Safety and cost

• AASHTO Green Book

Deceleration: $3.4 \text{ m/s}^2$.

Locked-wheel braking on a poor, wet pavement with worn tires at 40 mph

• Kummer and Meyer (1967)

37 (standard rib tire)
20 smooth tire at 40 mph
7. Friction Data Management

Fig. 16 INDOT pavement friction data management program

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8. Facts of INDOT Pavement Frictions

- Pavement Network Friction Performance

Fig. 17 Mainline pavement friction performance
### Network Ramp Pavement Friction Performance

<table>
<thead>
<tr>
<th>Road</th>
<th>Length (miles)</th>
<th>No. of Ramps</th>
<th>Ramp Pavement Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Tested</td>
</tr>
<tr>
<td>I-164</td>
<td>21</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>I-265</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>I-275</td>
<td>3</td>
<td>1</td>
<td>~</td>
</tr>
<tr>
<td>I-465</td>
<td>52</td>
<td>35</td>
<td>12</td>
</tr>
<tr>
<td>I-469</td>
<td>31</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>I-865</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>I-64</td>
<td>124</td>
<td>22</td>
<td>3</td>
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<tr>
<td>I-65</td>
<td>261</td>
<td>71</td>
<td>5</td>
</tr>
<tr>
<td>I-69</td>
<td>158</td>
<td>43</td>
<td>3</td>
</tr>
<tr>
<td>I-70</td>
<td>156</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>I-74</td>
<td>171</td>
<td>43</td>
<td>3</td>
</tr>
<tr>
<td>I-80/94</td>
<td>62</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>I-90</td>
<td>157</td>
<td>17</td>
<td>~</td>
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</table>

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### Various HMA Mixes

<table>
<thead>
<tr>
<th>Type of Surface Mix</th>
<th>Coarse Aggregate</th>
<th>ESALs (10^6)</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGFC</td>
<td>Steel slag</td>
<td>≥ 30</td>
<td>56.2</td>
<td></td>
</tr>
<tr>
<td>SMA</td>
<td>Crushed gravel</td>
<td>≥ 10</td>
<td>43.7</td>
<td>41.7 - 46.7</td>
</tr>
<tr>
<td></td>
<td>Steel slag</td>
<td></td>
<td>46.8 - 52.9</td>
<td>47.3 - 55.5</td>
</tr>
<tr>
<td>SuperPave 9.5 mm Mix</td>
<td>Crushed gravel</td>
<td></td>
<td>34.8 - 41.9</td>
<td>36.7 - 42.8</td>
</tr>
<tr>
<td></td>
<td>Crushed stone</td>
<td>3 - 10</td>
<td>31.1 - 44.6</td>
<td>32.1 - 48.9</td>
</tr>
<tr>
<td></td>
<td>Dolomite</td>
<td></td>
<td>34.5 - 49.6</td>
<td>31.7 - 48.6</td>
</tr>
<tr>
<td></td>
<td>Steel slag</td>
<td></td>
<td>36.7 - 48.2</td>
<td>45.2</td>
</tr>
<tr>
<td>Regular</td>
<td>Crushed gravel</td>
<td>3 - 10</td>
<td>47.7</td>
<td>45.1</td>
</tr>
<tr>
<td>9.5 mm Mix</td>
<td>Dolomite</td>
<td>3 - 10</td>
<td>44.3</td>
<td>42.6</td>
</tr>
</tbody>
</table>

**TABLE 6 Friction Properties for HMA Mixes**
9. Conclusions

- Monthly and weekly system verifications:
  - Important to maintain consistent system performance, and
  - Enhance testing reliability
- The friction variations due to system errors varying with pavement surface features:
  1.2 (15%) on slick concrete
  3.8 (6.7%) on asphalt
  1.6 (2.3%) on tined concrete
- INDOT network inventory friction testing conducted on interstates every year and other roads every three years from April through November
- INDOT network inventory friction testing conducted using the smooth tire at 30, 40 or 50 mph
- INDOT network inventory friction testing conducted in the driving lanes in both directions
Questions?