Outline

● Introduction
● Objective
● Data collection
● Results and Analysis
  ➢ Assessment of Repeatability and Reproducibility
  ➢ Operational Factors Affecting the CFME Measurement
● Summary and Conclusion
Introduction

- Friction is known to be one of the contributing factors in reducing crashes
- FHWA Technical Advisory T 5040.17 (1980)
  - Skid Accident Reduction Program
  - Minimize wet-weather skidding accidents
- FHWA Technical Advisory T 5040.36 (2005)
  - Surface Texture for Asphalt and Concrete Pavements
  - Adequate texture, friction and low pavement-tire noise
  - Pavement Friction Management (PFM)
  - Highway Safety Improvement Program (HSIP)
  - Reducing fatal and injury-causing accidents
Data inputs for PFM program

- **Pavement friction**
  - Locked-wheel skid tester
    - Smooth tire (ASTM E-524)
    - Ribbed tire (ASTM E-501)
  - Fixed slip (Griptester, Dynatest HFT 6875)
  - Side force (Mu-meter, SCRIM)
  - Variable slip
  - DFT, British Pendulum
- **Pavement texture**
  - Circular Texture Meter (CTM)
  - Sand Patch Method (SPM)
  - High-speed laser
- **Crash rates**

Highway Speed

Static
Objective

- Most appropriate way to measure the repeatability and reproducibility of CFME measurements
- Operational factors affecting the CFME measurements:
  - Effect of water film thickness on the CFME measurement
  - Speed effects on the repeatability of the measurements
Data Collection

- Data were collected at the Smart Road
- 8 Asphalt Sections and two Concrete surfaces were tested
- Equipment that was used:
  - CFME
    - GripTester
    - Dynatest 6875H
CFME instruments

GripTester

Dynatest 6875H
Virginia Smart Road

Sections Loop-A-B-C-D

Sections E-F-G-H-I-J-K-L

CRCP, JRCP, and bridges

VTTI labs
Virginia Smart Road

- CRCP section
- JRCP section
- RR Bridge
- Smart Road Bridge

VTI labs
Available Pavement Surfaces

SM 9.5 D
SUPERPAVE

OGFC

SMA 9.5 D

Cargill
SafeLane™

Tined CRCP

JRCP

Ground
JRCP

VDOT EP5LV
Cross-correlation for evaluation of repeatability and reproducibility of CFME measurements

- Processing of Continuous Friction Measurement using Cross-Correlation
- Synchronization of the Measurements using Cross-correlation
- Assessment of Repeatability and Reproducibility of the measurements
Cross-correlation Function

- Cross-correlation is a measure used to verify the similarity of two waveforms.
- It is defined as follows (Stearns, 2003):

\[
\varphi_{xy}(\tau) = E[x(t)y(t+\tau)] = \lim_{L \to \infty} \frac{1}{L} \int_0^L x(t)y(t+\tau)dt; \quad \tau \geq 0
\]

where,

- \( E[\cdot] \) = expected value
- \( \tau \) = shift factor
- \( x(t), y(t) \) = two waveforms defined in the range of \( t = [0, \infty) \)
GripTester measurements taken at 40 mph, before shifting
Normalized cross-correlation
GripTester measurements after shifting
Evaluation of Repeatability and Reproducibility of CFME’s Measurements

- Using the Standard Deviation of average measurements
  - More convenient for network evaluation
- Using Cross-Correlation
  - More rigorous than using average friction since it requires the measurements to follow the same trend at each location.
  - Sensitive to low friction spots
Average Standard Deviations for Evaluation of Repeatability for GripTester

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- Average measurements are more repeatable at lower speeds
## Maximum Cross-correlation Value for Evaluation of Repeatability of GT

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Virginia Tech Transportation Institute

VTRC Virginia Transportation Research Council
Maximum Cross-correlation Value for Evaluation of Reproducibility of GT

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- Average correlation of 0.74
Comparison of GripTester and Dynatest (40 mph)
Maximum Cross-correlation = 0.44
Operational Factors Affecting CFME Measurements

- Effect of Speed
  - Speed adjustment factors
- Effect of water film thickness
Effect of Speed on GripTester Measurements

● Test Speeds:
  ➢ 25 mph
  ➢ 40 mph
  ➢ 55 mph

● Speed Adjustment:
  ➢ $CF = 0.06 \times |V2 - V1|$
  ➢ $\begin{cases} 
  GN2 = GN1 \times CF, & \text{if } V2 > V1 \\
  GN2 = GN1 / CF, & \text{if } V2 < V1 
\end{cases}$

➢ For our example:
  $CF = 0.06 \times (40-25) = 0.9$
Measurements Before Shifting
Measurements After the Shift
Effect of water film thickness on GripTester Measurements

- **0.25 mm**
- **0.5 mm**
- **1 mm**

**Equation for 0.25 mm:**

\[ y = -0.12x + 0.86 \]

\[ R^2 = 0.90 \]

**Equation for 0.5 mm:**

\[ y = 0.74x^{-0.09} \]

\[ R^2 = 0.93 \]
Summary and Conclusions

- Cross-correlation was used to process CFME measurement:
  - Easy and objective method to align different measurements
  - Evaluation of the repeatability and reproducibility
  - Comparing the sensitivity of two systems to low friction spots
  - GripTester’s measurements have many peaks due to the low weight of the system
    - Needs filtration

- Operational factors affecting the CFME measurement:
  - Effect of Speed
    - Speed adjustment factors
  - Effect of water film thickness
    - Measurements are sensitive to water film thickness
Questions?