Pavement Surface Properties Consortium

Performance Characteristics of Continuous Friction Measurement Equipment (CFME)

VirginiaTech
Invent the Future

VDOT
Virginia Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

PENNDOT

MDOT

GDOT
Keeping Georgia on the Move

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Virginia Transportation Research Council

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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
- FHWA Technical Advisory T 5040.38 *(2010)*
  - 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

Highway Speed

⇒ Static

- **Pavement texture**
  - Circular Texture Meter (CTM)
  - Sand Patch Method (SPM)
  - High-speed laser
- **Crash rates**

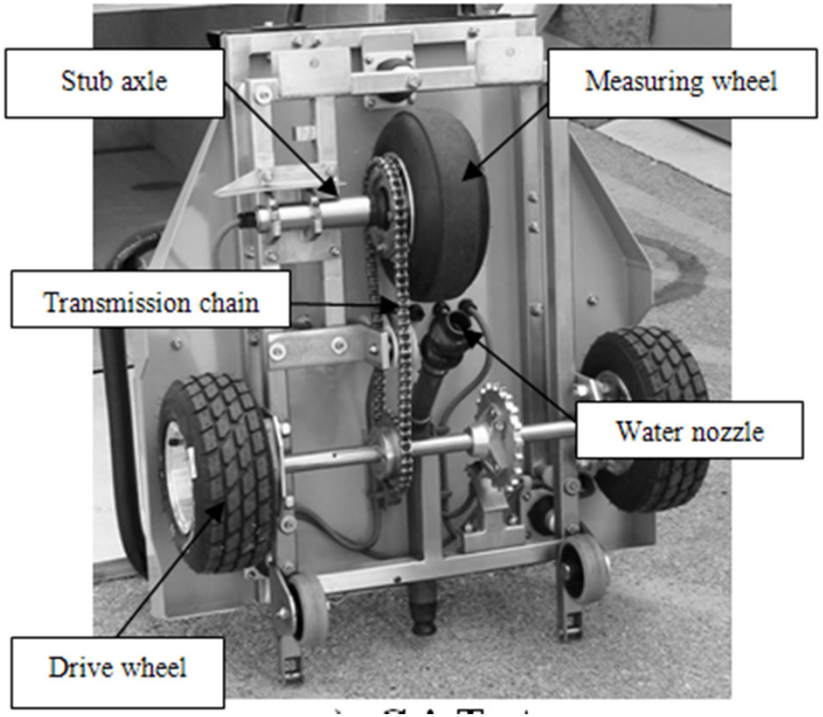
Objective

- 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

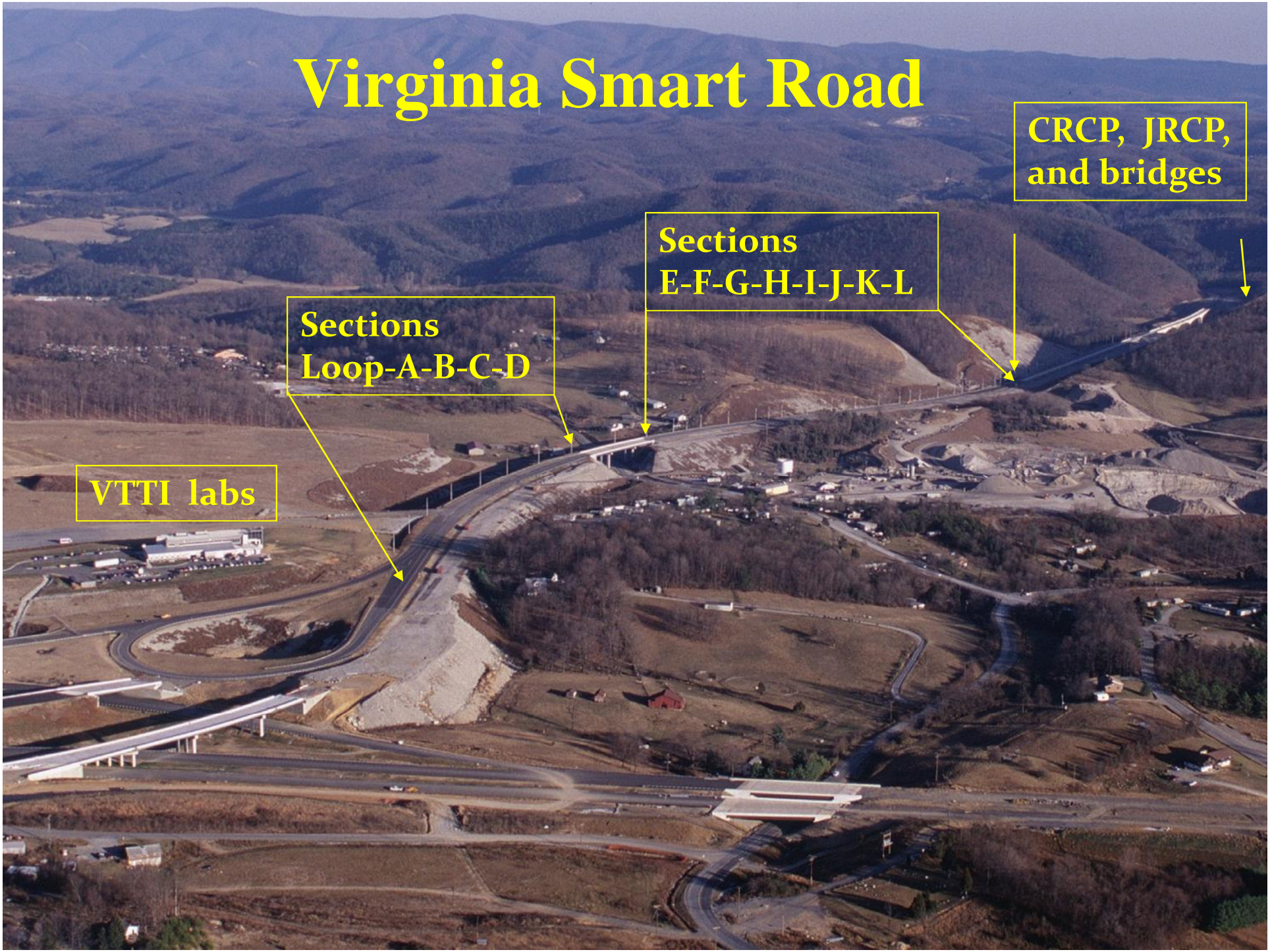
- Data were collected at the Smart Road
- 8 Asphalt Sections and two Concrete surfaces were tested
- Equipment that was used:
  - CFME
    - GripTester
    - Dynatest 6875H

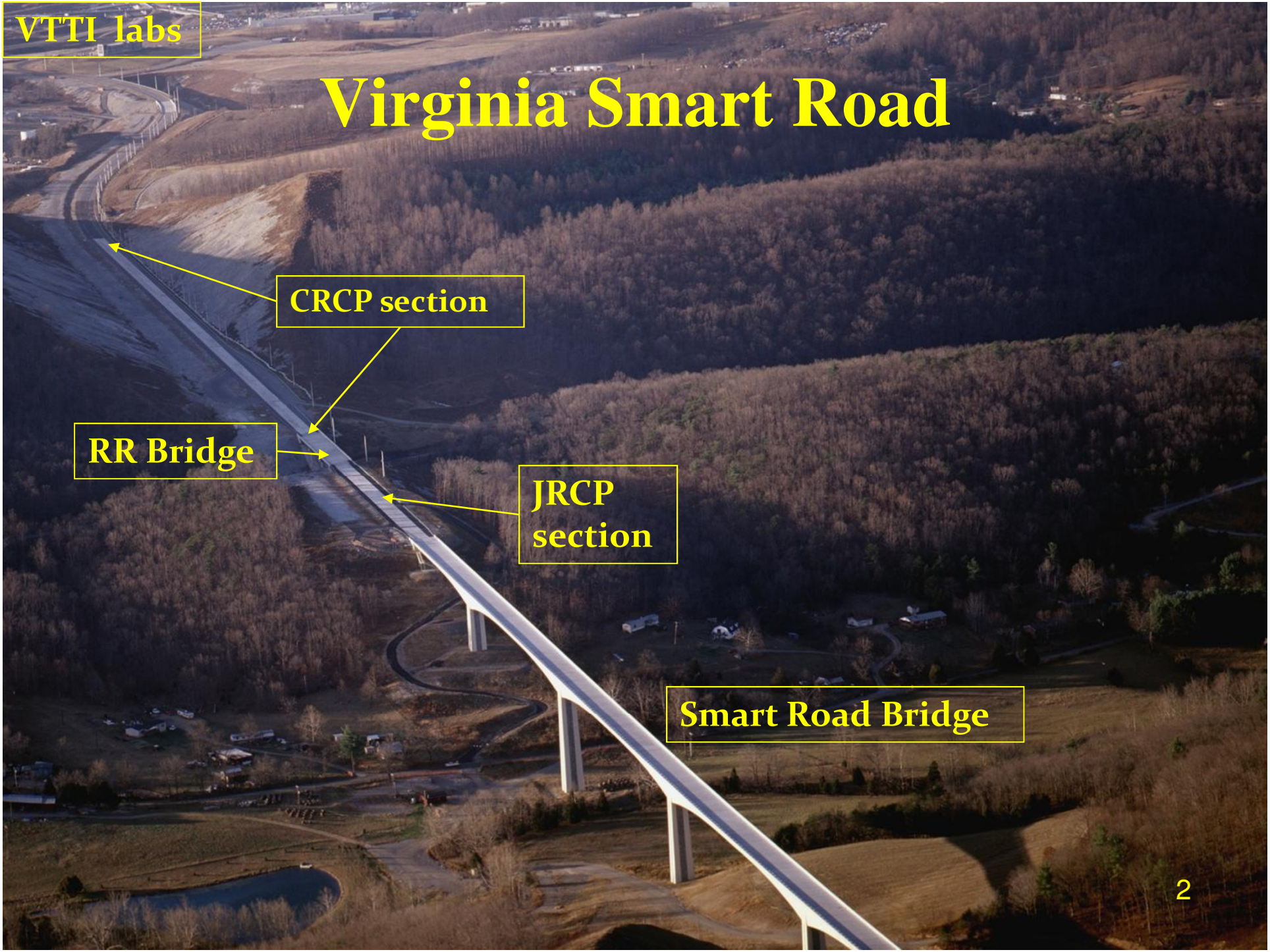
CFME instruments



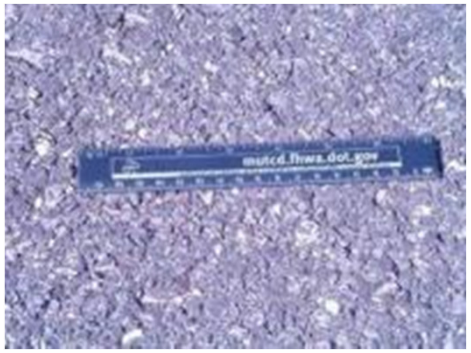
GripTester

Dynatest 6875H


Virginia Smart Road
CRCP, JRCP, and bridges
Sections E-F-G-H-I-J-K-L
Sections Loop-A-B-C-D
VTTI labs


VTTI labs
Virginia Smart Road
CRCP section
RR Bridge
JRCP section
Smart Road Bridge

Available Pavement Surfaces



SM 9.5 D
SUPERPAVE

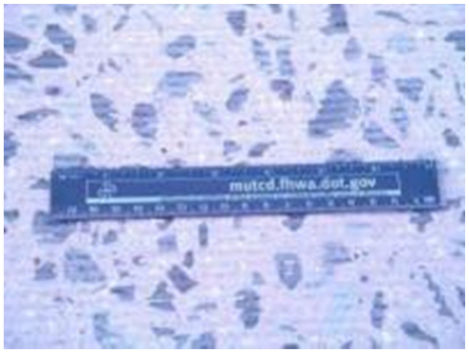
OGFC

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*):**

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

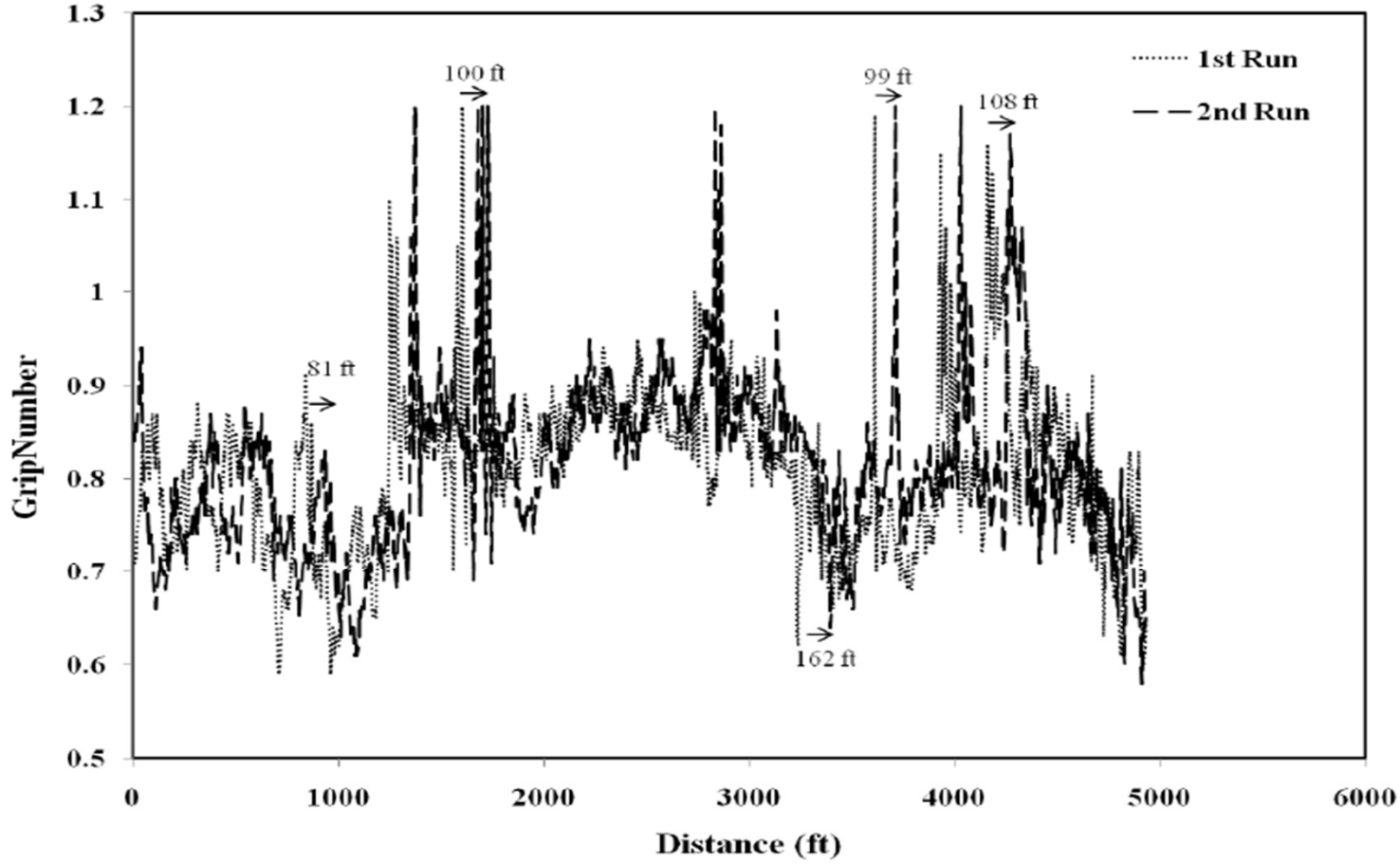
where,

E[·] = expected value

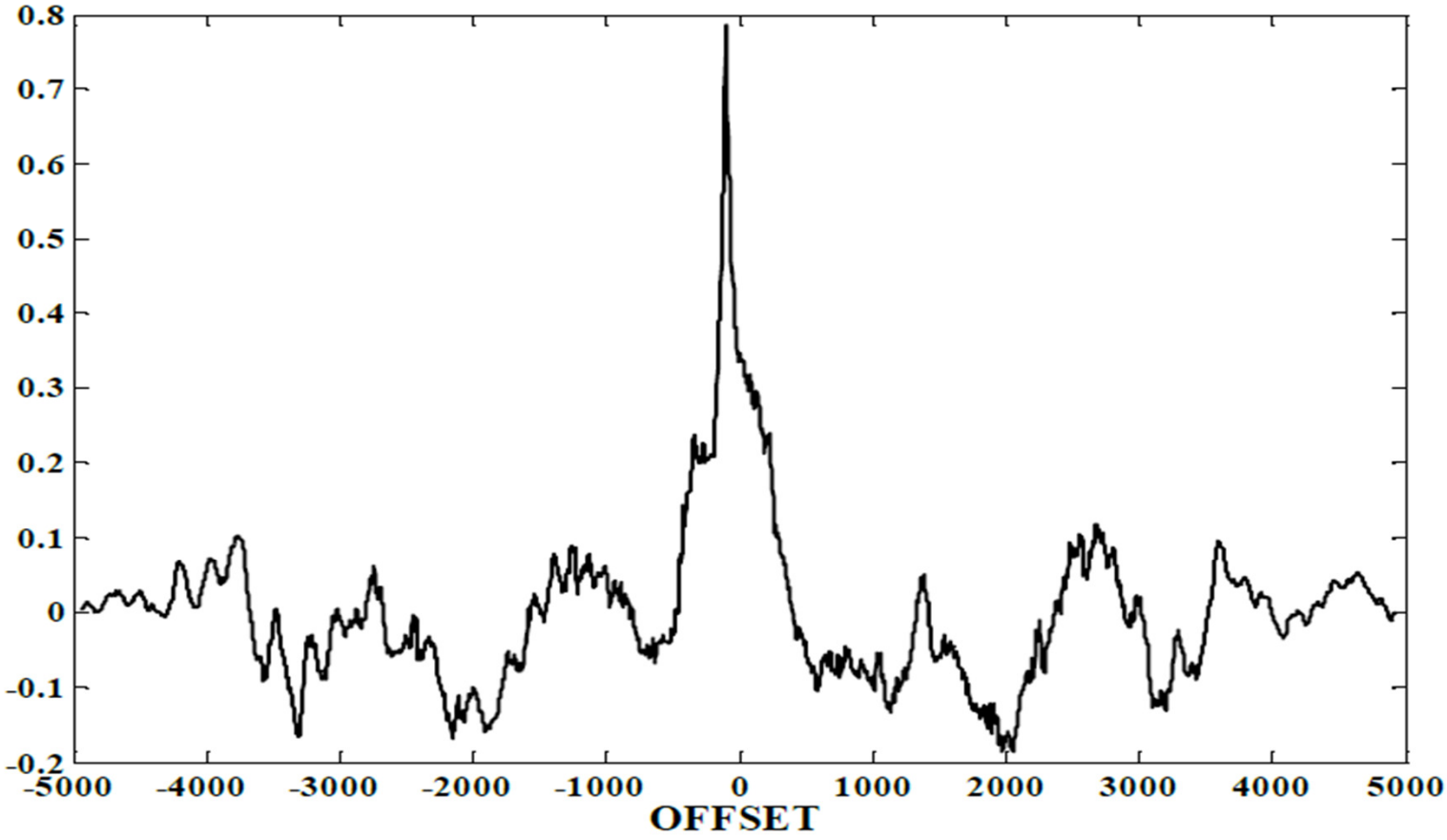
τ = shift factor

x(t), y(t) = two waveforms defined in the range of t = [0 , ∞)

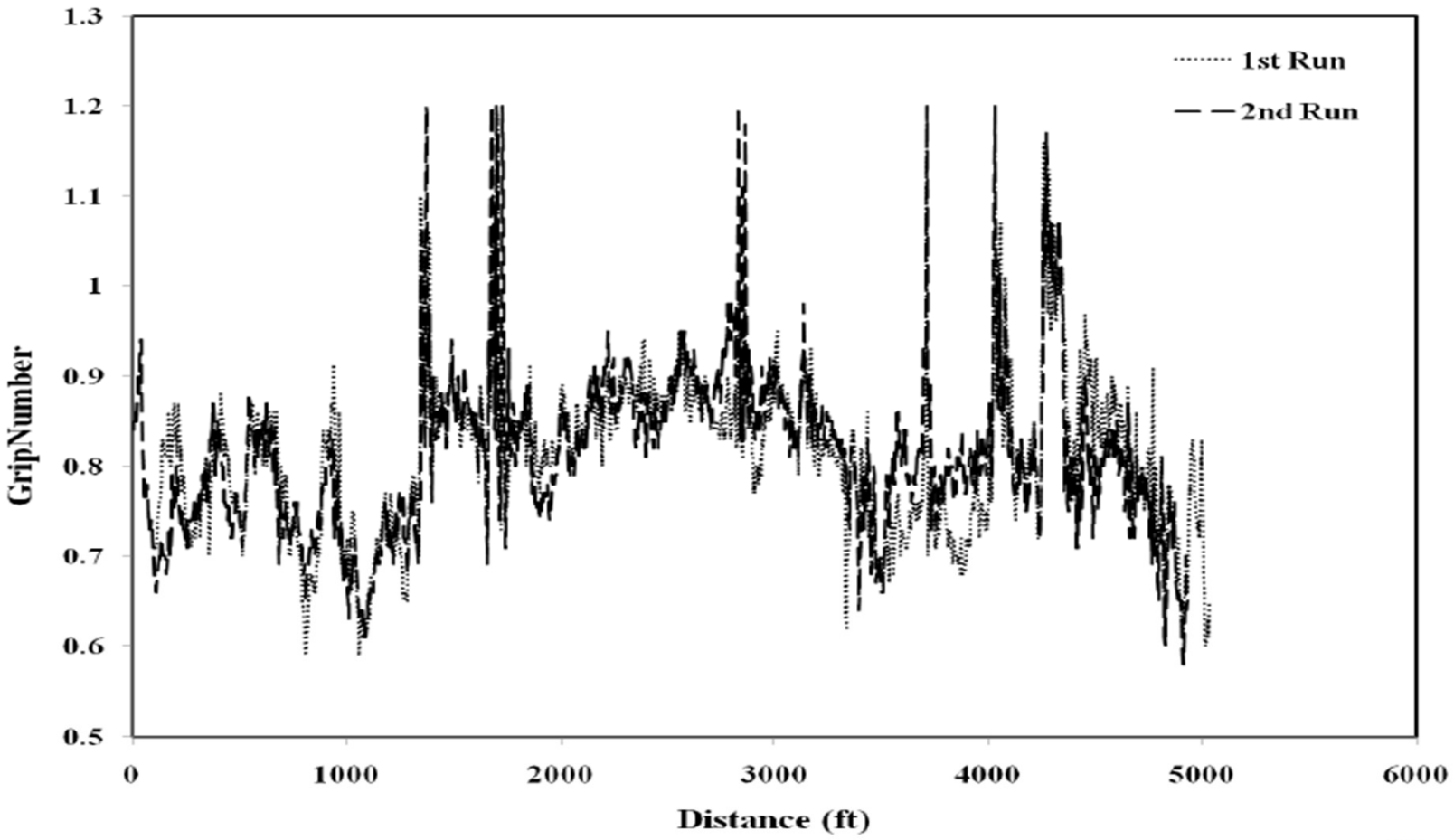
GripTester measurements taken at 40 mph, before shifting



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

	30 mph	40 mph	50 mph
Eastbound	0.025	0.031	0.041
Westbound	0.026	0.027	0.038

- **Average measurements are more repeatable at lower speeds**

Maximum Cross-correlation Value for Evaluation of Repeatability of GT

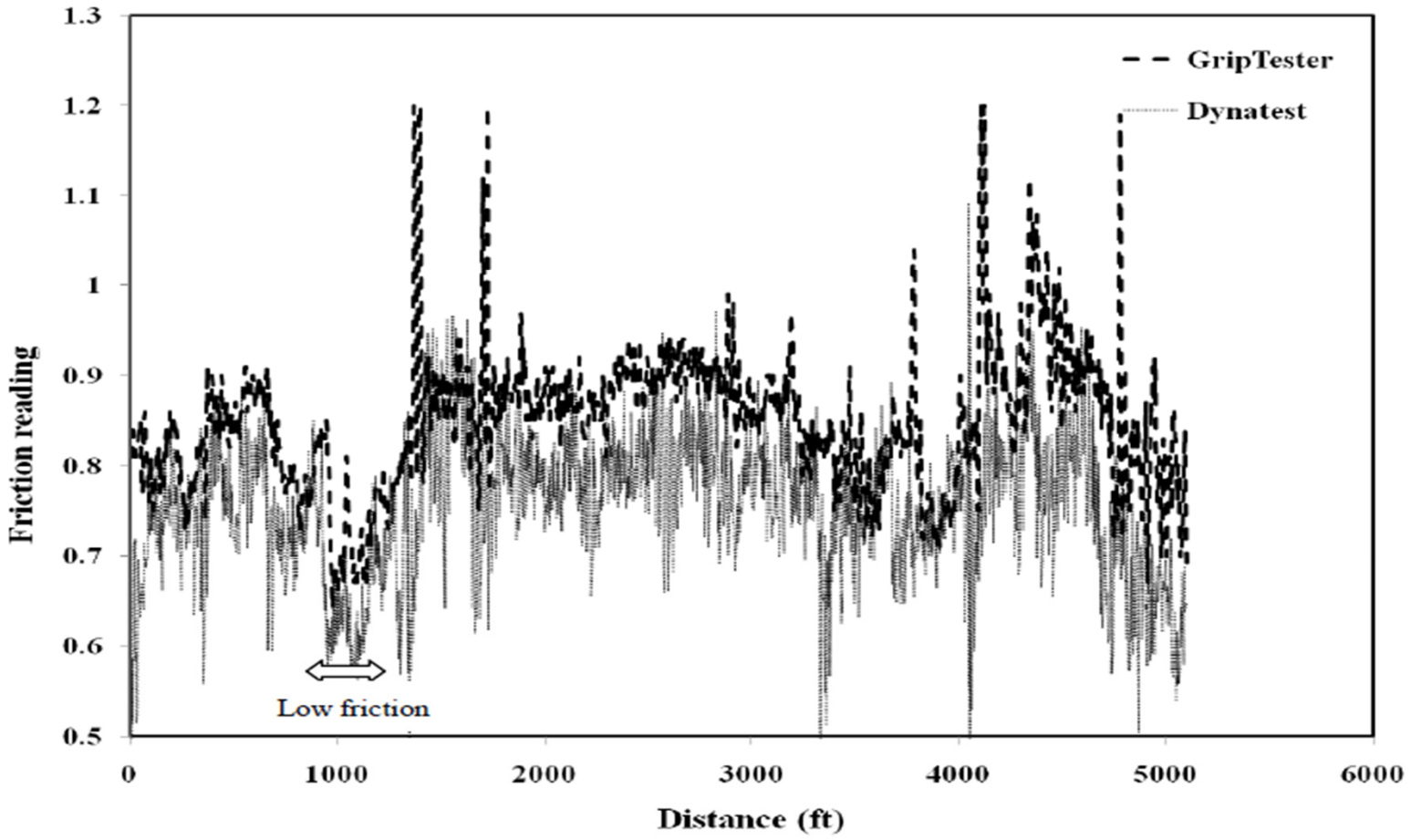
	Eastbound						Westbound					
30 mph	# of run	1	2	3	4	5	# of run	1	2	3	4	5
	1	-	0.74	0.68	0.69	0.59	1	-	0.64	0.73	0.68	0.52
	2	-	-	0.72	0.67	0.62	2	-	-	0.80	0.72	0.57
	3	-	-	-	0.66	0.71	3	-	-	-	0.75	0.63
	4	-	-	-	-	0.58	4	-	-	-	-	0.60
	5	-	-	-	-	-	5	-	-	-	-	-
Average		0.66						0.66				
40 mph	# of run	1	2	3	4	5	# of run	1	2	3	4	5
	1	-	0.88	0.76	0.77	0.73	1	-	0.78	0.74	0.64	0.79
	2	-	-	0.78	0.75	0.72	2	-	-	0.79	0.61	0.86
	3	-	-	-	0.70	0.72	3	-	-	-	0.64	0.75
	4	-	-	-	-	0.81	4	-	-	-	-	0.64
	5	-	-	-	-	-	5	-	-	-	-	-
Average		0.76						0.72				
50 mph	# of run	1	2	3	4	5	# of run	1	2	3	4	5
	1	-	0.70	0.65	0.78	0.75	1	-	0.78	0.78	0.67	0.49
	2	-	-	0.75	0.70	0.72	2	-	-	0.77	0.73	0.52
	3	-	-	-	0.54	0.59	3	-	-	-	0.73	0.58
	4	-	-	-	-	0.78	4	-	-	-	-	0.51
	5	-	-	-	-	-	5	-	-	-	-	-
Average		0.70						0.66				

Maximum Cross-correlation Value for Evaluation of Reproducibility of GT

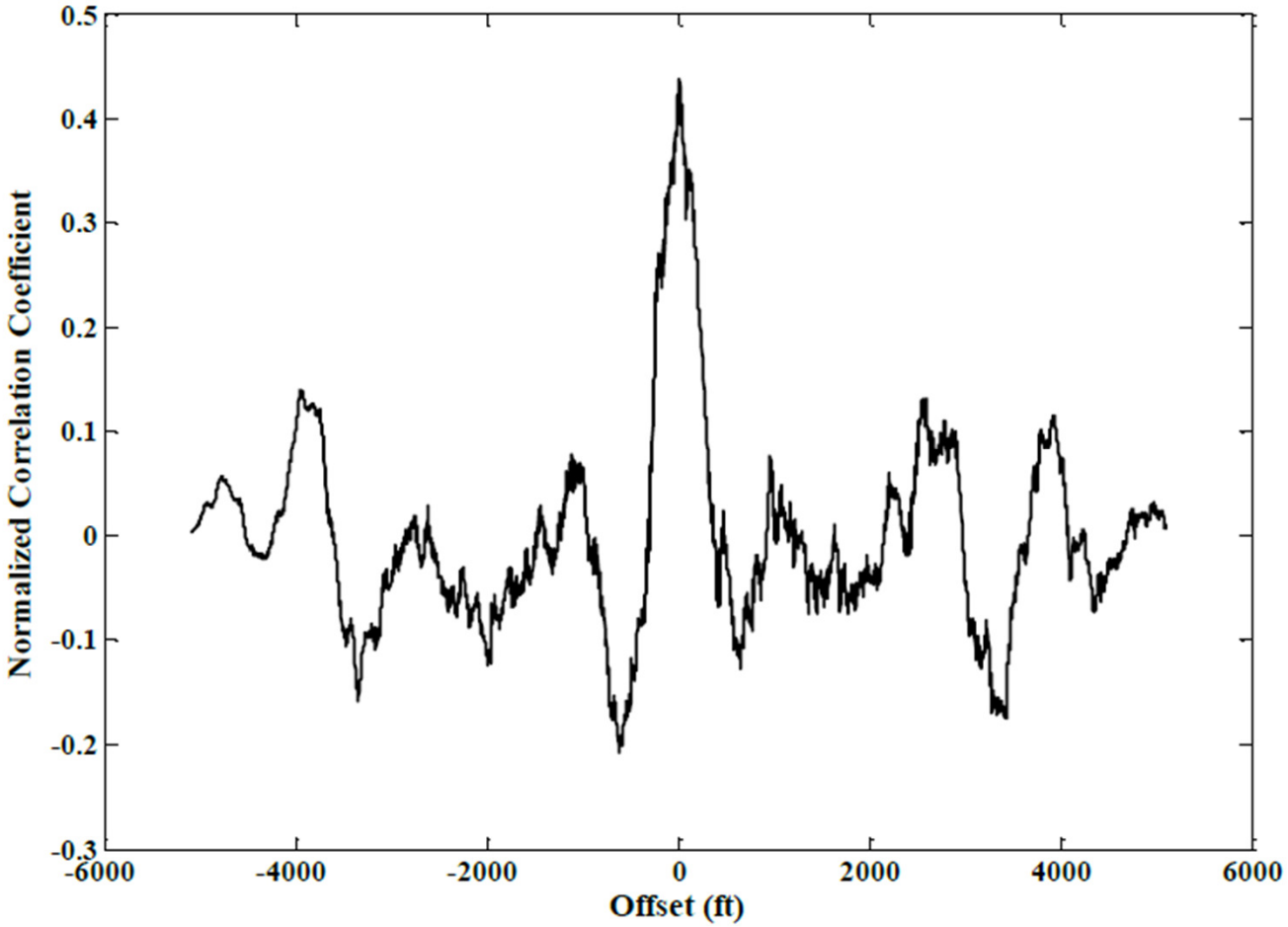
Eastbound				Westbound			
# of run	1	2	3	# of run	1	2	3
1	0.64	0.72	0.72	1	0.75	0.76	0.75
2	0.71	0.77	0.78	2	0.73	0.74	0.74
3	0.73	0.74	0.79	3	0.72	0.73	0.73

- **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**

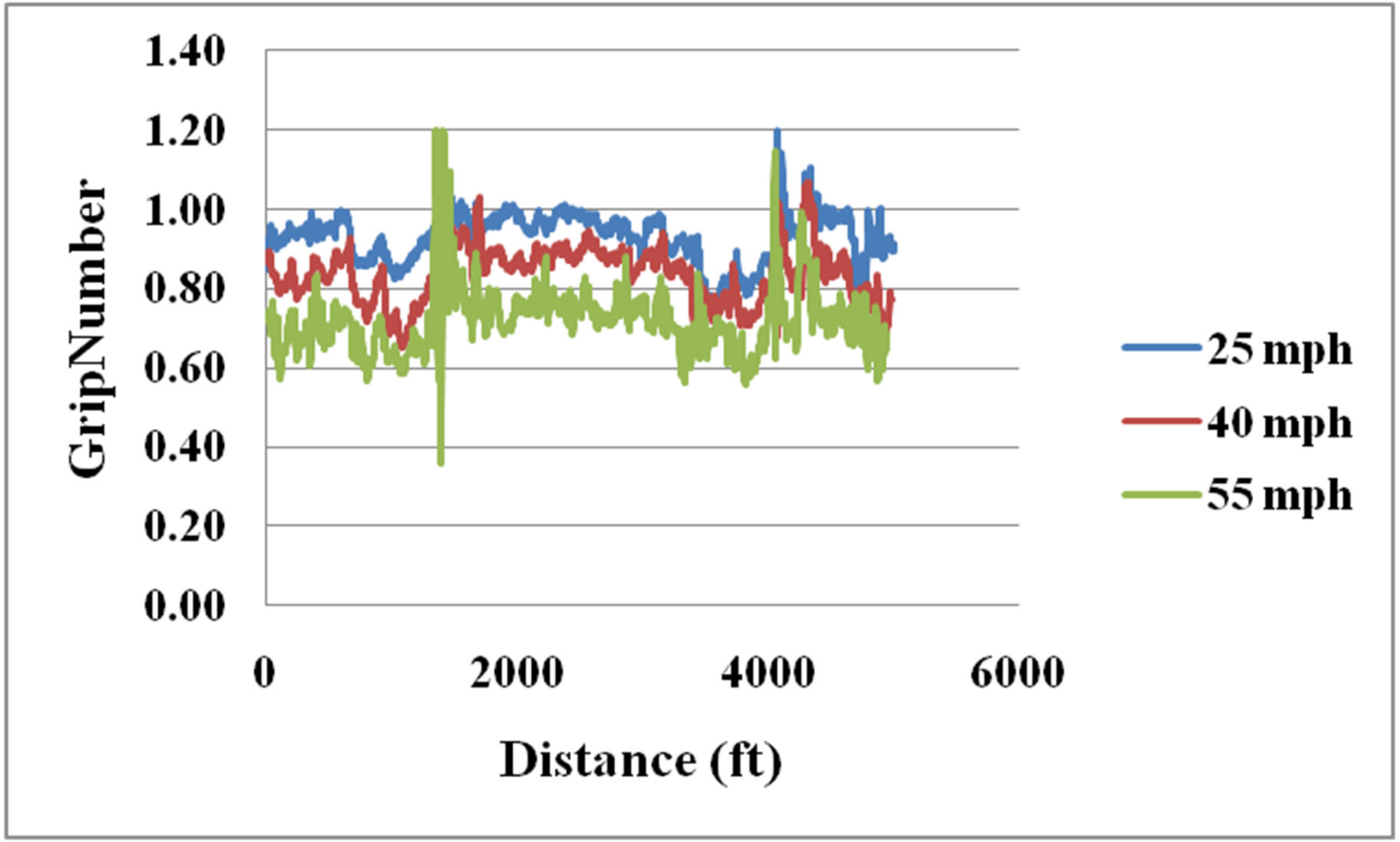
Effect of Speed on GripTester Measurements

- **Test Speeds:**
  - 25 mph
  - 40 mph
  - 55 mph

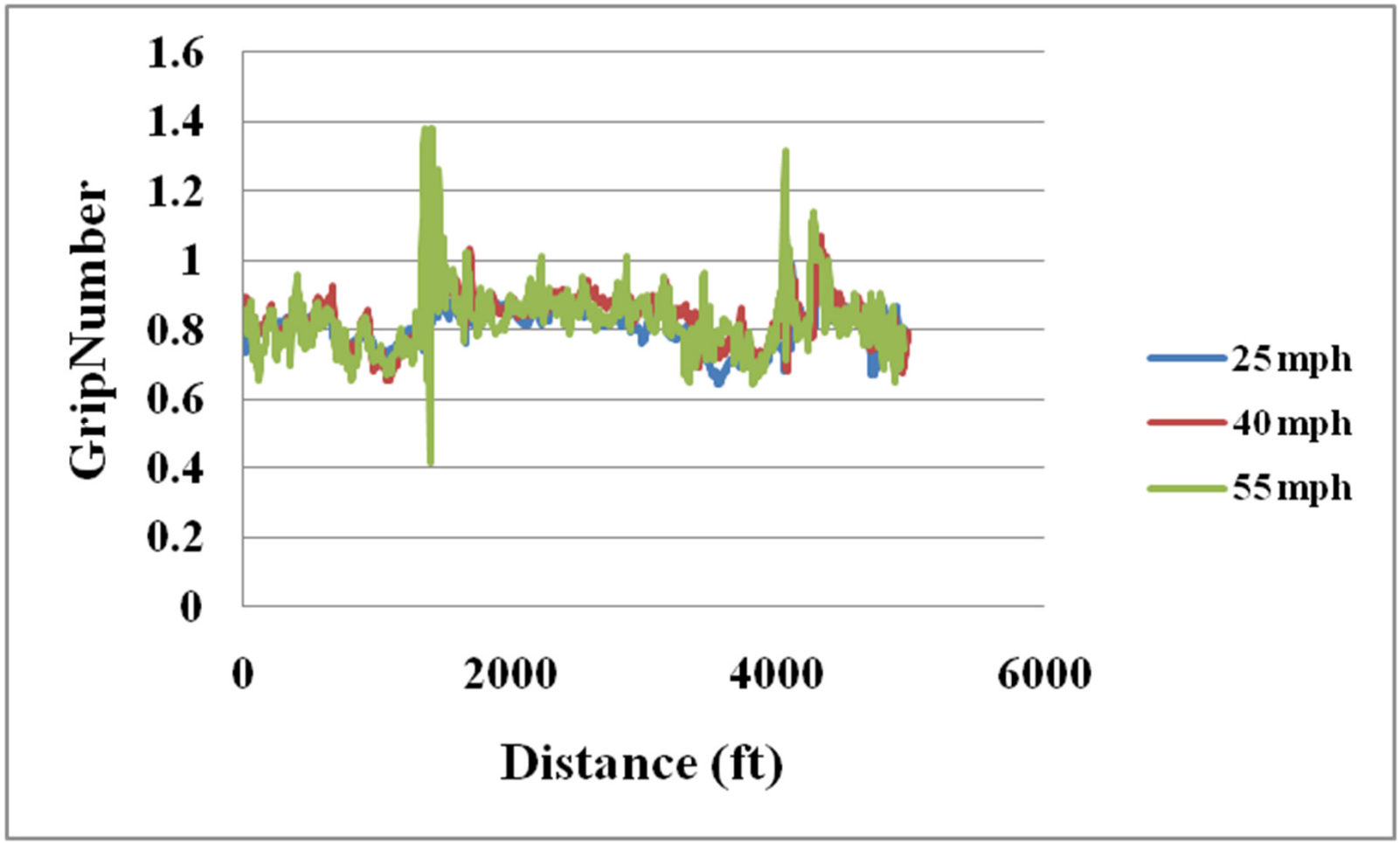
- **Speed Adjustment:**
  - $CF = 0.06 * |V2 - V1|$
  - $GN2 = GN1 * CF$, if $V2 > V1$
  - $GN2 = GN1 / CF$, if $V2 < V1$

  - **For our example:**
    $CF = 0.06 * (40-25) = 0.9$

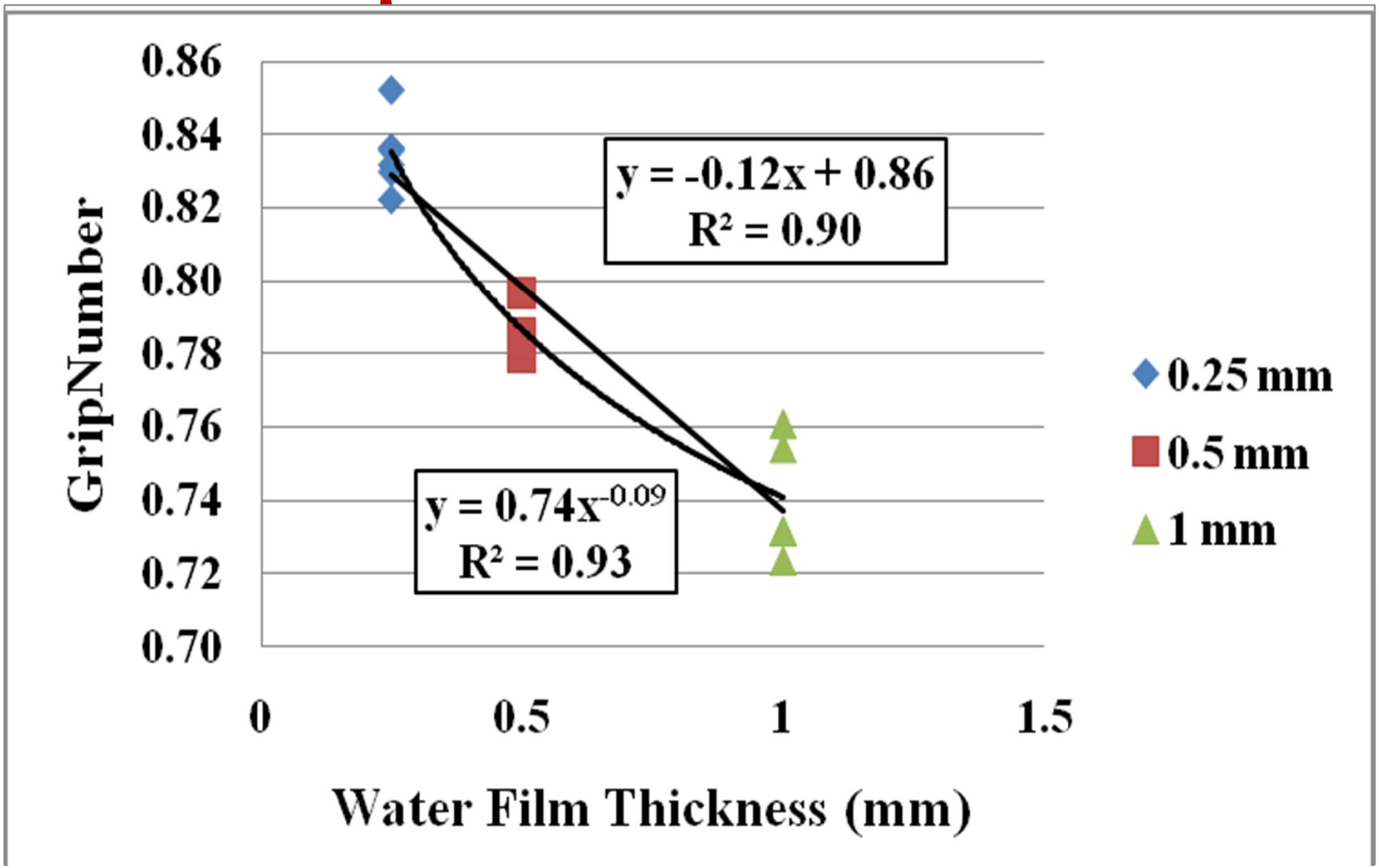
Measurements Before Shifting



Measurements After the Shift



Effect of water film thickness on GripTester Measurements



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?

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