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VALIDATION OF A PHYSICAL ALIGNMENT APPROACH FOR FULL-SCALE PAVEMENT FRICTION MEASUREMENT DEVICES (PFMDS)

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Outline

1. Pavement friction measurement and its harmonization
2. Objectives
3. Development of a method to physically align different PFMDs
4. Alignment of locked-wheel skid trailer to runway friction tester
5. Validation experiments
6. Validation results
7. Conclusion

1. Pavement Friction Measurement and Its Harmonization

- **Different devices - different measurement mechanisms**
- **Categorization of PFMDs**
  - **Spot Friction Measurement Equipment (SFME)**
  - **Continuous Friction Measurement Equipment (CFME)**
    - **Fixed-slip devices**
    - **Variable-slip devices**
- **Different measurements on the same pavement**
- **Harmonization is important in comparing measurements taken by various devices in different parts of the world**

1.1 Harmonization of Measurements

- **ASTM E 1960: "Standard Practice for Calculating International Friction Index (IFI) of a Pavement Surface"**
- **PIARC experiment 1993**
- **PIARC model equations (based on Penn State model)**

$$FR_{60} = FR_S \cdot e^{\left(\frac{v.s-60}{S_p}\right)}$$

$$Sp = 14.2 + 89.7 \times MPD$$

S_p **- Macro-texture parameter measured by Circular Track Meter (CTM)**

1.1 Harmonization of Measurements ctd…

- **IFI**

$$F_{60} = 0.081 + 0.732 \times DFT_{20} \cdot e^{\left(\frac{-40}{S_p}\right)}$$

***DFT_{20}* - the reference friction value for calibration**

- **Linear regression**

$$F_{60} = A + B \times FR_{60}$$

***A* and *B* - regression constants**

- ***A and B* for a PFMD are used to estimate the IFI from its measurements**

1.2 Problems Faced in Harmonization

- FR_{60} calculated using data at different speeds is different

$$FR_{60} = FR_S \cdot e^{\left(\frac{v.s-60}{S_p}\right)}$$

- F_{60} vs. FR_{60} linear relationship is inconsistent

- Difficult to capture variations due to different pavement conditions (e.g. water level)

- Cannot account for disparity in same type of device,
  - I. differences in parameters of the mechanism and
  - II. dynamics of operation

2. Research Objectives

- How can we improve the harmonization?
- It's not only a problem about measurement data
- Align the devices as much as possible, so that their measurements can be effectively harmonized
- Needs physical adjustments to the measurement mechanisms of selected devices

3. Development of a Method to Physically Align Different PFMDs

- **Identify the differences in measurement mechanisms that affect their measurements?**

Device	Tire	Slip	WFT	Inflation	Load
LWST	E524	100%	0.5 mm	24 psi	1085 lb
RFT	E1551	13%	1 mm	30 psi	300 lb

- **Determine the adjustments that can be made so that the devices are aligned?**
- **Is there a 'sweet spot' for each device?**
- **Answering the above questions is only practical if they can be simulated to a reasonable degree of accuracy**

3.1 LuGre Tire Friction Model

- **Longitudinal average lumped LuGre friction model**

$$\overline{\mu} = \sigma_0 \bar{z} + \sigma_1 \frac{d\bar{z}}{dt} + \sigma_2 v_r$$

$$\frac{d\bar{z}}{dt} = v_r - \frac{\sigma_0 |v_r|}{g(v_r)} \bar{z}$$

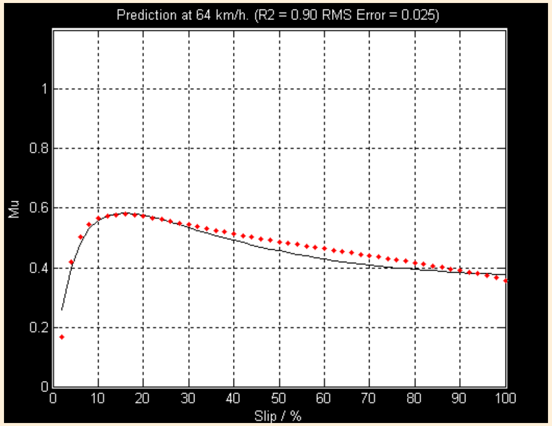
$$g(v_r) = \mu_c + (\mu_s - \mu_c) e^{-\left|\frac{v_r}{v_s}\right|^{\alpha}}$$

μ_c - Coulomb friction coefficient
μ_s - static friction coefficient
σ_0 – tangential tire (bristle) stiffness
σ_1- tangential tire (bristle) damping constant
σ_2 - viscous damping constant
α - Stribeck exponent
v_s - Stribeck velocity
t - time
v_r - slip speed
z - tangential tire (bristle) deflection

- **Equations can be derived for CFME**

3.2 LWST Prediction Accuracy of the Model

Pred Speed / km/h	Pred Error	Optimum Parameters				Cal Error
		μ_c	μ_s	v_s / m/s	σ_0 / m^{-1}	
32	0.042	0.321	0.944	6.6	160	0.024
48	0.024	0.338	0.954	5.6	164	0.028
64	0.026	0.336	0.976	5.4	167	0.028
80	0.029	0.335	0.972	5.5	167	0.027
96	0.037	0.346	0.942	5.7	186	0.025



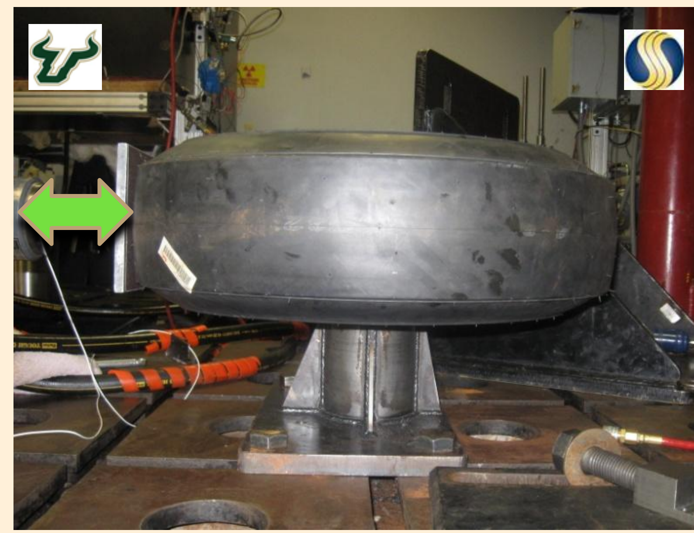
- **Measured on Fowler Ave. Tampa, FL.**
- **Calibrating the model with LWST data at 4 speeds and predicting at the 5th speed**
- **Predictions are accurate with controlled data**

3.3 Laboratory Tests to Determine LuGre Tire Parameters of ASTM E524 Tire used in the LWST

Longitudinal

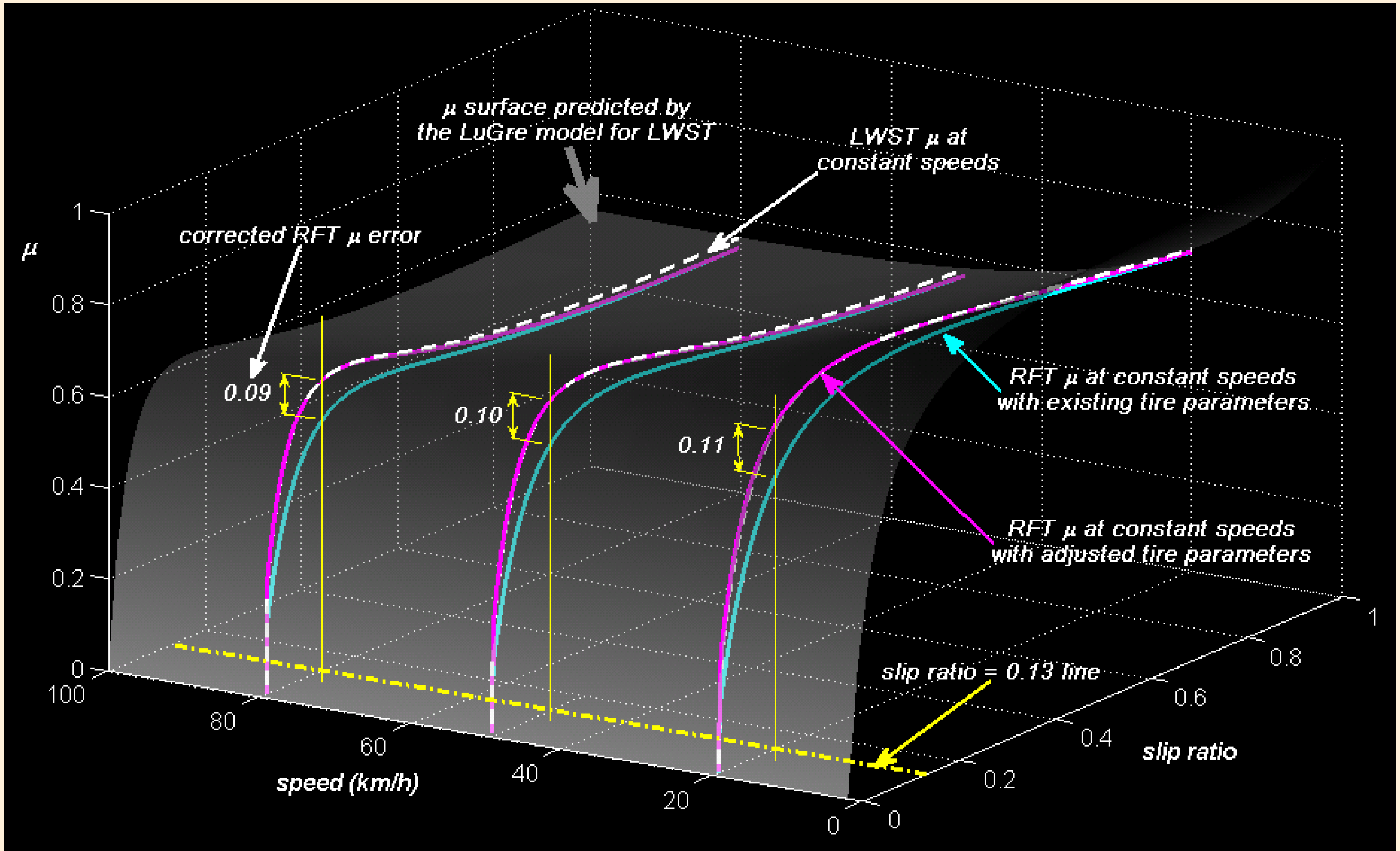
Lateral

Vertical



- **Tested at Smithers Rapra, Akron Laboratory, Ohio.**
- **Analyzed the hysteresis loops obtained by sinusoidal excitations to determine LuGre tire parameters**

3.4 Envisioned Harmonization between LWST and RFT

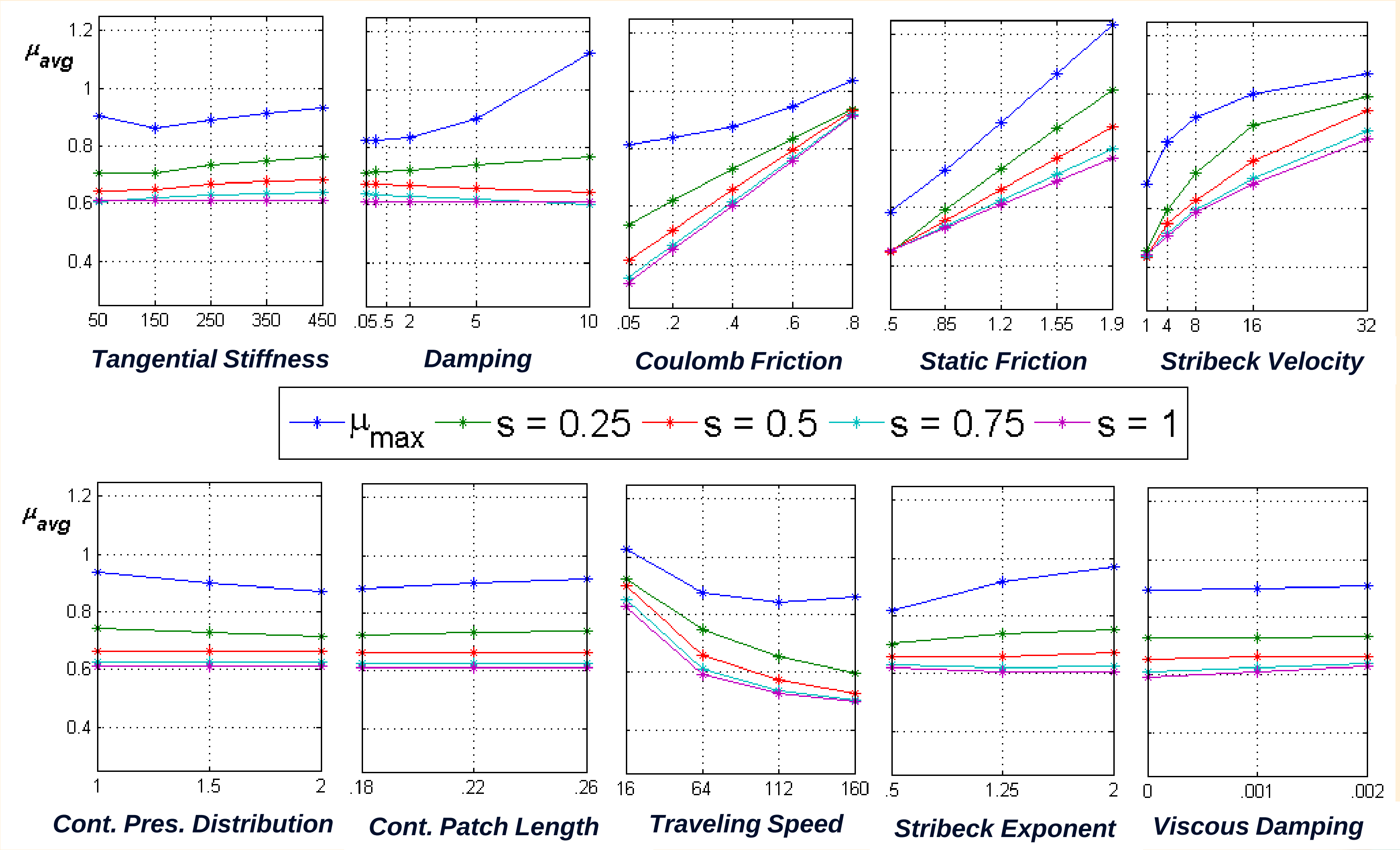


Harmonization achieved between locked-wheel skid trailer (LWST) and runway friction tester (RFT)

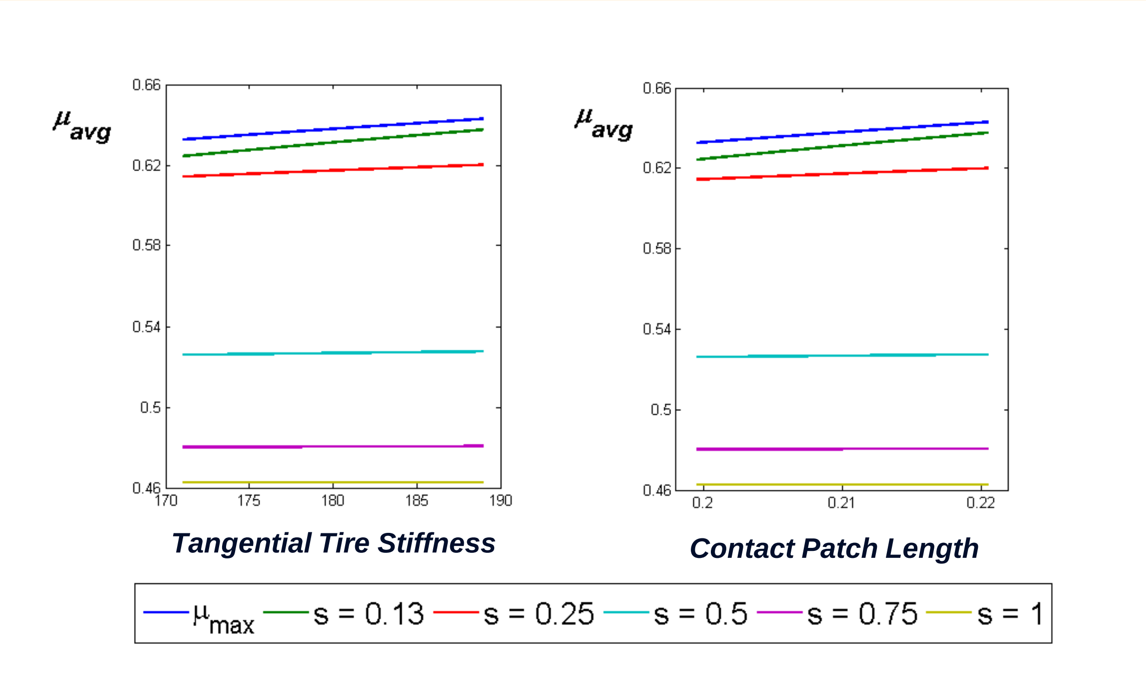
3.5 Which parameters to change?

- **What are the feasible adjustments for each device?**
- **What are the best parameters to change in order to align the friction measurements?**
- **Simulation can help**

3.6 Sensitivity Analysis



4. Alignment of LWST to RFT



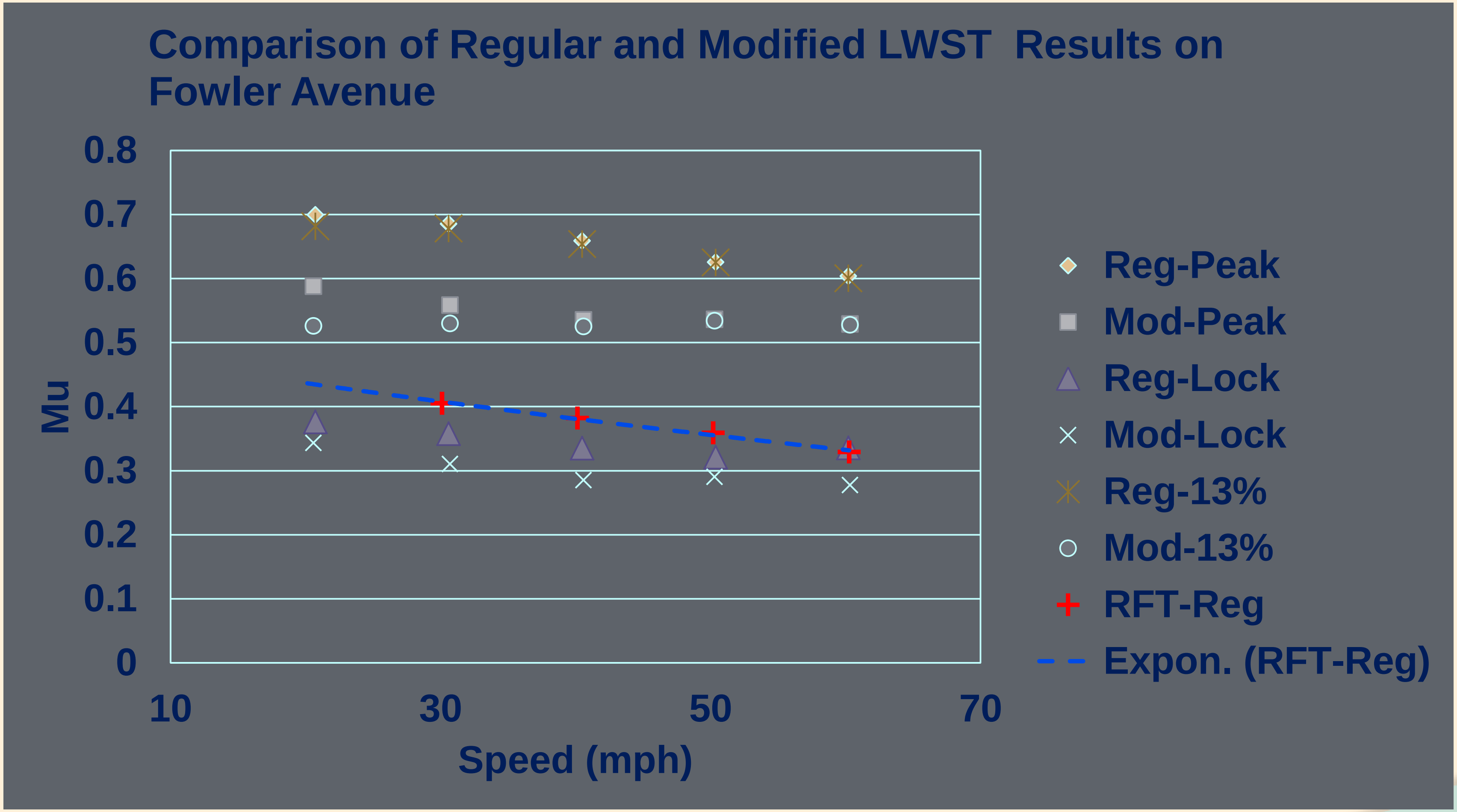
- **In LWST both pressure and normal load can be adjusted**
- **Therefore, adjustments were made to the LWST**

  24 psi -> 19 psi and 1085 lb -> 750 lb

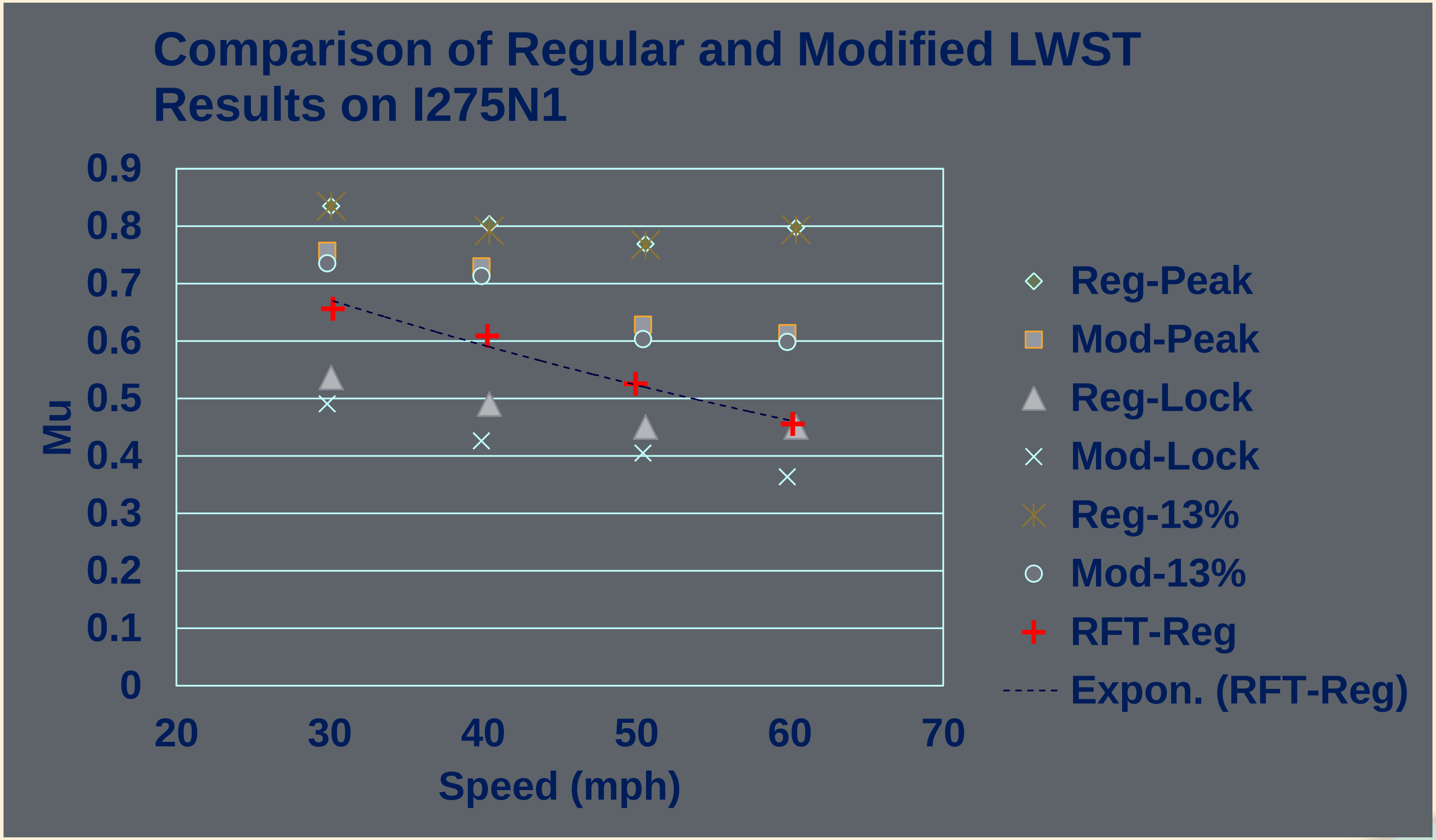
5. Validation Experiments

Segment ID	Location	Road Type	Pavement Type
Fowler	West Fowler avenue, Tampa, Florida. Under South I-75	Arterial Highway	Asphalt with Open-Graded Friction Course (OGFC)
I-275N1	North I-275, Tampa, Florida. Above Howard Avenue	Interstate Highway	Transversely grooved concrete
I-275N2	North I-275, Tampa, Florida. Above Howard Avenue	Interstate Highway	Longitudinally grooved concrete

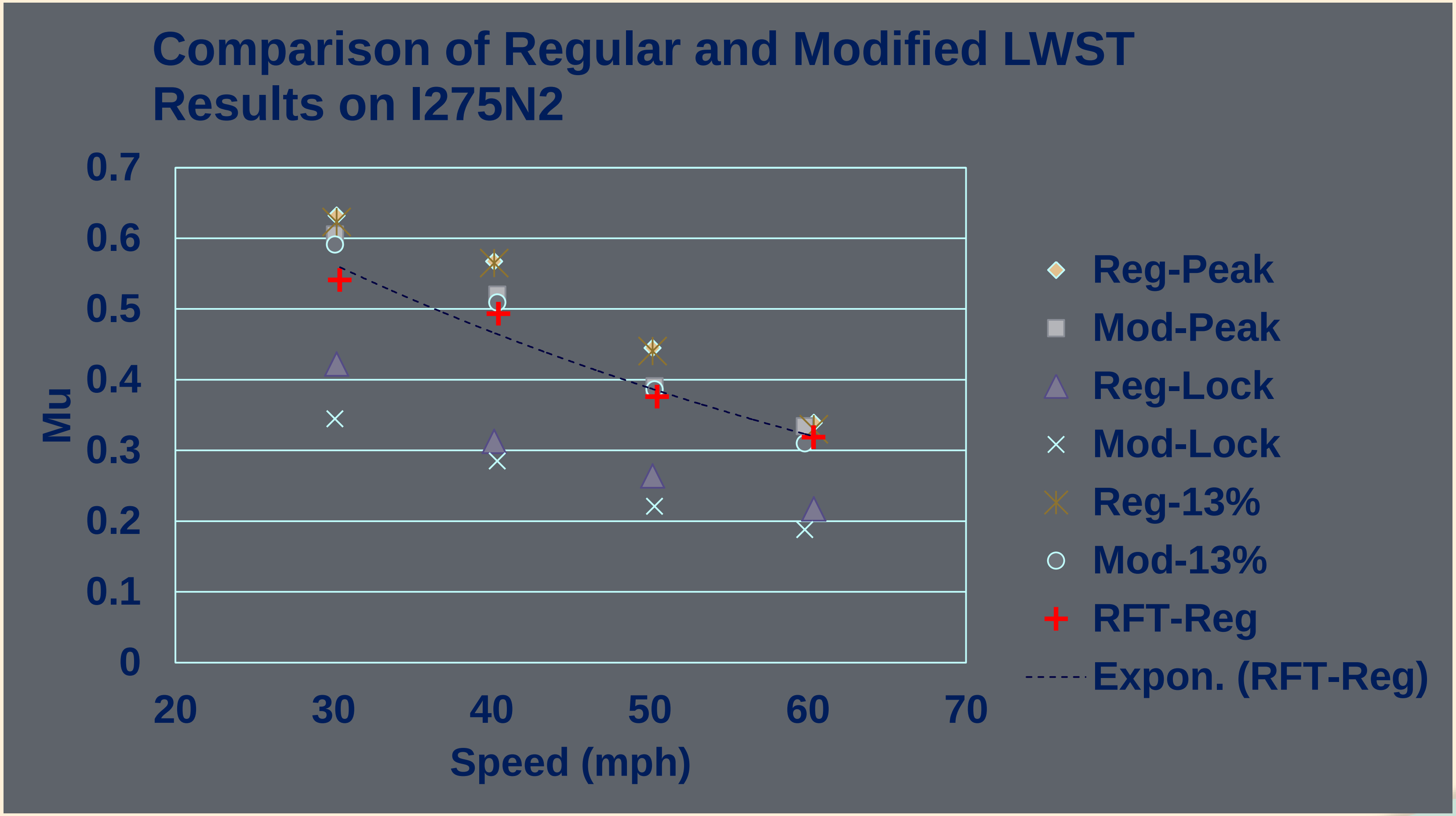
6. Validation Results on Open-graded Asphalt



6. Validation Results on Transversely Grooved Concrete



6. Validation Results on Longitudinally Grooved Concrete



7. Conclusion

- **Introduction of physical adjustments to the CFME measurement mechanisms is suggested to improve their harmonization**
- **A semi-empirical model has been applied to determine and evaluate possible adjustment**
- **The method has a high potential according to the experimental results with LWST and RFT**
- **An extended analysis is required to identify the feasible and optimum adjustments that give acceptable harmonization**
- **Other adjustable parameters: tire geometry, material properties, water film thickness**

Further Information

- **Physically Meaningful Harmonization of Tire/Pavement Friction Measurement Devices, M.P.N. Rajapakshe, *Ph.D. Dissertation,* University of South Florida, Tampa, Florida, 2011**

- **Evaluation of LuGre Tire Friction Model with Measured Data on Multiple Pavement Surfaces, M.P.N. Rajapakshe, M. Gunaratne and A.K. Kaw, *Tire Science and Technology,* 38(3) pp. 213-227, 2010**

- **Field Calibration of an Analytical Model for Pavement Friction Testing Applications, H. N. Seneviratne, M. P. N. Rajapakshe and M. Gunaratne, ASTM *Journal of Testing and Evaluation,* 37(1), pp. 21-30, 2009**

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