FINAL REPORT

Harmonization of Texture and Skid-Resistance Measurements

Florida Department of Transportation
Research Report
FL/DOT/SMO/08-BDH-23

by

N. Mike Jackson, Ph.D., P.E.

University of North Florida
College of Computing, Engineering and Construction
1 UNF Drive
Jacksonville, FL 32224
(904) 620-1847
njackson@unf.edu

September 30, 2008

UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

DISCLAIMER

THIS PAGE INTENTIONALLY LEFT BLANK

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		AREA		
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

SI* (MODERN METRIC) CONVERSION FACTORS (Continued)

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Harmonization of Texture and Skid-Resistance Measurements**		5. Report Date **September 30, 2008** 6. Performing Organization Code
7. Author(s) **N. Mike Jackson, Ph.D., P.E.**		8. Performing Organization Report No. **FL/DOT/SMO/08-BDH-23**
9. Performing Organization Name and Address **University of North Florida** **College of Computing, Engineering and Construction** **1 UNF Drive** **Jacksonville, Florida 32224**		10. Work Unit No. (TRAIS) 11. Contract or Grant No. **BDH-23**
12. Sponsoring Agency Name and Address **FLORIDA DEPARTMENT OF TRANSPORTATION** **605 SUWANNEE ST. MS 30** **TALLAHASSEE, FLORIDA 32399** **(850)414-4615**		13. Type of Report and Period Covered **FINAL REPORT** 14. Sponsoring Agency Code
15. Supplementary Notes **PREPARED IN COOPERATION WITH THE FLORIDA DOT**		

16. Abstract

Due to safety concerns associated with friction testing on both high and low-speed facilities, testing at variable speeds has been previously investigated by the Florida DOT. The American Society for Testing and Materials (ASTM) has endorsed this concept with the publication of a standard method for the calculation of the International Friction Index (IFI) as described in ASTM E 1960.

Previous research conducted by the Florida DOT and the principal investigator has demonstrated that a 64 kHz non-contact, laser measurement system can provide a repeatable and accurate measure of pavement macro-texture in terms of Mean Profile Depth (MPD) at highway operating speeds. With a repeatable measure of MPD and wet friction, IFI may be approximated in general accordance with ASTM E 1960. This report summarizes the results of an effort to "harmonize" such texture and skid-resistance measurements in Florida.

The results of this effort confirm that the Circular Track Meter (CTM) is highly correlated with the 64 kHz high speed laser texture measuring device. The Dynamic Friction Tester (DFT) was also found to provide a reasonable correlation with the Florida DOT full-scale, locked-wheel friction test units. However, the speed gradient (slope) obtained from DFT test data was not found to be well correlated with pavement texture (MPD). Since this correlation is fundamental to the implementation of IFI, as described in ASTM E 1960, it is concluded that IFI cannot be implemented in Florida at this time without significant reservations.

A practical methodology for measuring pavement friction and texture at variable highway speeds with the Florida DOT locked-wheel friction test unit and the ribbed tire is presented. Since the results of the ribbed-tire test are known to be significantly influenced by pavement micro-texture, and MPD is a direct measure of pavement macro-texture, FN_{40R} and the complementary MPD data together may be readily employed to characterize frictional properties on Florida roadways.

17. Key Word **Dynamic Friction Test (DFT), Circular Track Meter (CTM), Pavement Texture, Skid Test, Variable Test Speeds, International Friction Index (IFI), Speed Gradient.**	18. Distribution Statement **NO RESTRICTION** **THIS REPORT IS AVAILABLE TO THE PUBLIC THROUGH THE NTIS, SPRINGFIELD, VA 22161**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**182**	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Due to safety concerns associated with friction testing on both high and low-speed facilities, testing at variable speeds has been investigated by the Florida Department of Transportation (DOT). The standard locked-wheel friction test speed, as established by the Florida DOT and the American Society for Testing and Materials (ASTM) is 40 mph (64.4 km/h). Ongoing research has indicated that reasonable correlations may be developed between friction test data obtained at the standard speed and data obtained at other speeds. ASTM has endorsed this concept with the publication of a standard method for the calculation of the International Friction Index (IFI) as described in ASTM E 1960.

Previous research conducted by the Florida DOT and the principal investigator has demonstrated that a 64 kHz non-contact, laser measurement system can provide a repeatable and accurate measure of pavement macro-texture in terms of Mean Profile Depth (MPD) at highway operating speeds. With a repeatable measure of MPD and wet friction, it is believed that IFI may be approximated in general accordance with ASTM E 1960. This report summarizes the results of an effort to "harmonize" such texture and skid resistance measurements in Florida, as described in ASTM E 1960.

The research team has coordinated closely with Florida DOT Pavement Evaluation Section personnel in making the results of this effort practical. The results of this effort confirm that the Circular Track Meter (CTM) is highly correlated with the 64 kHz high speed laser texture measuring device currently being employed by the Florida DOT. This means that the CTM is well suited for calibration verification and spot reference testing purposes. The excellent correlation of this instrument with the high speed laser should also facilitate direct comparison of texture measurements on Florida roadways with those from other states and research facilities.

The Dynamic Friction Tester (DFT) was also found to provide a reasonable correlation with the full-scale locked-wheel friction test units currently employed by the Florida DOT. However, the speed gradient (slope) obtained from DFT test data was not found to be well correlated with pavement texture (MPD). Since this proposed correlation is fundamental to the equipment harmonization methodology described in ASTM E 1960, it is concluded that IFI cannot be implemented in Florida at this time without significant reservations.

A practical methodology for measuring pavement friction and texture at variable highway speeds with the Florida DOT locked-wheel test unit and the ribbed tire is presented. Since the results of the ribbed tire test are significantly influenced by pavement micro-texture, and by definition MPD is a direct measure of macro-texture, FN_{40R} and the complementary MPD data together may be readily employed to characterize pavement surface frictional properties on Florida roadways.

UNF UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

Page

LIST OF FIGURES (Continued)

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

1 INTRODUCTION

Due to safety concerns associated with friction testing on both high and low-speed facilities, testing at variable speeds has been previously investigated by the Florida Department of Transportation (DOT). The standard test speed, as adopted by the Florida DOT and the American Society for Testing and Materials (ASTM) is 40 mph (64.4 km/h). Ongoing research has indicated that reasonable correlations may be developed between friction test data obtained at this standard speed and data obtained at other speeds [1]. ASTM has further endorsed this concept with the adoption of a standard practice for the calculation of International Friction Index (IFI) as described in ASTM E 1960 [2]. As part of this practice, full-scale friction test equipment is "harmonized" with portable reference test equipment including the Circular Track Meter (CTM) and the Dynamic Friction Tester (DFT).

Previous research conducted by the Florida DOT and the principal investigator has demonstrated that a 64 kHz non-contact, laser measurement system may be employed for quick, repeatable and accurate measurement of pavement macro-texture in terms of Mean Profile Depth (MPD) [1]. ASTM E 1960 reports that with a repeatable measure of both MPD and wet friction, IFI can be calculated and used to transform friction test data from one test speed to another. This report summarizes the results of a comprehensive effort to harmonize the Florida DOT full-scale friction test equipment with the portable CTM and DFT reference equipment and ultimately implement IFI in Florida.

2 BACKGROUND

2.1 International Friction Index (IFI)

Guidelines for the implementation of IFI were developed as part of the Permanent International Association of Road Congresses (PIARC) experiment to compare and harmonize texture and skid resistance measurements [3]. IFI is now being evaluated worldwide as a possible standard for skid resistance reporting. The IFI consists of two parameters: 1) one (F_{60}) that represents the wet friction of a pavement at 60 km/h (37.3 mi/hr), and 2) a speed constant of wet pavement friction (S_p). Figure 1 exhibits what these two parameters represent in practical terms. As shown, the S_p parameter is closely related to the Skid Number Speed Gradient (G_v) as described in ASTM E 867 [4]. As shown in Equation 1, G_v is the slope of the Skid Number (SN) versus test speed (v) multiplied by -1, or:

$$G_v = -(SN_1 - SN_2)/(v_1 - v_2) \quad (1)$$

Figure 2 exhibits an example of the calculation of this speed gradient from DFT data. In theory, with a known friction value at a given slip speed, the speed gradient may be employed to transform friction data at any other test speed to the standard speed.

As proposed in ASTM E 1960, the IFI equivalent of G_v, the speed constant of wet pavement friction, S_p may be estimated from a measurement of the pavement macro-texture, MPD in millimeters (mm) as follows:

$$S_p = 14.2 + 89.7 * MPD \quad (2)$$

The premise that a linear relationship exists between speed gradient and texture, as described in Equation 2 and illustrated in Figure 2, is fundamental to the implementation of IFI. This proposed relationship provides a mechanism for transforming friction results obtained at different speeds and texture to the harmonized friction value, as would be measured with the portable reference equipment.

It is also proposed that the wet friction parameter (F_{60}) may be estimated from the results of full scale friction testing in accordance with ASTM E 274 [5], presumably using either the standard ribbed tire in accordance with ASTM E 501 [6] or the standard smooth tire in accordance with ASTM E 524 [7].

ASTM E 1960 outlines the specific method of harmonizing such friction testers with the portable reference equipment. In this procedure, it is prescribed that ten (10) representative pavement surfaces be tested in accordance with ASTM E 1911, “Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester” [8], and ASTM E 2157, “Standard Test Method for Measuring Pavement Macro-texture Properties Using the Circular Track Meter” [9].

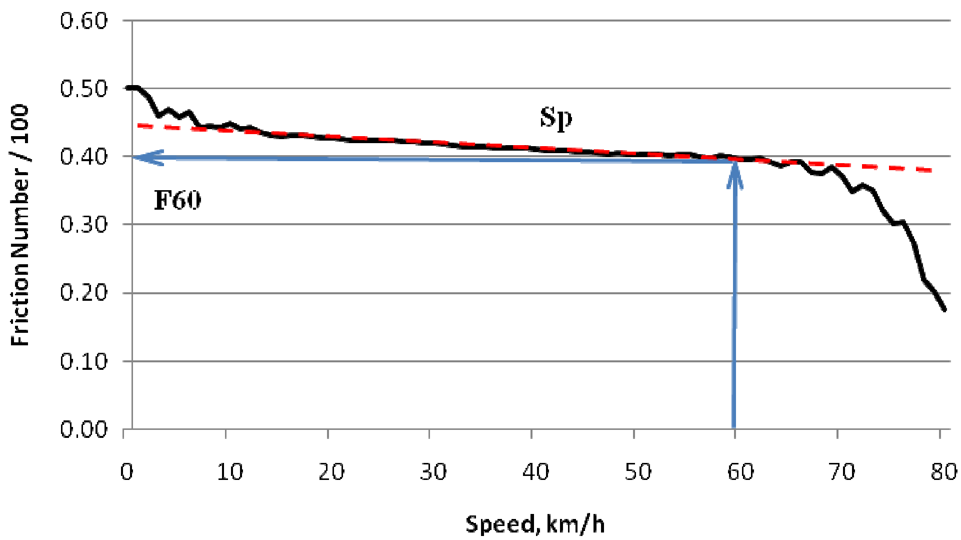


FIGURE 1 IFI Parameters of Wet Friction (F_{60}) and Speed Constant (S_p).

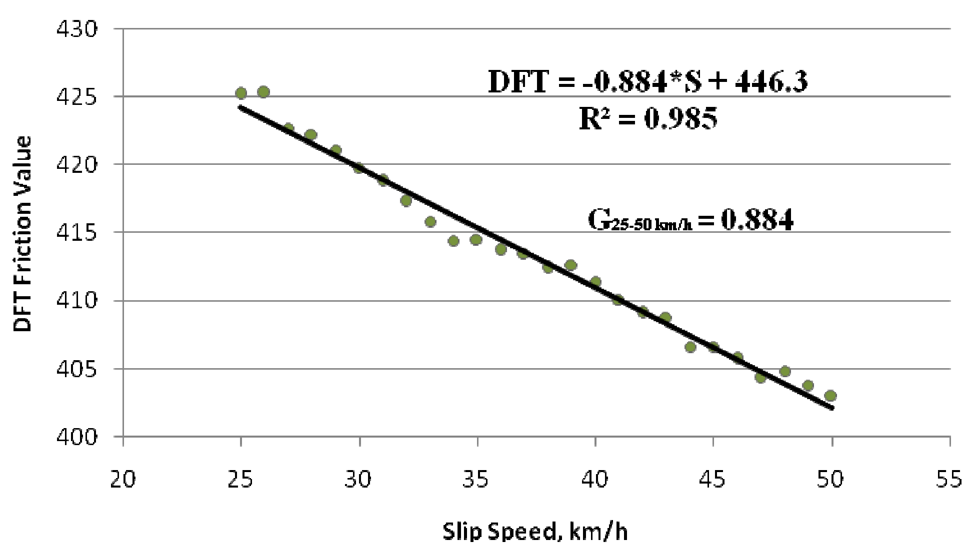


FIGURE 2 Example of Computation of Skid Number Speed Gradient from DFT Data.

As described in ASTM E 1960, S_p is calculated in accordance with Equation 2 and F60 is calculated as:

$$F60 = 0.081 + 0.731*DFT_{20km/h}*\exp(-40/S_p) \quad (3)$$

Where $DFT_{20km/h}$ is the DFT number at a test speed of 20 km/h (12.4 mph). FR60, the friction of the equipment being harmonized at 60 km/h is calculated as:

$$FR60 = FRS*\exp[(S-60)/S_p] \quad (4)$$

Finally, the harmonization constants, A and B are obtained from a linear regression of the values of FR60 and F60, that is:

$$F60 = A + B*FR60 \quad (5)$$

A direct measurement of pavement texture using high-speed laser technology has also been standardized in ASTM E 1845, “Standard Practice for Calculating Pavement Macro-texture Mean Profile Depth” (MPD) [10]. In accordance with ASTM E 1845, such laser texture data is processed to estimate the mean segment depth for a given 100 mm segment of pavement. This computation is illustrated in Figure 3. Mean segment depths are averaged over the length of pavement section being tested to obtain an estimate of MPD. The Florida DOT locked-wheel friction test equipment was instrumented with an LMI Technologies, Selcom, Opticator 64kHz high speed laser texture measurement system meeting the requirements of ASTM E 1845 as part of a previous research effort [1]. This equipment, as installed is pictured in Figure 4.

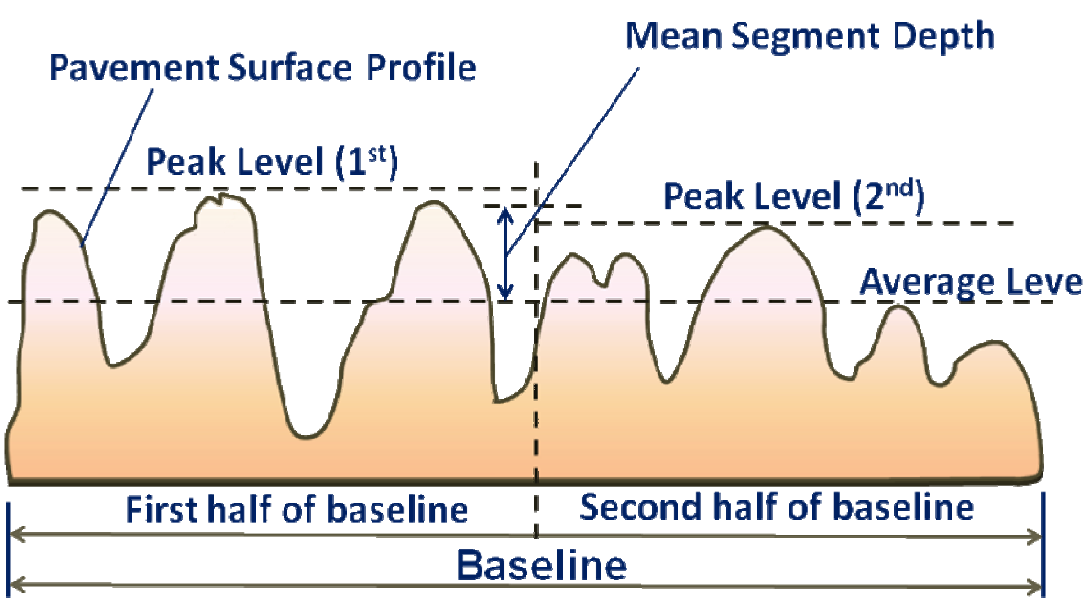
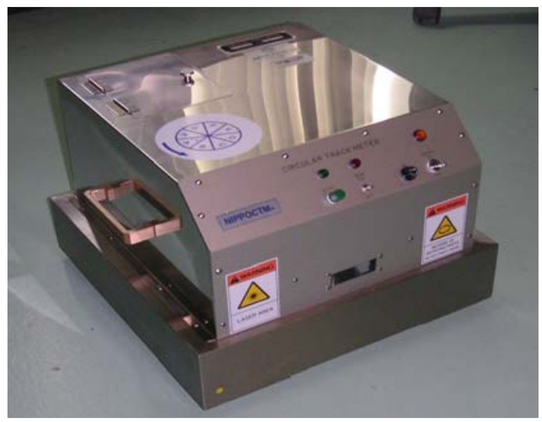


FIGURE 3 Procedure for Computation of Mean Segment Depth from Laser Texture Data [10].

a) Florida DOT Locked-Wheel Friction Test Unit.

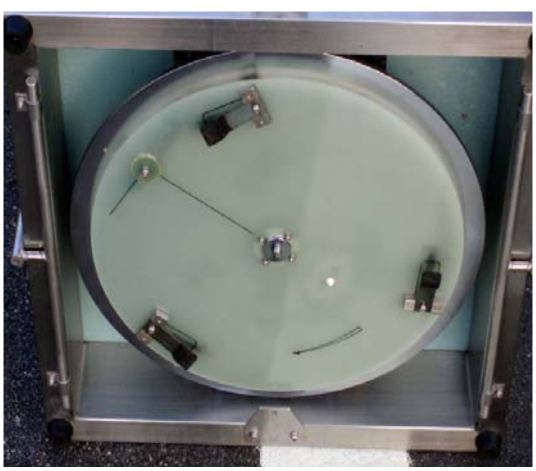
b) 64 kHz Laser Mounted on Truck.

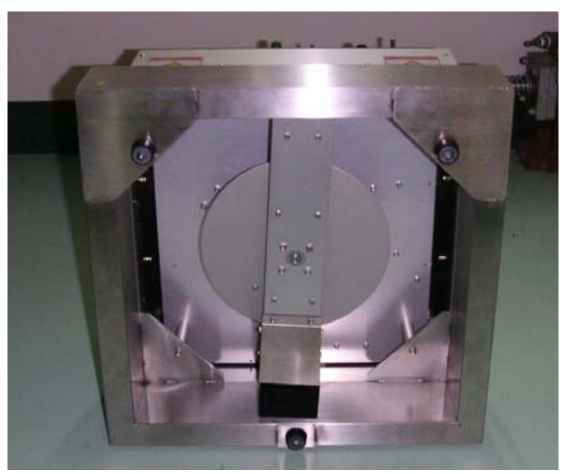
FIGURE 4 LMI Technologies, Selcom, Opticator 64kHz Laser Texture Measurement System, as Mounted on Florida DOT Locked-Wheel Friction Testing Unit [1].



a) Dynamic Friction Tester (DFT).

b) Circular Track Meter (CTM).





c) DFT Rubber Slider Pads.

d) CTM Rotating Arm and Laser Sensor.

FIGURE 5 DFT and CTM Portable Friction and Texture Testing Equipment.

2.2 Equipment Description and Operation

2.2.1 Locked-Wheel Friction Test Unit

The Florida DOT locked-wheel friction test unit consists of a truck and a friction trailer (See Figure 4a). The truck contains a water storage tank and supply system, electrical power supply, and a computer system to activate, process, and record the measured data. This equipment measures the steady-state friction force on a locked test wheel as it is dragged over a wetted pavement surface under constant load and at a constant speed while its major plane is parallel to the direction of motion and perpendicular to the pavement.

It is noted in the ASTM standard that the values measured represent the frictional properties obtained with the specific equipment and procedures described in ASTM E 274 and do not necessarily agree or correlate directly with those obtained by other pavement friction measuring methods. The values are intended for use in evaluating the skid resistance of a pavement relative to that of other pavements or for evaluating changes in the skid resistance of a pavement with the passage of time [5].

Calibration and verification of the Florida DOT locked-wheel friction test units are performed once per month. As part of this calibration/verification procedure, the friction units are also compared and checked out on designated test sections in the vicinity of the Florida DOT State Materials Office in Gainesville.

2.2.2 64 kHz High-Speed Laser

As a result of previous research, the Florida DOT locked-wheel friction testing units are also equipped with LMI Technologies, Selcom, Opticator 64 kHz laser texture measurement systems, as shown in Figure 4b. This system enables collection of pavement macro-texture data in the same general location that the locked-wheel testing unit measures pavement friction data. An on-board computer processes the data in accordance with ASTM E 1845 to calculate the measured MPD for the test location. The sampling and processing of the data are accomplished using proprietary International Cybernetics Corporation (ICC), WinSkid, Version 1.04 software. Calibration/verification of the laser system is also performed monthly, in conjunction with the locked-wheel friction testing unit calibrations.

2.2.3 Dynamic Friction Tester (DFT)

The DFT equipment and test method are described in ASTM E 1911 [8]. The DFT consists of a horizontal spinning disk fitted with three spring loaded rubber sliders which contact the paved surface as the disk rotational speed decreases due to the friction generated between the sliders and the paved surface. Each slider is spring-loaded to 11.8 *N* (2.65 lbf). A water supply unit delivers water to the paved surface during testing. The water supply is regulated by elevation, and the optimum positioning for the water tank is

0.6 m (1.97 ft) above the test surface. At this position, the water flow is maintained at 3.6L/min (0.95 gal/min). The torque generated by the slider forces measured during the spin down is used to calculate the friction as a function of speed. The device is pictured in Figures 5 a and c. The user operation manual and calibration protocol for the DFT is provided in Appendix A of this report.

2.2.4 Circular Track Meter (CTM)

The CTM equipment and test method are described in ASTM E 2157 [9]. The CTM consists of a Charge Coupled Device (CCD) laser-displacement sensor which is mounted on an arm that rotates such that the displacement sensor follows a circular track having a diameter of 284 mm (11.2 in.). The device is pictured in Figures 5 b and d. The CTM is designed to measure the same circular track that is measured by the DFT. The software provided with the CTM directly reports MPD for the pavement surface tested. The texture measurement sensor for the CTM is similar to the high speed laser system installed on the full scale locked wheel test units. The main difference is that the CCD system provided with the CTM has a significantly slower data acquisition rate and is mounted on a rotational arm that performs a full revolution during the data collection at fixed elevation, while the vehicle mounted system collects data along the linear wheel path, and at highway speeds. The user operation manual and calibration protocol for the CTM is provided in Appendix B of this report.

3 OBJECTIVE

The primary objective of this research effort was to facilitate the implementation of IFI in Florida, thus enabling friction testing to be conducted at variable speeds, for enhanced safety to FDOT personnel and the traveling public. As part of this effort, the reproducibility of the CTM and the DFT equipment and procedures were evaluated. Ultimately, harmonization relationships as described in ASTM E 1960 were evaluated for the Florida DOT equipment and pavement conditions. As previously noted, this Final Report also includes standard operating procedures and calibration protocols for the portable reference test equipment in Appendices A and B.

4 SCOPE

4.1 Review of Literature and Ongoing Relevant Research

This task included a review of related literature and ongoing research regarding the use of the CTM and DFT equipment and the harmonization of locked-wheel friction test data with such equipment. The current state-of-the-practice in non-contact laser measurement of pavement texture was also documented as part of this task.

4.2 Equipment Comparison Testing

The FDOT CTM and DFT equipment was compared with similar portable equipment owned and operated by the National Center for Asphalt Technology (NCAT) in an attempt to quantify the reproducibility of test data obtained. The FDOT portable reference equipment was mobilized to Auburn, Alabama for side-by-side testing with similar equipment owned and operated by NCAT. This task also provided the Florida DOT with an opportunity to gain experience with the operation of the equipment prior to field testing on Florida roadways.

4.3 Equipment Harmonization

4.3.1 Texture and Friction Measurement with the CTM and DFT

The International PIARC experiment to compare and harmonize texture and skid resistance measurements reported that the Mean Texture Depth (MTD), as obtained in accordance with ASTM E 965 [11] and MPD, as obtained from the CTM are "highly correlated." Since MTD has been found to correlate well with MPD measured with a 64 kHz laser, it follows that MPD, as obtained from the CTM should also be found to have a favorable correlation with MPD as measured with the 64 kHz high speed laser.

CTM and DFT testing was conducted on selected pavement test sections in an attempt to harmonize the results obtained with this equipment with that obtained with the Florida DOT full-scale equipment. This "harmonization" procedure is outlined in ASTM E 1960.

4.3.2 Measurement of Friction Number (FN) and Laser Texture (MPD)

Locked-wheel friction tests were conducted on selected test sections in general accordance with ASTM E 274 at different speeds and with both the ribbed and smooth tires. The 64 kHz laser texture sensor was also used to simultaneously measure MPD for the selected test sections. It should be noted that the Florida DOT employs the designation of Friction Number (FN) in lieu of Skid Number (SN) as described in ASTM due to the legal implications of the word "skid." However, the two terms are generally mathematically equivalent and synonymous.

4.4 Implementation of IFI

As part of this study, FN and MPD values obtained from the Florida DOT full-scale equipment were compared with the friction and texture values obtained from the DFT and CTM reference equipment. The FN values, as obtained by the locked-wheel friction test at different test speeds on the same pavement surfaces were compared with F_{60}, as obtained from the DFT. The MPD values, as obtained by the 64 kHz laser were also compared with values measured with the CTM.

Based on these comparisons, the potential for implementing IFI in Florida was evaluated. The research team has coordinated closely with Florida DOT friction testing personnel in making the results of this effort practical and implementable.

4.5 Operation Manuals and Calibration Protocols

This Final Report may be employed as future training materials and reference documentation. As previously noted, the pertinent user operation manuals and calibration protocols for the portable DFT and CTM equipment are provided in Appendices A and B, respectively.

5 LITERATURE REVIEW

5.1 Florida Skid Hazard Elimination Program

The Federal Highway Administration (FHWA) encourages all states to implement a Skid Accident Reduction Program [12]. This requirement for skid resistant pavements states that "every state shall have a program of highway design, construction, and maintenance to improve highway safety." It goes on to state that "this program shall provide that there are standards for pavement design and construction with specific provisions for high skid resistance qualities." The practical result is that "highway agencies should have an organized system to identify and correct hazardous locations … in conformance with reasonable standards. Such a systematic process is the best way to execute the highway agency's duty to maintain a reasonable safe roadway." The Florida DOT implements these requirements via Section B: Skid Hazard Elimination Program, of its Annual Work Program [13].

5.2 Recent Florida DOT Friction Research

In addition to meeting the above-referenced requirements of FHWA, the Florida DOT has continued to pursue practical and safe ways to characterize the friction properties of the state highway system [1,14,15,16]. Due to ongoing safety concerns related to the field testing of high-speed facilities, considerable attention has been focused in recent years on non-contact based sensor technology. Such sensors have been demonstrated to be well suited for surveying the surface texture characteristics of pavements while operating at highway speeds [1,17,18].

5.3 Documented Research by Other State Agencies

The Virginia DOT has also found success with the use of such sensors, concluding that "surface macro-texture can be measured quite efficiently using noncontact technologies and provides important information regarding pavement safety." [19,20,21] Researchers in Texas have also investigated the use of modern non-contact instruments in the measurement of pavement texture and have reported success in the measurement of macro-texture [22, 23].

Researchers at the National Concrete Pavement Technology Center at Iowa State University have noted the complexity of the interrelationship between the different pavement surface characteristics, including texture, noise, friction, splash/spray, rolling resistance, reflectivity/luminance, and smoothness [24]. For example, it is generally understood that a general trade-off exists between friction and noise; i.e., surface textures with higher friction tended to produce greater tire-pavement noise [25]. Research sponsored by the Institute for Safe, Quiet and Durable Highways and Purdue University, documented that Porous Friction Courses (PFC) in Indiana produce significantly lower noise levels than conventional Hot Mix Asphalt (HMA) as measured by both the pass-by and close-proximity methods [26]. These PFC surfaces were also found to provide substantially higher friction values, reduced splash and spray and improved visibility during rain events. The Florida DOT employs open-graded friction courses on high-speed facilities for just these reasons [14, 15].

A 2004 synthesis performed by the Texas Transportation Institute and Texas A&M University summarized skid resistance issues on high-speed corridors and safety issues related to splash and spray, among other topics pertinent to the Texas Department of Transportation (TxDOT) [27]. This synthesis also provides recommendations for future research to fill gaps in knowledge and to take emerging technology to the stage where it can be implemented during the design and construction of pavements. It is proposed that non-transportation related technology that might be adapted to transportation issues should be further researched. The use of high speed lasers to measure pavement texture is an example of such adaptation [1].

5.4 National and International Research

Significant research related to texture and friction testing has also been performed on the national and international stages. As previously noted, guidelines for the implementation of IFI, resulting from the International PIARC Experiment were originally published in 1995 [3]. The National Cooperative Highway Research Program (NCHRP) "Synthesis of Highway Practice 291: Evaluation of Pavement Friction Characteristics," documented the characteristics of pavement texture that affect wet pavement friction as micro-texture, consisting of wavelengths (characteristic dimensions) of 1 micrometer to 0.5 mm (0.0004 in. to 0.02 in.), and macro-texture, consisting of wavelengths of 0.5 mm to 50 mm (0.02 in. to 2 in.) [28]. This synthesis summarized the methods and models used for evaluating wet pavement friction. It also helped introduce the concept of the IFI in the US. A Follow-up effort funded by NCHRP "Guide for Pavement Friction, Final Guide," will provide more recent recommendations for managing and designing for friction on highway pavements [29]. Specific methods for monitoring the friction of in-service pavements and determining appropriate actions in the case of friction deficiencies (friction management) are described. ASTM Designation E 1845 provides clear and implementable specifications for the use of high speed laser technology in the measurement of pavement macro-texture [10]. ASTM Designation E 1960 also provides what appear to be practical guidelines for the calculation of IFI from a measurement of pavement macro-texture and wet pavement friction. This practice provides for harmonization of friction reporting for devices that use a smooth tread test tire. From this index, it is proposed that the friction at 60 km/h may be estimated from a measurement made at any speed [2].

5.5 Other Relevant Research

It is noted that the Florida DOT typically employs the ribbed tire when testing pavement friction characteristics [14]. The test results from the ribbed tire test are generally acknowledged to be influenced to a greater extent by pavement micro-texture whereas the results from the smooth tire test are understood to be influenced to a greater extent by the pavement macro-texture. The Ohio Department of Transportation (ODOT) posted a request for proposals in 2007 to compare wet and smooth tire friction testing on Ohio roadways as part of an effort to reduce rear-end crashes by 25% by 2015 [30]. Where significant pavement macro-texture is provided, such as with Florida's open graded friction courses, micro-texture is critical to friction measurements. Micro-texture, 1 micrometer to 0.5 mm (0.0004 in. to 0.02 in.), is also known to be highly correlated with aggregate properties [31]. For PCC pavements, both macro-texture and micro-texture are highly dependent on the pavement surface finish [32].

Recent research by the Virginia DOT, the New Jersey DOT, and others has suggested that high speed laser technology may be useful as a tool to improve the uniformity of pavement surfaces [33, 34]. These researchers concluded that macro-texture measurement holds great promise as a tool to detect and quantify segregation for quality assurance purposes. Researchers at NCAT have also recommended that it would be beneficial to develop a testing procedure and laboratory equipment that may be used to evaluate the frictional resistance in the laboratory that represents field measured results [35]. The difficulty in accomplishing this remains the replication of field surface texture and friction properties in laboratory specimens. The Florida DOT has attempted this in the past with little or no success.

6 EQUIPMENT COMPARISON TESTING

6.1 NCAT Pavement Test Track

The NCAT pavement test track is a full-scale Accelerated Pavement Testing (APT) facility. Experimental sections on the 2.8 kilometer (1.7 miles) track are cooperatively funded by external sponsors, including the Florida DOT. A total of 10,000,000 Equivalent Single Axle Loads (ESALs) are applied over a two year period of time, with subsequent pavement performance documented on a regular basis. The ESALs are applied with 4 fully loaded trucks with 3 trailers per tractor. The track consists of 26 different pavement test sections in the tangents and another 20 sections in the curves. Individual pavement test sections are approximately 200 feet (60 meters) in length [36]. An aerial view of the NCAT pavement test track facility is presented in Figure 6 a.

As previously noted, the Florida DOT CTM and DFT equipment was compared with comparable equipment owned and operated by NCAT on the pavement test track in an attempt to quantify the repeatability and reproducibility of test data obtained. This side-by-side testing also provided the researchers with an opportunity to gain experience with the operation of the equipment prior to subsequent field testing on Florida roadways.

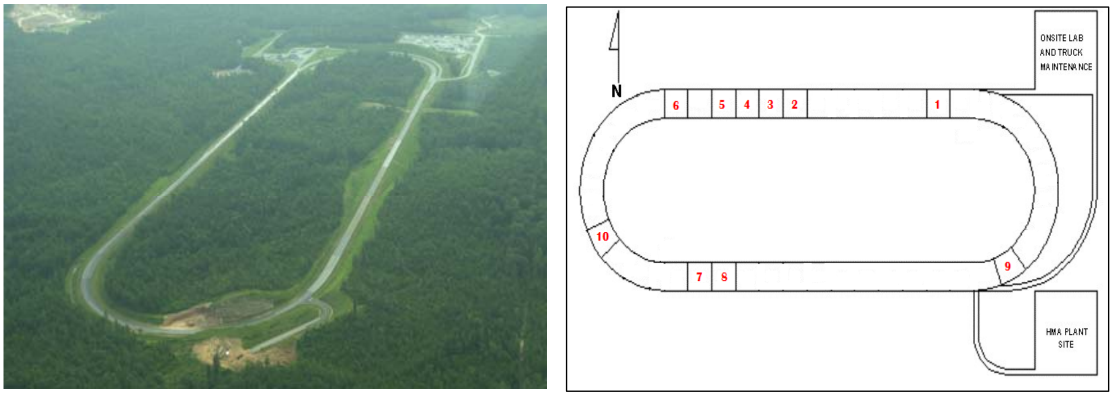
6.2 Test Sections

Ten different test sections were selected by NCAT personnel to provide a diverse range of friction and texture characteristics. The relative locations of these test sections on the test track are shown in Figure 6 b. Although the total length of each test section is 200 feet (60 meters), all testing for this study was conducted within the middle 150 feet (45 meters) of each section, beginning and ending within a 25 feet (7.5 meters) offset from the posted test section limits.

6.3 Data Collection

The DFT and CTM testing was performed in the same spot locations, but by independent operators and equipment. This was done to quantify the reproducibility of test data obtained, while minimizing any influence of surface irregularities and/or contamination. The overall testing program conducted at the NCAT pavement test track is summarized in Table 1.

Full-scale friction tests were conducted with the Florida DOT locked-wheel friction test unit in the center of the outside wheel path of each test section in general accordance with ASTM E 274. High-speed laser texture and friction data were collected with the ribbed tire (FN_{40R}) in accordance with ASTM E 1845 and E 501, respectively. Friction data with the smooth tire (FN_{40S}) was also collected in accordance with ASTM E 524. The location of the full-scale lock-up was marked within each pavement test section, and five spot test locations within the lock-up interval were identified for DFT and CTM testing. Two DFT tests and two CTM tests were performed at each of these five spot test locations by both Florida DOT and NCAT representatives. Thus, 10 DFT and 10 CTM test runs were conducted per test section with each piece of reference test equipment.



a) Aerial Photograph of NCAT Test Track. b) Approximate Test Section Locations.

FIGURE 6 NCAT Pavement Test Track Near Auburn University, Alabama.

TABLE 1 Summary of Comparison Testing Conducted at the NCAT Pavement Test Track.

Test Method	ASTM Designation	Test Sections	Test Locations	Replicate Tests per Location	Total Tests Conducted
FN_{40R}	E 501	10	1	1	10
FN_{40S}	E 524	10	1	1	10
Laser MPD	E 1845	10	1	3	30
CTM	E 2157	10	5	2	100*
DFT	E 1911	10	5	2	100*

* NCAT personnel also performed replicate CTM and DFT tests with their equipment at the designated spot test locations within each full-scale test lock-up interval.

6.4 Data Analysis

6.4.1 CTM Unit-to-Unit Comparison

The mean results of the testing conducted on each of the selected pavement surfaces at the NCAT test track are summarized in Table 2. The individual data collected is provided in Appendix C. Analysis of the FDOT and NCAT portable CTM data was conducted with appropriate statistical test methods using MiniTab, Release 13.32, and Microsoft Excel statistical software. A paired t-test was performed to compare the difference between the means of the paired data sets. The null hypothesis for this analysis was that the mean difference in the MPD data from both the Florida DOT and the NCAT equipment was equal to zero, (H_0: $\mu_{FDOT} - \mu_{NCAT} = 0$). The paired t-test analysis resulted in a p-value of 0.5139. Since this value is significantly greater than 0.05, it indicates that the null hypothesis was accepted and the means of the data sets are not statistically different. In other words, the data collected with the NCAT CTM is statistically equivalent to that collected with the FDOT CTM device. A linear regression model was also used to examine the correlation between the two data sets. The results of the linear regression analysis are presented in Figure 7. The calculated coefficient of determination (R^2) value of 0.965 also illustrates an undeniably strong, dependent relationship between the NCAT and FDOT CTM test data [37].

Two of the most important measures of the usefulness of any testing device are repeatability (precision), and accuracy (bias). As such, every ASTM test method is required to include precision and bias statements. For the DFT and CTM equipment, these statements, as published in ASTM are presented in terms of the standard deviation of eight measurements made on the same test surface. The values currently reported by ASTM are presented in Table 3. As there is no absolute standard measure for either of these test methods, there is no basis for determination of accuracy, bias.

The repeatability and reproducibility of the data were analyzed statistically with respect to range, standard deviation, and coefficient of variation. The range serves herein as a convenient measure of data dispersion, while the standard deviation is a measure of the deviation around the mean. The coefficient of variation (COV) is commonly used as a normalized measure of how much variance exists in the data. It is the ratio of the standard deviation to the mean for the data set, expressed in percent. The results of this analysis are summarized in Table 4.

As shown in Table 4, the CTM measurements exhibit very little dispersion in data. For any given section tested, the maximum range measured within a given unit was 0.39 mm. As would be expected, this maximum range was observed for the test section with the greatest measure of macro-texture (1.6 mm). The standard deviation was also found to be relatively small, with a maximum deviation of 0.084 mm, also obtained for the test section with the greatest measure of macro-texture. Further, this measured standard deviation was found to be lower for the test sections possessing less macro-texture. The coefficient of variance is used to normalize these observations, reducing the skewing effect of the magnitude of the measurement from the comparison. In general, the coefficient of variance was found to be consistent for both the Florida DOT and NCAT equipment. This observation indicates that these two different units provided similar levels of repeatability. Similarly, the reproducibility of the data obtained with the CTM is deemed to be relatively good based on the data presented.

Based on the results of this statistical analysis, the maximum standard deviation observed for the macro-texture measured with the Florida DOT CTM equipment was 0.084 mm. It is noted that this value exceeds that currently published by ASTM (see Table 3). However, this is not surprising as the pavement surfaces tested in this study provide more realistic variability than the one surface currently documented in ASTM. The resulting calculated acceptable range of difference in two results of two properly conducted tests with the Florida DOT CTM equipment should not exceed 0.084 x 2.8, or 0.235 mm, in accordance with ASTM C 670, "Standard Practice for Preparing Precision Statements for Test Methods [38]." Similarly, the maximum standard deviation observed between the two units was observed to be 0.103. Thus the acceptable range of difference in two results of two properly conducted tests, by different operators, with different equipment should not exceed 0.103 x 2.8, or 0.288. These values are summarized in Table 6, and represent the difference two-sigma (d2s) limits described in ASTM C 670. It should also be noted that the applicable range of macro-texture measurements represented by these limits is about 0.4 to 1.6 mm.

TABLE 2 Summary of Data Collected at the NCAT Test Track.

Test Section	Mean Test Results						
	FDOT CTM MPD (mm)	NCAT CTM MPD (mm)	64 kHz Laser MPD (mm)	FDOT DFT_{60}	NCAT DFT_{60}	FDOT FN_{40R} (x 0.01)	FDOT FN_{40S} (x 0.01)
N2	0.549	0.556	0.532	0.254	0.242	0.450	0.326
N8	1.195	1.216	1.080	0.258	0.251	0.411	0.363
N9	1.113	1.153	0.896	0.237	0.223	0.422	0.347
N10	0.705	0.676	0.670	0.170	0.166	0.356	0.278
N11	1.602	1.626	1.504	0.262	0.240	0.465	0.446
N13	1.192	1.154	1.128	0.248	0.226	0.470	0.465
S2	0.448	0.419	0.463	0.224	0.220	0.421	0.262
S3	1.380	1.385	1.302	0.224	0.215	0.415	0.397
E2	1.033	1.017	0.948	0.401	0.290	0.663	0.540
W8	0.976	0.946	0.950	0.166	0.147	0.302	0.275

TABLE 3 Current ASTM Precision Statements for CTM and DFT Test Methods [8, 9].

ASTM Procedure	Standard Deviation[a]
E 2157 - CTM	0.03 mm (0.001 in)
E 1911 - DFT	0.038 at 60 km/h

[a] Standard deviation of eight measurements on the same test surface.

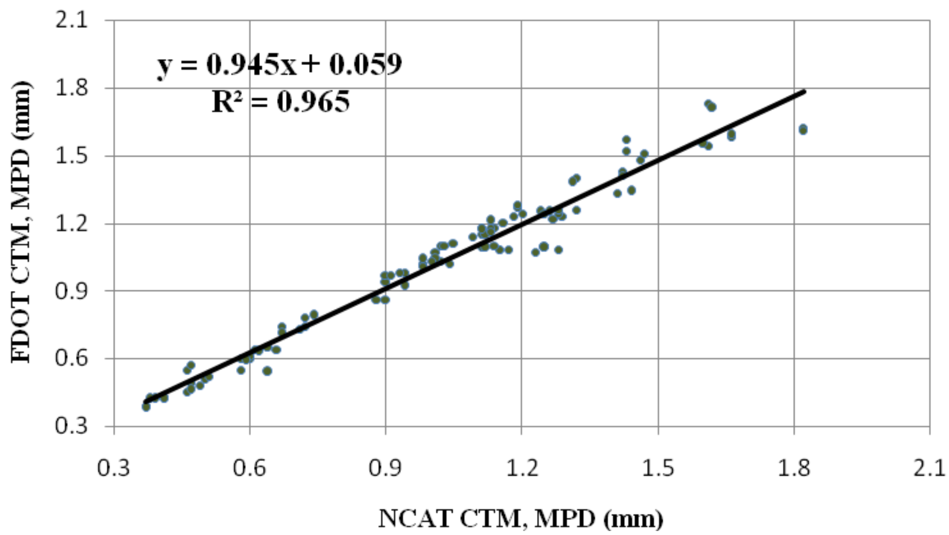


FIGURE 7 Florida DOT CTM vs. NCAT CTM Data, MPD (mm).

TABLE 4 Summary of Repeatability and Reproducibility Statistics for the CTM in Terms of Range, Standard Deviation, and Coefficient of Variation.

	Within Unit Repeatability						Between Unit Reproducibility		
Test Site	FDOT CTM			NCAT CTM			CTM		
	Range (mm)	Std. Dev. (mm)	COV (%)	Range (mm)	Std. Dev. (mm)	COV (%)	Range (mm)	Std. Dev. (mm)	COV (%)
N2	0.130	0.049	8.859	0.170	0.058	10.425	0.170	0.052	9.448
N8	0.170	0.066	5.498	0.180	0.066	5.458	0.210	0.065	5.406
N9	0.100	0.040	3.570	0.270	0.096	8.329	0.270	0.074	6.568
N10	0.160	0.061	8.596	0.130	0.045	6.660	0.180	0.054	7.827
N11	0.210	0.069	4.333	0.390	0.132	8.088	0.390	0.103	6.387
N13	0.200	0.068	5.742	0.110	0.037	3.196	0.200	0.057	4.855
S2	0.190	0.064	14.227	0.100	0.042	10.028	0.200	0.055	12.597
S3	0.250	0.084	6.092	0.190	0.070	5.051	0.250	0.075	5.448
E2	0.190	0.066	6.390	0.220	0.069	6.829	0.220	0.066	6.483
W8	0.180	0.068	6.919	0.130	0.050	5.278	0.180	0.060	6.224

TABLE 5 Summary of Repeatability and Reproducibility Statistics for DFT_{60} in Terms of Range, Standard Deviation, and Coefficient of Variation.

	Within Unit Repeatability						Between Unit Reproducibility		
	FDOT DFT_{60}			NCAT DFT_{60}			DFT_{60}		
Test Site	Range	Std. Dev.	COV (%)	Range	Std. Dev.	COV (%)	Range	Std. Dev.	COV (%)
N2	0.031	0.010	4.087	0.080	0.031	12.719	0.080	0.024	9.452
N8	0.034	0.012	4.699	0.104	0.038	15.354	0.104	0.029	11.194
N9	0.031	0.012	4.887	0.026	0.011	4.953	0.048	0.014	6.124
N10	0.011	0.004	2.338	0.040	0.017	10.151	0.040	0.012	7.228
N11	0.034	0.013	4.928	0.025	0.008	3.473	0.058	0.019	7.448
N13	0.015	0.005	1.949	0.032	0.012	5.412	0.052	0.017	6.920
S2	0.017	0.006	2.733	0.076	0.029	13.363	0.076	0.021	9.366
S3	0.019	0.007	3.078	0.039	0.015	7.144	0.039	0.014	6.113
E2	0.028	0.011	2.659	0.091	0.034	11.824	0.153	0.061	17.667
W8	0.035	0.014	8.337	0.026	0.010	6.992	0.052	0.016	10.116

TABLE 6 Proposed Precision Statements for CTM and DFT Equipment.

Test Method	Test Index	Standard Deviation	Acceptable Range of Two Test Results, d2s
E 2157 - CTM	Single Unit Precision[a]	0.084 mm	0.235 mm
	Multi-Unit Precision[b]	0.103 mm	0.288 mm
E 1911 – DFT_{60}	Single Unit Precision[a]	0.014	0.039
	Multi-Unit Precision[b]	0.061	0.171

[a]The acceptable range of difference in two results of two properly conducted tests, by the same operator, with the same equipment should not exceed the d2s value listed herein.

[b]the acceptable range of difference in two results of two properly conducted tests, by different operators, with different equipment should not exceed the d2s value listed herein.

6.4.2 DFT Unit-to-Unit Comparison

Similar statistical analyses of the Florida DOT and NCAT portable DFT data were also conducted. Again, a paired t-test was performed to compare the difference between the means. The null hypothesis for this analysis was that the mean difference in the friction number DFT_{20} from the Florida DOT and the NCAT equipment was equal to zero, (H_0: $\mu_{FDOT} - \mu_{NCAT} = 0$). This paired t-test analysis resulted in a p-value of 0.0000. Since this value is significantly less than 0.05, it indicates that the null hypothesis is rejected and the means of these two data sets are statistically unequal. In other words, the data collected with the NCAT DFT is statistically different from that collected with the Florida DOT DFT device. A linear regression model was again used to observe the correlation between these two data sets. The results of the linear regression analysis are presented in Figures 8 and 9 for $DFT_{20\ km/h}$ and $DFT_{60\ km/h}$, respectively. The calculated R^2 values of 0.62 to 0.75 in this case reveal relatively close correlations between the NCAT and Florida DOT DFT test data, although the observed unit-to-unit repeatability was determined to be less than statistically acceptable. It is noted that in this case, the lower R^2 value was calculated for the $DFT_{60\ km/h}$ test data.

The repeatability and reproducibility of the DFT data were also analyzed statistically with respect to range, standard deviation, and coefficient of variation. The results of this analysis are summarized in Table 5. As shown in Table 5, the DFT_{60} measurements made with the Florida DOT equipment exhibit far less dispersion and deviation than those reported with the NCAT equipment. The significantly lower coefficient of variance measured for the Florida DOT results supports this observation. It is unknown why the NCAT DFT equipment yielded significantly more variable data than the Florida DOT equipment. It is known that the Florida DOT equipment was calibrated immediately prior to testing, and operated in accordance with ASTM E 1911. Regardless, based on the observed discrepancy in results, the decision was made to base further repeatability assessment on the results of the Florida DOT unit.

The maximum standard deviation obtained with the Florida DOT DFT equipment was 0.014. It should be noted that this value is actually less than that currently published by ASTM. Based on this standard deviation, the calculated acceptable range of difference in two results of two properly conducted tests with the Florida DOT equipment should not exceed 0.039. Due to the more variable data obtained with the NCAT unit, the maximum standard deviation observed between the two units was relatively large, 0.061. Thus the calculated acceptable range of difference in two results of two properly conducted tests, by different operators, with different equipment should not exceed 0.171. Again, these acceptable ranges are summarized in Table 6, and represent the difference two-sigma (d2s) limits, as described in ASTM C 670. The applicable range of DFT values represented by these limits is about 0.15 to 0.40.

6.4.3 Correlations with Full Scale Equipment

A linear regression model was used to assess the correlation between the FDOT CTM data and that collected with the high speed laser texture measurement system mounted on the Florida DOT locked-wheel friction testing unit. The results of the linear regression analysis are presented in Figure 10. The resulting R^2 value of 0.945 reveals that the portable and the full scale texture measurement equipment are highly correlated.

Similarly, a linear regression model was used to observe the correlations between the Florida DOT DFT data and that collected with the Florida DOT locked-wheel friction testing unit. These results are presented in Figures 11 though 14 for both the ribbed and smooth tire tests, at 20 and 60 km/h. Based on these comparisons, it is shown that the ribbed tire test data are better correlated with the data collected with the portable DFT device than with the data from the smooth tire test. The R^2 value for the correlation between DFT_{60} and FN_{40R} was determined to be 0.928 (see Figure 13), while that for the correlation between DFT_{60} and FN_{40S} was determined to be 0.634 (see Figure 14). This was an unexpected discovery since the DFT has been reported by others to correlate best with the smooth tire test, and at 20 km/h [2,3]. Based on this observation, it is concluded that the portable DFT better simulates the results of the full scale ribbed tire test, and thus provides information related to micro-texture as opposed to macro-texture.

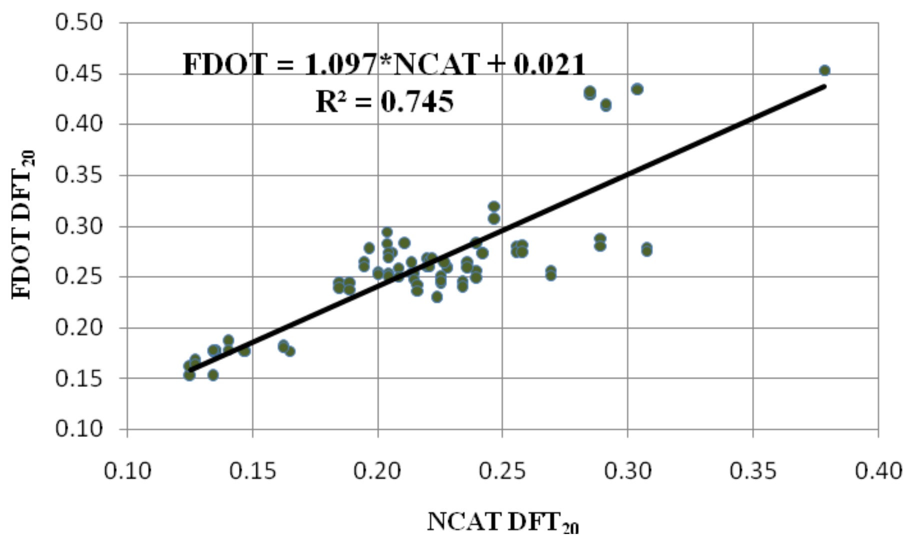


FIGURE 8 Florida DOT DFT vs. NCAT DFT Friction Data, DFT_{20}.

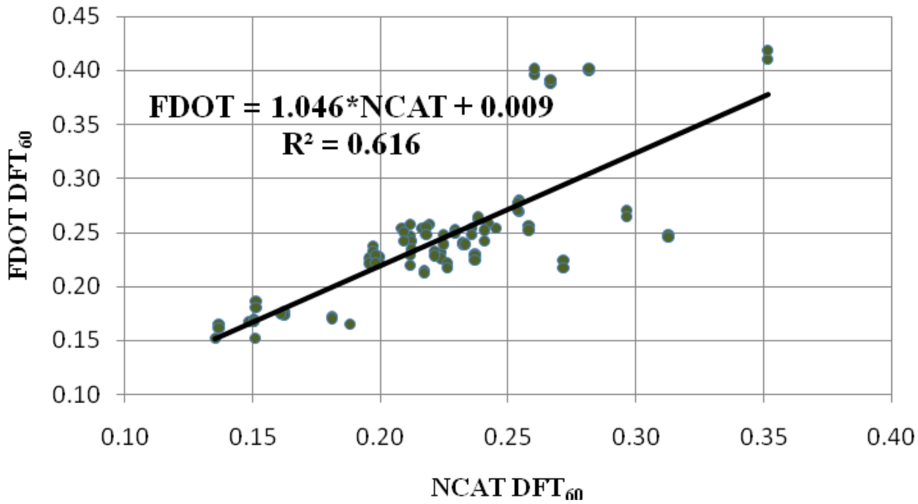


FIGURE 9 Florida DOT DFT vs. NCAT DFT Friction Data, DFT_{60}.

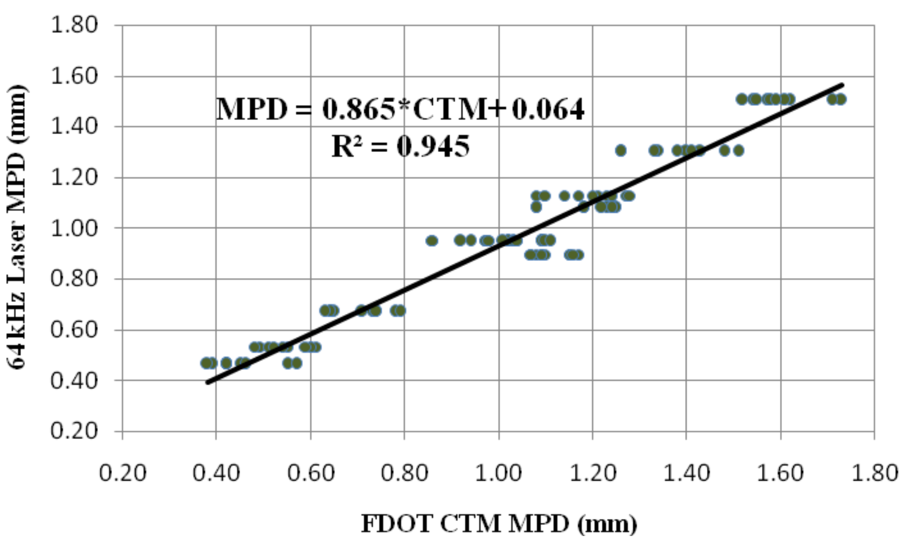


FIGURE 10 Florida DOT CTM vs. 64 kHz Laser Data, MPD (mm).

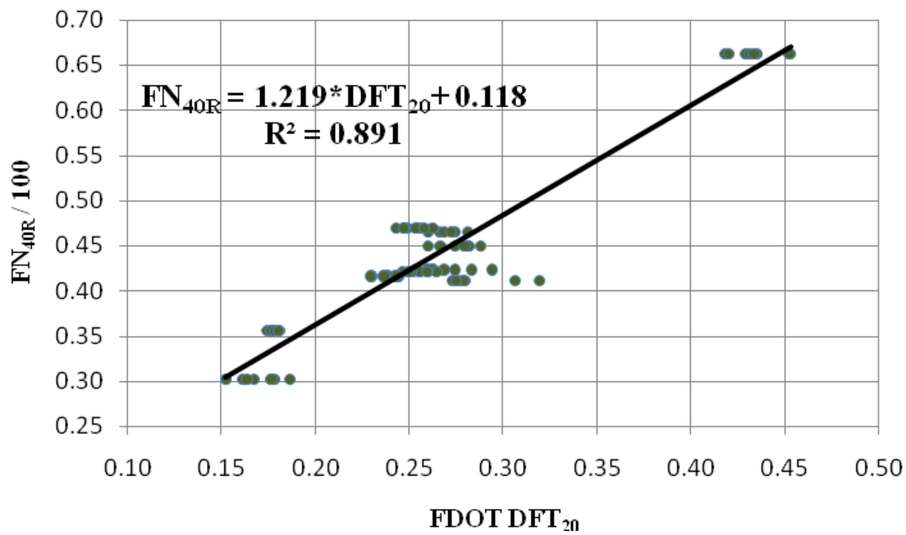


FIGURE 11 Florida DOT DFT_{20} vs. Ribbed Tire Friction Number (FN_{40R}).

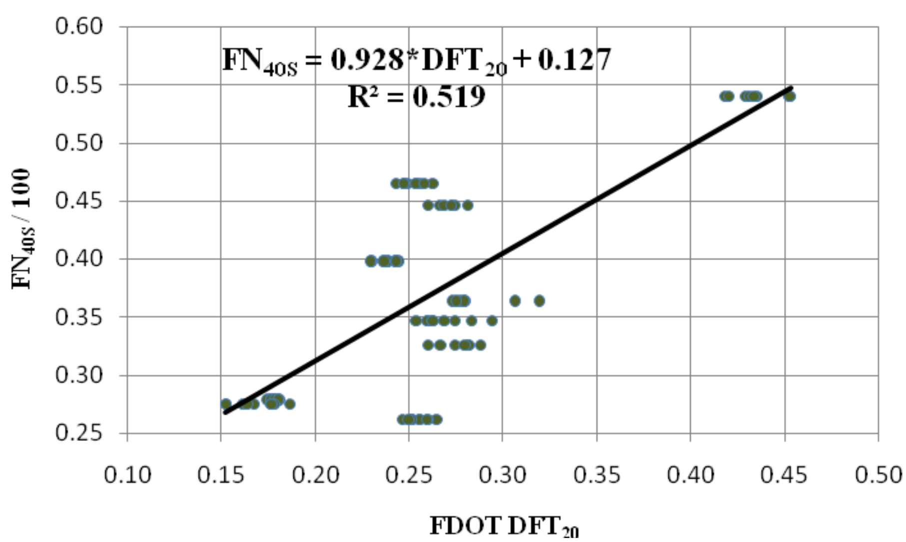


FIGURE 12 Florida DOT DFT_{20} vs. Smooth Tire Friction Number (FN_{40S}).

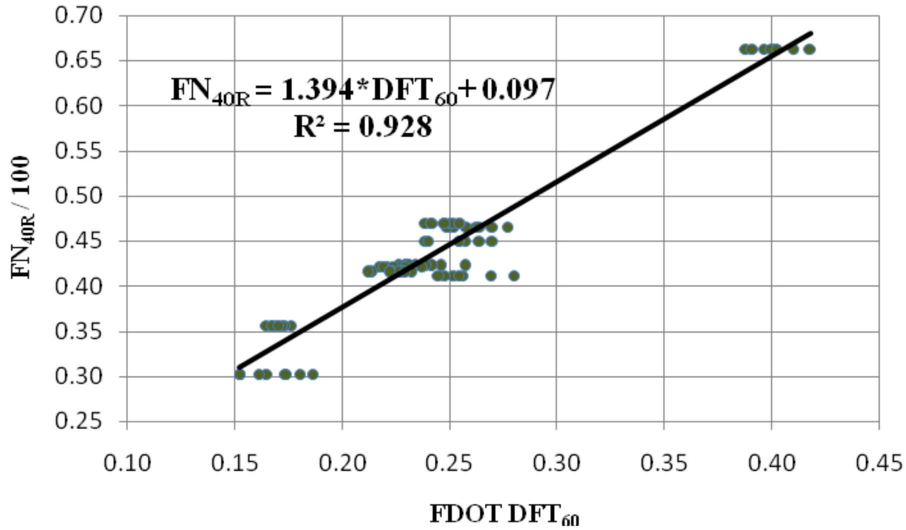


FIGURE 13 Florida DOT DFT_{60} vs. Ribbed Tire Friction Number (FN_{40R}).

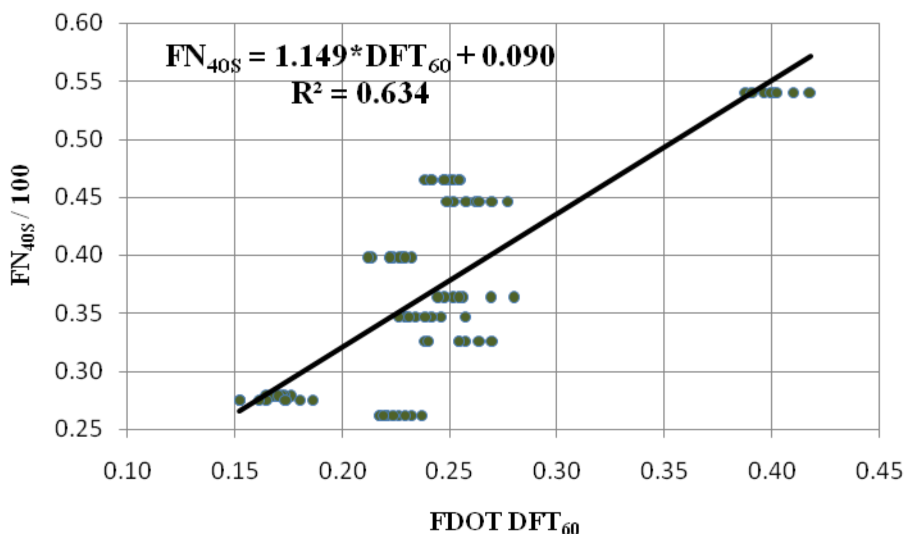


FIGURE 14 Florida DOT DFT_{60} vs. Smooth Tire Friction Number (FN_{40S}).

6.4.4 IFI Computations

ASTM E 1960 outlines the method of harmonizing friction testers with the DFT and CTM reference equipment. In this procedure, ten (10) pavements are selected and the $DFT_{20\ km/h}$ and the MPD are determined for each section in accordance with ASTM E 1911 and E 1845, respectively. S_p is calculated in accordance with Equation 2. F60 and FR60 are calculated from DFT and Sp in accordance with Equations 3 and 4. For example, the described calculations for NCAT Test Section N2:

Sp = 14.2 + 89.7 * 1.04 = **107.5**,

F60 = 0.081 + 0.731*0.43*exp(-40/107.5) = **0.30**, and

$FR60_{FN40R}$ = 0.30*exp[(64.4-60)/107.5] = **0.69**.

Ultimately, the harmonization constants, A and B are obtained from linear regression of the FR60 versus F60 data.

The results of these and the computations for all ten NCAT pavement sections tested are presented in Figures 15 and 16 for the Florida DOT locked-wheel friction unit with both the ribbed and smooth tires, respectively. The values for F60 and FR60, as calculated in the above example correspond to the data in the extreme upper right hand region of Figure 15. The values determined for the regression coefficients, A and B, and the corresponding R^2 values are also shown in Figures 15 and 16, and are summarized below in Table 7.

TABLE 7 IFI Harmonization Coefficients from NCAT Testing.

Locked-Wheel Friction Test Unit, ASTM E 274	A	B	R^2
Ribbed Tire Test, ASTM E 501	0.044	0.359	0.683
Smooth Tire Test, ASTM E 524	0.054	0.398	0.789

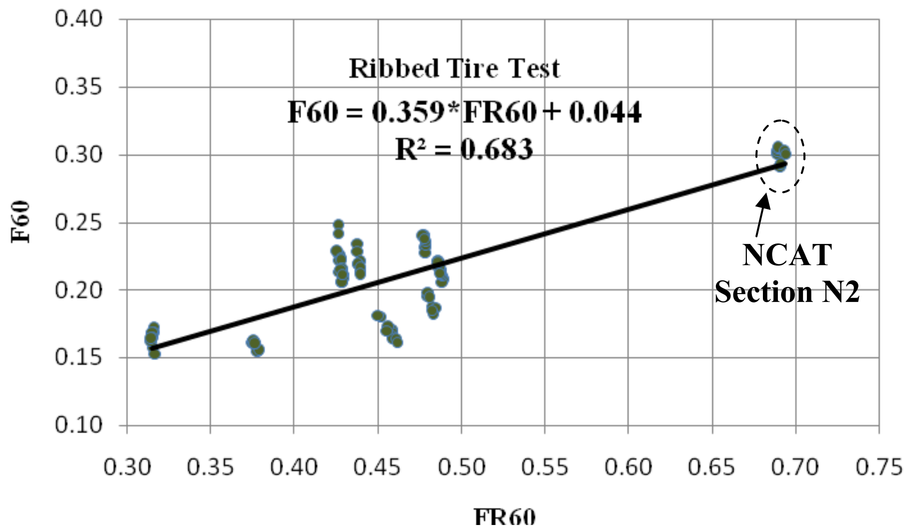


FIGURE 15 FR_{60} vs. F_{60} for the FDOT Locked-Wheel, Ribbed Tire Test (FN_{40R}).

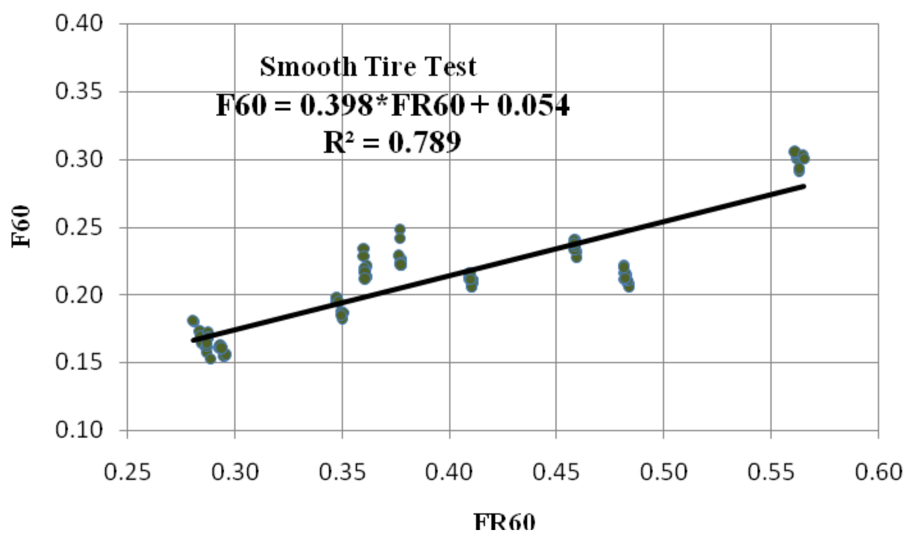


FIGURE 16 FR_{60} vs. F_{60} for the FDOT Locked-Wheel, Smooth Tire Test (FN_{40S}).

7 VALIDATION TESTING ON FLORIDA STATE ROADWAYS

7.1 Florida Test Sections

The results from the preliminary testing conducted at the NCAT test track were validated on typical Florida roadways. This validation testing was conducted on ten (10) additional test sites. These test sites were selected to include the range of pavement surfaces common to Florida state roadways. The ten different test sites included in this validation effort are summarized in Table 8. In general, these sites included three (3) open-graded Hot Mix Asphalt (HMA) friction courses (Sites 2, 3 and 6); five dense-graded HMA surfaces (Sites 1,4,5,7 and 8); and two (2) Portland Cement Concrete (PCC) pavements (Sites 9 and 10). The coarse aggregate type (limestone vs. granite) for each test section is also documented in Table 8.

7.2 Data Collection

Representatives of the Florida DOT Pavement Evaluation Section conducted one (1) locked wheel friction test with the smooth tire in accordance with ASTM E 524 and one (1) test with the ribbed tire in accordance with ASTM E 501 on each of the ten test sites. Each of these tests consisted of the average of five (5) wheel lock-ups within the limits of the test site. All of these tests were also conducted at three different test speeds: 30, 40, and 50 mph (48.3, 64.4 and 80.5 km/h). Two (2) high speed laser texture measurements were also collected per section in general accordance with ASTM E 1845. Each full-scale test consisted of 5 lock-up segments. Within each lock-up segment, 5 spot test locations were identified for DFT, CTM, and Sand Patch testing. This validation testing program is summarized in Table 9. The results of this validation testing are summarized in Table 10. The detailed test data used to develop these summaries are provided in Appendices G and H of this report.

TABLE 8 Summary of Florida DOT Validation Test Sections.

Site ID	**Surface Type**	**Reference Location**	**Aggregate Type**	**Mix Design Number**	**Project ID**
1	FC 12.5 M	SR 24, Sonny's	Granite	SPM 06-4852B	26050000
2	FC 5	SR 24, Austin Cary Memorial	Limestone	QA 00-9506A	26050000
3	FC 5	SR 24, Waldo	Granite	LD 02-2523A	26050000
4	FC 9.5	SR 222 FDOT Maintenance	Granite	SP 04-3068A	26005000
5	FC 9.5 M	SR 26, Fletcher's Mill	Granite	SPM 05-4408A	26070000
6	FC 5 M	US 441, Paynes Prairie	Granite	SPM 07-5509A	26010000
7	FC 12.5	SR 16	Limestone	SP 02-1920A	28030001
8	FC 12.5 M	SR 501	Limestone	SPM 06-4609C	70011000
9	Burlap Drag	SR 600 / US 92	PCC		79060000
10	Long Grind	SR 600 / US 92	PCC		79060000

TABLE 9 Summary of Validation Testing Conducted on Florida Roadways.

Test Method	**ASTM Designation**	**Test Speed (mph)**	**Test Sections**	**Lock-up Segments**	**Spot Test Locations**	**Total Tests Conducted**
FN_{30R}	E 501	30	10	5	1	50
FN_{40R}		40				50
FN_{50R}		50				50
FN_{30S}	E 524	30	10	5	1	50
FN_{40S}		40				50
FN_{50S}		50				50
Laser MPD	E 1845	30	10	5	1	50
		40				50
		50				50
CTM	E 2157	---	10	5	5	250
DFT	E 1911	---	10	5	5	250
Sand Patch	E 965	---	10	5	5	250

TABLE 10 Summary of Validation Test Data Collected on Florida Roadways.

Test Site	Mean Test Results									
	CTM MPD (mm)	64 kHz Laser MPD (mm)	Sand Patch MTD (mm)	DFT_{60}	Ribbed Tire Test FN_{VR} / 100			Smooth Tire Test FN_{VS} / 100		
					30 mph (48.3) km/h	40 mph (64.4) km/h	50 mph (80.5) km/h	30 mph (48.3) km/h	40 mph (64.4) km/h	50 mph (80.5) km/h
1	0.431	0.473	0.564	0.336	0.513	0.483	0.454	0.417	0.338	0.292
2	1.270	1.352	1.987	0.231	0.328	0.313	0.304	0.319	0.308	0.293
3	1.879	1.829	2.831	0.301	0.352	0.340	0.337	0.360	0.349	0.335
4	0.443	0.425	0.667	0.332	0.478	0.442	0.422	0.331	0.265	0.208
5	0.404	0.390	0.597	0.321	0.476	0.455	0.429	0.381	0.282	0.247
6	1.651	1.692	5.954	0.311	0.448	0.420	0.393	0.438	0.402	0.394
7	0.468	0.459	0.638	0.273	0.441	0.406	0.373	0.327	0.248	0.190
8	0.449	0.517	0.605	0.232	0.365	0.356	0.338	0.310	0.242	0.209
9	0.395	0.437	0.585	0.352	0.585	0.557	0.527	0.379	0.295	0.245
10	0.670	0.423	0.726	0.294	0.459	0.423	0.387	0.392	0.315	0.261

7.3 Data Analysis

7.3.1 IFI Harmonization Coefficient Validation

The IFI computations for the data collected on the ten (10) Florida DOT test sections are summarized in Figures 17 and 18. The values determined for these regression coefficients, A and B, and the corresponding R^2 values are summarized in Table 11. Table 11 also includes the coefficients developed from the NCAT test track pavement sections for comparison purposes. As exhibited in Table 11, the coefficients developed from the testing at NCAT were not replicated on the Florida roadway test sections. It is noted that the coefficients developed from the smooth tire test data are much closer in comparison than those developed from the ribbed tire test data. This confirms that IFI is best suited for harmonization with the smooth tire test equipment, as described in ASTM E 1960, and cannot be implemented with the ribbed tire test. Based on this observation, it is clear that the Florida DOT would have to adopt the smooth tire test in accordance with ASTM E 524 in order to successfully implement IFI. This is not recommended since the Florida DOT maintains an extensive historical database of ribbed tire test data and understanding of the implications of ribbed tire test results relative to pavement micro-texture.

TABLE 11 IFI Harmonization Coefficients Developed from the NCAT Test Track and on Florida Roadways, Presented Side-by-Side.

Locked-Wheel Friction Test Unit, ASTM E 274	A		B		R^2	
	NCAT	FDOT	NCAT	FDOT	NCAT	FDOT
Ribbed Tire Test, ASTM E 501	0.044	-0.019	0.359	0.225	0.683	0.002
Smooth Tire Test, ASTM E 524	0.054	0.013	0.398	0.628	0.789	0.803

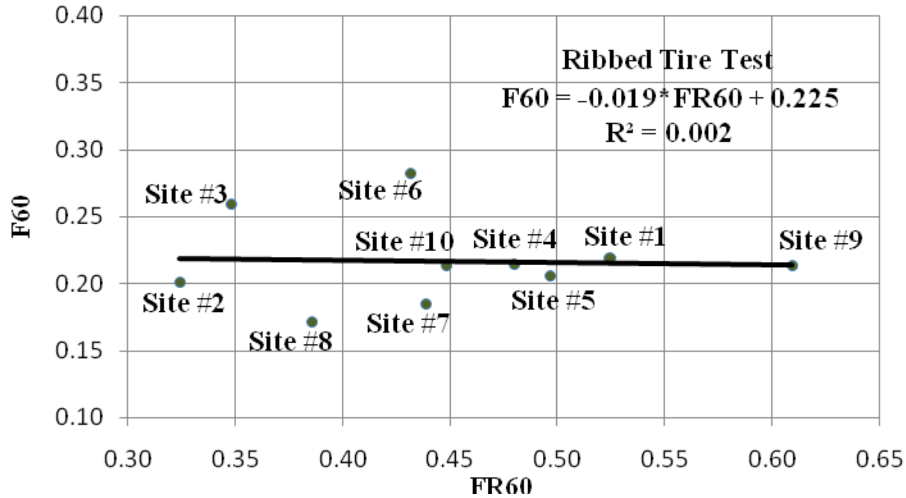


FIGURE 17 FR_{60} vs. F_{60} for the FDOT Locked-Wheel, Ribbed Tire Test (FN_{40R}).

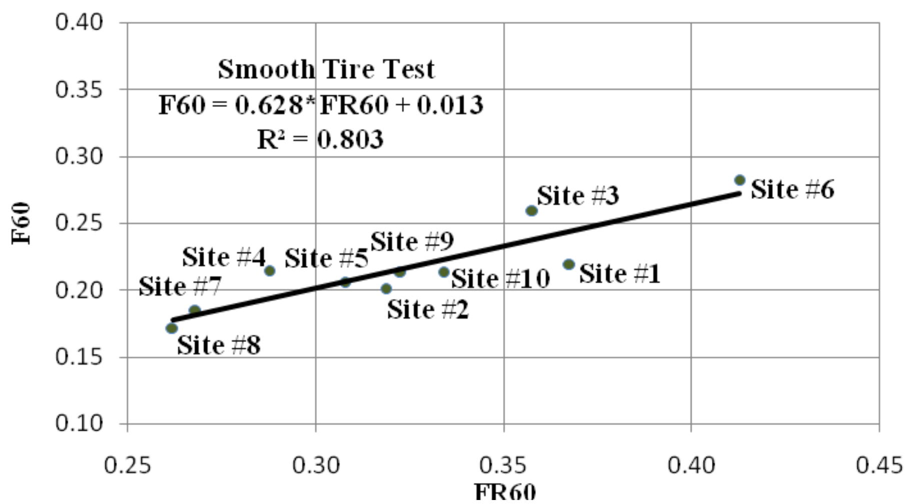


FIGURE 18 FR_{60} vs. F_{60} for the FDOT Locked-Wheel, Smooth Tire Test (FN_{40S}).

7.3.2 Pavement Texture

As was observed from the data collected at the NCAT test track, the texture data collected on the selected Florida DOT pavements with the CTM and the high speed laser was found to be very well correlated. As shown in Figures 19 and 20, the relationship between the two methods of measure is extremely close to unity. It is also clear that both the CTM and the high speed laser clearly differentiate between dense and open-graded surfaces. Figure 20 shows that the texture data from Site #10 are not as well correlated as are the data from the other pavements tested in this study. Additional testing of longitudinally ground surfaces (Site #10) is recommended to quantify how the subject equipment performs on such surfaces.

As part of this study, the sand patch test (volumetric measure of pavement texture) was also evaluated relative to MPD. As shown in Figures 21 and 22, the sand patch test appears to be highly correlated with MTD up to a limiting volumetric texture of about 4 mm. Figure 22 illustrates that when the outlier texture data from the highly porous pavement at Site #6 is removed, the relationship between MTD and MPD is much better correlated. This confirms that the laser devices are not well suited for the measurement of porosity. The volumetric sand patch test, ASTM E 965 has the potential to measure the volume of voids below surface aggregates particles in highly porous pavement surfaces. These pores are erroneously reported as texture. Thus, the results of the sand patch test (MTD) are not well correlated with the results of laser testure measurements (MPD) for such pavements.

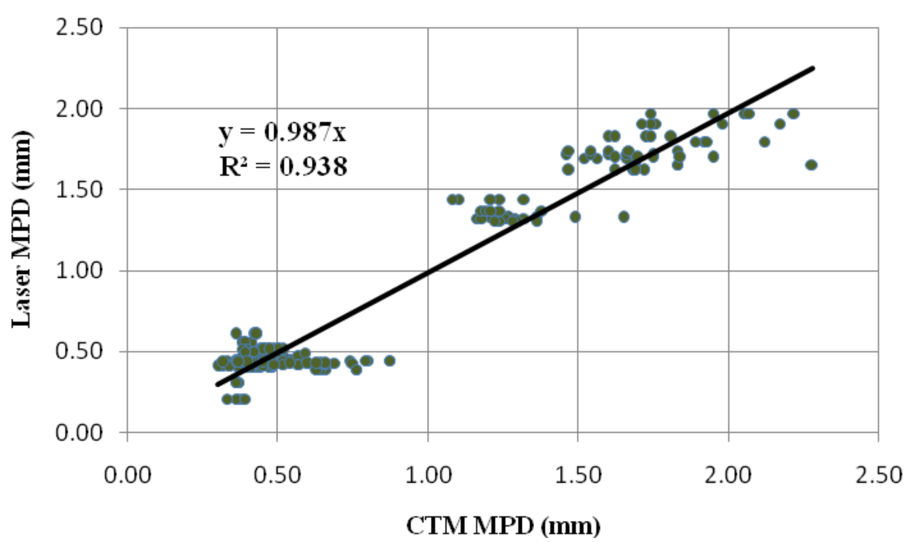


FIGURE 19 CTM vs. Laser Texture Data at 40 mph, MPD (mm).

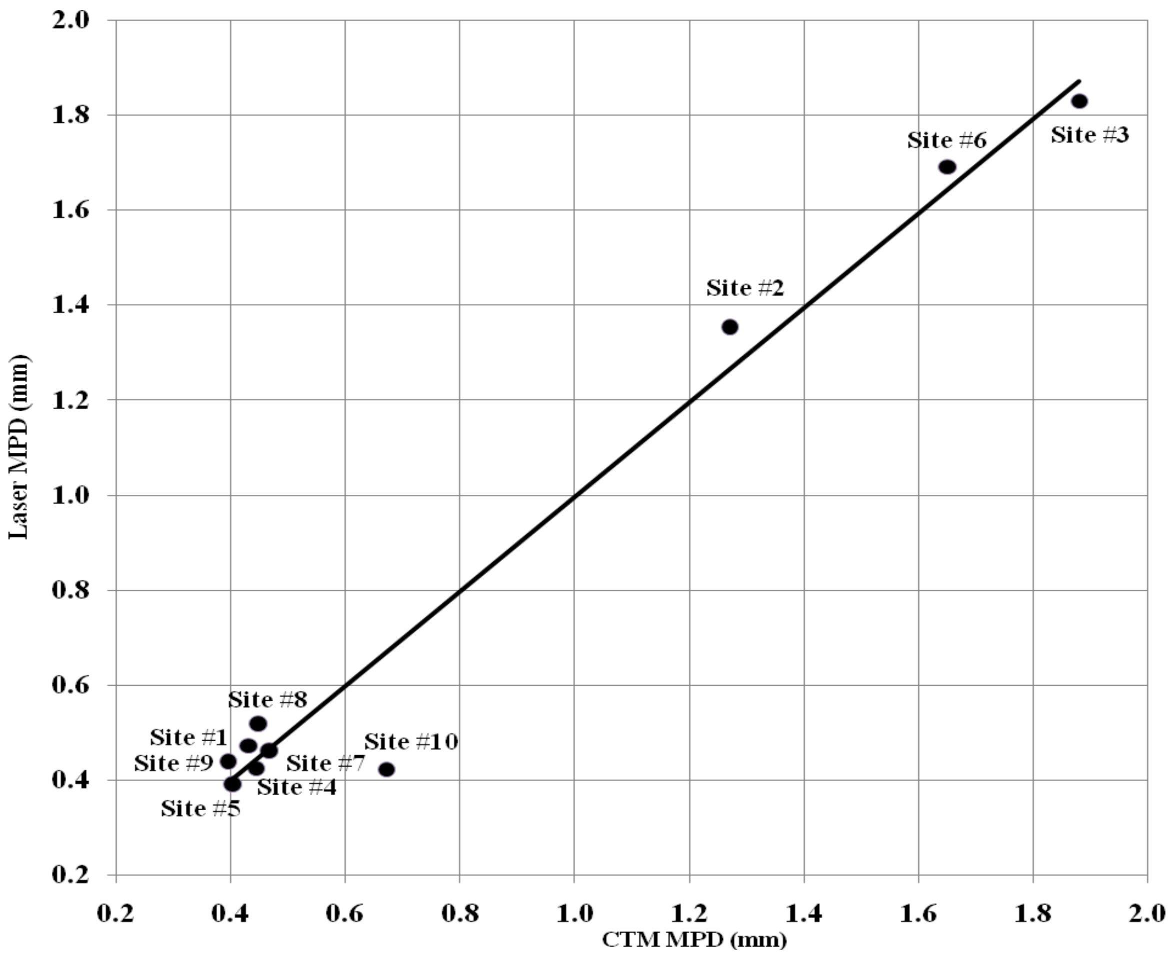


FIGURE 20 CTM vs. Laser Texture Data, Showing Open Graded Surfaces (Sites 2, 3 and 6) as Clearly Differentiated from the Other Data.

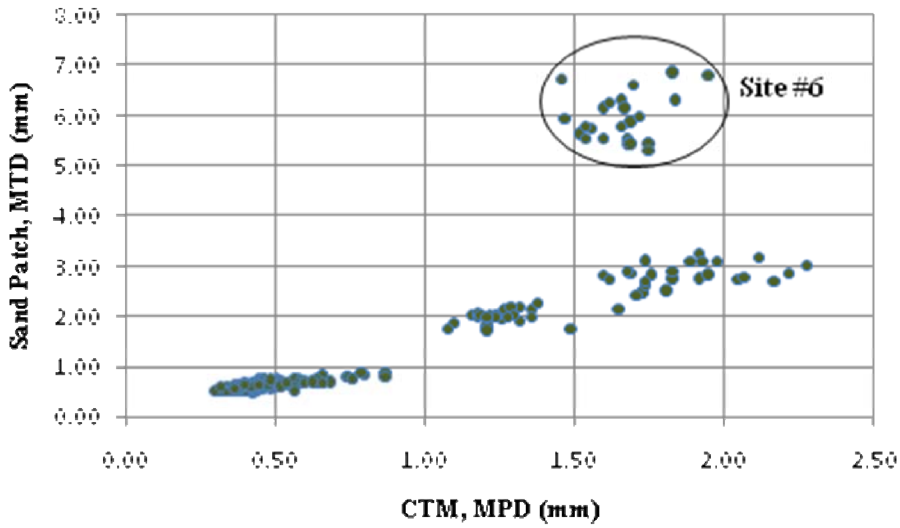


FIGURE 21 Plot of MTD versus MPD on Florida Pavements, Showing Site #6 as Outlier.

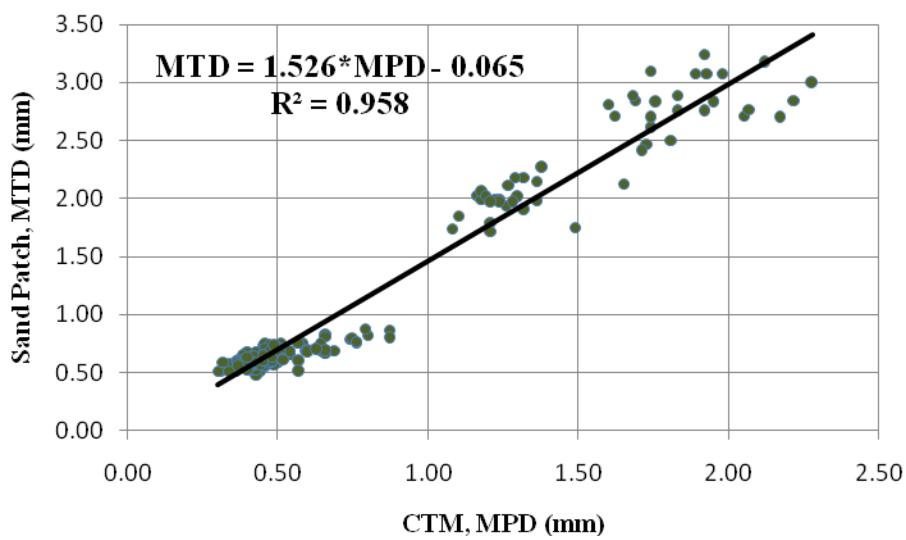


FIGURE 22 Correlation of MTD with MPD on Florida Pavements.

7.3.3 Pavement Friction

The observed correlation between DFT and FN_{40R} on typical Florida pavements is presented in Figure 23. As was observed from the data collected at the NCAT test track, the ribbed tire test is far better correlated with the results of the portable DFT device than is the smooth tire test. The linear regression correlation equations are also very similar, with a slope ranging from 1.4 to 1.5. As noted on the plot, there are also no obvious outliers, specific pavement surfaces, or aggregate types that cause any specific pavement surface to stand out from the others.

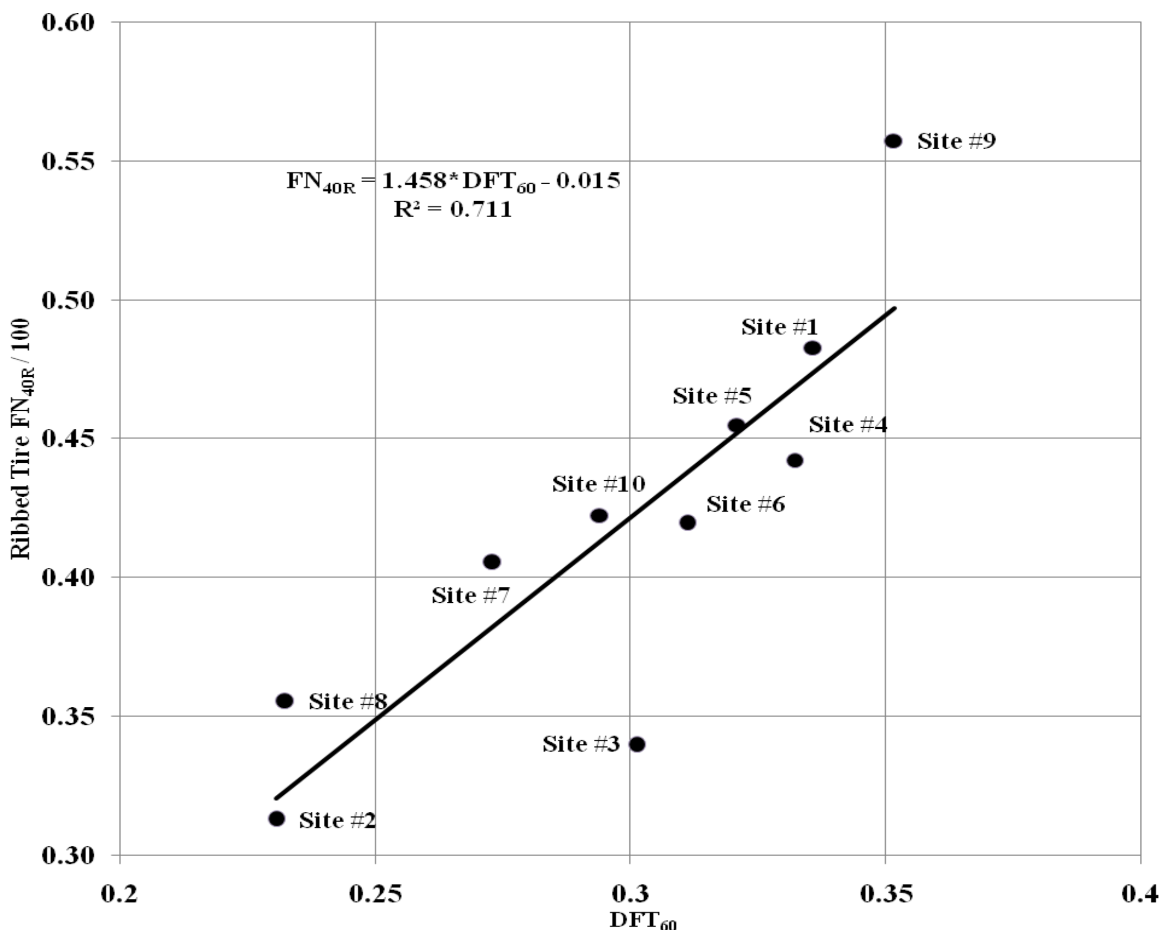


FIGURE 23 Correlation of DFT_{60} with FN_{40R} on Florida Pavements.

7.3.4 Speed Gradient Observations

The IFI concept hinges on the relationship between the speed gradient (G_v), as described in Equation 1, and the pavement surface texture (MPD) [3,20]. This relationship is fundamental to the S_p parameter. In an attempt to identify the reason why the transform coefficients computed from the NCAT data could not be validated with the follow-up testing on Florida roadways (see Table 11), speed gradients computed from the DFT data collected on the NCAT test track pavements, as previously illustrated in Figures 1 and 2, were plotted against MPD determined from CTM testing on the same test sections. This correlation is shown in Figure 24. Unfortunately, there is no discernable relationship exhibited, as indicated by the resulting R^2 value of 0.038. This discovery is extremely problematic, and potentially fatal to the proposed implementation of IFI, as recommended in ASTM E 1960. As a result, an alternative method of quantifying the relationship of test speed with frictional properties is proposed.

Figures 25 and 26 exhibit the slopes, or speed gradients for locked-wheel friction tests conducted at different speeds on the subject test sections. As can be seen in Figure 25, there is very little difference in slope for the range of pavements tested with the ribbed-tire, although the texture was measured to vary significantly for these pavements with the high speed laser. In observing Figure 26 (smooth-tire test data), it is interesting to note again that there is an obvious difference in slope for the three open graded friction courses (Sites 2, 3 and 6) relative to the other surfaces. These observations confirm that the results of the smooth-tire test are primarily affected by macro-texture, whereas the ribbed tire test is more affected by micro-texture.

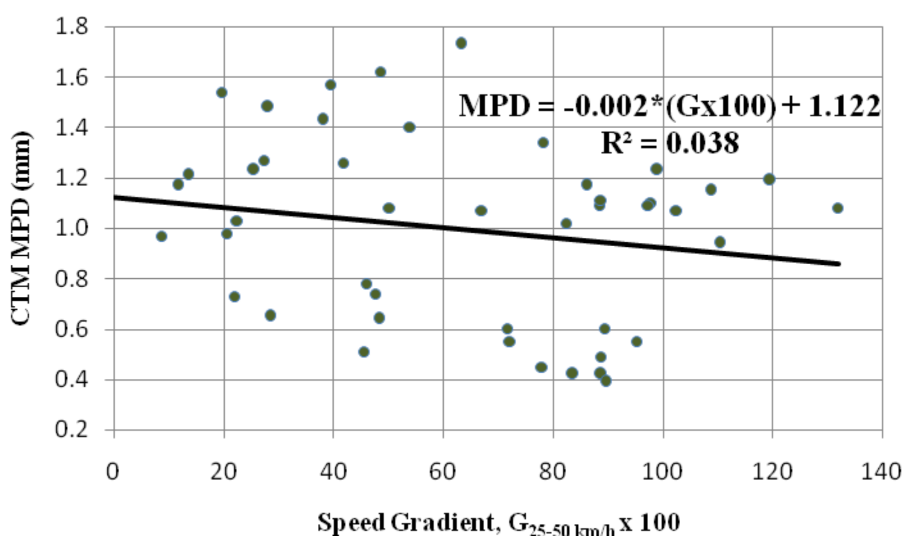


FIGURE 24 Plot of Speed Gradient versus MPD from NCAT Data.

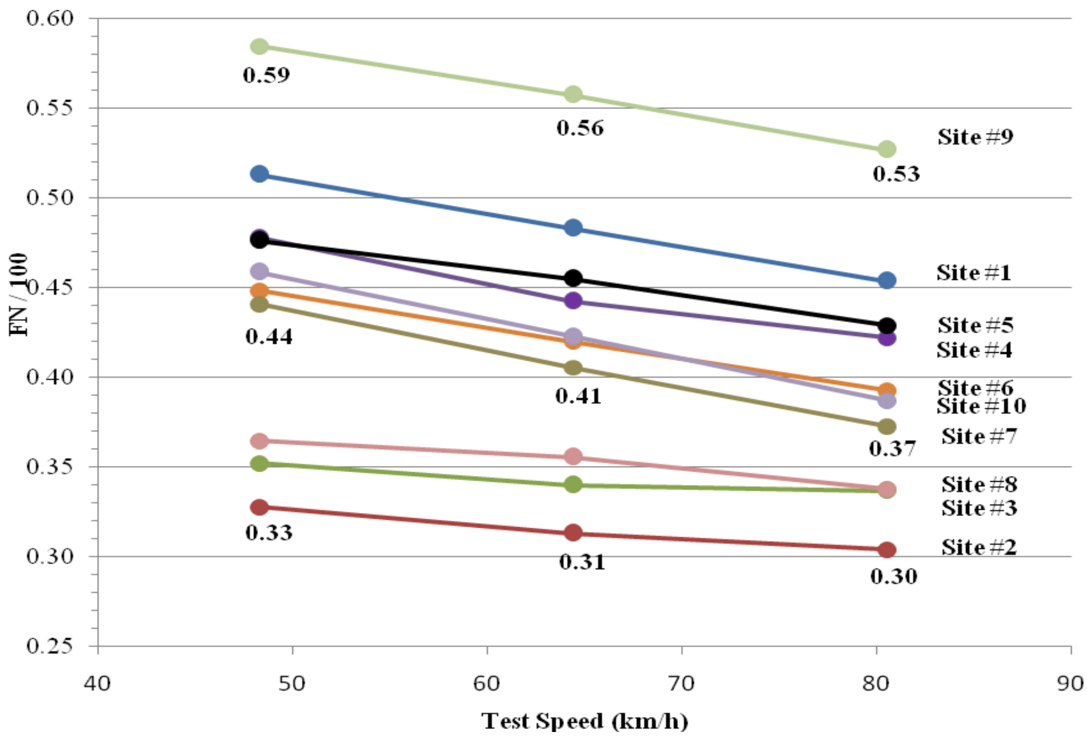


FIGURE 25 Plots of FN_{40R} versus Test Speed, Locked-Wheel, Ribbed-Tire Speed Gradient.

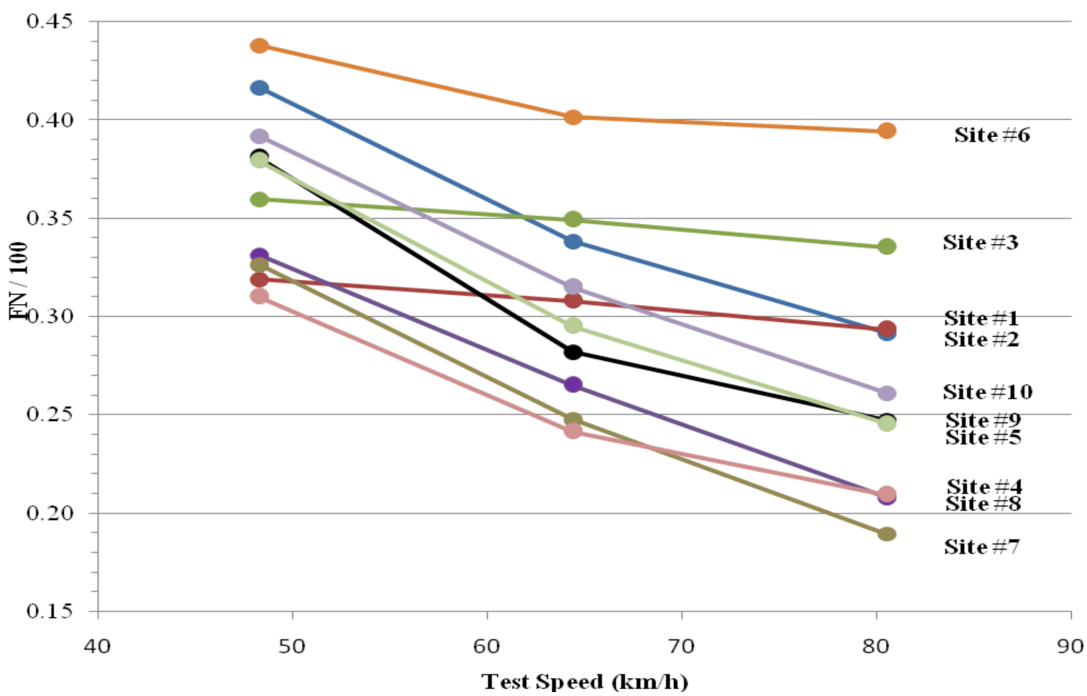


FIGURE 26 Plots of FN_{40S} versus Test Speed, Showing Locked-Wheel, Smooth-Tire Speed Gradient.

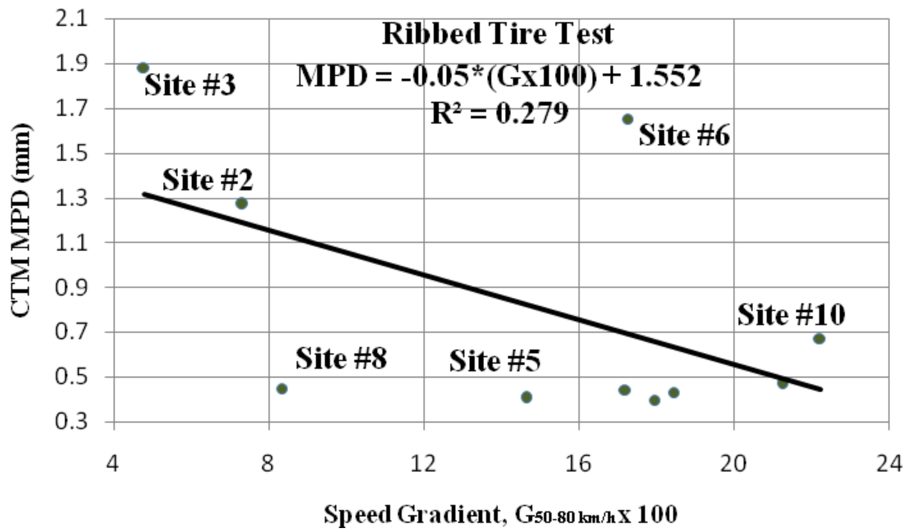


FIGURE 27 Plot of Speed Gradient versus MPD for Ribbed-Tire Test.

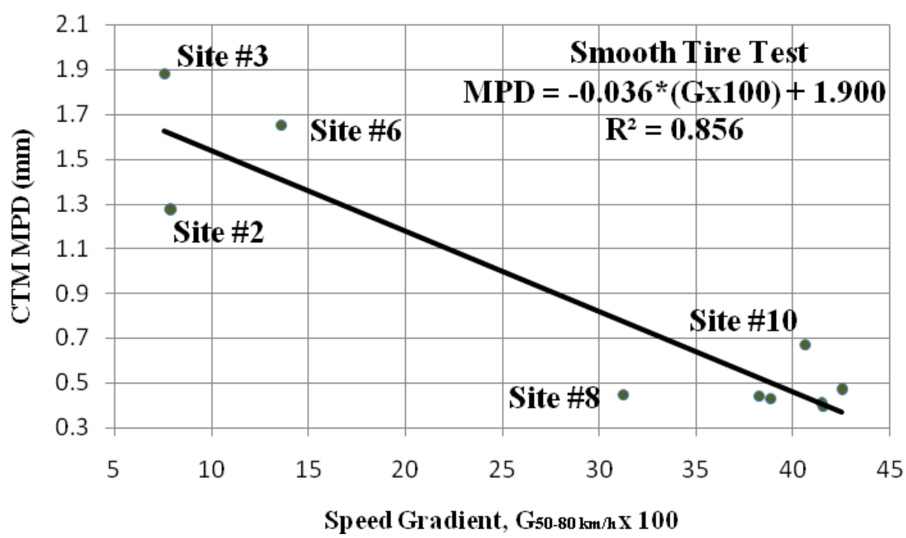


FIGURE 28 Plot of Speed Gradient versus MPD for Smooth-Tire Test.

Exploring the relationship of speed gradient for the locked-wheel equipment to pavement macro-texture further, the slopes of the data collected with the locked-wheel friction test unit at different speeds and with both the ribbed and smooth tires were plotted in Figures 27 and 28, respectively. As can be seen, there is no discernable correlation for the ribbed tire test data (Figure 27), but a reasonable correlation ($R^2 = 0.856$) was found for the smooth tire test data (Figure 28). Again, these observations confirm that the smooth tire test captures macro-texture to a greater extent than does the ribbed tire test. Unfortunately, this observation is of little practical benefit since macro-texture is readily quantified with the high-speed laser, in accordance with ASTM E 1845. Further, the correlation documented in Figure 28 appears to be highly dependent on the extreme differences in texture measured between the open-graded surfaces (Sites 2,3 and 6) and the other, dense-graded surfaces tested in this study.

Based on these findings, it is concluded that the proposed IFI methodology of correlating speed gradient with pavement texture may be valid for the locked-wheel, smooth-tire test, and for a wide range in macro-texture (open graded versus dense graded surface courses). However, as previously described, the DFT results obtained in this study were not found to correlate well with the locked-wheel, smooth-tire test data. Ultimately, the fundamental premise of proportionality between speed gradient and macro-texture is shown to be of little practical benefit to the Florida DOT.

In further observing the data presented in Figure 25, it can be seen that there is very little difference in slope for the range of pavements tested with the ribbed-tire test (slopes are nearly parallel). Based on this observation, it is proposed that an average of the ribbed-tire speed gradient may be employed to transform locked-wheel, ribbed-tire friction test data at 30 and 50 mph (48.3 and 80.5 km/h) to the standard 40 mph (64.4 km/h) value, FN_{40R}. The mean FN_{40R} values for all sections tested in this study are summarized in Table 12. The percent difference in ribbed tire friction number measured at +/- 10 mph (+/- 16.1 km/h) on Florida roadways is documented here to be about +/- 5.5 percent. The corresponding 95% confidence interval for this estimate is about +/- 3 friction numbers. It is noted that this observation provides a practical method for transforming friction test results measured at different speeds with the Florida DOT locked-wheel friction testing unit and the ribbed tire. Similar data for high-speed laser texture measurements at different speeds are summarized in Table 13. These results also confirm that the 64 kHz laser is highly repeatable within a practical range of highway test speeds, between 30 and 50 mph (48.3 and 80.5 km/h). With a mean difference of +/- 1.0%, it is noted that corrections to high-speed laser texture measurements are not necessary within the practical range of test speeds evaluated herein.

TABLE 12 Statistical Data Related to Ribbed-Tire, Locked-Wheel Speed Gradient.

Locked-Wheel Friction Number	30 mph (48.3 km/h)	40 mph (64.4 km/h)	50 mph (80.5 km/h)	Mean Difference
Mean	44.4	41.9	39.6	+/- 5.5 %
Std. Deviation	7.84	7.21	6.52	+/- 2.4
95% Conf. Int.	+/- 4.9	+/- 4.5	+/- 4.0	+/- 2.7

TABLE 13 Statistical Data Related to 64 kHz High-Speed Laser Texture Speed Gradient.

High Speed Laser Texture	30 mph (48.3 km/h)	40 mph (64.4 km/h)	50 mph (80.5 km/h)	Mean Difference
Mean	0.794	0.800	0.810	+/- 1.0 %
Std. Deviation	0.593	0.582	0.547	+/- 0.008
95% Conf. Int.	+/- 0.368	+/- 0.361	+/- 0.339	+/- 0.009

8 IMPLEMENTATION

The research team has coordinated closely with Florida DOT Pavement Evaluation Section personnel in making the results of this effort practical. In accordance with the Florida DOT Skid Hazard Elimination Program, the results of this research will assist the state in its efforts to reduce accidents and improve highway safety [12, 13]. The results of this research may be readily incorporated into the Florida DOT SHRS database. Locked-wheel friction and high-speed laser texture data can now be collected within a reasonable range of highway speeds, 30 to 50 mph (48.3 and 80.5 km/h) and transformed to the standard speed of 40 mph (64.4 km/h) for reporting purposes. As previously noted, the results of the ribbed tire test are highly influenced by pavement micro-texture, while MPD is a direct measure of pavement macro-texture [1]. Thus, FN_{40R} and the complementary MPD data can be used to fully characterize the frictional properties of the pavement. Two implementation examples are provided here for clarity.

8.1 Implementation Example #1

Locked-wheel, ribbed-tire friction testing was performed at a test speed of 30 mph (48.3 km/h) due to heavy traffic conditions on an urban state roadway. The average test results at 30 mph (48.3 km/h) are:

$$FN_{30R} = 51.3, \text{ and } MPD_{30} = 0.446 \text{ mm}$$

The transformed results at 40 mph (64.4 km/h) are:

$$FN_{40R\ Transformed} = FN_{30R}/(1 + 5.5\%) = 51.3/1.055 = \underline{\mathbf{48.6}}$$

$$MPD_{40\ Transformed} = MPD_{30}/(1 - 1.0\%) = 0.446/0.99 = \underline{\mathbf{0.451\ mm}}^{*}$$

8.2 Implementation Example #2

Locked-wheel, ribbed-tire friction testing was performed at a test speed of 50 mph (80.5 km/h) on a high-speed state highway. The average test results at 50 mph (80.5 km/h) are:

$$FN_{50R} = 42.2, \text{ and } MPD_{50} = 0.439 \text{ mm}$$

The transformed results at 40 mph (64.4 km/h) are:

$$FN_{40R\ Transformed} = FN_{50R}/(1 - 5.5\%) = 42.2/0.945 = \underline{\mathbf{44.7}}$$

$$MPD_{40\ Transformed} = MPD_{50}/(1 + 1.0\%) = 0.439/1.01 = \underline{\mathbf{0.435\ mm}}^{*}$$

*Note that transformation of the high-speed laser texture data is not necessary.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based on the results of this assessment, it was confirmed that the test results obtained with the CTM are both repeatable and reproducible. It was also confirmed that the CTM is highly correlated with the 64 kHz high speed laser texture measuring device currently employed by the Florida DOT. These observations confirm that the CTM is very well suited for calibration verification and spot reference testing purposes. The excellent correlation of this instrument with the high speed laser will also facilitate direct comparison of texture measurements on Florida pavements with those from other states and research facilities.

The DFT was also found to be highly repeatable, but far less reproducible than the CTM in this study. While providing reasonable correlations with the full scale, locked-wheel friction test data, the DFT was not found to be statistically reproducible with like equipment owned and operated by others (NCAT). It is expected that the reproducibility of the DFT may improve upon further testing, depending on the condition of the equipment being compared with. It is noted that calibration, maintenance, and close conformance with the ASTM test methods and the general operation and calibration procedures described in Appendix A of this report are critical to the success of such comparisons. Further, it was found that the ribbed tire test data were better correlated with the results of the FDOT portable DFT device than were those from the smooth tire test. It was also confirmed that the smooth tire test is uniquely suited for IFI implementation. Based on this observation, it is clear that the Florida DOT would have to adopt smooth tire testing in accordance with ASTM E 524 in order to successfully implement IFI. This is not recommended since the Florida DOT currently maintains an extensive historical database of ribbed tire test data and institutional knowledge of the implications of ribbed tire test results relative to pavement micro-texture.

As an alternative to the implementation of IFI, a practical method of transforming pavement friction and macro-texture test data obtained within a working range of highway speeds with the Florida DOT locked-wheel friction test unit and the ribbed tire is proposed. Since the results of the locked-wheel, ribbed-tire friction test are known to be significantly influenced by pavement micro-texture, and high-speed laser measurements in terms of MPD are demonstrated to provide a direct measure of macro-texture, FN_{40R} and the complementary MPD data together may be readily employed to fully characterize the frictional properties of a given pavement surface. This recommended approach allows the Florida DOT to maintain its historical database of locked-wheel, ribbed-tire friction test data, while adding a direct measure of macro-texture and the flexibility of testing at variable speeds.

9.2 Recommendations

The methods and procedures described in this report have not been fully validated, and continued monitoring of inventory test data is recommended. Regardless, it is recommended that the results from this research be immediately implemented, and if necessary, the correlations presented herein be modified, as necessary to better reflect field conditions when sufficient data to support such modifications become available. Thus, it is highly recommended that friction test results should be input into the SHRS database as collected, and with a note of the test speed if different from the standard. Any transformation of test data, as described herein should be performed by the end user.

The results of this study reveal that a reliable and repeatable measure of pavement texture may be obtained with both the high-speed laser and the CTM. Other researchers have suggested that this technology may also be used to detect and quantify segregation for quality assurance purposes [34, 35]. It is recommended that the Florida DOT consider further research employing the methods proposed in NHRCP Report 441. The expected result of such research would include a methodology to measure and accept pavements based on macro-texture, using acceptance bands for pavement macro-texture similar to those currently used for density, and using the standard deviation of the measured macro-texture as another measure of construction uniformity.

A practical calibration standard that can be employed for both the truck-mounted 64 kHz, high speed laser and the portable CTM is desirable. It is recommended that a mechanical turntable device be designed and fabricated for such purposes. The proposed turntable would have to function in the static mode when being used with the CTM device (see Appendix B, Section B 4) and spin at a constant speed in the dynamic mode when being used with the truck-mounted laser. The proposed calibration turntable would also need to provide leveling capability, resistance to vibration and wobble during dynamic operation, and interchangeable calibration disks to accommodate a practical range of surface textures.

Other researchers have also recommended that it may be beneficial to develop a testing procedure and laboratory equipment that could be used to evaluate the frictional resistance in the laboratory that represents field measured results [35]. Based on the reasonably good correlation between DFT test data and the results of the Florida DOT locked-wheel friction test, it is proposed that the DFT may be used for laboratory testing purposes. Research into the potential use of the DFT in conjunction with laboratory prepared test specimens (perhaps from the Superpave™ Gyratory Compactor) to predict friction properties on the roadway is also recommended. Although such attempts have historically failed due to difficulties in producing laboratory test specimens with similar frictional properties to field conditions, advancements in laboratory equipment technology, including the gyratory compactor and the DFT may enhance the potential for success.

10 REFERENCES

[1] Jackson, N.M., "Measuring Pavement Friction Characteristics at Variable Speeds for Added Safety," Final Report, FDOT Order No. DO-51684 (DO-2022), FDOT, State Research Office, Tallahassee, FL, July 31, 2005.

[2] American Society for Testing and Materials, "Standard Practice for Calculating International Friction Index of a Pavement Surface," ASTM Designation: E 1960-03, *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1226-1230.

[3] Wambold, J.C., Antle, C.E., Henry, J.J., and Rado, Z., "International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements, Final Report," *Permanent International Association of Road Congresses (PIARC)*, Paris, 1995.

[4] American Society for Testing and Materials, "Terminology Relating to Vehicle-Pavement Systems," ASTM Designation E 867-06, *Annual Book of ASTM Standards,* Vol. 04.03, ASTM International, west Conshohocken, PA, 2007, pp. 1049-1058.

[5] American Society for Testing and Materials, "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire," ASTM Designation: E 274-06, *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1000-1005.

[6] American Society for Testing and Materials, "Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests," ASTM Designation: E 501-06, Annual *Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1015-1018.

[7] American Society for Testing and Materials, "Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests," ASTM Designation E 524-06, *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1024-1026.

[8] American Society for Testing and Materials, "Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester," ASTM Designation E 1911-98 (Reapproved 2002), *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1189-1193.

[9] American Society for Testing and Materials, "Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter," ASTM Designation: E 2157-01 (Reapproved 2005), *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1249-1253.

[10] American Society for Testing and Materials, “Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth,” ASTM Designation: E 1845-01 (Reapproved 2005), *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, Pa., 2007, pp. 1168-1171.

[11] American Society for Testing and Materials, “Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique,” ASTM Designation E 965-96 (Reapproved 2006), *Annual Book of ASTM Standards*, Vol. 4.03, ASTM International, West Conshohocken, PA, 2007, pp. 1065-1067.

[12] U.S. Department of Transportation, Federal Highway Administration, “Skid Accident Reduction Program,” Technical Advisory #T 5040.17, Dec. 23, 1980.

[13] Florida Department of Transportation, Office of Work Program (OWP), Section B: Skid Hazard Elimination Program, Tentative Work Program – FY 08/09-12/13 Sep. 21, 2007, http://www.dot.state.fl.us/programdevelopmentoffice/Development/WP/.

[14] Hewett, D. L. and Miley, W. G., “Use of the Smooth Tire in Evaluation of Friction Characteristics of Surface Courses in Florida,” *Presented at the meeting of TRB Committee A2B07 on Surface Properties-Vehicle Interaction*, Transportation Research Board, National Research Council, Washington, D.C., 1992.

[15] Jackson, N.M., Choubane, B., and Musselman, J.A., “A Preliminary Evaluation of FC-5 and FC-6 Friction Courses in Florida,” Paper Presented and contained in the *Proceedings of the Pavement Evaluation 2002 Conference*, Roanoke, VA, October 21-25, 2002.

[16] Jackson, N.M., “Evaluation of Variable Friction Properties of FDOT Friction Courses: Phase I,” Final Report, FDOT Contract # BD-273, FDOT, State Materials Office, Gainesville, FL, November 15, 2003.

[17] Jackson, N.M., Choubane, B., Holzschuher, C., and Gokhale, S., “Measuring Pavement Friction Characteristics at Variable Speeds for Added Safety,” Journal of ASTM International, Vol. 2, No. 10, November/December 2005, Paper ID JAI13041, Available online at http://www.astm.org.

[18] Jackson, N.M., “Implementation of International Friction Index (IFI) in Florida,” Invited Presentation at the *19th Annual Road Profiler User Group (RPUG) Meeting*, Danville, VA, October 15-17, 2007.

[19] McGhee, K.K, Flintsch, G.W., “High-Speed Texture Measurement of Pavements, Final Report”, VTRC 03-R, Virginia Transportation Research Council, Charlottesville, Virginia, December 2002.

[20] Flintsch, G.W., León, E.D., McGhee, K.K., Al-Qadi, I.L., "Pavement Surface Macrotexture Measurement and Application," Presented and contained in the Proceedings of the 82nd Annual Meeting of the Transportation Research Board, National Research Council, Washington, D.C., January 12-16, 2003.

[21] Mokarem, D.W., "Use of the Digital Surface Roughness Meter in Virginia," Virginia Transportation Research Council, Report No. VTRC 07-R4, July 2006.

[22] Liu, R., Chen, X., Gan, X., Li, J., Rao, Y., Xing, H., Liang, R., "Investigation of Short Range Sensing Devices for use in Non-Destructive Pavement Evaluation," TxDOT &-3969-1, Texas Department of Transportation, Austin TX, October 2000.

[23] Walker, R. S., "Development of a Laser Based Texture Measuring System," Research Project #2981, The University of Texas at Arlington, Transportation Instrumentation Laboratory, 2001.

[24] Cackler, E.T., Ferragut, T., Harrington, D.S., "Strategic Plan for Improved Concrete Pavement Surface Characteristics", National Concrete Pavement Technology Center, Iowa State University, 2711 South Loop Drive, Suite 4700 Ames, IA 50010. Sponsored by FHWA under coop. agreement DTFH61-01-X-00042 (Project 15, Part 1, Task 3).

[25] Hoerner, T.E., Smith, K.D., Larson, R.M., Swanlund, M.E., "Current Practice of PCC Pavement Texturing", submitted for Presentation and Publication at the 82nd Annual Meeting of the Transportation Research Board, National Research Council, Washington, D.C., January 12-16, 2003.

[26] McDaniel, R.S., Thornton, W.D., Dominguez, J.G., "Field Evaluation of Porous Asphalt Pavement", sponsored by The Institute for Safe, Quiet and Durable Highways, Heritage Research Group, and Milestone Contractors, L.P. and Purdue University**,** Final Report SQDH 2004 – 3**,** May 2004.

[27] Button, J.W., Fernando, E.G., Middleton, D.R., "Synthesis of Pavement Issues Related to High-Speed Corridors", performed by Texas Transportation Institute, The Texas A&M University System, College Station, Texas, funded by Texas Department of Transportation Research and Technology Implementation Office, Austin, TX., Report No.FHWA/TX-05/0-4756-1, September 2003 – August 2004.

[28] Henry, J. J., *NCHRP Synthesis of Highway Practice 291: Evaluation of Pavement Friction Characteristics*, Transportation Research Board, National Research Council, Washington, D.C., 2000.

[29] Hall, J.W., Titus-Glover, L., Smith, K.L., Evans, L.D., Wambold, J.C., Yager, T.J., and Rado, Z., "Guide for Pavement Friction, Final Guide - Draft," National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., 2006.

[30] ODOT Research Request for Proposals, "Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations", PS-07-17.

[31] Kuennen, T., "Creating Friction Where Rubber Meets the Road," *Better Roads,* Vol. 73 Number 10, October 2003.

[32] Burgé, P.L., Travis, K., Rado, Z., "A Comparison of Transverse Tined and Longitudinal Diamond Ground Pavement Texturing for Newly Constructed Concrete Pavement," prepared for the Transportation Research Board, funded by the New York State Thruway Authority and the Federal Highway Administration., November 2001.

[33] McGhee, K.K, Flintsch, G.W., "Using High-Speed Texture Measurements to Improve the Uniformity of Hot-Mix Asphalt, Final Report", VTRC 03-R12, Virginia Transportation Research Council, Charlottesville, Virginia, May 2003.

[34] Rowe, G.M., Meegoda, J.,Jumilkis, A.A., Sharrock, M.J., Bandara, N., Hettiarachchi, H., "*Detection of Segregation in Asphalt Pavement Materials using the ARAN Profile System,"* FWD and Road Profile User group, New Jersey, October 2002.

[35] Vollor, T.W., Hanson, D.I., "Development of Laboratory Procedure For Measuring Friction of HMA Mixtures – Phase 1", Sponsored by the Federal Highway Administration, NCAT Report 06-06, December 2006.

[36] Jackson, N.M., Malley, S.W., and Whitten, B.N., "Analysis of Flexible Pavement Performance Under Accelerated Loading at the National Center for Asphalt Technology Oval Test Track Facility - Phase I," Final Construction Report, TDOT Project # (TNSPR) RES1135, Contract # CUT181, Tennessee Department of Transportation, Nashville, TN, November, 2000.

[37] Iman, R.L. (1994), A Data-Based Approach to Statistics, Duxbury Press, Belmont California.

[38] American Society for Testing and Materials, "Standard Practice for Preparing Precision and Bias statements for test Methods for Construction Materials," ASTM Designation C 670-03, Annual *Book of ASTM Standards*, Vol. 4.02, ASTM International, West Conshohocken, Pa., 2006, pp. 347-355.

[39] Nippo Sangyo Co., Ltd., "Dynamic Friction Tester Manual," 12-26 Higashi-Tokura 2-chome, Kokubuji-Shi, Tokyo 185-0002, Japan, www.nippou.com/en/products/dft.html

[40] Nippo Sangyo Co., Ltd., "C-T-Meter Instruction Manual," 12-26 Higashi-Tokura 2-chome, Kokubuji-Shi, Tokyo 185-0002, Japan.

11 APPENDICES

Page

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A

Dynamic Friction Tester (DFT) Operations & Reference Manual

APPENDIX A

TABLE OF CONTENTS

A 1 INTRODUCTION

A 1.1 PURPOSE AND BASIC FUNCTION

The DFT is used to measure the frictional properties of paved surfaces as a function of speed. The DFT equipment and test method are described in ASTM E 1911 [8]. The DFT consists of a horizontal spinning disk fitted with three spring loaded rubber sliders which contact the paved surface as the disk rotational speed decreases due to the friction generated between the sliders and the paved surface. Each slider is spring-loaded to 11.8 *N* (2.65 lbf). A water supply unit delivers water to the paved surface during testing. The water supply is regulated by elevation, and the optimum positioning for the water tank is 0.6 m (1.97 ft) above the test surface. At this position, the water flow is maintained at 3.6L/min (0.95 gal/min). The torque generated by the slider forces measured during the spin down is used to calculate the friction as a function of speed.

A 1.2 MEASURING PRINCIPLES

Figure A 1 shows the force diagram that pertains to the friction calculation used by the DFT. The test pad (tire rubber) is pressed against the ground with a force **W**. A horizontal force **F** is applied to move the rubber along the road surface at a speed (tangential velocity) **V**. The coefficient of friction, **μ**, can be found from the relationship between **F** and **W** (both known quantities):

$$\mu = F/W \quad (1)$$

Since **W** is constant, a constant of proportionality (**K**) can be substituted in for 1/**W** in equation (1) to obtain:

$$\mu = K * F \quad (2)$$

It is seen from equation (2) that the coefficient of friction, **μ**, varies in direct proportion to the force, **F**. On the DFT, the tire rubber (test pads) is fitted to the underside of a horizontal spinning disk. The disk drops to the test surface under a constant load **W**, perpendicular to the surface. The disk rotates at a speed where the tangential velocity at the location of the test pads is **V**. The force, **F,** needed to overcome the dynamic friction is measured and converted to **μ** with equation (1). The linear speed, **V**, of the test pads is determined from the following:

$$V = L * \omega \quad (3)$$

where, **L** is the distance, in meters, from the center of the rotating disk to the test pads and, **ω** is the rotational velocity, in Hertz, of the rotating disk.

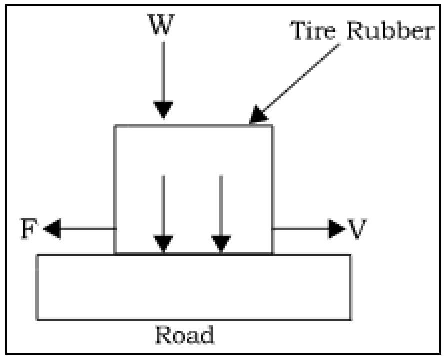


Figure A 1 Force Diagram

A 1.3 PRECAUTIONS PRIOR TO OPERATION

ASTM standard E1911 proposes that the DFT operator should determine a standard of safety to implement in the laboratory and field. For FDOT, the following guidelines have been identified and are recommended to be adhered to:

- When turning the DFT on its side for maintenance or calibration, make sure the switch on the DFT body is off. This prevents the rotor from spinning and reduces the potential for serious injury as a result.
- Before running tests, insure that the screws holding the rubber test pads in place are securely tightened. During extended periods of testing, periodically check to see that the screws did not loosen. Loose components can result in objects being projected from the DFT.
- As a precautionary measure keep all body parts at least three feet away from the DFT during operation.
- In sandy environments, try to keep dust and sand from entering any of the mechanical components of the DFT.
- Do not add chemicals to the water supply or use saltwater in the DFT. Use only clean, freshwater to prevent corrosion or blockages in the lines.
- Make sure that the pavement surface being tested is free from loose pebbles and other debris.

A 1.4 DEVICE AND COMPONENT DIMENSIONS

See Figures A 2 - A 5 below for the dimensions (in mm) of the Dynamic Friction Tester.

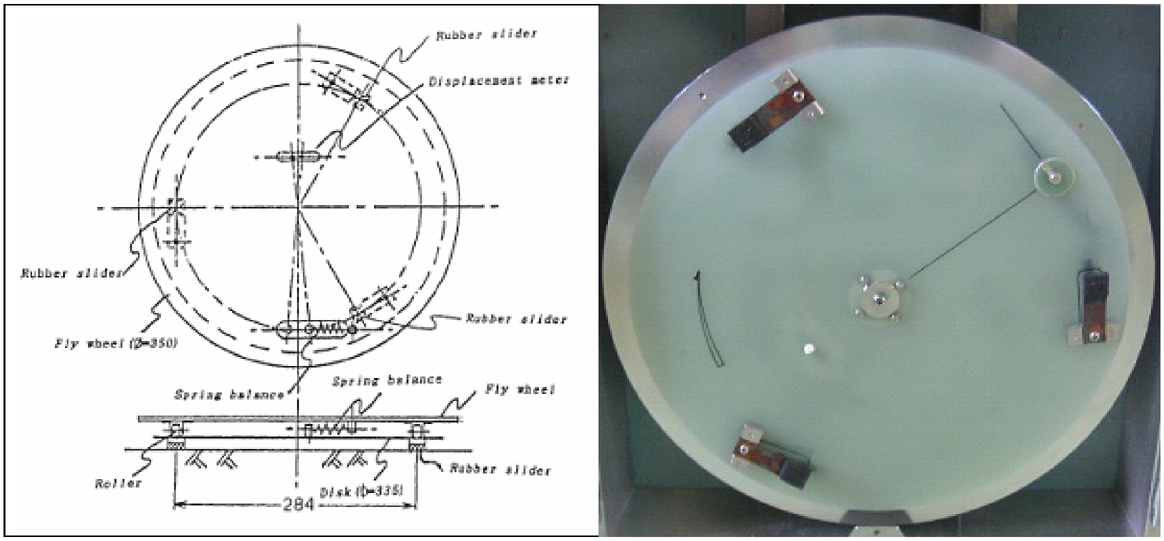


Figure A 2 The Dynamic Friction Tester Bottom View [8]

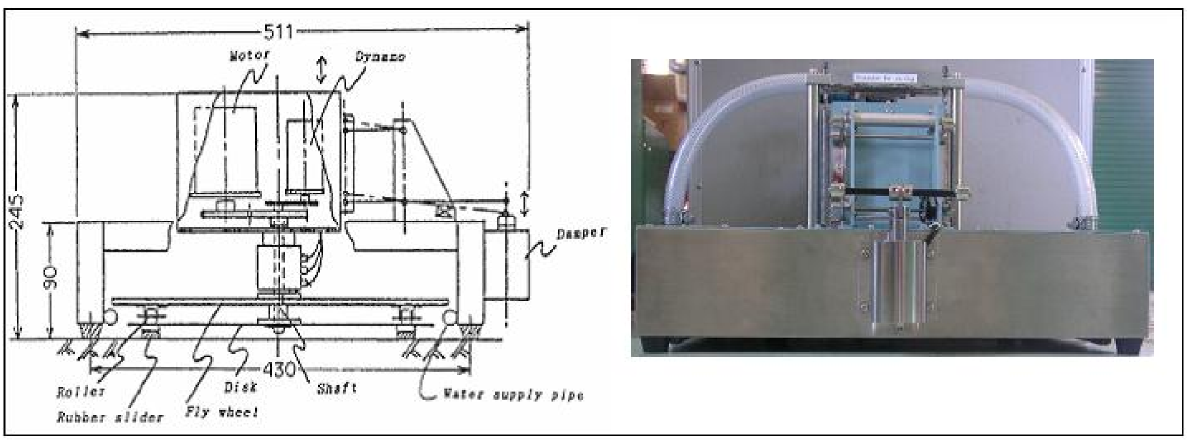


Figure A 3 The Dynamic Friction Tester Front View [8]

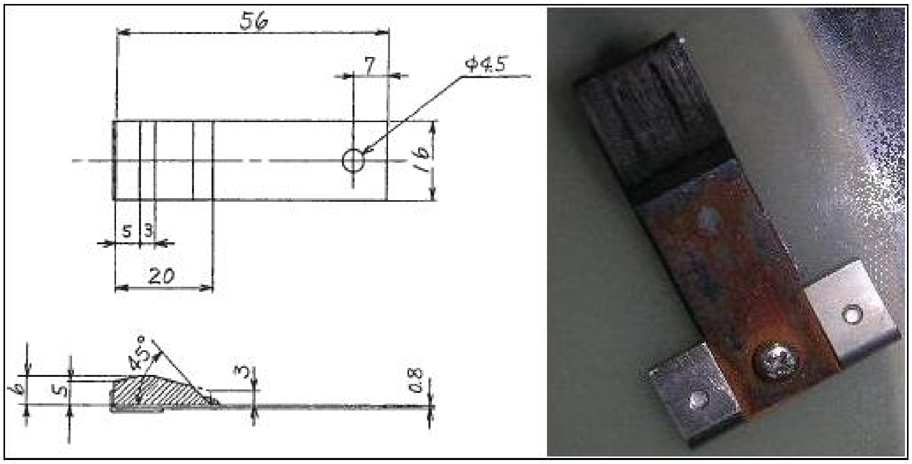


Figure A 4 The Rubber Slider [8]

See Figure A 5 below for the schematic of the water supply tank connected to the DFT.

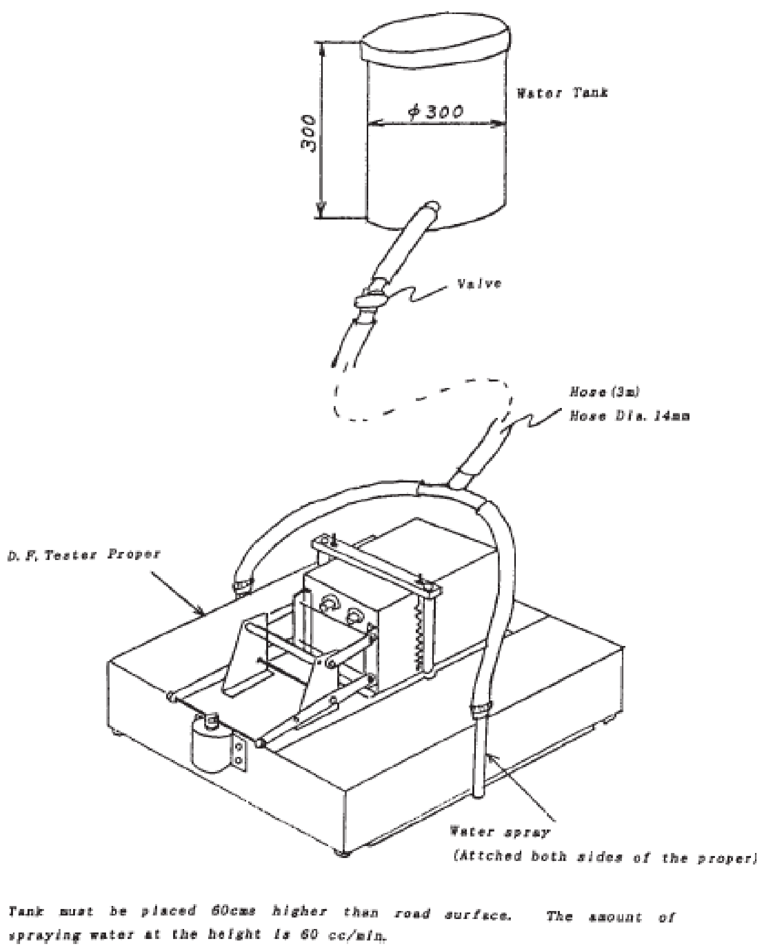


Figure A 5 The DFT Water Supply Tank [39]

A 1.5 CONTROLS AND DATA ACQUISITION SYSTEM

The DFT is interfaced by an external controller which allows data to be directly stored and downloaded for later analysis. A laptop computer can also be used in conjunction with the controller to perform testing with the DFT. See Figure A 6 below for a labeled diagram of the controller and a picture of the **'D.F. Tester Menu'** screen.

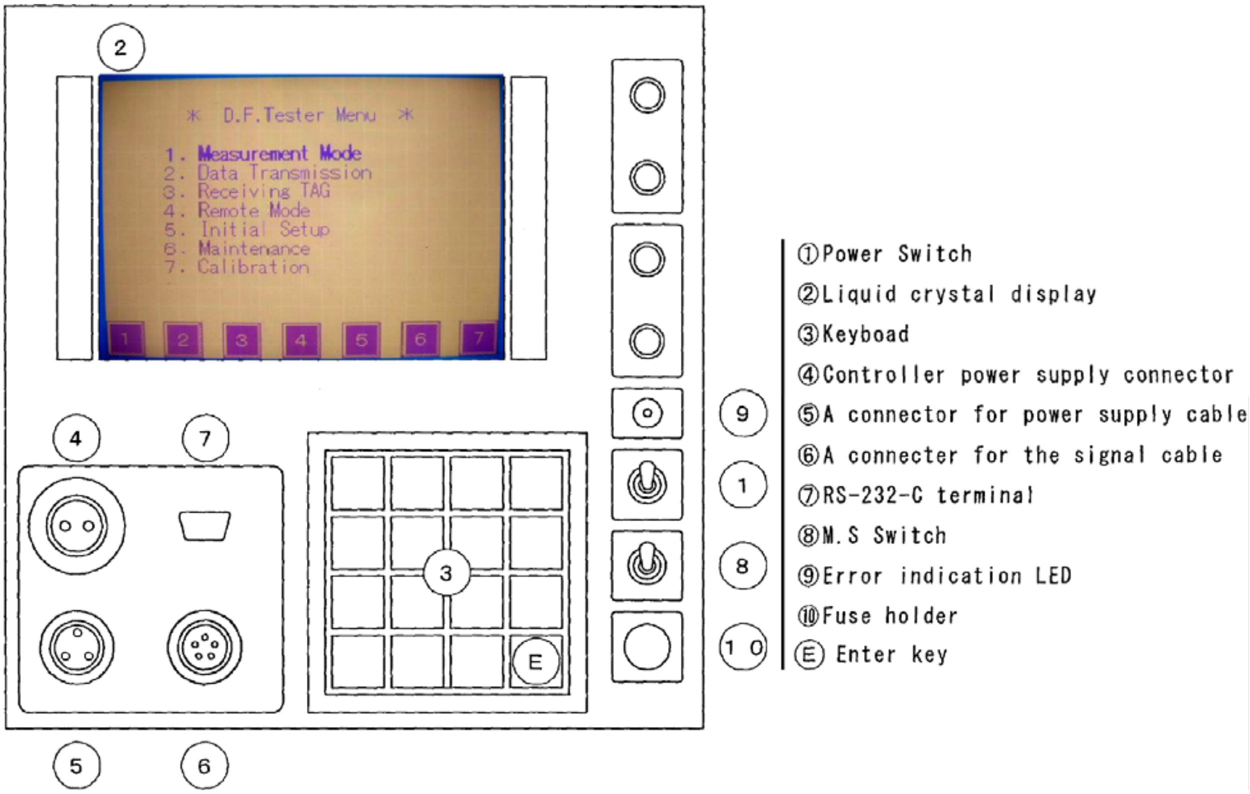


Figure A 6 Controller Diagram [39]

The DFT comes with software that must be installed on the laptop to establish a link to be established between the DFT controller and laptop. Once the software is installed, the operator can run tests from the laptop, retrieve data stored on the controller, send information about tests to the controller, initialize the communication settings, and display data from files downloaded to the laptop.

A 2 DFT TEST PREPARATION

A 2.1 HARDWARE

Before setting up the DFT, make sure that the rubber test pads on the spinning rotor are not in need of replacement. The pads need replacement when they become worn down to half of their original size (this can be checked with micron calipers). If replacement is necessary, turn the DFT on its side on the rubber stoppers and remove each of the Phillips head screws holding the sliders in place. Replace the test pads and return the DFT to its normal operating position (See "Section A 5: DFT Maintenance Procedures" for more detail). Also, make sure that when moving the DFT the correct handle is used.

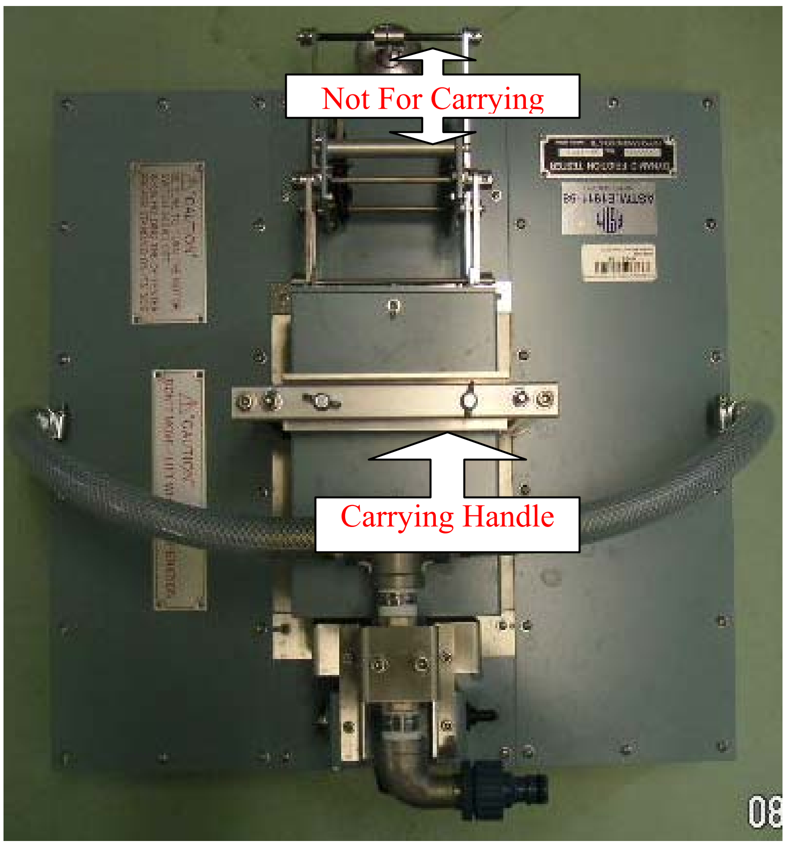


Figure A 7 Handle for Carrying

1. If the Circular Track Meter (CTM) is being used in conjunction with the DFT, place the DFT on the outline from the previous CTM test. Make sure that the switch on the DFT body is off. Also make sure the ground is free from debris.
2. Connect the DFT to the controller (refer to Fig. A 6 #5 & #6) with the supplied 3-prong (power) and 5-prong (data) cables.
3. Connect the DFT to the water supply tank with the hose provided. Make sure to elevate the water tank because the DFT is gravity fed water when the solenoid valve opens. Note: Water flow will start immediately if test is in manual mode or speed is set to less than 60 km/h, otherwise flow will start at 60 km/h.
4. Connect a Power Supply
    a. If AC voltage is available, or the testing vehicle has an inverter installed, and AC-to-DC converter will be necessary to convert the AC voltage into 12V DC. Connect the 2-prong end of the power cable to the controller and the alligator clips to the AC-to-DC converter.
    b. Car Battery Power Source – Connect the 2-Prong end of the power cable to the controller (refer to Fig. A 6 #4) and the alligator clips directly to the battery – make sure to have enough amp-hour capacity since the DFT will draw 15-20 Amps of current at 12V DC or have the battery hooked to an alternator charger system while running tests.
    c. An AC adapter is supplied with the DFT controller unit, but is only used for powering the controller to transfer data to a laptop. This adapter will not provide the power necessary to run the drive motor on the DFT.
5. Connect the RS-232C cable from the controller (refer to Fig. A 6 #7) to the laptop serial port. Data transfer is slightly slower through this port on the laptop, so an alternative would be to use a serial-to-USB converter cable. If using the converter, the cable should show up in the laptop Device Manager under ports (com & LPT), not Universal Serial Bus. See Software Setup section for more details.
6. Turn the power switch on the DFT body to on.
7. Turn the power switch on the controller (refer to Fig. A 6 # 1).

At this point the DFT is ready for testing and data collection. See Figure A 8 for a schematic of the DFT preparation setup.

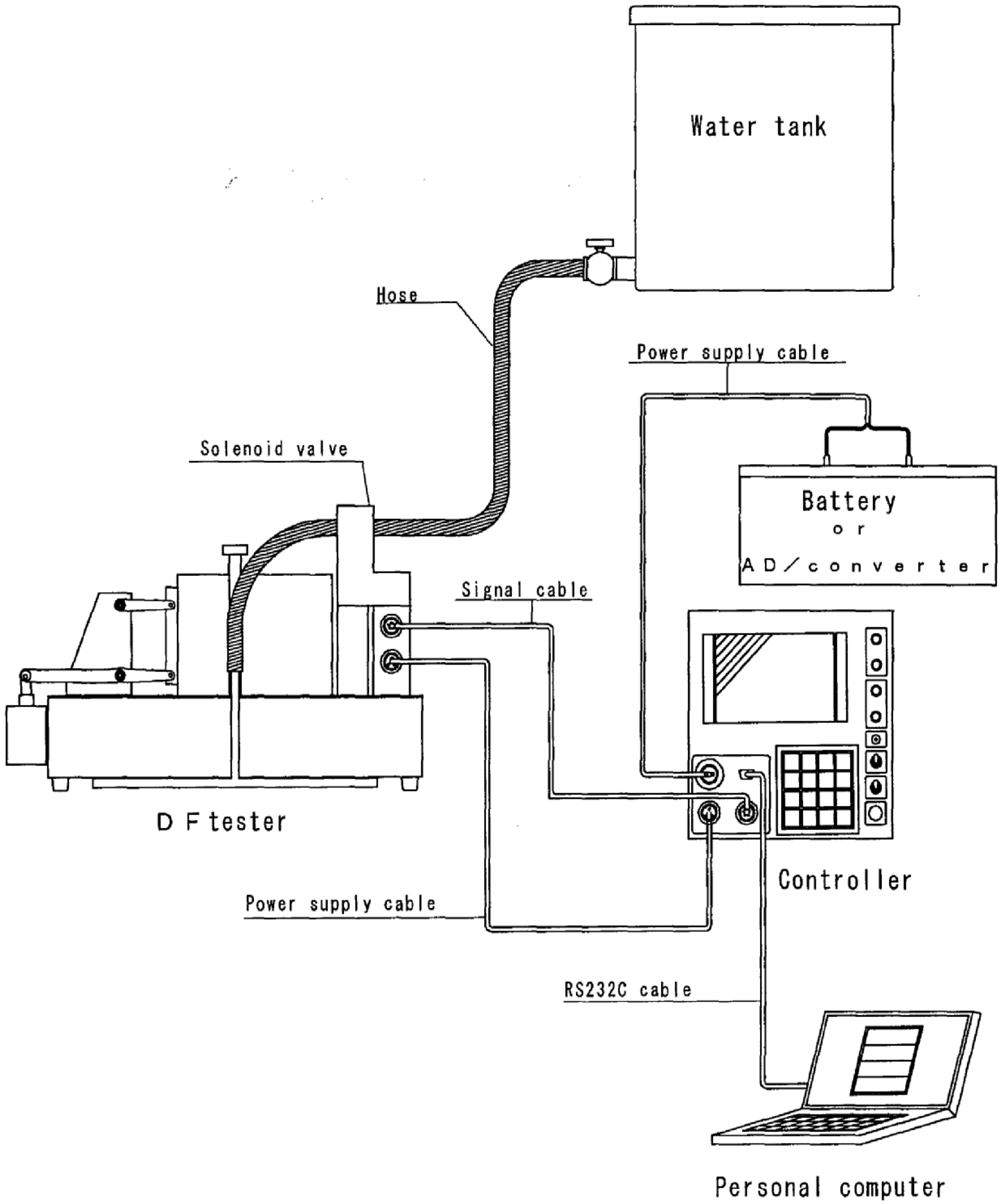


Figure A 8 DFT Preparation Schematic [39]

A 2.2 SOFTWARE

Software must be installed on the laptop that is to be used for data acquisition in conjunction with the DFT. Below are the steps required for successful software installation and initialization with the DFT.

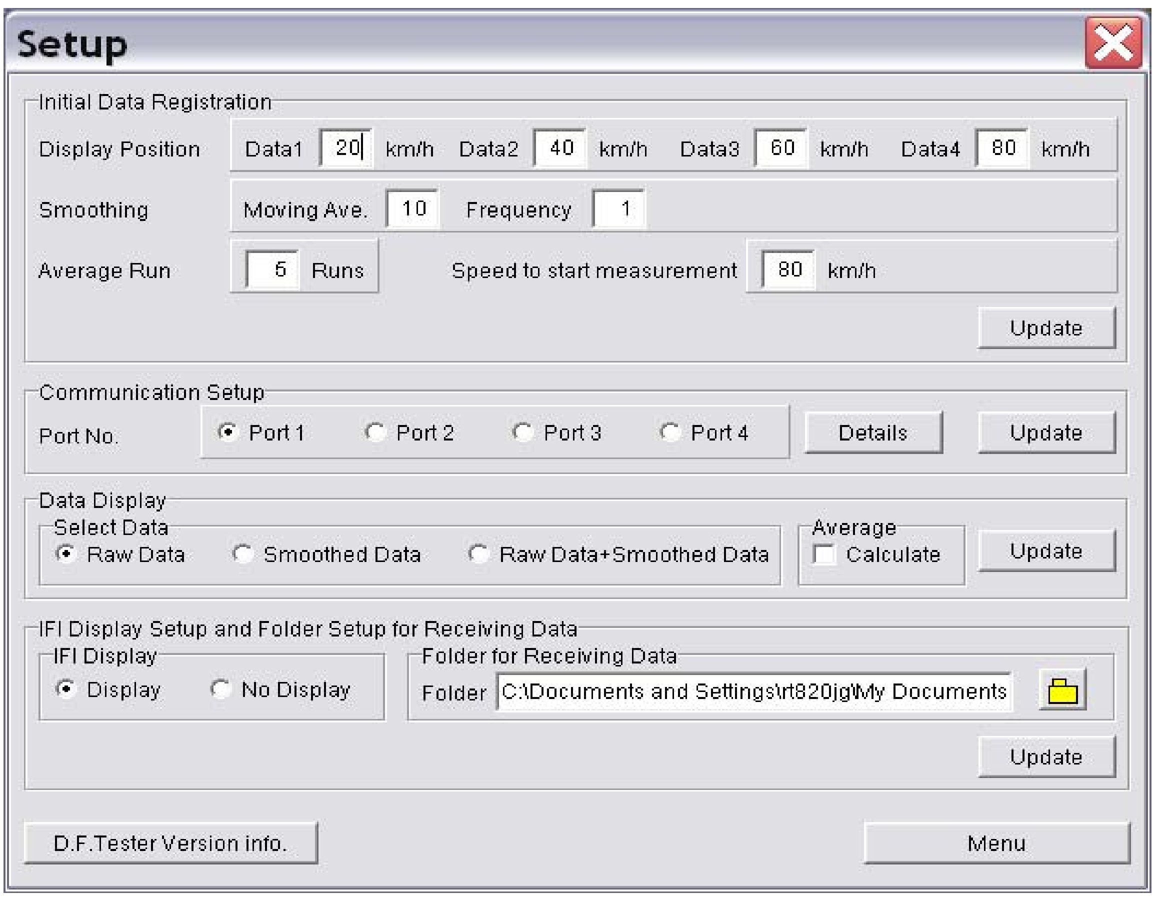
1. Installation to Laptop
   a. Insert the Dynamic Friction Tester Applications CD-ROM into the disk drive of the laptop computer. A window should immediately open with a file called DFTester.exe. Double-Click on this file.
   b. A prompt will come up inquiring where to extract the files to for the installation. Pick an easily remembered location – for example a New Folder on the desktop – and press expand (or extract depending on the program).
   c. Once the files are extracted a new window should come up that is called D.F. Tester Installer. It is necessary to close all open programs before continuing with the installation. Once all programs are closed, press the continue install button on the lower left.
   d. Next the Software User Agreement will come up. You should read it to make sure that you will conform to the guidelines for use of the software and then press the Accept button.
   e. Choose a directory for the file to be installed or accept the default directory and press the start install button.
2. Laptop Port Configuration
   a. Right-Click on My Computer and click Properties.
   b. Click on the hardware tab and then click Device Manager.
   c. Click on Ports (Com & LPT) and double-click on the port that is being used by the DFT – it may be called prolific serial-to-USB.
   d. Click on the tab that says Port Settings
   e. Click on “Advanced”
   f. Set the desired port (choose between port 1, 2, 3 or 4) and leave the other settings as default as they are the same as the default settings for the DFT

Application software. Remember the desired port so that it may be selected in the settings of the DFT software application in step 3, part b.

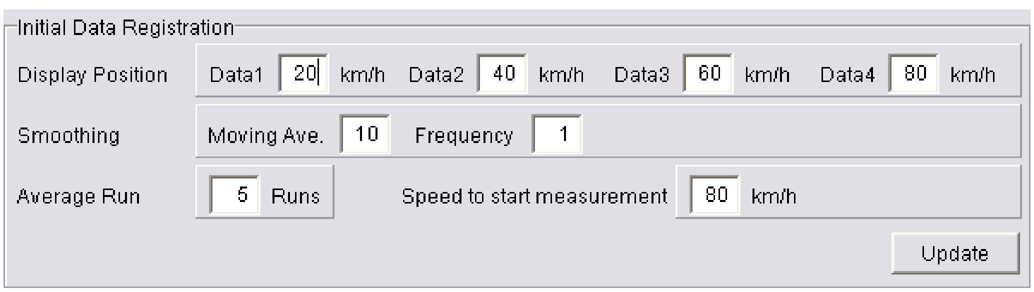
3. Setup and use of DFT Applications Software

a. To begin setting up the software on the laptop click the icon that says DFEnglish.

b. Click the Setup (F10) button to input the necessary parameters for communication between the laptop and the controller. The figure below shows a view of the Setup menu. Each subsection of the Setup menu has an Update button. Press the Update button for any subsection in which changes are made in order to save the new settings.

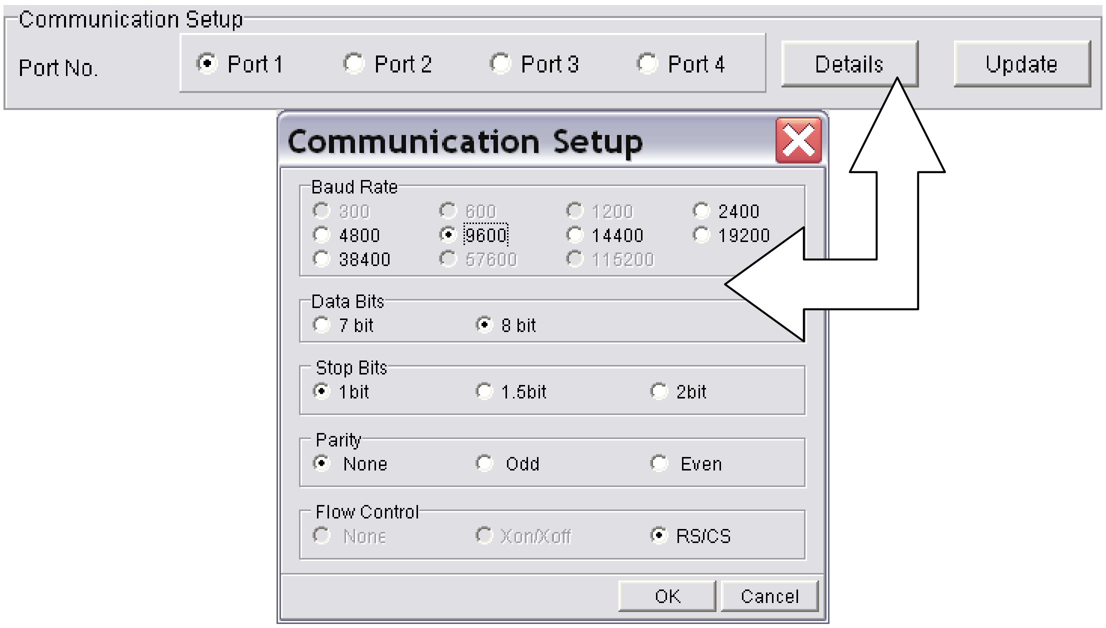


c. Initial Data Registration–This subsection contains four different fields to change your output parameters. The **Display Position** section will determine at what speeds the friction values will be displayed once data is collected and the output graph is viewed. To change any of these values, simply click the boxes and input the desired value. The **Smoothing** section sets the interval for collecting data points (it is recommended to be left at its default value). The **Average Run** section tells the DFT how many runs to average per test and brings out a single averaged value for the runs in one test. Usually this is set to a value of 1 (one) and the tests are not averaged. The **Speed to start measurement** will tell the controller at what speed to drop the rotating disk and start collecting data. This value can go up to 100 km/h but it is recommended to set the value from 20 km/h up to 95km/h. Click the Update button if any changes are made in this subsection.

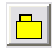


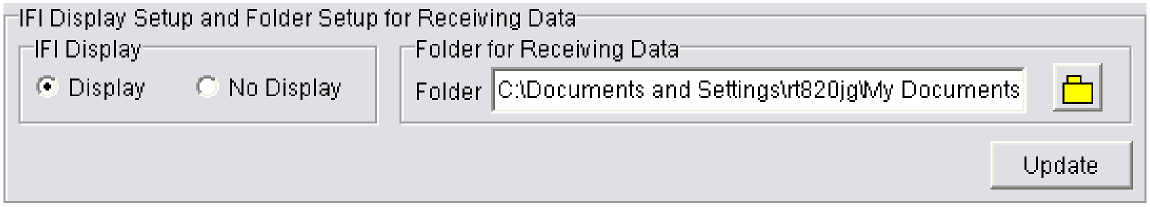
d. Communication Setup - Settings that affect data transfer between the laptop and DFT controller can be altered here. The default settings are usually the same as the settings for the ports on the laptop so it is recommended that the port only be changed if absolutely necessary. If it is necessary to change any other communication settings, click on the Details button. The values for Baud Rate (speed of data transfer in bytes-per-second, use default of 9600), Data Bits, Stop Bits, and Parity need to be the same as the values set on the laptop and DFT controller.

Once again, you must hit update in the **Communication Setup** section if any changes are made.



e. Data Display – In this section, choices can be made for the way the collected data is output to the **Data Display** section. You can choose from raw data, smooth data or a combination of both. Selections should be based on accuracy needs. Also, this section contains a checkbox for calculating the average friction value. Check this box if it desired to have an average friction value displayed in the **Data Display** mode.

f. IFI Display and Folder Setup for Receiving Data – In order to display the International Friction Index parameters in the **Data Display** mode check on the **Display** box. (Other parameters must be input to get values for the IFI. If interested in calculating the IFI, refer to ASTM E1960-03[4] for a full explanation.) To choose a different file to store data in than the default file click on the  icon and select the desired folder.



g. When completed making changes in the **Setup Menu**, click the 

button to return to the **Main Menu**. The DFT and Laptop should now be properly configured to perform tests and acquire data.

4. Initial Setup on Controller for use with Laptop

a. To setup the controller to test and communicate with the laptop, press **'Initial Setup'** (option 5, Fig. A 9) on the **'D.F. Tester Menu'**.

Figure A 9 DFT Controller Main Menu

b. There will be three options in **'Initial Setup'** to change: **'Average Run'**, **'Setup Speed'**, and **'Communication Condition'**. Set the **'Average Run'** (Fig. A 10, option 1) to the number of runs needed per test to be averaged. Set the **'Setup Speed'** (Fig. A 10, option 2) to the desired speed that the tests will be run. Press the **'Next'** button of the **'Communication Condition'** (Fig. A 10, option 3). Make sure that the **Baud Rate**, **Bit**, **Parity**, and **Stop** settings are the same values as set on the DFT Applications software and the laptop device manager. If the settings are not the same on the controller, laptop and DFT software the devices will not be able to communicate. Once this is done, the controller is ready for testing and communication with the laptop.

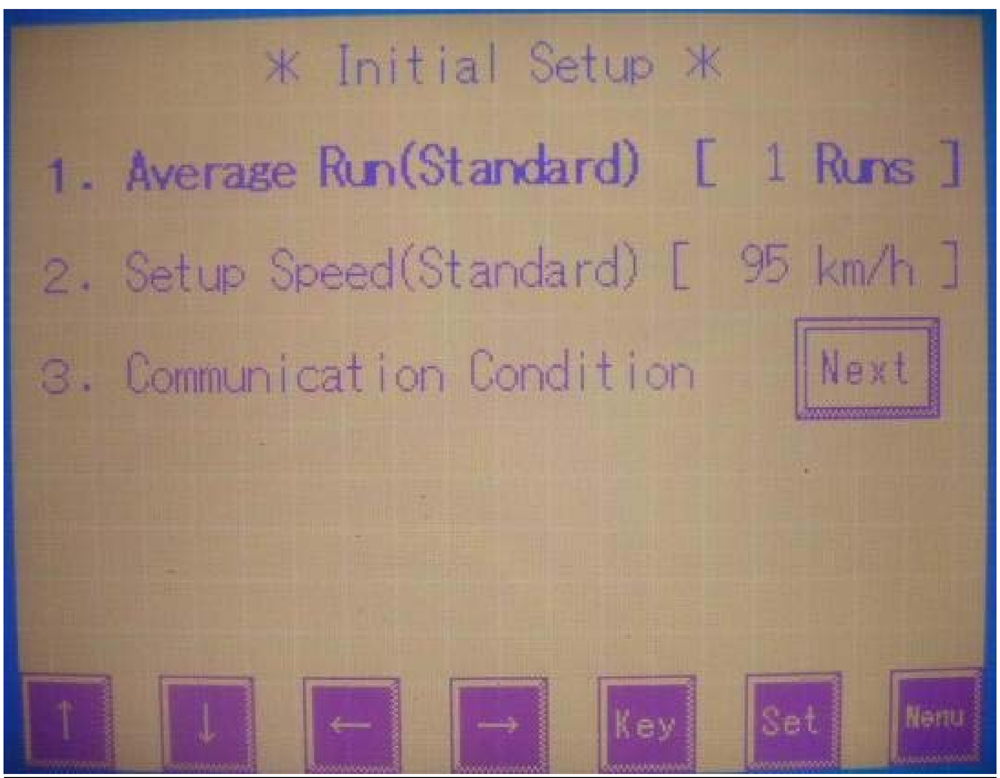


Figure A 10 Controller Initial Setup Screen

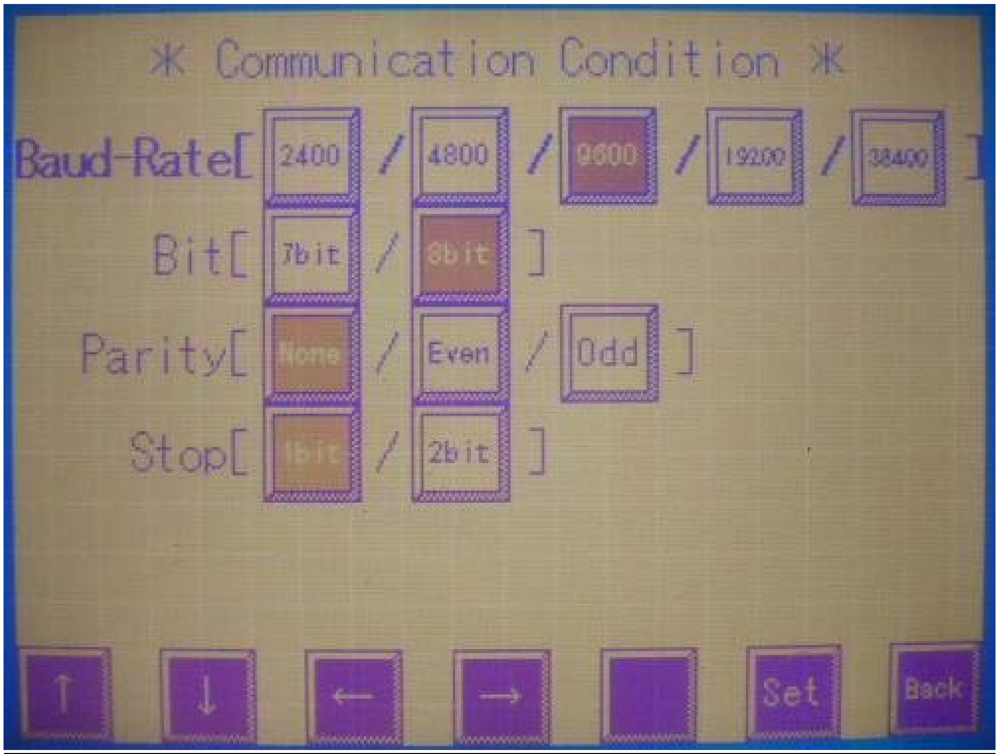


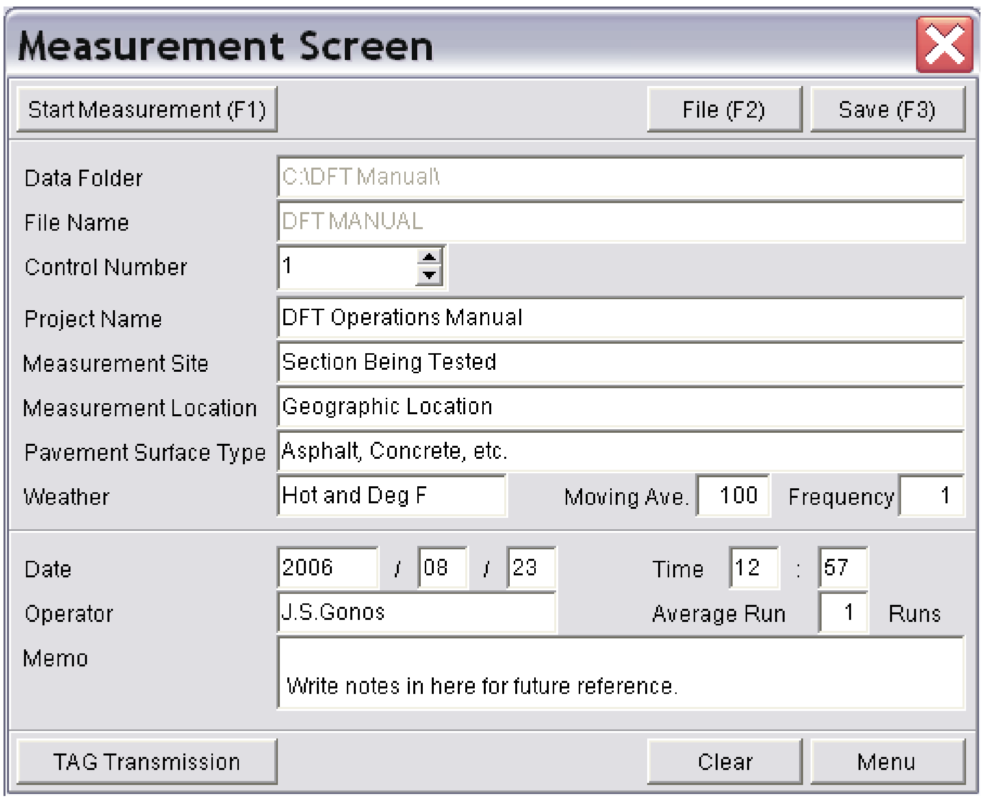
Figure A 11 Controller Communication Setup

A 3 DFT OPERATION PROCEDURES

A 3.1 FIELD OPERATION WITH LAPTOP

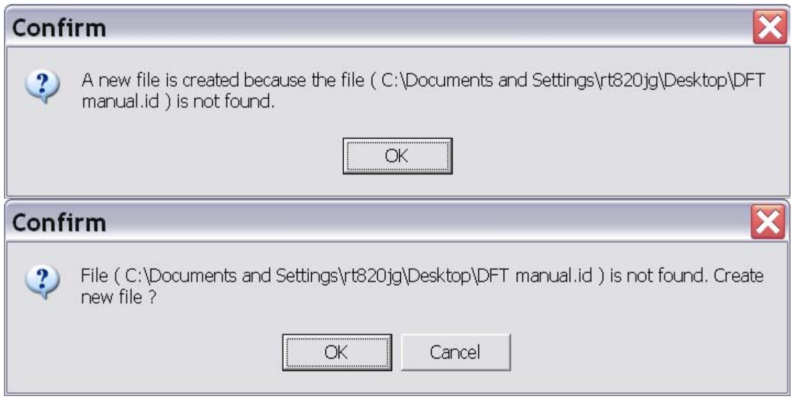
In the previous section, the hardware and software were configured to use the laptop in conjunction with the DFT controller. This section addresses procedures for controlling the DFT with the laptop and collecting data immediately, in lieu of collecting the data with the controller and manually transferring files to the laptop.

1. In the **Main Menu** of the DFT applications software, click the [Measurement Screen (F1)] button.



2. Press the [File (F2)] button and choose a destination folder. Specify a name for the new data file. You will be asked to confirm overwriting an existing file or creating a new file because the one specified is not found. Fill in the blank fields in the **Measurement Screen** and press the [Save (F3)] button. This will save the file to the prescribed data folder and request confirmation for overwriting

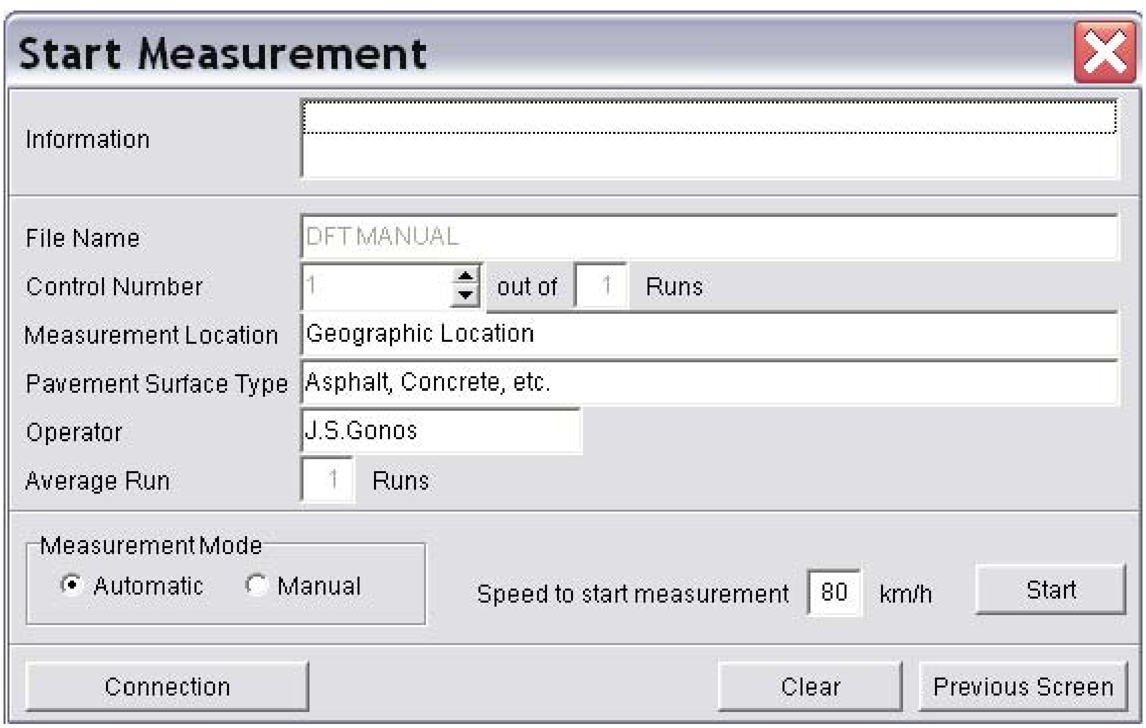
data. Press **OK** for either of the confirmation prompts (shown below) to continue.



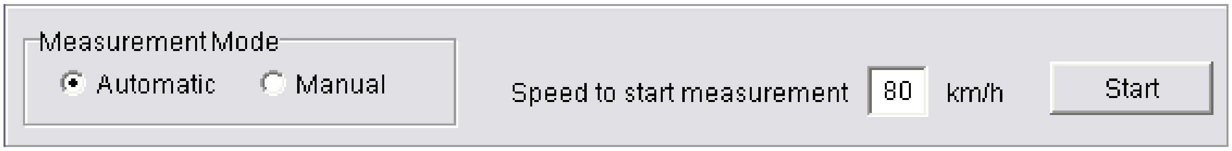
3. The 'Average Runs' checkbox at the bottom of the **Measurement Screen** will be the same value that was initially set in the **Setup Menu**. If it is not, change it to the desired value. The 'Project Name', 'Measurement Site', 'Measurement Location', 'Pavement Surface Type', 'Weather', 'Operator', and 'Memo' fields are up to the operator to input and unnecessary for data collection. Detailed information is recommended though, for future reference.

4. Press the 

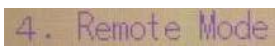
button to connect to the laptop and begin testing.



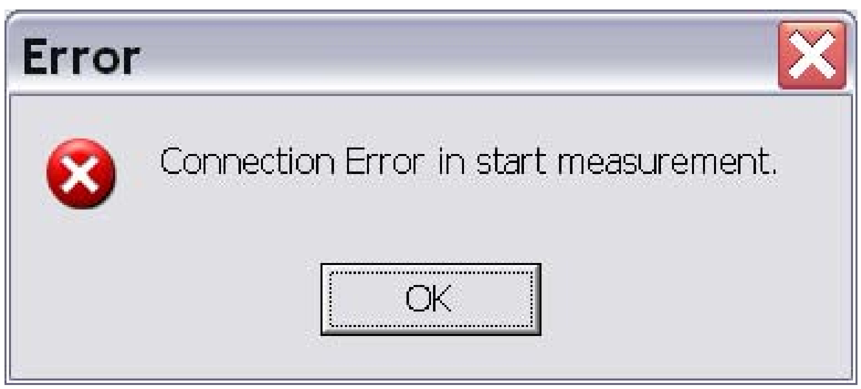
5. Choose between ‘Automatic’ and ‘Manual’ mode. Double check the ‘Speed to Start Measurement’ to make sure it is the desired speed.



6. Click on the 

button and within ten seconds press the 

button (option 4) on the **‘D.F. Tester Menu’** to initialize the connection between the DFT controller and laptop. If the connection is not established within ten seconds, the following error will show. Just click **OK** and try again.



7. Once a connection is established, the ‘**Measurement Mode**’ screen will be displayed on the DFT controller.

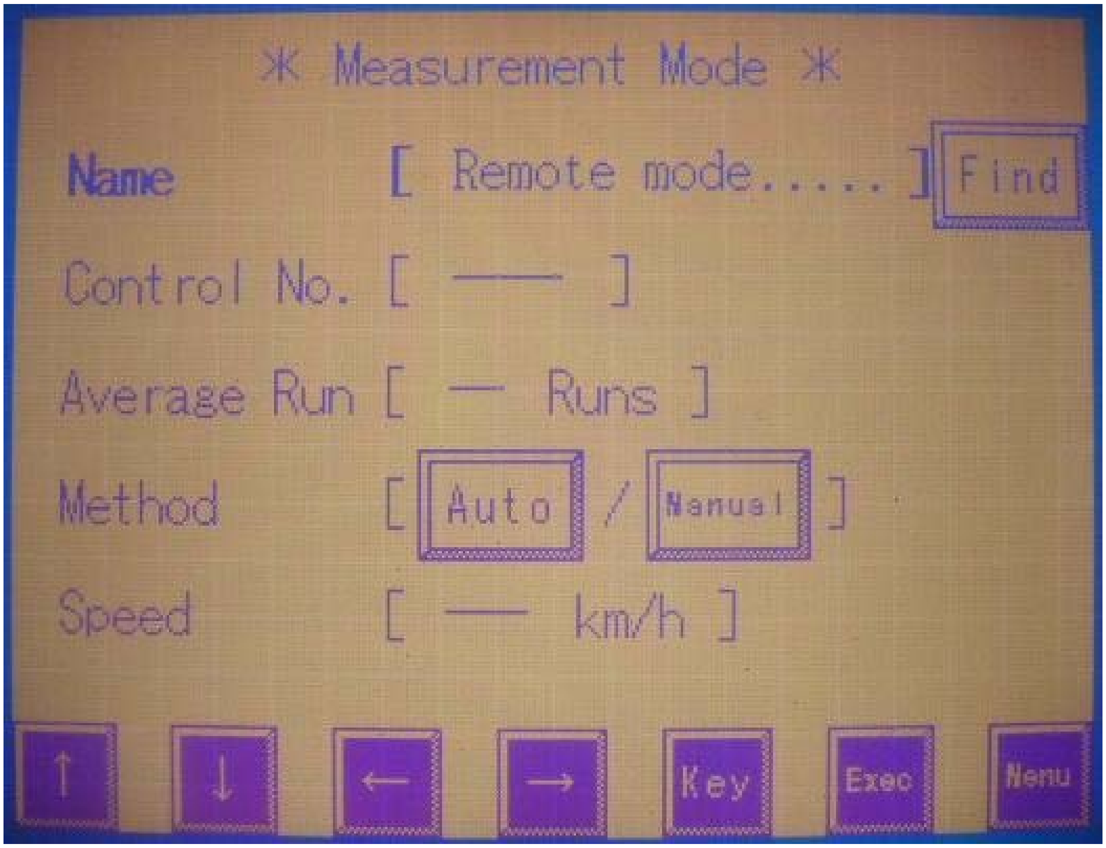
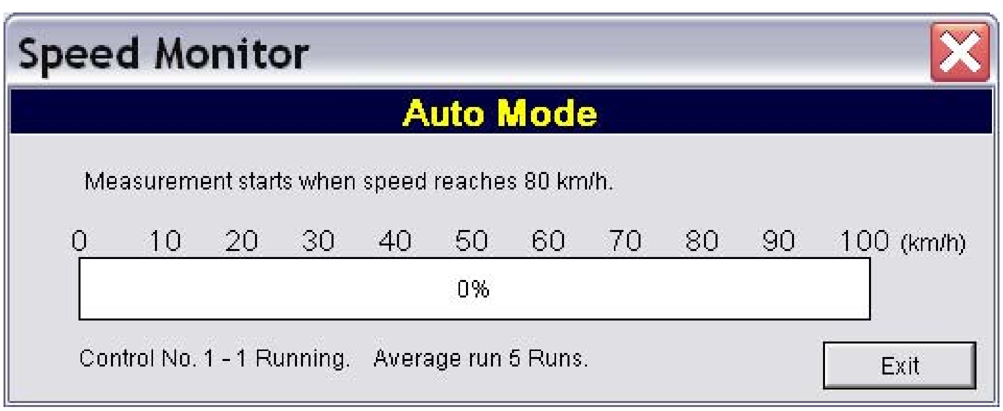


Figure A 12 Controller Measurement Mode Screen

8. Press the 

button on the laptop **Start Measurement** dialog. The **Speed Monitor** screen will be shown on the laptop that will display the speed of the disk during the test.



9. Press down on the counterweight of the DFT to start the test. Make sure that the power on the DFT body is turned on. The disk will start to spin immediately.

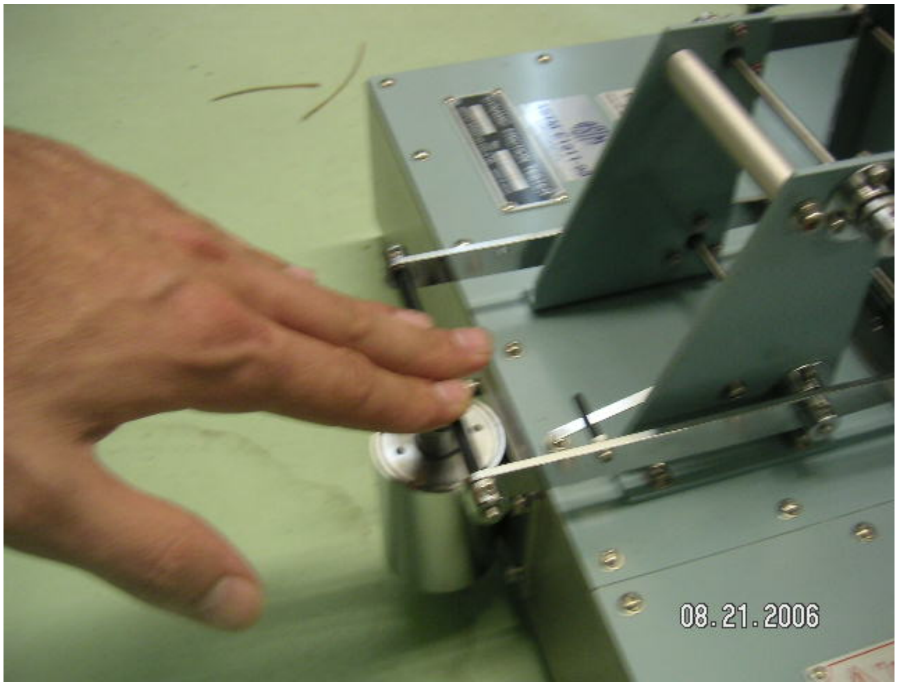
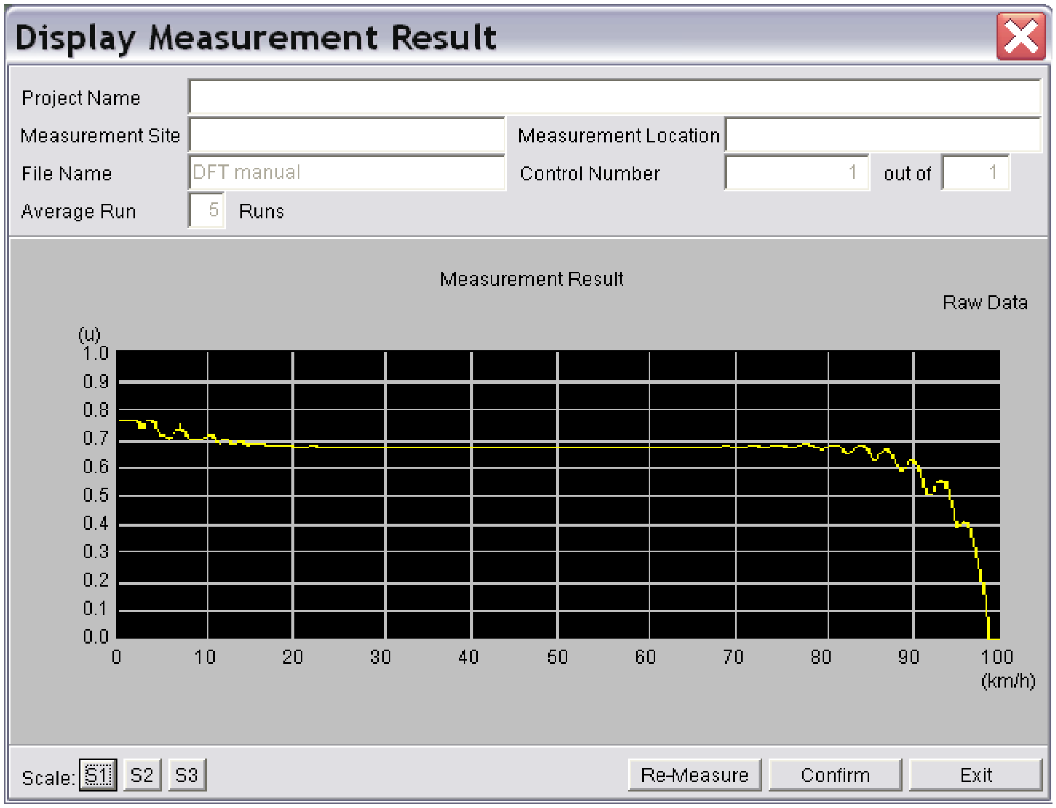


Figure A 13 Starting Disk Rotation

10. Once the test is completed, the data will be transferred to the laptop and a **Display Measurement Result** screen will be shown.



11. Data may be considered unsatisfactory if the transient effects (seen on the **Display Measurement Result** screen between 75 and 100 km/h) do not smooth out. This could be from debris on the test surface or inadequate water coverage. If the data is unsatisfactory, on the laptop, click the [Re-Measure] button to run the test again and the **Speed Monitor** screen will be displayed. If the data is satisfactory, on the laptop, click the [Confirm] button. Once the data is confirmed the **Speed Monitor** screen will be displayed again and the next control number (subsection of each test) will start. The DFT can now be moved to the next test location with the control number noted. Multiple control numbers can be run per file to run tests more quickly. Press the counterweight down again to run the next control number. If a new test is not needed, click on the [Exit] button of the **Speed Monitor** screen to go back to the **Start Measurement** screen. Press the [Previous Screen] button to return to the **Measurement Screen**. Press the [Save (F3)] button to save the collected data.

12. If a new test file is needed press the 

button and repeat the steps in this section.

A 3.2 FIELD OPERATION WITHOUT LAPTOP

To run the DFT without a laptop, setup the hardware as described in the Hardware section (page 58) without plugging in the RS-232c cable. Note that it is still necessary to have the laptop port settings and DFT Applications software configured to transfer files to a laptop later. Regardless of how the DFT will be used, (with or without a laptop) it is still necessary to follow the entire DFT Test Preparation section at the beginning of this manual. The steps for running tests in automatic mode without the laptop interfacing the controller are as follows:

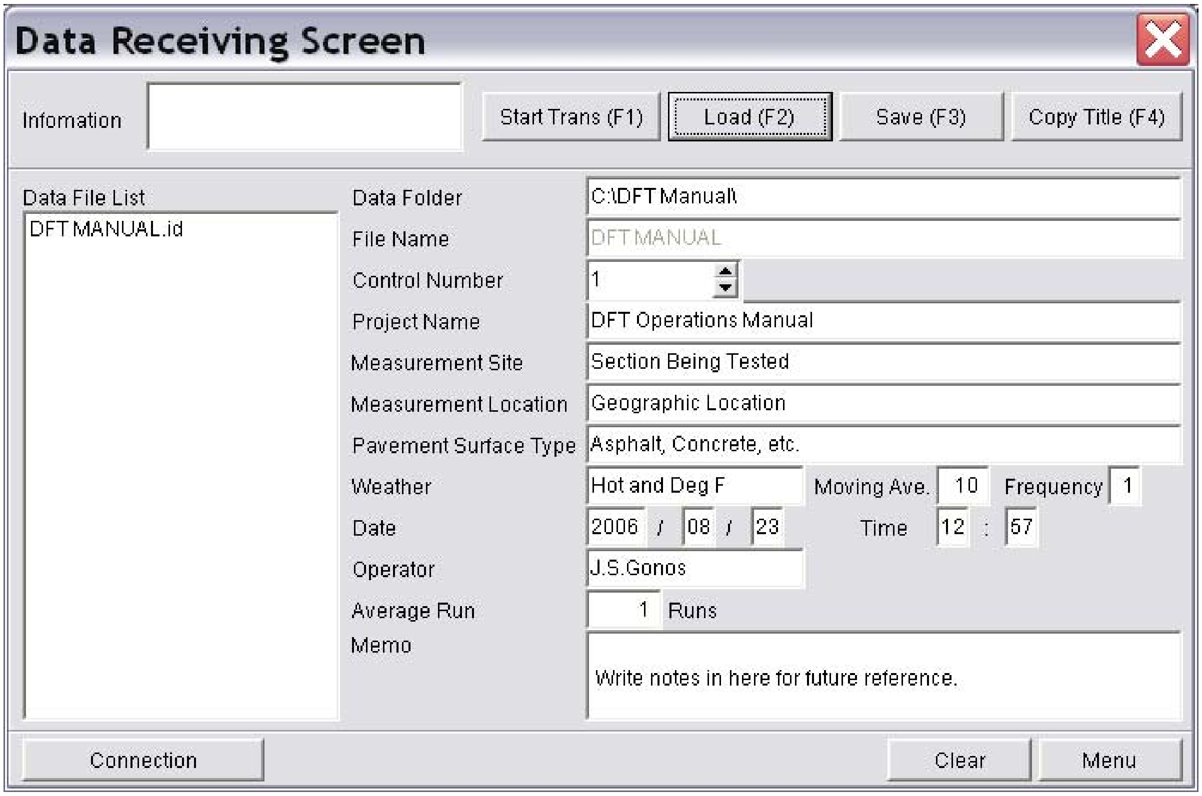
1. On the main menu of the DFT controller press **'Measurement Screen'** (option 1).
2. On the **'Measurement Screen'** press the **'FIND'** button in order to key in a name for the test to be run.
3. Press **'KEY'** at the bottom of the controller screen to type in a name for the next test and then press **'SET'**.
4. Once back on the **'Measurement Screen'** specify the number of runs you would like averaged per test. Set the speed that the disk should drop and acquire data.
5. Press the **'EXEC'** button at the bottom of the screen to enter the information and begin the test.
6. Press down the counterweight on the DFT body down to initiate the disk spinning.
7. Once the disk has dropped and come to a complete stop, press **'Confirm'** to go on to the next run (if more than one run was entered for average runs) or for the next control number.
8. If that was the last test needed, press **'Confirm'** and then press **'Exit'**.

To transfer data from the controller to the laptop:

1. Connect the laptop to the controller via the RS-232C cable. The controller can be powered by the supplied AC Adapter instead of a high current source like a battery or AC-to-DC Converter.
2. On the **Main Menu** of the DFT Applications software, click the 

button.

3. Specify the Data Folder that you would like the files to be transmitted to by typing in the 'Data Folder' field or by clicking the Load (F2) button.



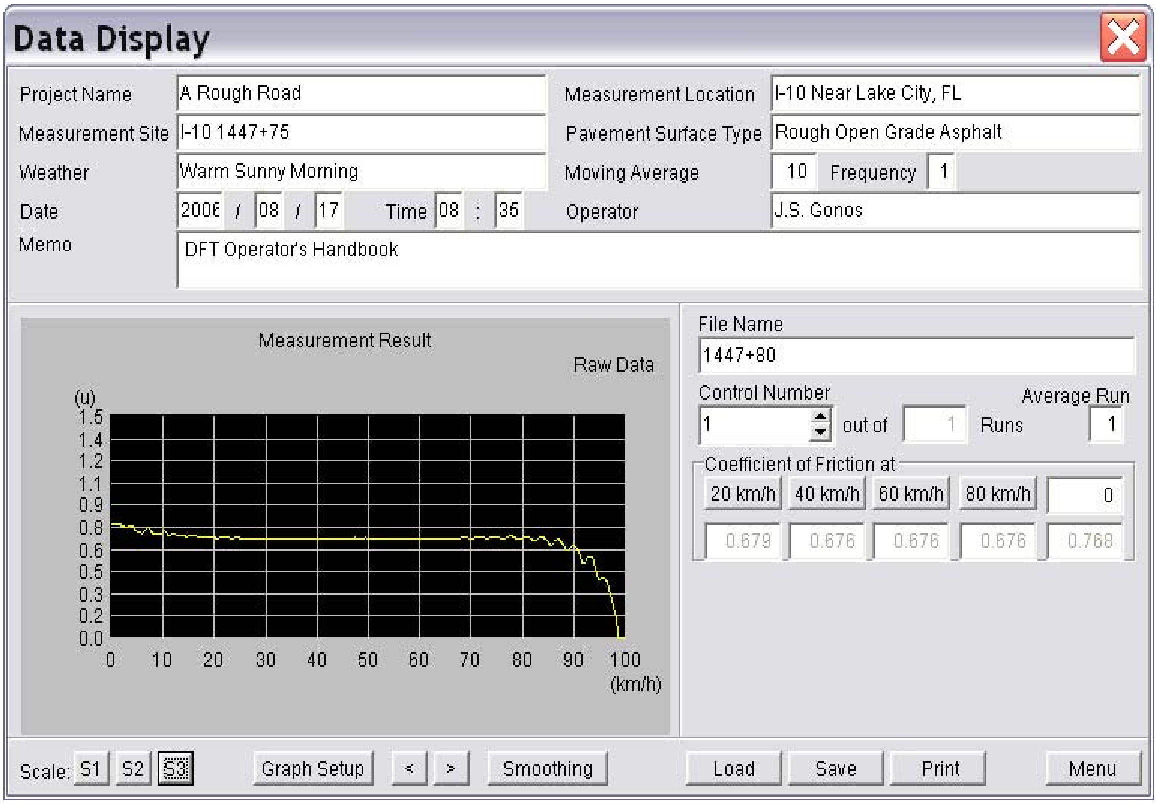
4. Once the **Data Receiving Screen** shows up, click the Connection button to send a signal from the laptop requesting a connection to the controller.
5. Within ten seconds, press the **'Data Transmission'** (Fig. A 9, option 2) on the **'D.F. Tester Menu'**. There will be an error message if the ten second time limit is exceeded. Click **OK** and try again. The connection will be confirmed and display **OK** status.
6. On the laptop press the Start Trans (F1) button.
7. Within ten seconds press the **'GO'** button on the DFT controller screen.

Every data file on the DFT controller will be transferred to the laptop. Even though there will be test files that have no data, they will still be transferred. The file transfer will take about fifteen to twenty minutes. This slow transfer rate makes it desirable to use the laptop for testing, since each test file can be transferred when completed.

A 4 DATA DISPLAY AND PROCESSING

A 4.1 DATA DISPLAY SCREEN IN DFT APPLICATIONS SOFTWARE

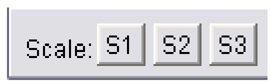
1. To display data once it has been downloaded to a laptop or other personal computer, click on the Data Display (F6) button of the main menu.



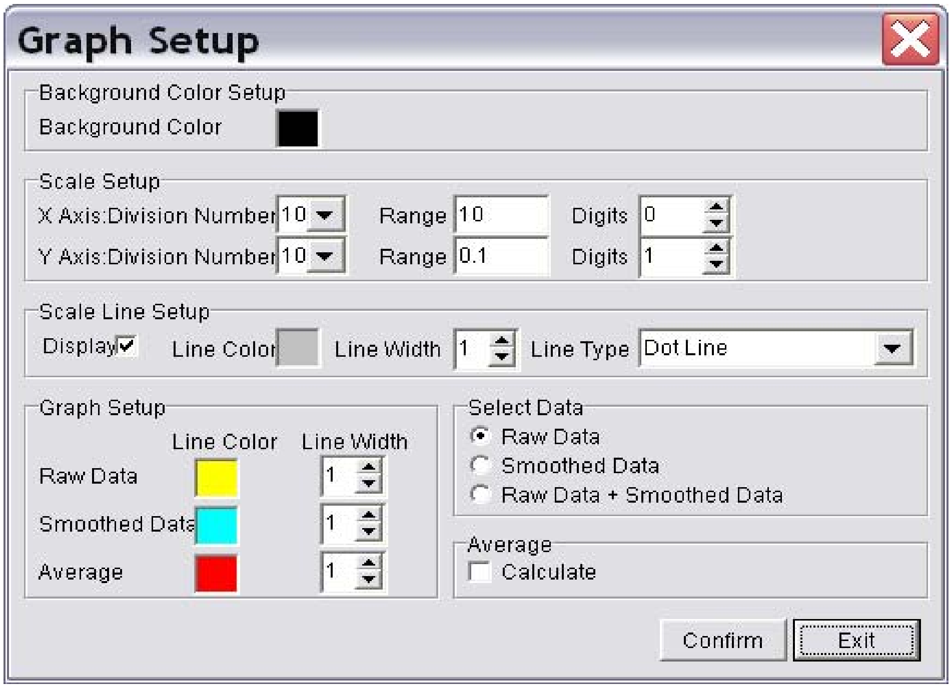
2. To view a particular file, click the Load button and select the file. The **Data Display** will show all of the data that was input by the operator and a graph of the friction data obtained during testing. The **Control Number** can be changed to view different control tests by clicking the up or down button.

3. The ‘Coefficient of Friction at’ section displays the different friction values at 20, 40, 60, and 80 km/h. In the blank field next to the 80 km/h box, a value from 0 to 100 can be entered to find the coefficient of friction at that value.

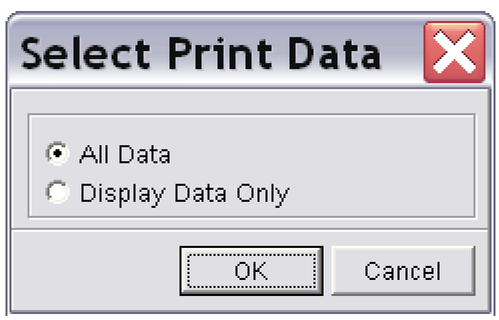
4. The scale of the display graph can be changed. The ranges are 0-0.5, 0-1.0, 0-1.5. Change these values with the buttons **S1**, **S2** and **S3** to operator preference.



5. Graphical settings can be changed by pressing the Graph Setup button. To change ‘Background Color’, click in the box and choose the desired color. For the ‘Scale Setup’, the range of the x- and y-axis can be changed, as well as the number of divisions per axis. The ‘Scale Line Setup’ section contains choices for putting lines at each x- and y-axis division number. In the ‘Graph Setup’ section, choose what color and line width are desired for raw data, smooth data, and average data. The ‘Select Data’ has choices for what type of data to display. If it is desired to have an average displayed on the graph, click the ‘Calculate’ box. If any changes are made click on the Confirm button to exit and save changes. Click the Exit button to exit without saving changes.



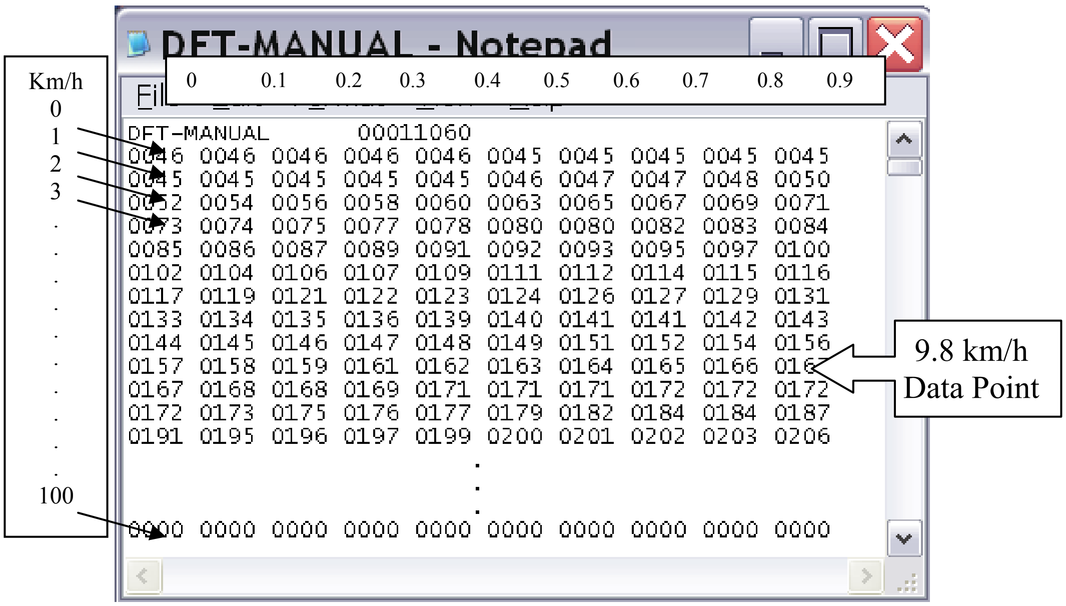
6. To print the graph and data, press the Print button. There are two options: 'All Data' or 'Display Data Only'. If 'All Data' is chosen, the graph and data pertaining to the file and test will be printed out together. If 'Display Data Only' is chosen, only the graphical data will be printed out.



7. When any changes are made, click the Save button to save changes to the file so that next time this data is displayed it will have the same graph parameters set.
8. When completed with viewing the data click on the Menu button to exit to the main menu.

A 4.2 EXPLANATION OF RAW DATA

The data from the DFT test will be stored in the pre-specified folder of the operator's choice. Each test file will be broken into two types of file. One file is a *.id file and the other is a *.dat file. To view the raw data open up the *.dat file in a text editor.

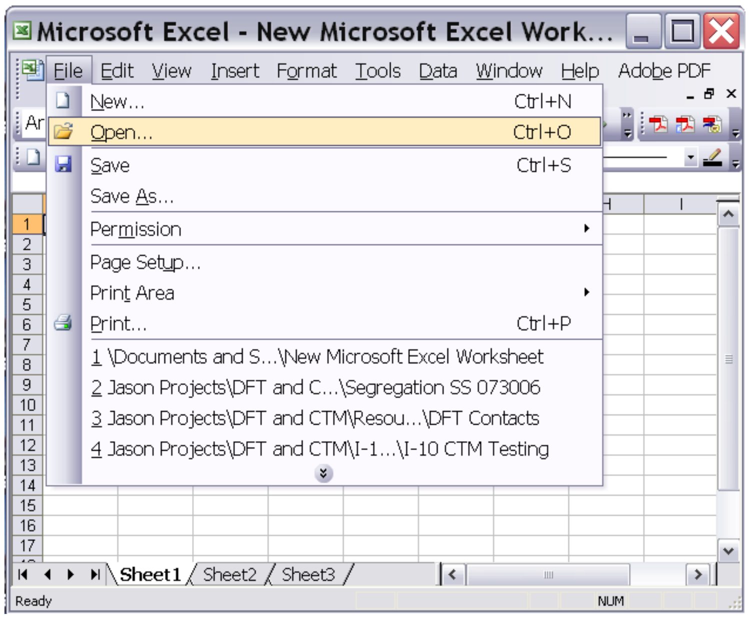


The file contains a header row followed by 100 rows of data. The header row contains the file name and an eight digit number. The first four digits of the eight digit number represent the control number of the test; the fifth digit represents the average runs; the last three digits represent the speed of the test in km/h.

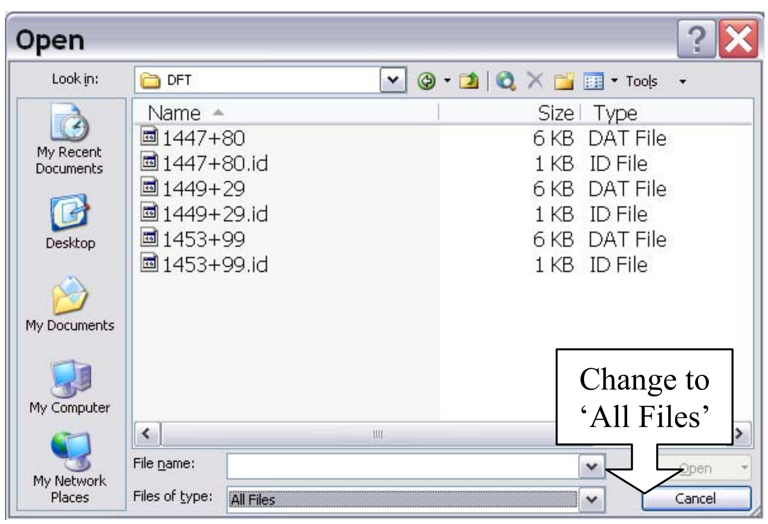
Each row of data contains ten columns. Each data row represents data collected for 1 km/h and each column represents a 0.1 km/h data point. This gives a total of 100 rows for 100 km/h. For example, if it is desired to know the friction value at 9.8 km/h, the value would be the tenth row down and nine columns to the right (not nine rows and eight columns since we start at zero in the first row and column). This would correspond to a value of 0166 in the above figure. This number is the coefficient of friction (0.165) multiplied by 1000 so there are no decimals in the raw data. If the test is not set to 100 km/h, the corresponding rows will be zeroed out. For example, if the test is for 30 km/h, there will only be thirty rows of data and seventy rows of zeros. There is a discrepancy with the software (only known to the software developer), that causes an extra 404 blank rows to be inserted after each control number.

The *.dat file can also be imported directly into Excel to be viewed similarly as in the text editor.

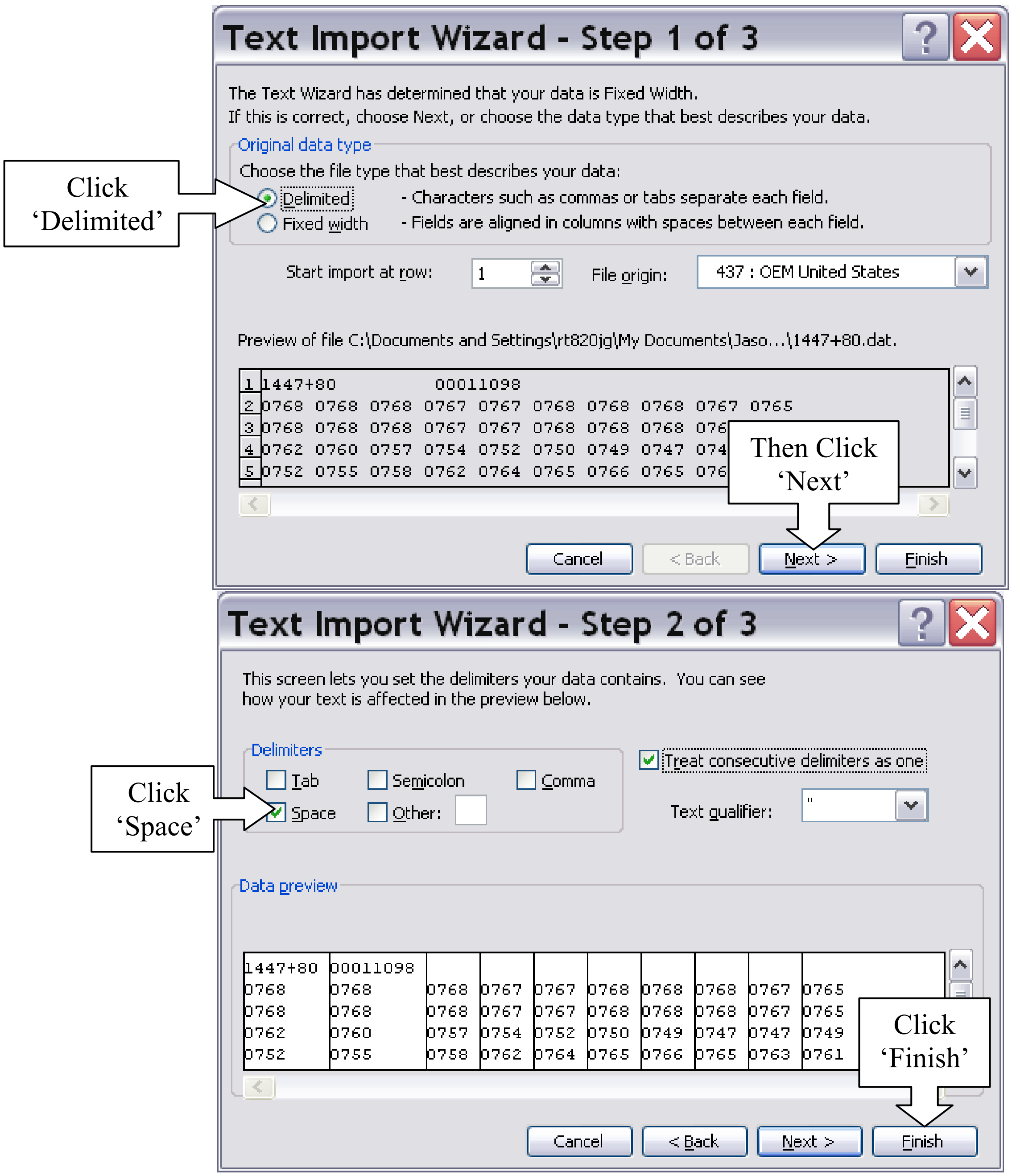
1. Open Excel and go to ‘File’ and ‘Open’.



2. In the ‘Open File’ dialog box, browse to the destination folder and select the *.dat file to be opened.



3. Because the *.dat file is not a standard excel spreadsheet file, the 'Text Import Wizard' will open. The file is space delimited; to get the data in the correct number of rows and columns when imported, it must be set to space delimited.



4. The file will be imported and separated into one hundred rows by 10 columns with a header row. The data is ready to be graphed or analyzed independently of the DFT Applications software.

A 5 DFT MAINTENANCE PROCEDURES

A 5.1 CLEANING AND STORING THE DFT

Turn the DFT on its side and wipe away any excess water that may have accumulated during testing before putting the unit away. Also, when changing out the test pads, any excess rubber build up on the disk should be wiped away with a damp cloth to prevent build-up that may be difficult to remove later. Another way to keep the DFT clean is to wipe away any fingerprints on the body casing before storage.

Once the DFT is cleaned, place it in its carrying case. Place the black bag with extra test pads on top of the body. Gently place the cover back on the DFT case and fasten the four latches to secure the unit in place. Do not try to force the DFT into its case because it will only fit one way.

A 5.2 REPLACING WORN TEST PADS

Good judgment should be used in determining how many tests can be run before the test pads need replacement. If tests are run on smooth, low-friction surfaces, the pads may only need replacement every thirty tests. If tests are run on harsh, abrasive surfaces, the pads may only last through six tests. Once the pads are about 2.5-3mm thick, they need replacement. Replacing test pads is very easy.

1. Turn the DFT on its side as shown below. Make sure that the power switch is turned off before turning the DFT on its side

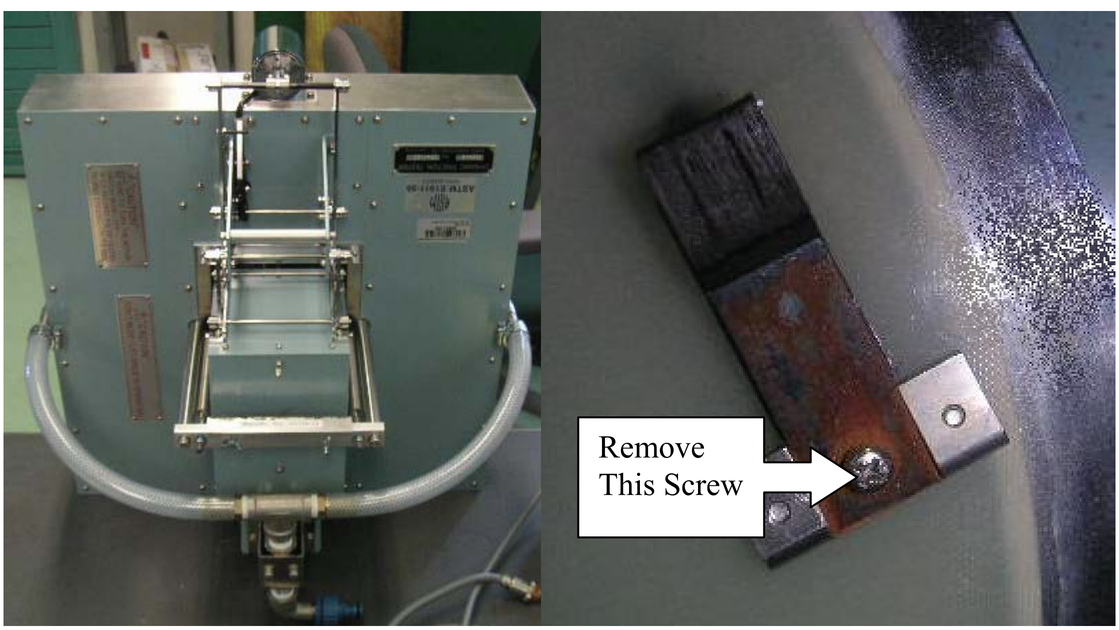


Figure A 14 DFT on its Side and Test Pad

2. Use a Phillip's head screwdriver to remove the screw in each test pad (refer to Fig. A 14). This may be a good time to clean underneath the pads to prevent rubber build-up.
3. Replace with a new test pad and tighten the screw back to its original position.

A 5.3 CALIBRATION PROCEDURES

All calibration methods should be performed at least once per month to make sure that the zero point is set correctly and that the friction measurement range is still accurate.

There are three types of calibration for the DFT. These include: 1) Friction Force Transducer Calibration, 2) Vertical Force Calibration, and 3) Slider Tangential Velocity Calibration.

A 5.3.1 FRICTION FORCE TRANSDUCER CALIBRATION

This calibration method allows quantifying the amount of force that is affecting the transducer during the operation of DFT while the spinning disk is lowered and dynamically sliding on the pavement surface. This calibration procedure requires the calibration mass, metal string and the calibration bolt.

To calibrate the device a weight (3.6 kg ≈ 8 lbs) must be prepared. A wire of at least three feet is needed with a hook to hang the calibration weight from the disk. The coefficient of friction is designed to be 1.00 as the loading pressure of the rubber slider is 3.6 kg.

1. Plug the controller into the supplied AC adapter and turn on the controller power switch.
2. The DFT and the controller must be connected with the data (5-prong) cable (Fig. A 6, #6).
3. Turn the DFT on the side as in test pad replacement procedure.
4. Insert the M4 bolt into the screw hole of the rotational disk and bracket of the DFT body to hold the disk in place.
5. On the '**D.F.Tester Menu**' press **'Calibration'** (option 7).

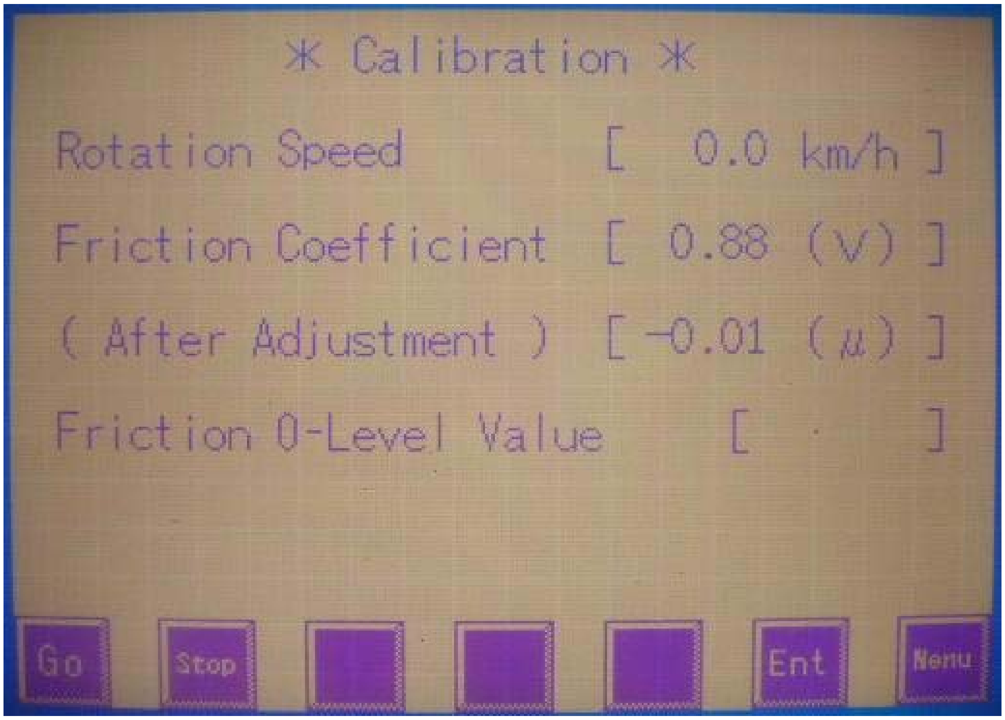


Figure A 15 Calibration Mode on DFT Controller

6. Press the **'GO'** button onscreen. This will cause the controller to read the two electric pressures.
7. Pull on the wire hanging from the disk a two or three times to try to get a steady friction reading. If the value is not zero press **'Stop'** onscreen and then press **'Enter'** onscreen.
8. Use the controller keypad to enter in the value that is in the **'Friction Coefficient'** field. (Ex. In Figure 15 the value is 0.88). This value will be the new **'Friction 0-Level Value'**.
9. Once the number is in the **'Friction 0-Level Value'** field press the **'ESC'** button on the controller keypad and then press **'GO'** onscreen. The value should be stored in the field the says **'(After Adjustment)'**
10. Add the 3.6 kg calibration weight to the wire as seen in the figure below. Pull on the weight two or three times as before without the weight.

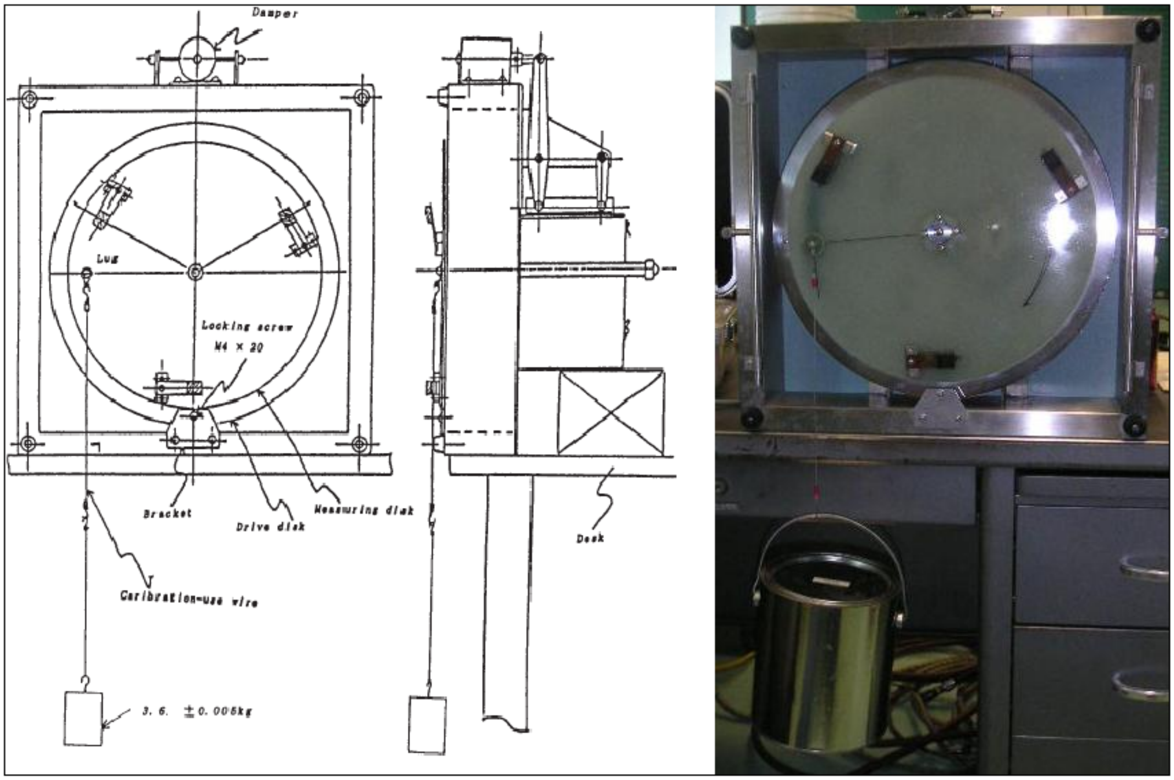


Figure A 16 DFT Calibration Setup [8]

11. If the value does not read 1.00, adjust the 2nd potentiometer knob on the side of the controller (See Fig. A 17) until the **'Friction Coefficient'** field reads 1.00. To adjust the knob, use a small flathead screwdriver.

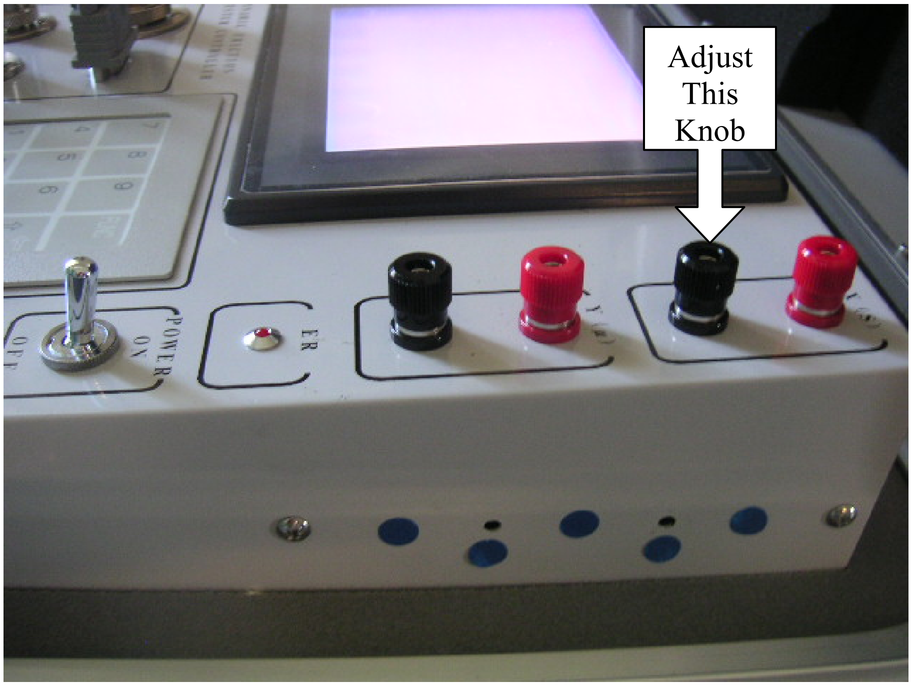


Figure A 17 Potentiometer Knob for Calibration

12. The DFT is now calibrated and ready for testing. Turn off the controller power switch and then on again to reactivate.

A 5.3.2 VERTICAL FORCE CALIBRATION

Vertical force calibration assures proper spring tension of the motor assembly. During testing, the motor assembly drops and the rubber sliders are "forced against the ground" with constant controlled force, which can be accounted for in friction coefficient calculations.

1. Set up the DF Tester on a smooth level surface as in the usual measurement condition as shown in Figure A 18.

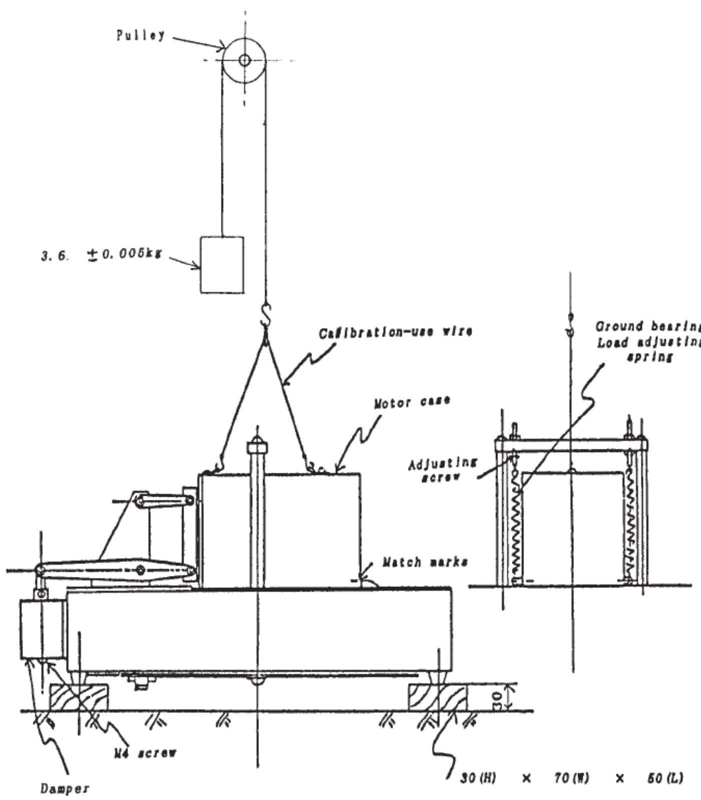
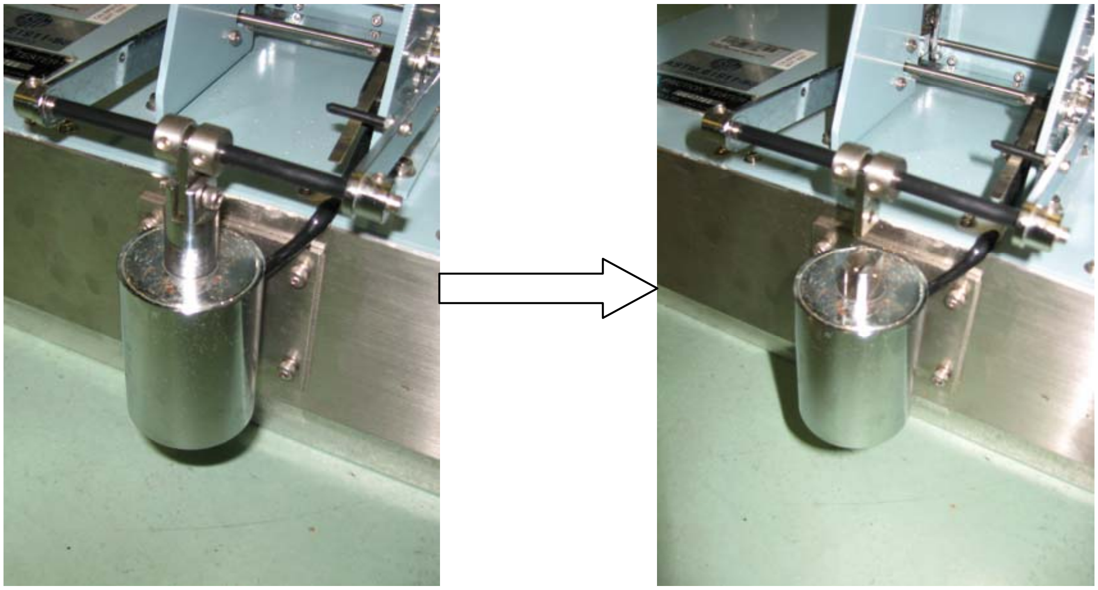


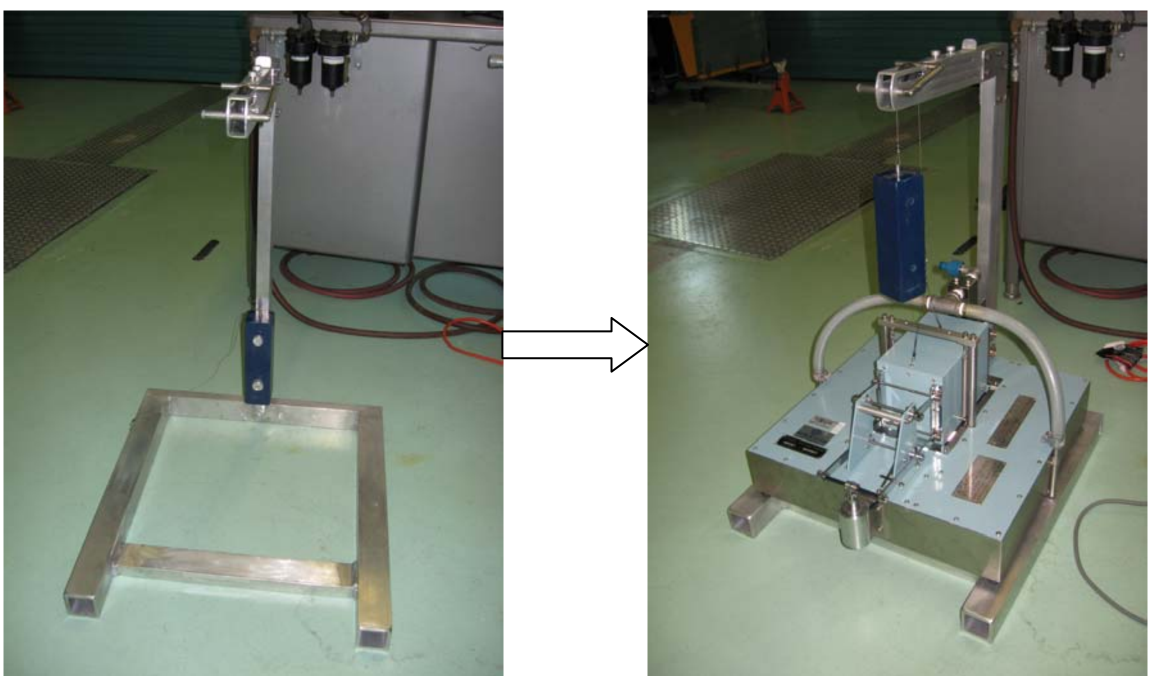
Figure A 18 Measurement Conditions for Vertical Force Calibration [8]

2. Mark the position of the motor case relative to the frame.

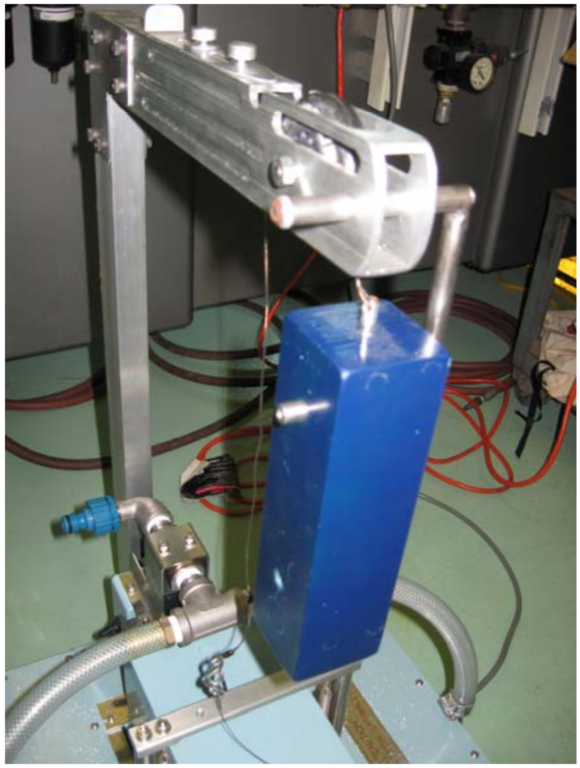
3. Remove the screw from the bottom of the damper.



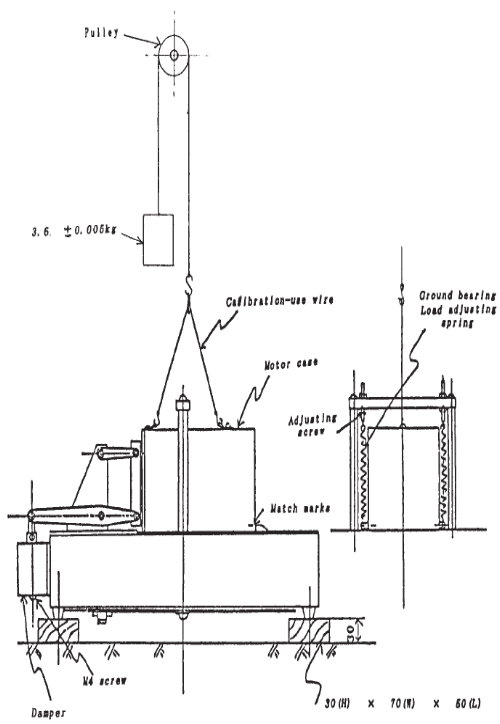
4. Place the tester on the calibration stand.



5. Attach the calibration mass of 3.6 kg (8 lb) to the top of the calibration stand.

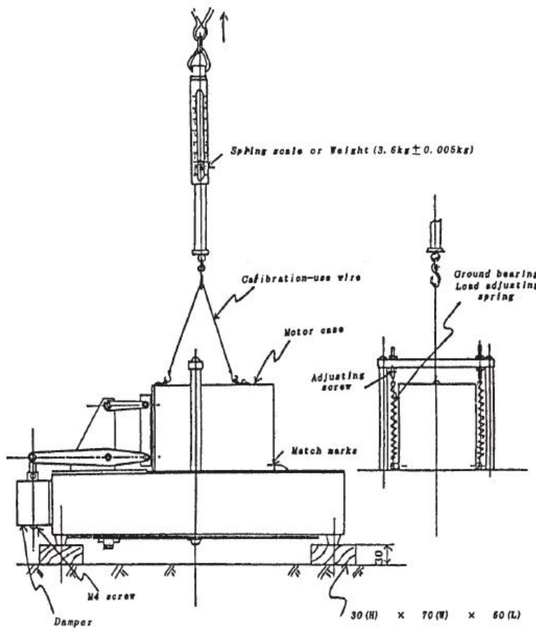


6. Attach the two clips on the end of the pulley cable to the motor case and then attach the other end of the cable to the calibration mass. Place the pulley cable on the pulley, allowing the calibration mass to hang freely, pulling up the motor case.



7. The mark on the motor case should line up with frame. If not, increase or decrease the spring tension using the adjusting screws as necessary such that the mark on the motor case lines up relative to the frame.

8. NOTE: For calibration in the field where it is impractical to use a pulley/weight system a spring scale can be used. If adjustments were made in the field using the spring scale this fact should be reported with the results.



A 5.3.3 SLIDER TANGENTIAL VELOCITY CALIBRATION

The DF Tester is designed so that when the disk rotates at 1500 rpm the slider tangential velocity is 80 km/h (48 mph). Adjust the S.GAIN knob on the control unit such that the speed of 80 km/h (48 mph) is recorded when the rotational speed is 1500 rpm. In order to measure the rotational speed, a light sensor should be used. It should measure a strip easily identified by the light sensor, which should be placed on the bottom on the DF Tester for the duration of the calibration process.

A 6 CONTACTS FOR TROUBLESHOOTING

1. Shima American Corporation – United States Nippo Sangyo Distributor

   222 Spring Lake Drive, Itasca, IL 60143
   Sally Suzuki – Sales Coordinator
   Direct Tel: 630-760-4333
   Fax: 630-285-0824
   E-Mail: ssuzuki@shimausa.com

2. Nippo Sangyo Co., Ltd. - Manufacturer
   12-7, Higashi-Tokura 2-Chome
   Kokubunji-shi, Tokyo 185-0002, Japan
   Tel: 042-323-8861 Fax: 042-321-3890
   E-Mail: info@nippou.com
   URL: http://www.nippou.com/

3. John J. Henry – Friction Experience
   E-Mail: jjhenry123@aol.com
   Tel: 814-643-4474
   Fax: 814-643-6428

4. Joel Visser – Calibration and DFT expert
   E-Mail: jvssr7001@imt.net
   Primary Tel: 406-282-7001
   Emergency Tel: 406-582-9801 ext. 105

5. Ayesha Shah - North Central Superpave Center

   E-Mail: bano@purdue.edu
   Research Engineer
   Purdue University
   West Lafayette, IN

UNF UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B

Circular Track Meter (CTM) Operations & Reference Manual

APPENDIX B

TABLE OF CONTENTS

Page

B 1 INTRODUCTION

The CTM equipment and test method are described in ASTM E 2157 [1]. The CTM consists of a Charged Coupled Device (CCD) laser-displacement sensor which is mounted on an arm that rotates such that the displacement sensor follows a circular track having a diameter of 284 mm (11.2 in.). The CTM is designed to measure the same circular track that is measured by the DFT. The software provided with the CTM directly reports MPD for the pavement surface tested. The texture measurement sensor for the CTM is similar to the high speed laser system installed on the Florida DOT full scale locked wheel test units. The main difference is that the CCD system provided with the CTM has a significantly slower data acquisition rate and is mounted on a rotational arm that performs a full revolution during the data collection at fixed elevation, while the vehicle mounted system collects data along the linear wheel path, and at highway speeds.

B 1.1 EQUIPMENT PRECAUTIONS

The following precautions are recommended by the CTM manufacturer prior to and during operation [40]:

- Do not look directly at the CTM laser displacement sensor.
- Only use the provided DC 12 V battery or the AC power converter for CTM power supply.
- Do not attempt to disassemble CTM unit.
- Do not drop of unnecessarily jar CTM unit.
- Do not operate CTM in rain or wet conditions.
- CTM operating temperature range is between 0^o and 50^o C.
- If condensation is observed on CTM unit, allow unit to stand for at least 1 hour prior to use.
- Do not store CTM at high temperatures or relatively high humidity (35% - 85%).

B 1.2 EQUIPMENT SPECIFICATIONS

The CTM device and component specifications are summarized below [40]:

- Model Name Circular Track Meter
- Outer Size 44 mm x 400 mm x 270 mm
- Weight 13 kgs (not including packing case)
- Power Supply DC 12 V, 24 W
- Displacement Sensor KEYENCE CCD Laser Displacement Sensor
- Laser Spot Size ϕ 70 μm (at standard distance)
- Wave length 670 mm
- Lower Sample Range 1,024 μs
- Measuring Range 30 mm
- Vertical Resolution 3μm
- Measuring Radius 142 mm
- Sample Spacing 0.9 mm
- Number of Sampling 1,024 S/R
- Rotation Speed 7.5 rpm
- Ambient Temperature 0^o - 50^o C
- Ambient Humidity 35% - 85% PH (No Condensation)

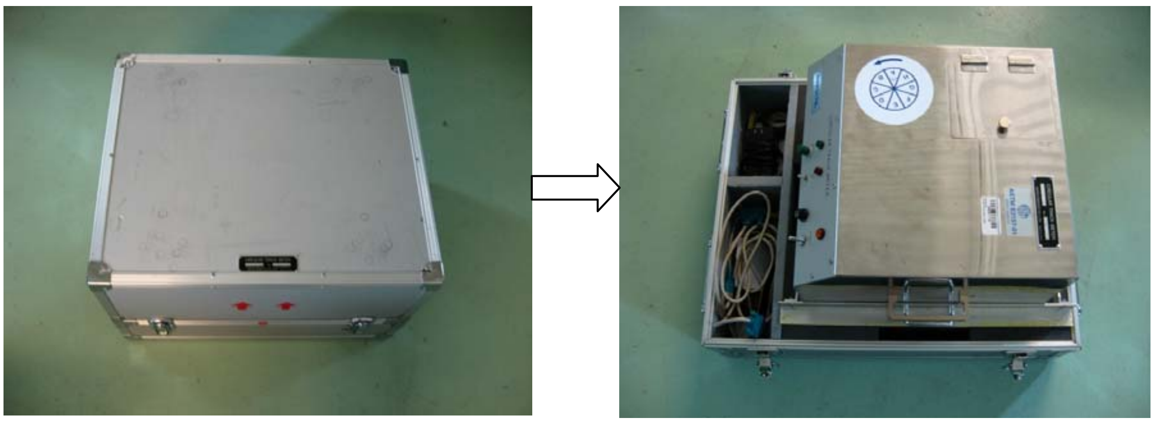
B 2 CTM OPERATING PROCEDURES

1. Plug in the designated CTM laptop computer into the wall outlet using the computer's AC to DC adapter. If the CTM is being set up for use in the field, use an automobile DC to AC inverter with the computer's AC to DC adapter.

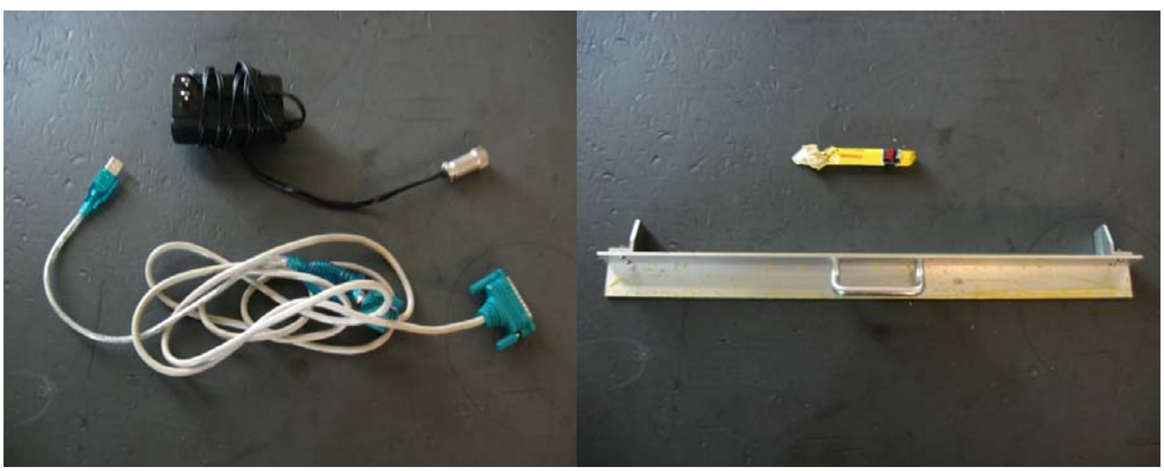
2. Power the laptop computer on.

3. Plug in the mouse to the USB port on the left side of the laptop computer.

4. Open the Circular Track Meter (CTM) Box.

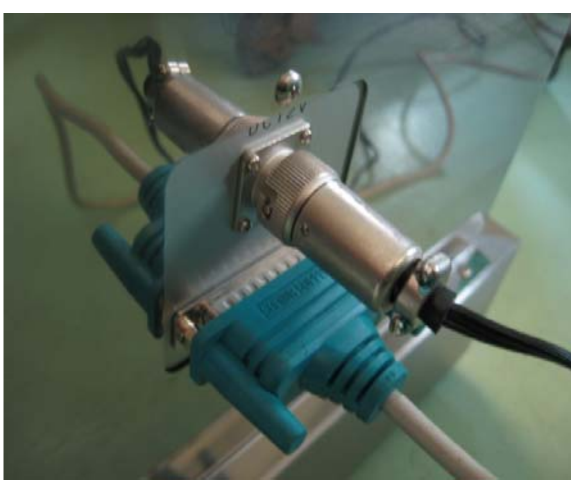


5. Carefully remove the Circular Track Meter, power plug, data cable, one yellow crayon, and metal bracket.



6. Ensure that all switches on the CTM are turned off. After the power cable is attached, none of the switch lights should be illuminated.

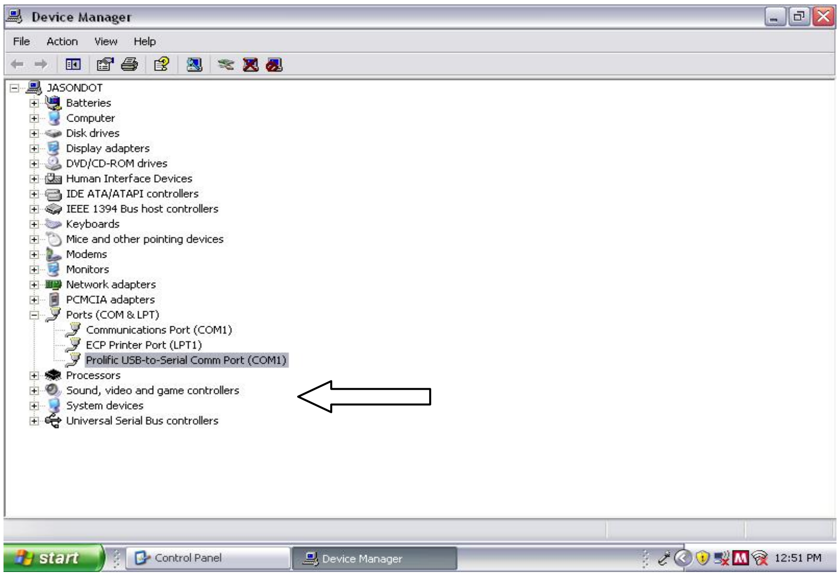
7. Plug in the CTM power cable to an electrical outlet or to the automobile DC to AC Inverter. Plug in data cable to the USB port on Computer and to the CTM. The CTM and computer ports should now look similar to the following pictures.



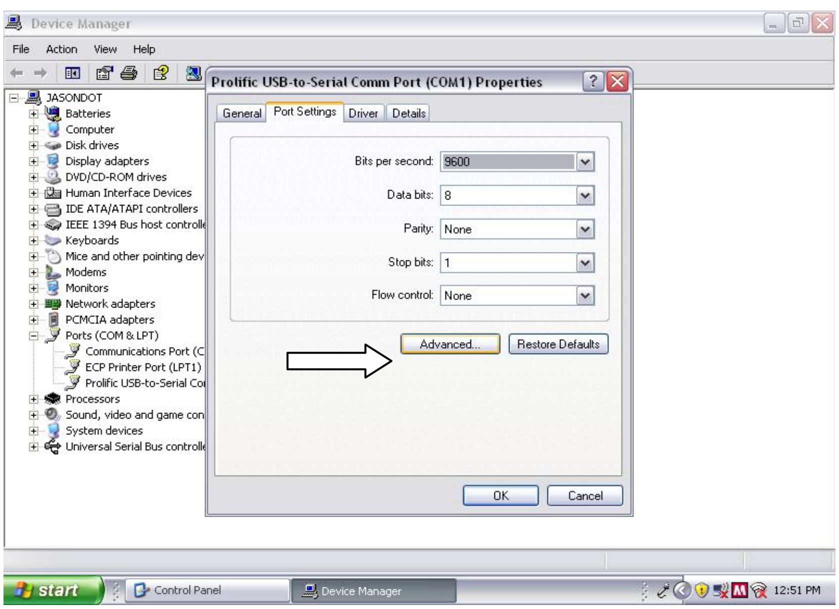
8. Turn on the Power Switch on the CTM. The orange power switch light and the green start light should illuminate.

9. Turn on the MSW Switch on the CTM. The red MSW switch light should illuminate.

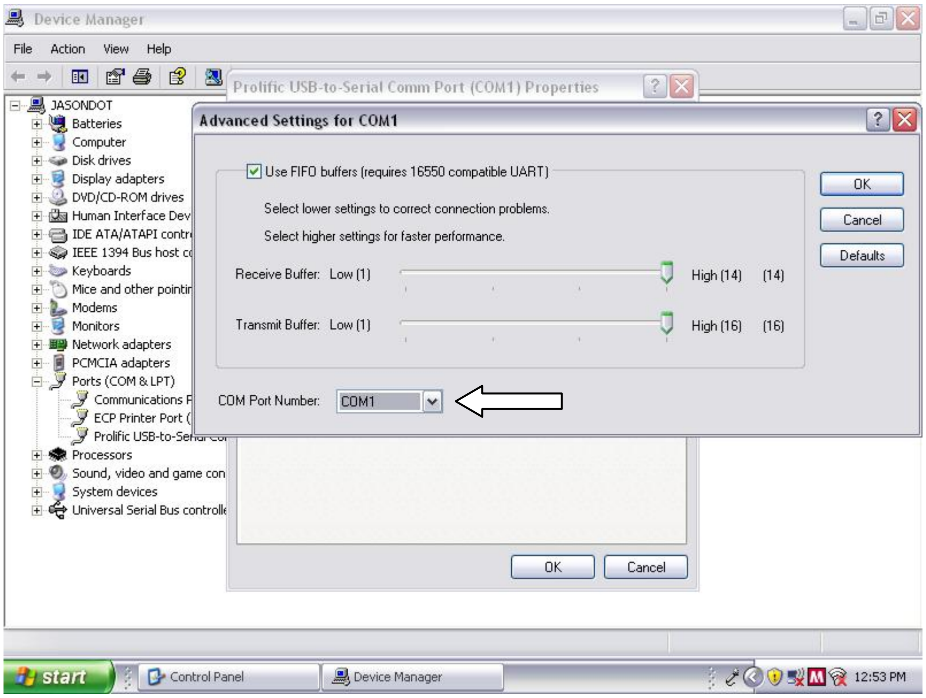
10. Open Windows Device Manager. This can be done multiple ways. Click on "Start", and then click on "Run." Type in "devmgmt.msc" without the quotations and click OK. Another way to open Device Manager is by clicking on "Start" and then "Control Panel." Double Click on "System." Click on the "Hardware" tab, and then click "Device Manager." In Device Manger, scroll down to **Ports (COM & LPT)** and expand it (click on the little plus sign to the left of the word "Ports"). Double click on "**Prolific USB-to-Serial Comm Port** (COM1)." The number after "COM" may be different depending on the most recent computer settings.



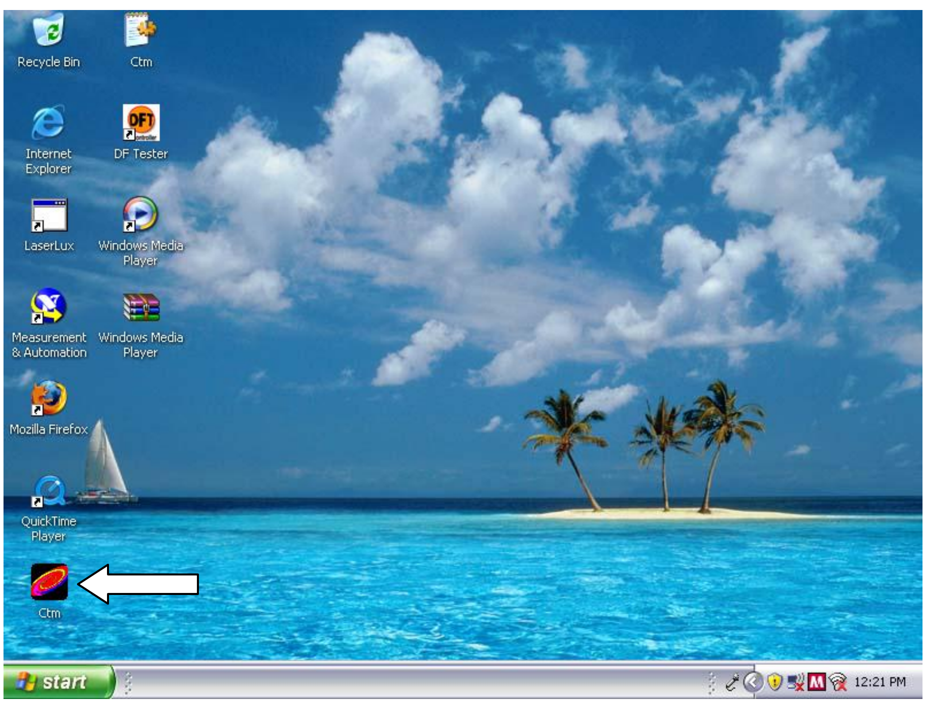
11. After the "Prolific USB-to-Serial Comm Port" window pops up, click on the "Port Settings" tab. Then, click on "Advanced..." at the bottom of the window.



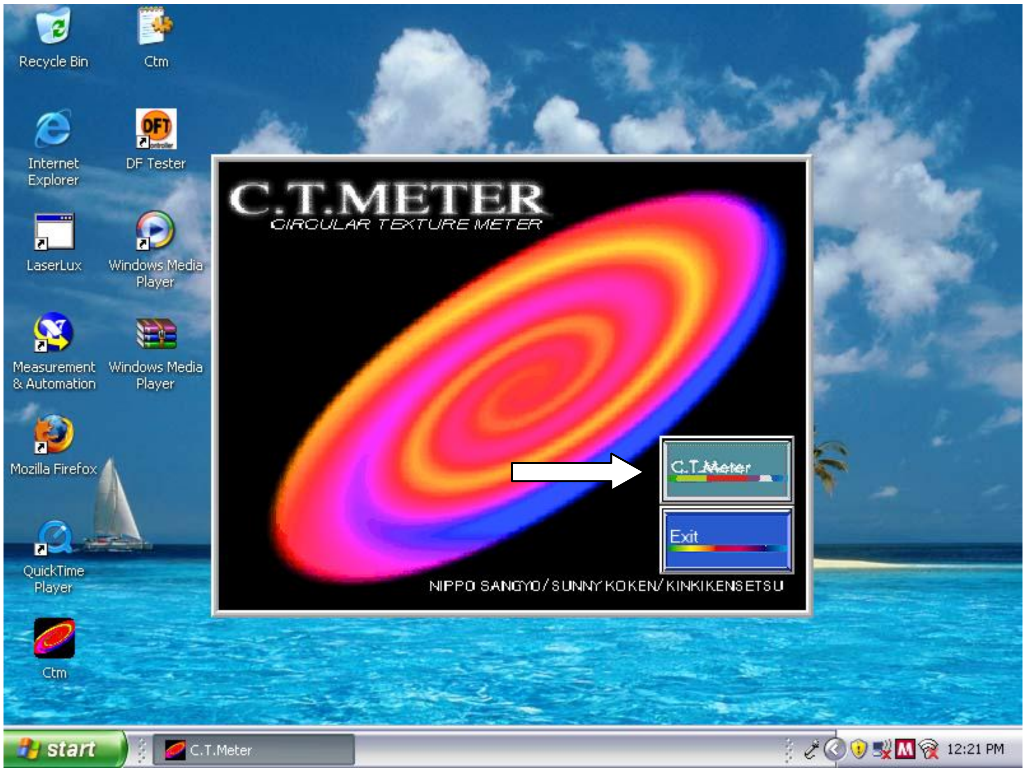
12. Ensure that the settings match those in the picture below. However, any COM port between 1 and 6 may be chosen under the COM Port Number selection box at the bottom of the window. Be sure to remember the COM Port Number you have selected, and then click "OK." Click "OK" in the "Prolific USB-to-Serial Comm Port" window, and then the Device Manager and the Control Panel (if open) may be closed.



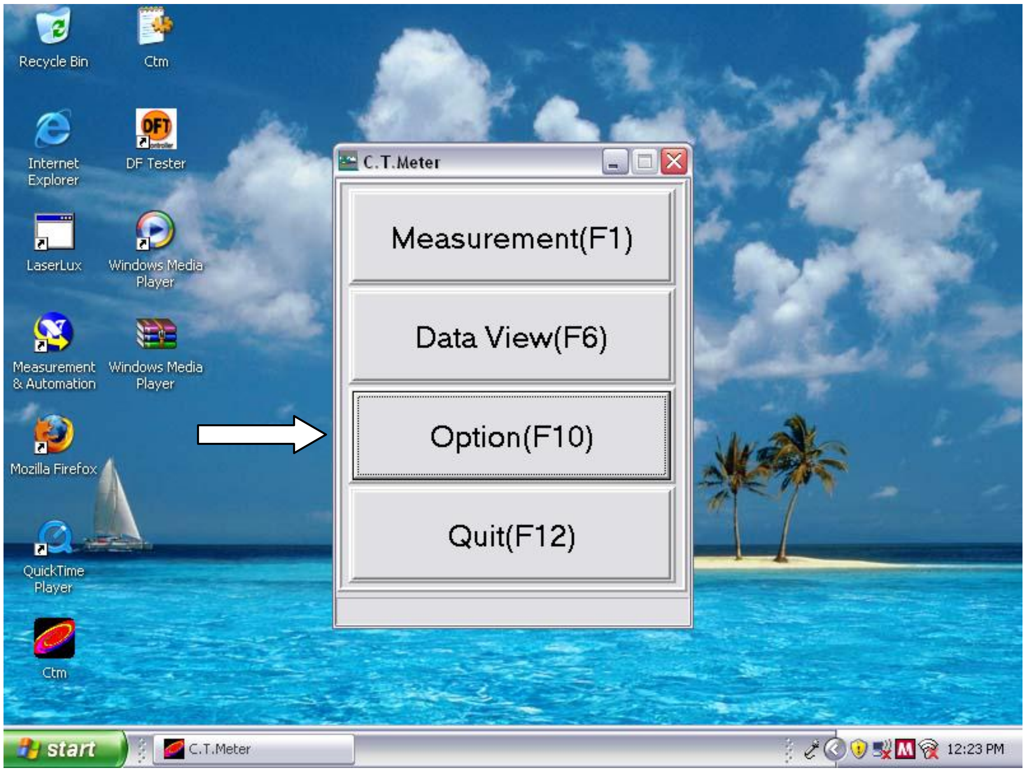
13. Open CTM Program. Double-click the desktop icon labeled, "CTM."



14. Click on the "C.T. Meter" button.

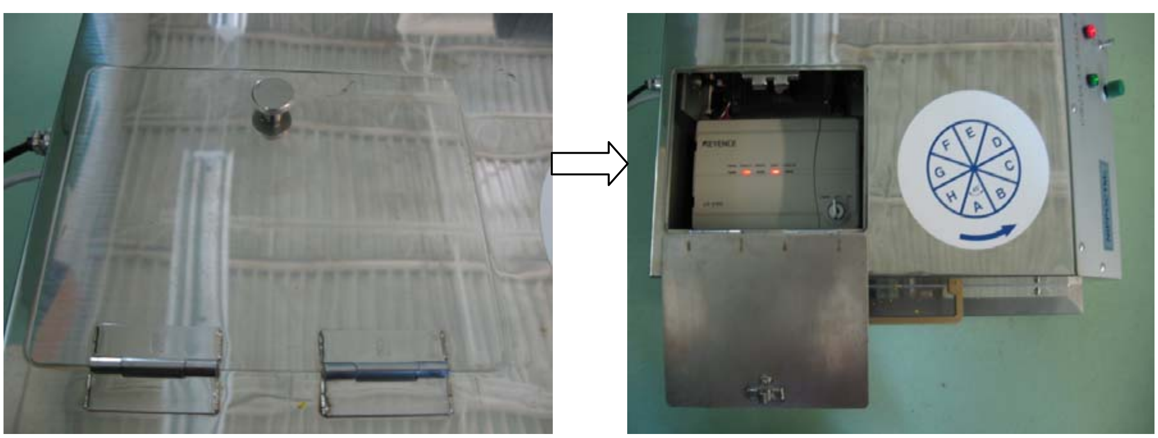


15. Click on the "Option" button.



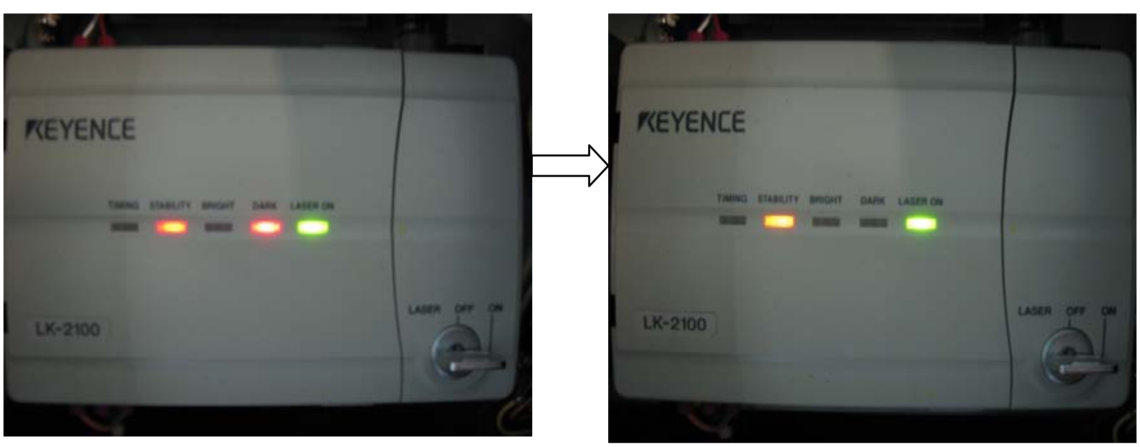
16. Select the appropriate Port number, ensuring that it matches the COM Port number that was selected earlier in the Device Manager. Select Language: English and Log Select: Disable [*sic*]. Click OK.

17. On the top of the CTM and in the upper left-hand corner, there is a metal door, which covers the laser and laser power supply. Carefully open this door.

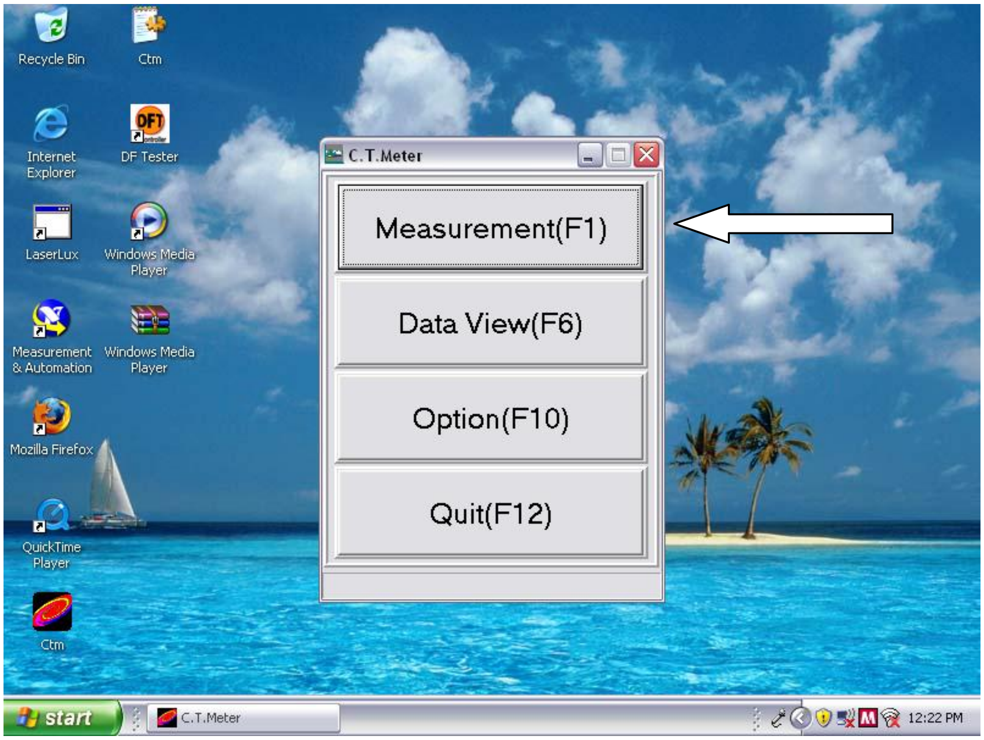


18. The laser should be turned off, with the "STABILITY" and "DARK" lights illuminated in red.

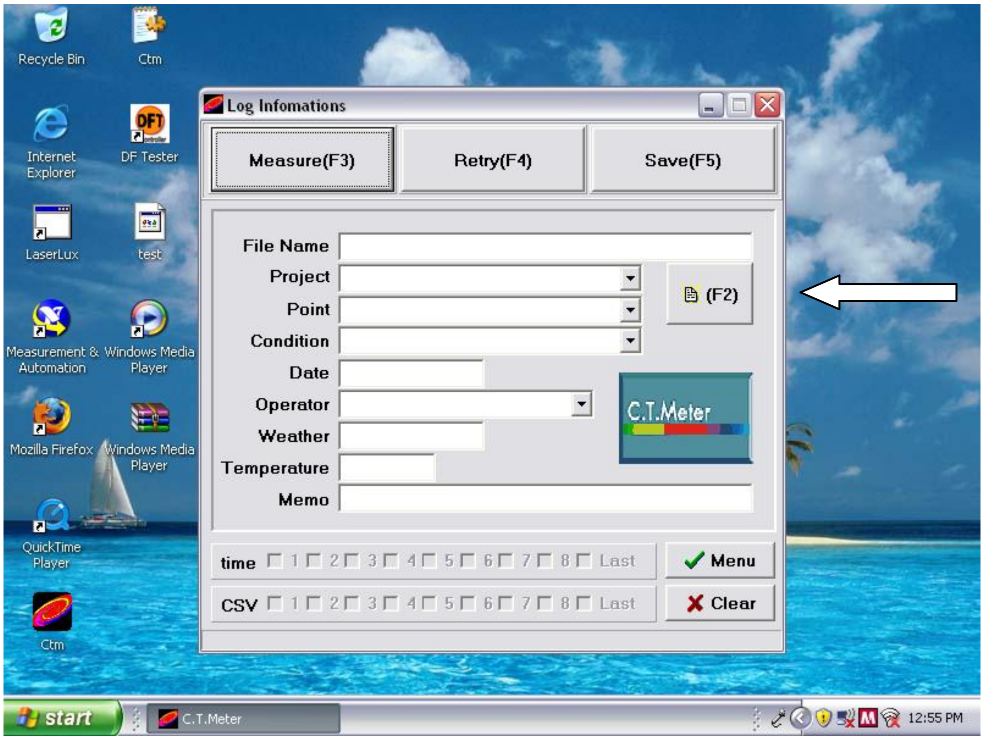
19. Turn the key to the "ON" position. The "STABILITY" and "DARK" lights should remain illuminated in red for a moment, while the "LASER ON" light shines green. Soon, the "STABILITY" light will shine orange, the "DARK" light will turn off, and the "LASER ON" light will remain green. Then, close the metal door to the laser.



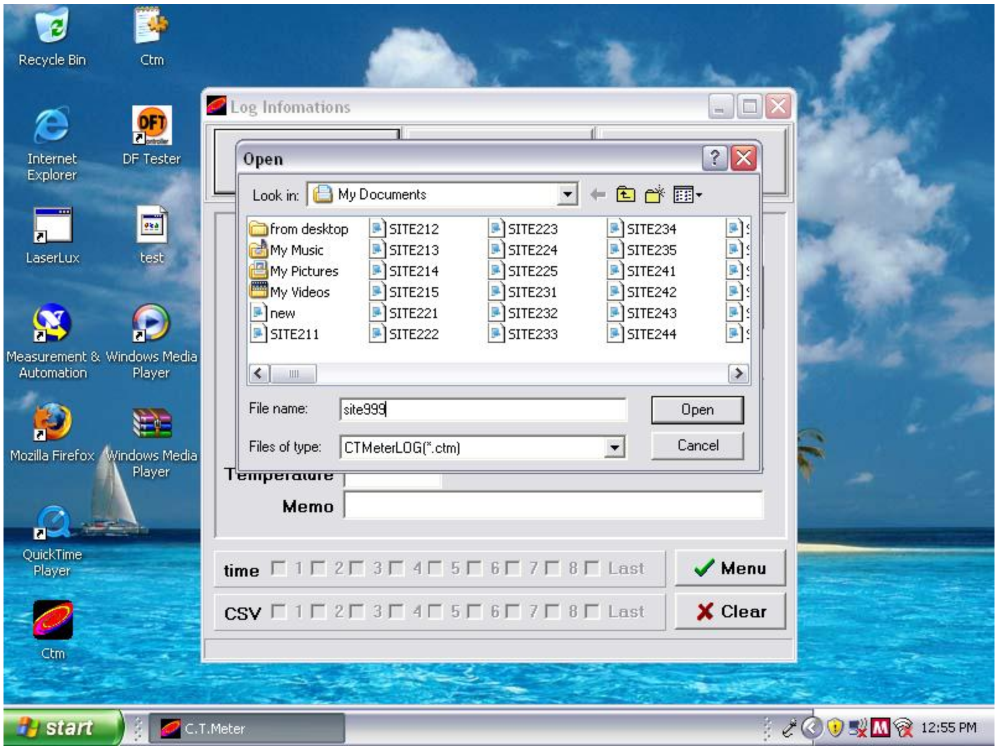
20. On the laptop computer, the CTM software program should still be open. If not, return to steps 13 and 14. Click on the "Measurement" button.



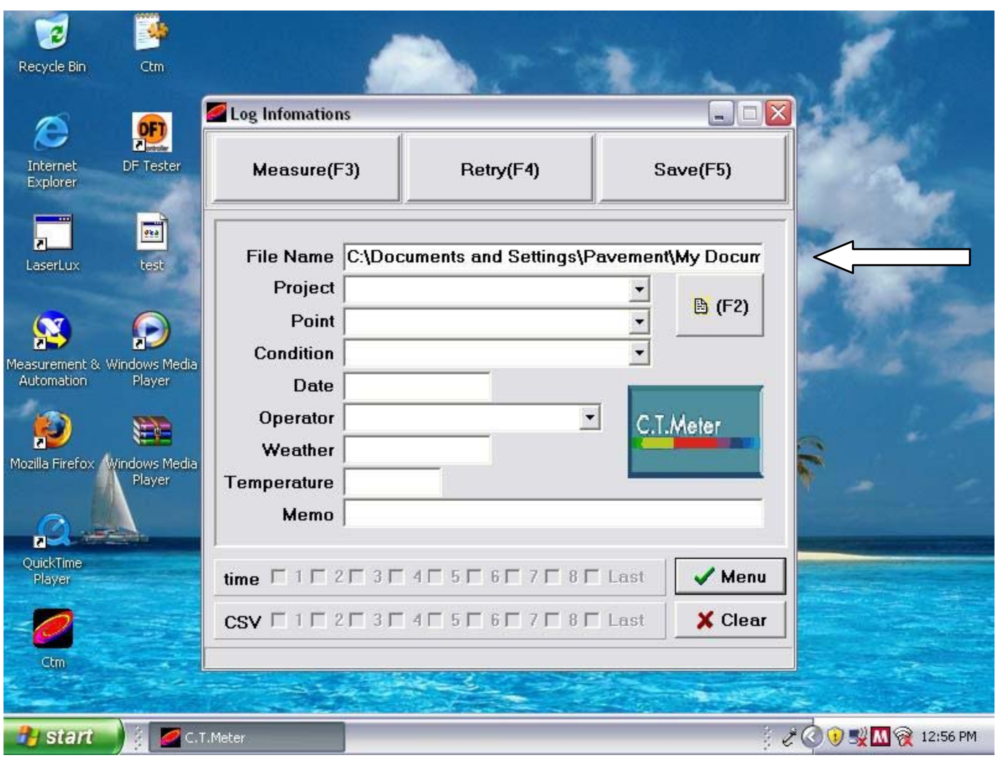
21. Click on the File Open (F2) button.



22. Pick a file location and type a new file name, and then click “Open.”

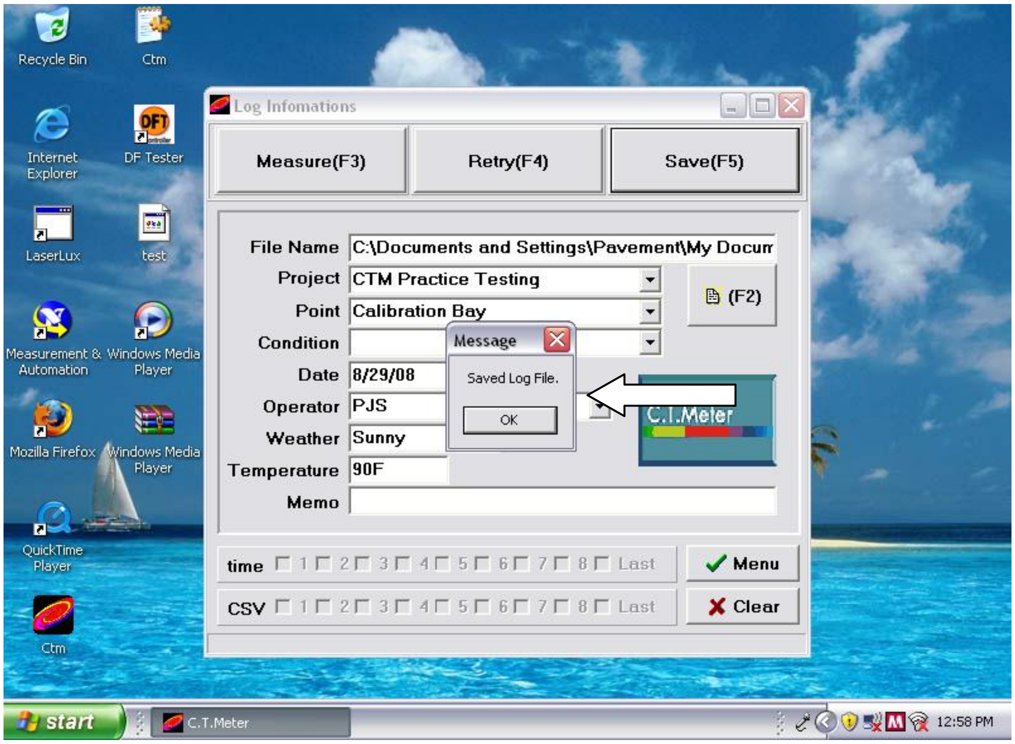


23. The file path should appear in the File Name program line.

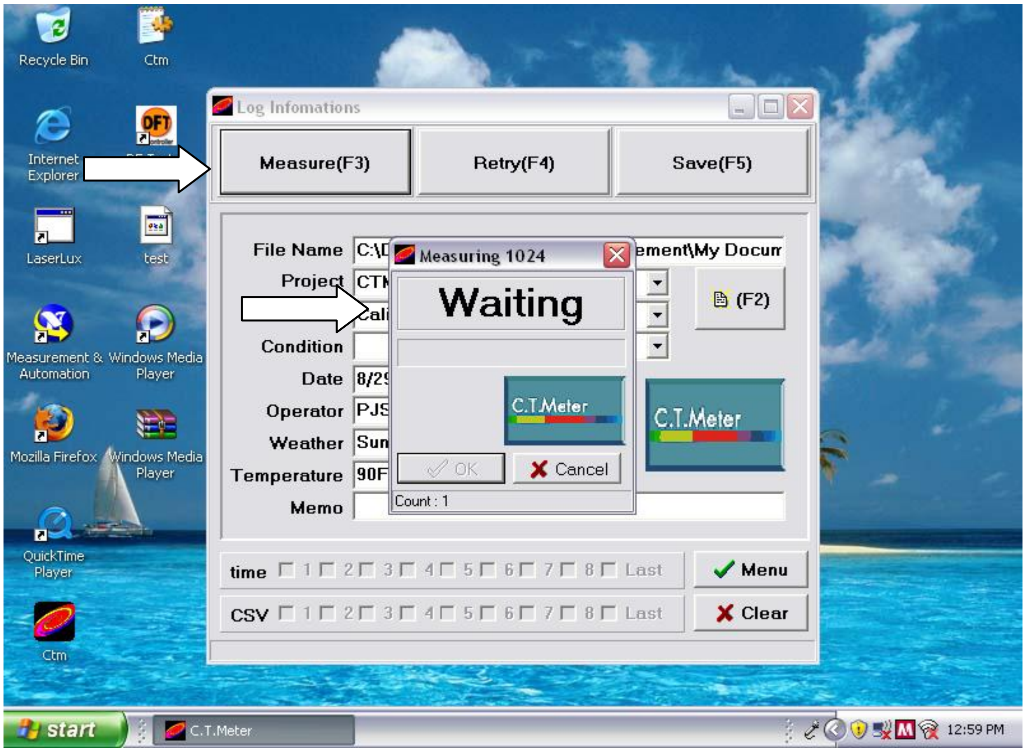


24. Fill out the rest of the program lines with the site information.

25. Click on "Save" (F5). The message: "Saved Log File" should appear.



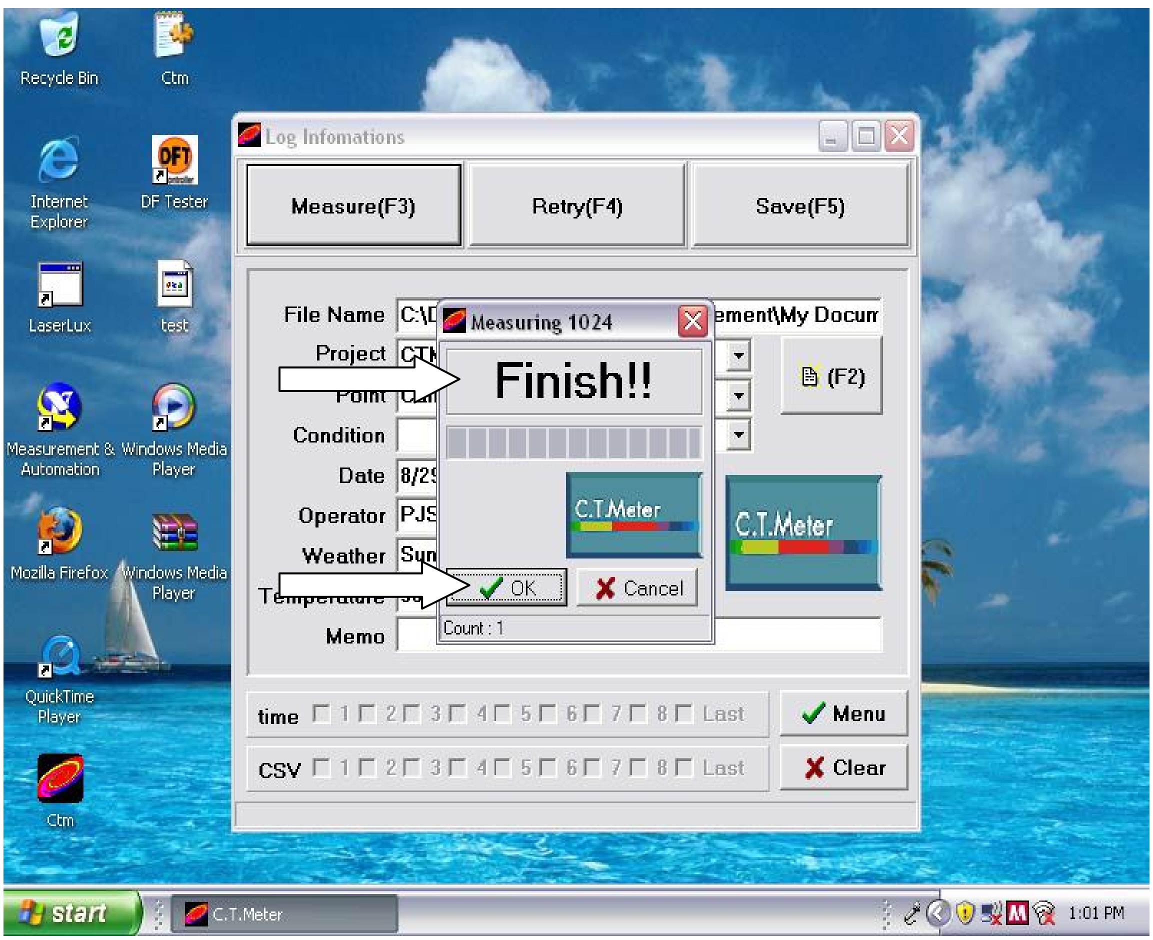
26. Click on the "Measurement" (F3) button. A "Waiting" dialogue should then appear.



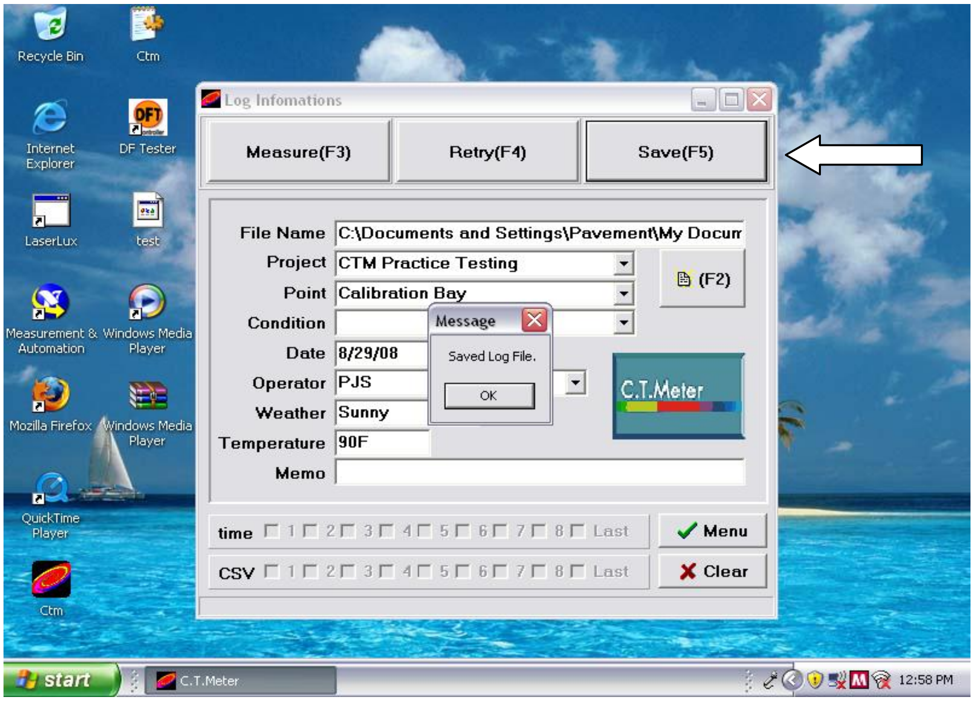
27. Press and hold the green "Start" button on CTM for a second, and then release it.

28. The software program and the CTM lights should look similar to the pictures below.

29. Click "OK" after "Finish" is displayed.

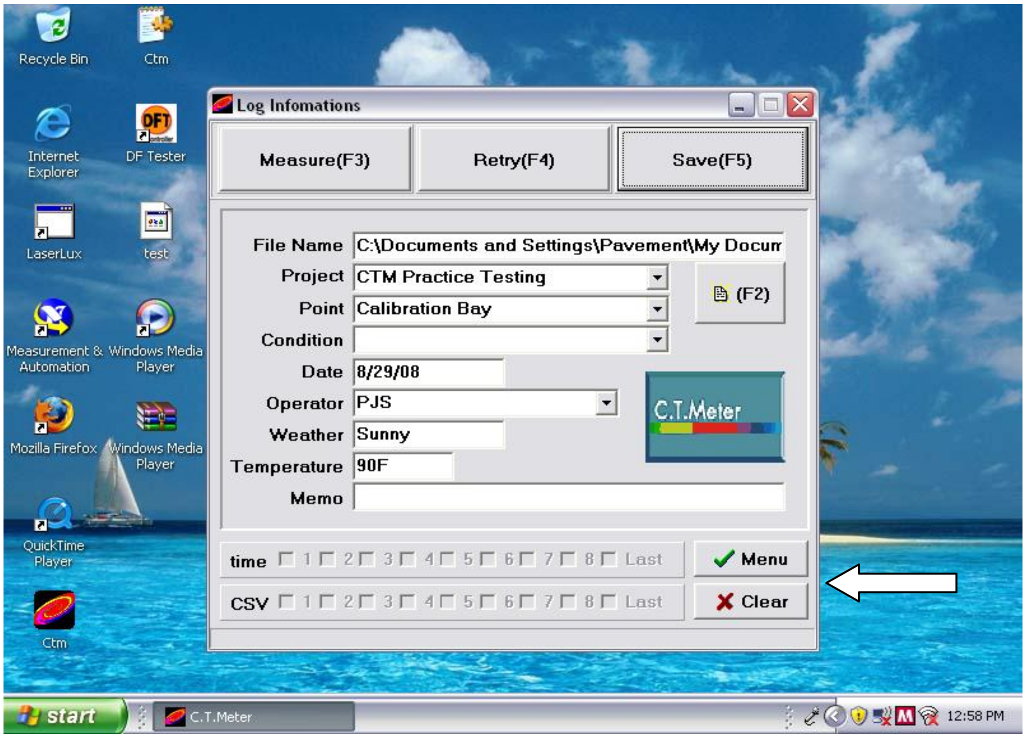


30. Click on “Save” (F5) again. The message: “Saved Log File” should appear. Click “OK.”

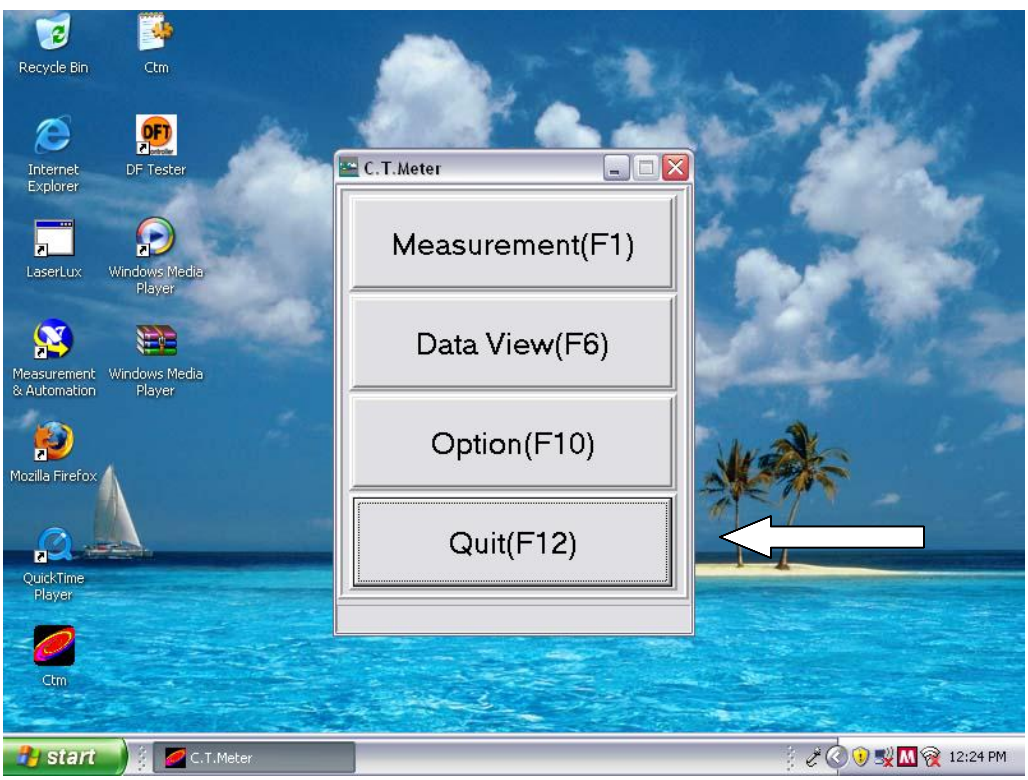


31. If using the CTM in the field, trace all four edges of the CTM with the yellow crayon and the metal bracket. Eventually, the Dynamic Friction Tester (DFT) will be placed within this yellow box.

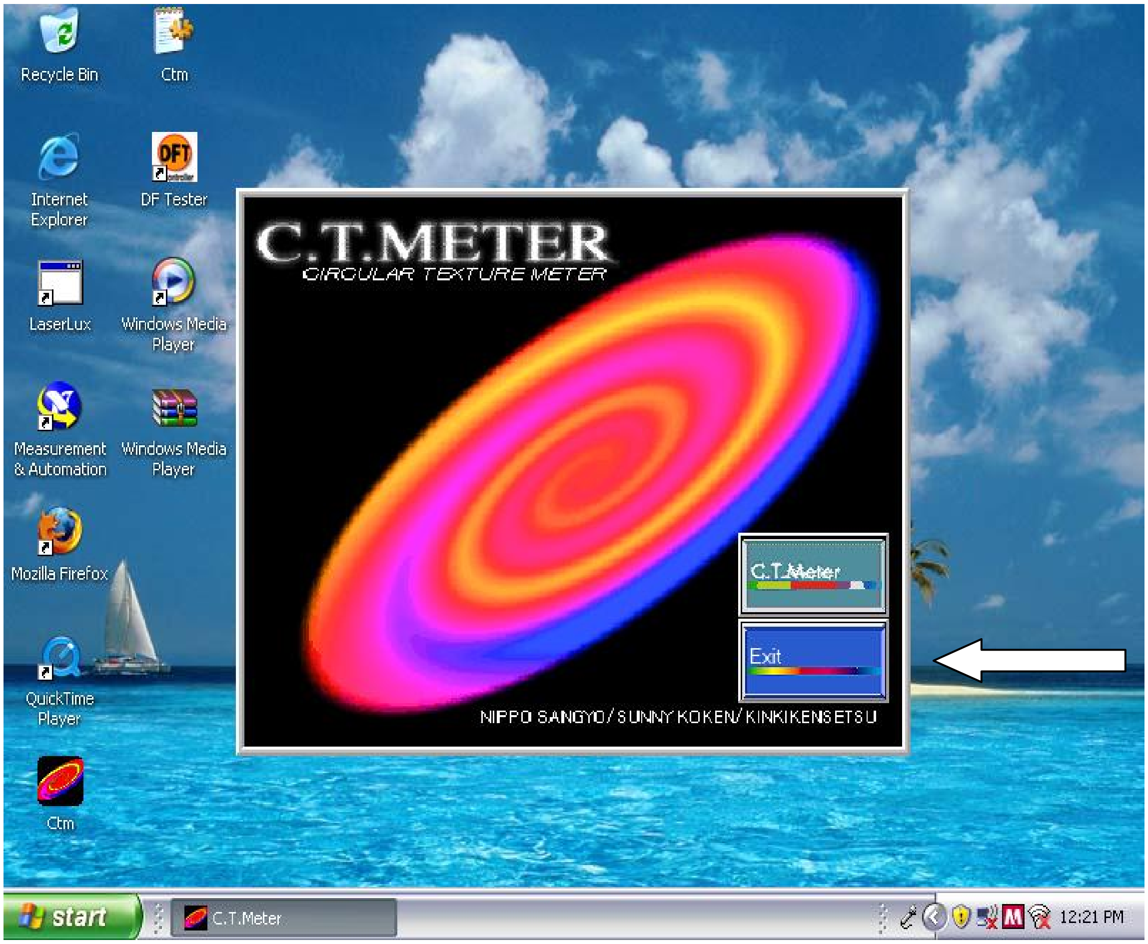
32. Click on the "Menu" button.



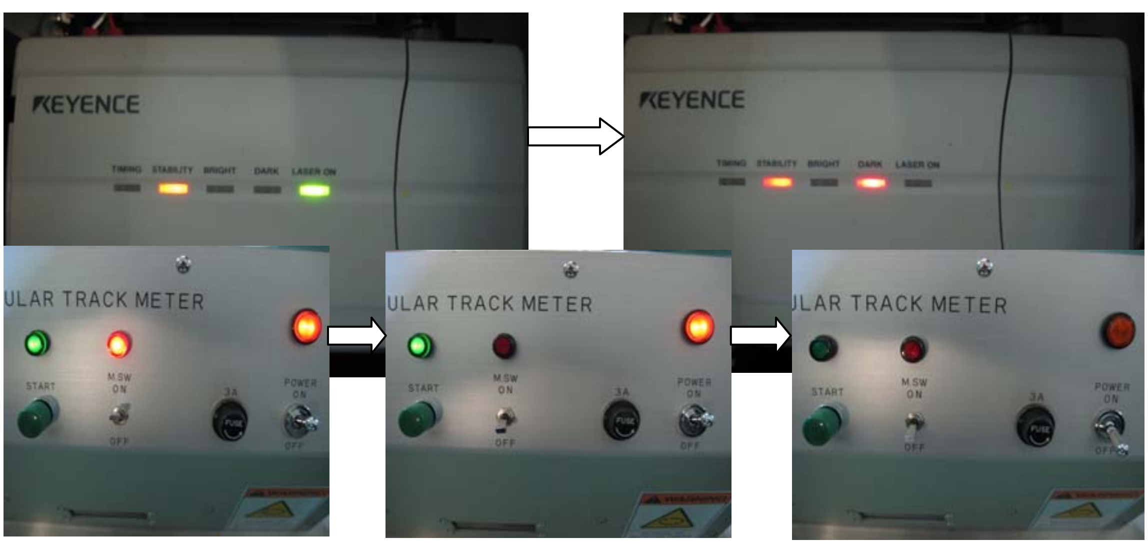
33. If continuing to perform more tests, return to **Step 20**, otherwise, click "Quit" (F12).



34. Click on the "Exit" button.



35. Then turn off the laser, then the MSW switch, then the power, and unplug the cables.



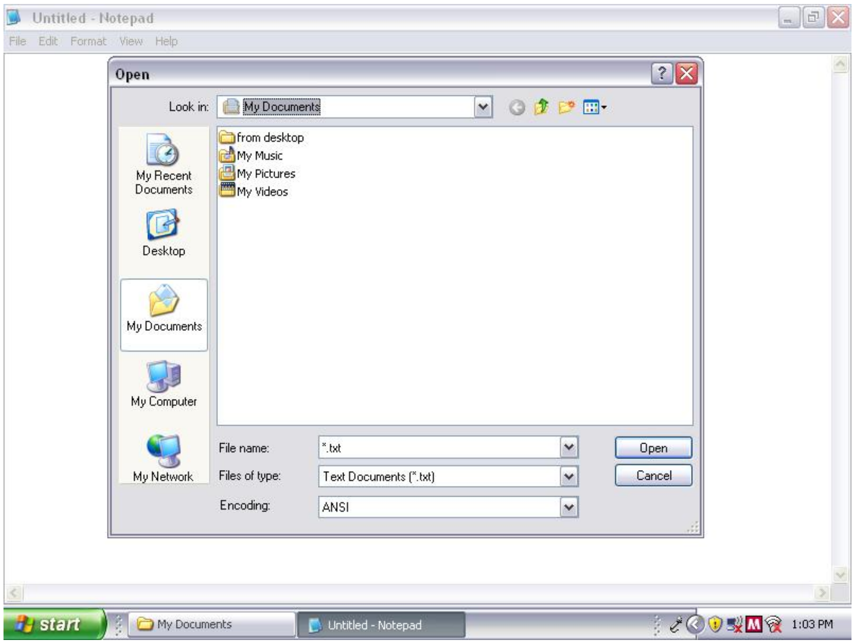
36. Remove crayon and any other debris from CTM, if any is present. Place the clean CTM, yellow crayon, metal bracket, power adapter and data cable back in the CTM box and close the box.

37. If finished with the computer, shut it down. Gather the power adapter and mouse.

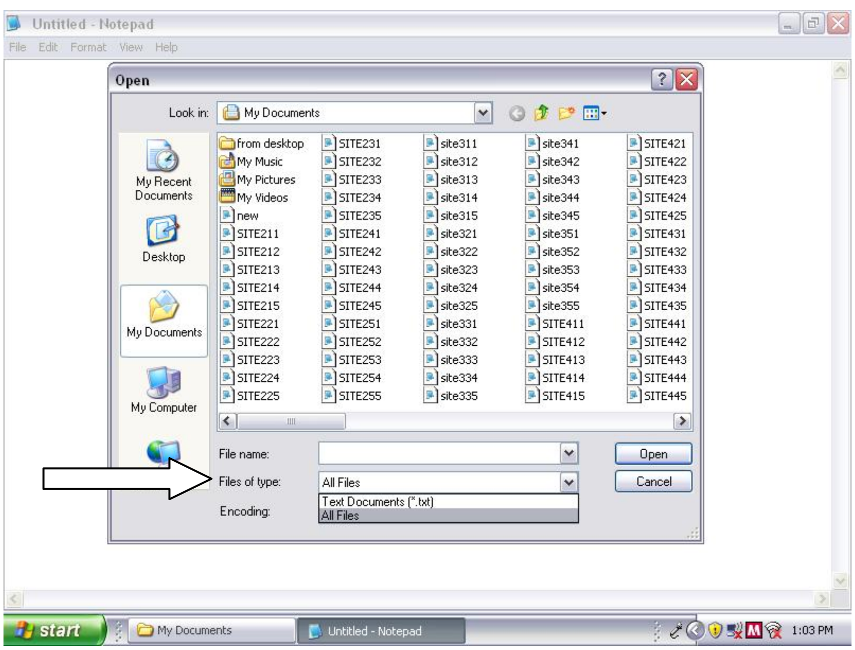
B 3 DATA DISPLAY AND PROCESSING

1. Click on the “Start” menu, choose “Programs,” then “Accessories,” then Notepad.

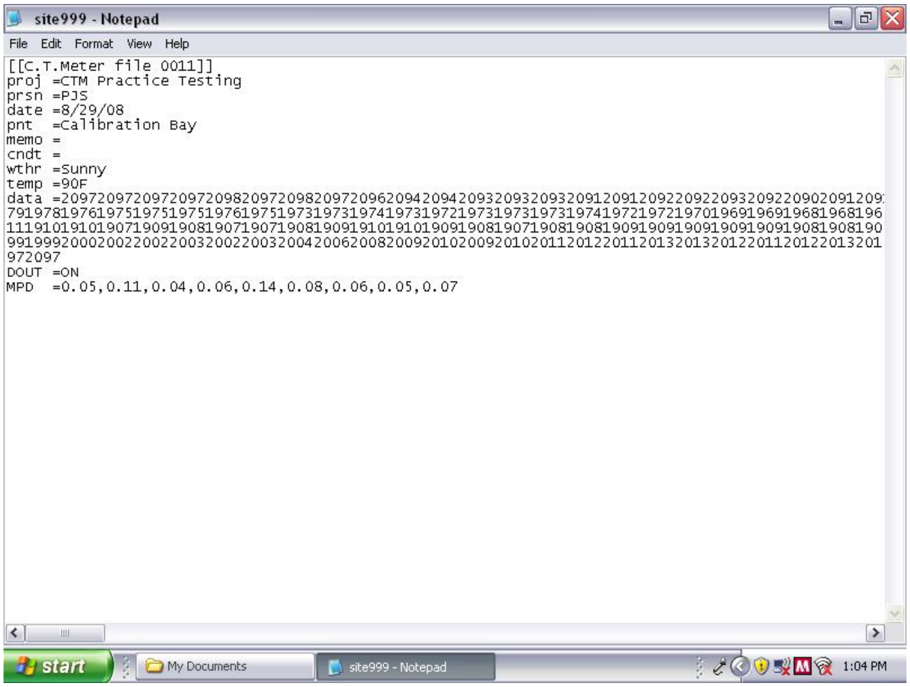
2. In Notepad, click on “File” and then “Open.”



3. Find the directory where the CTM data file is located. Click on “Files of type:” and select “All Files.”

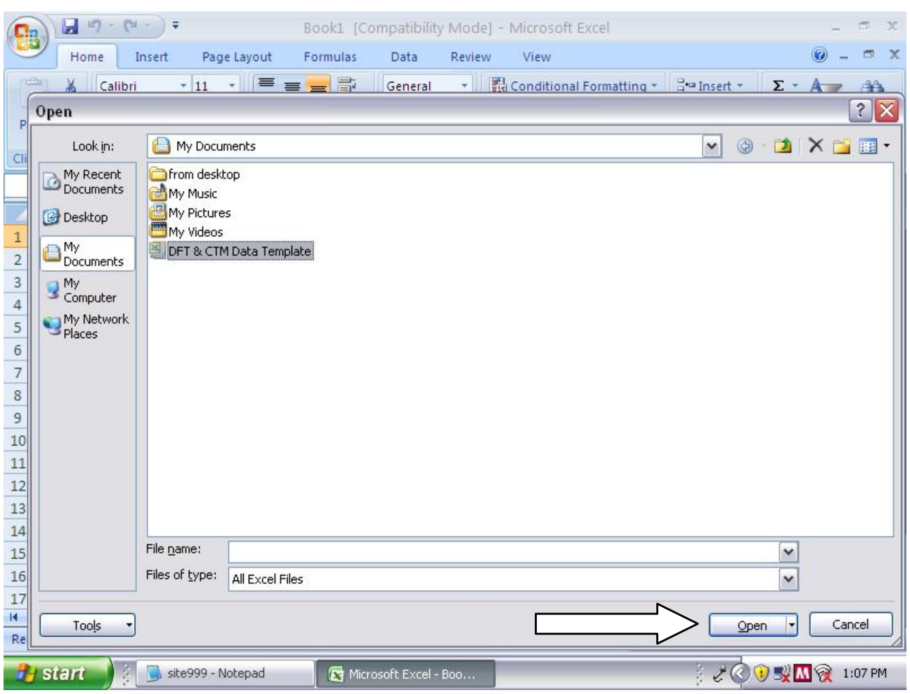


4. Open the desired CTM data file.

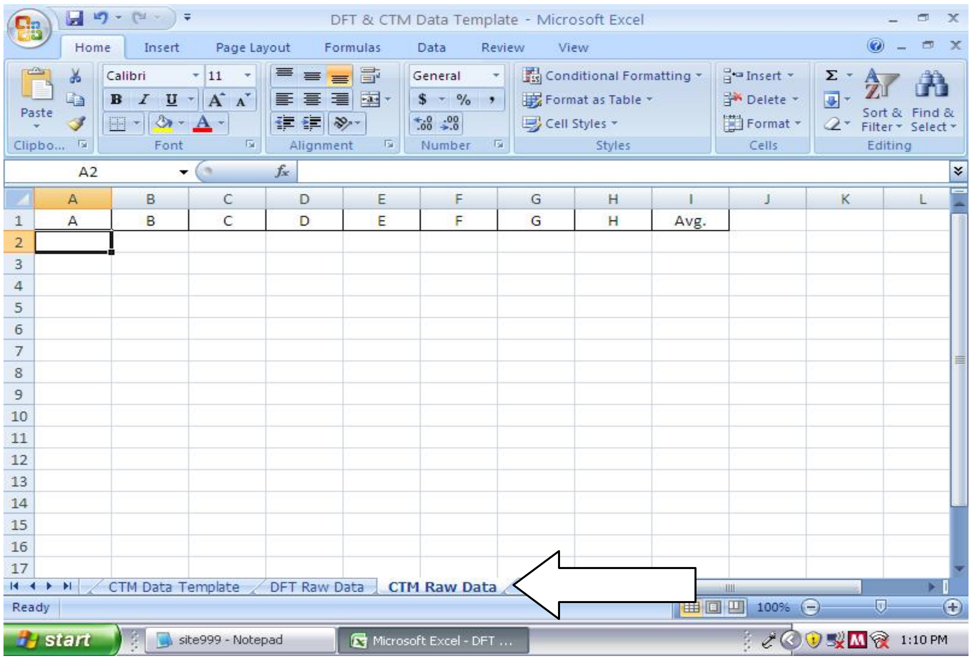


5. Open Microsoft Excel. It may be located by following the “Start” menu, “All Programs” and “Microsoft Office.”

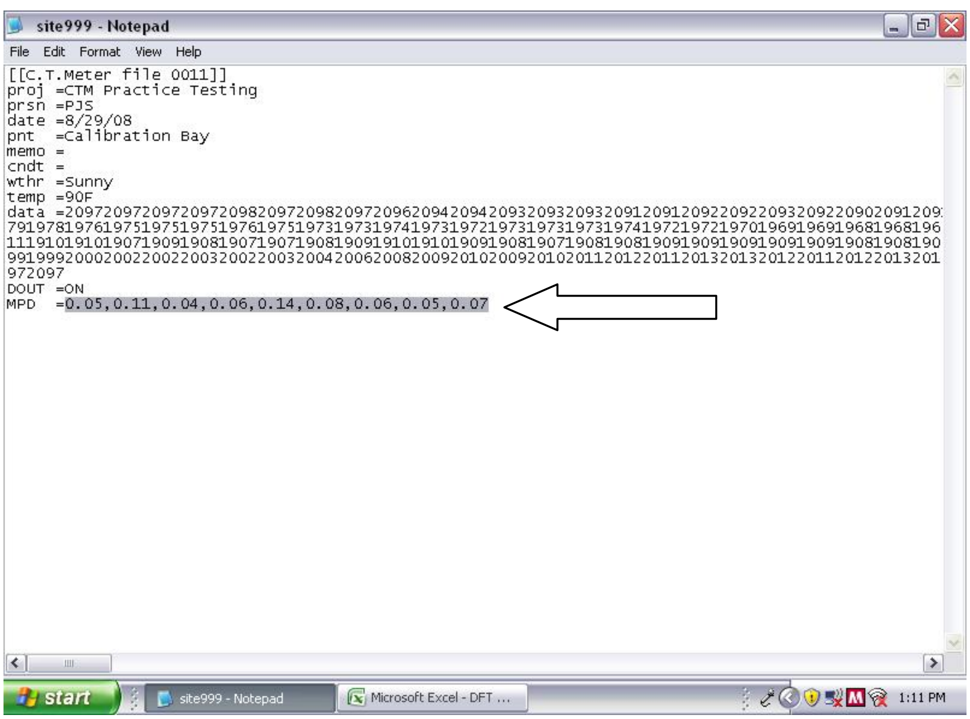
6. In Microsoft Excel, click on “File” and then “Open.” Locate the “DFT & CTM Data Template” file and click “Open.”



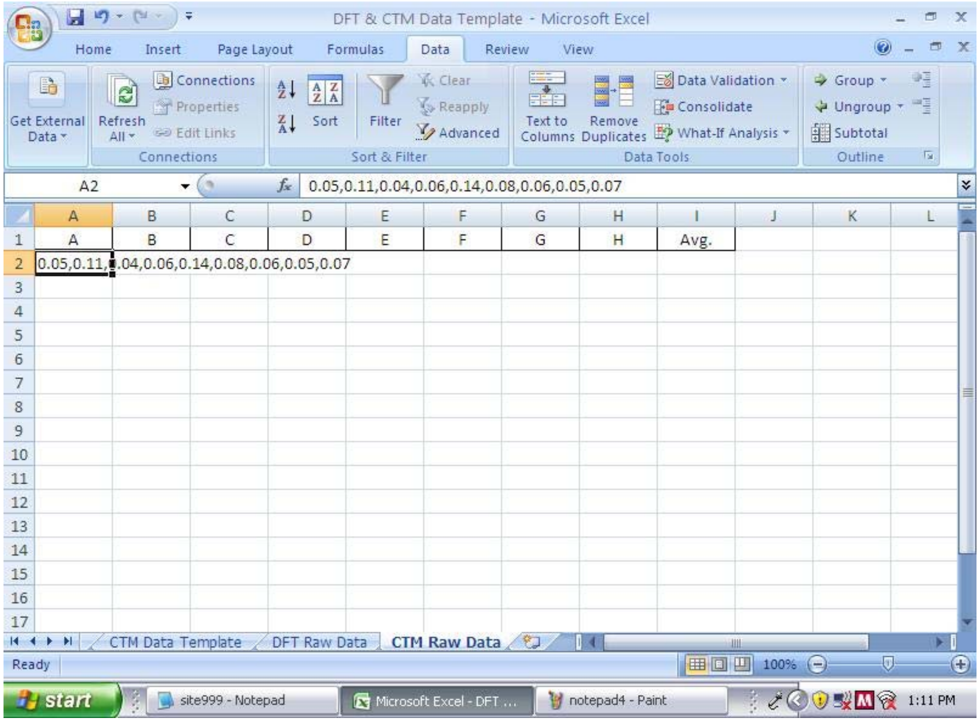
7. Click on the "CTM Raw Data" tab at the bottom of the Excel spreadsheet.



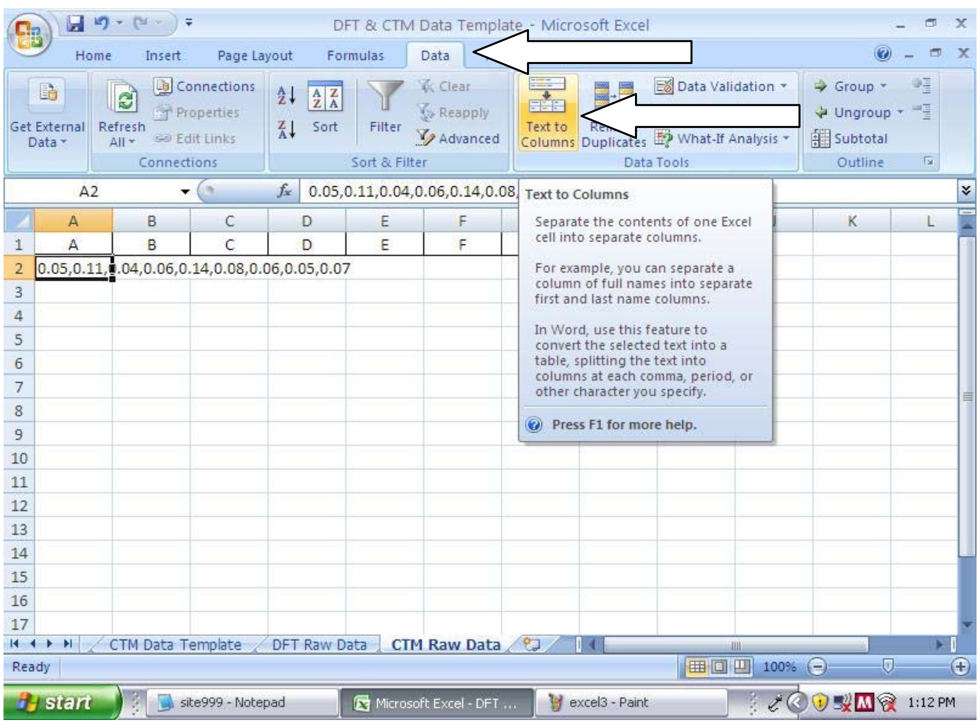
8. Go back to the Notepad application. Highlight the line of data at the bottom of the file, beginning with the first number that appears after the text, "MPD =". Type Ctrl-C or click "Edit" and "Copy."



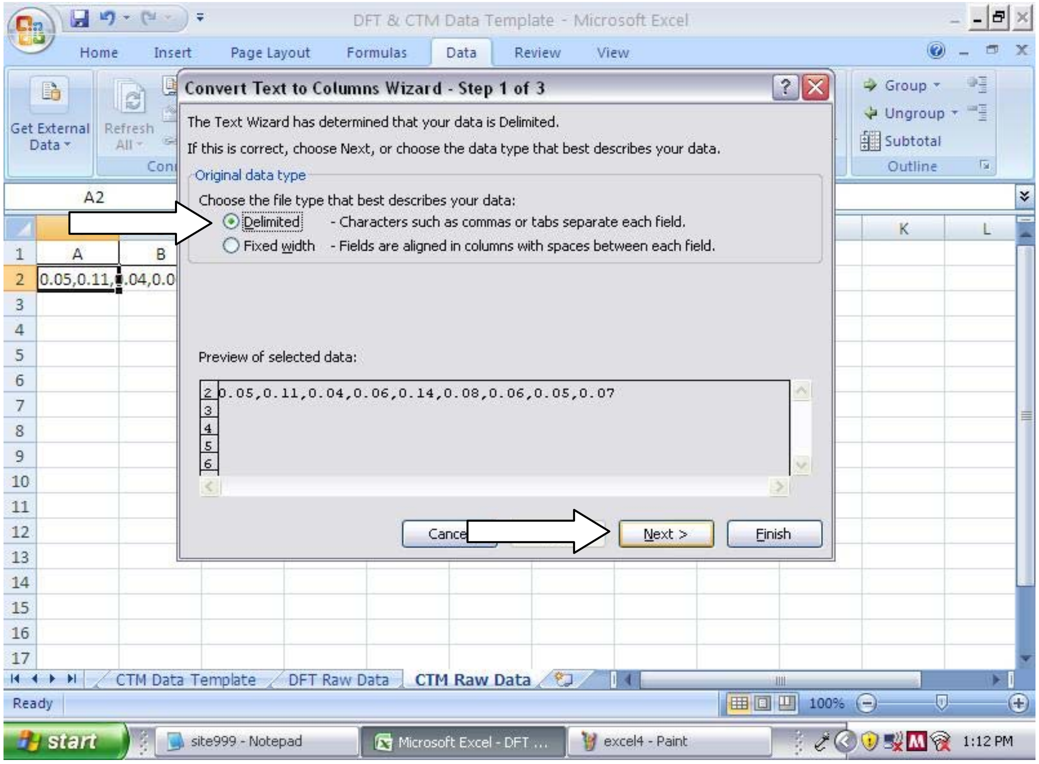
9. Go back to the Microsoft Excel application. Select cell A2. Type Ctrl-V or click "Edit" and "Paste."



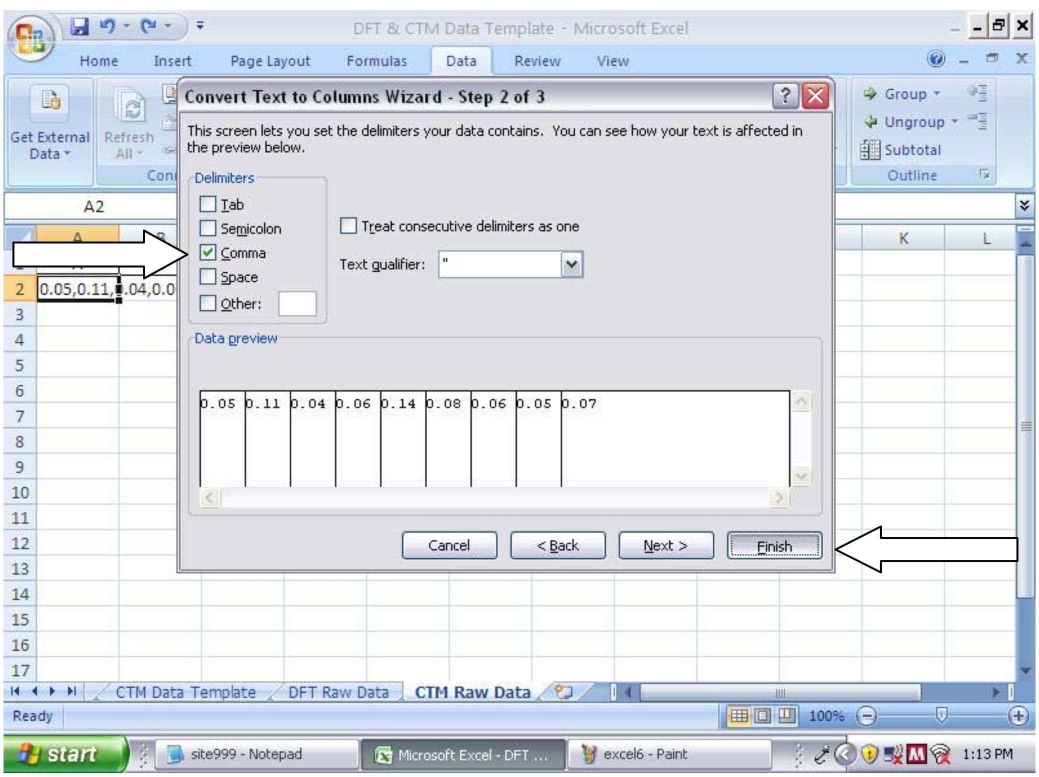
10. Click on the "Data" tab at the top of the screen. Select the "Text to Columns" button under the "Data Tools" section.



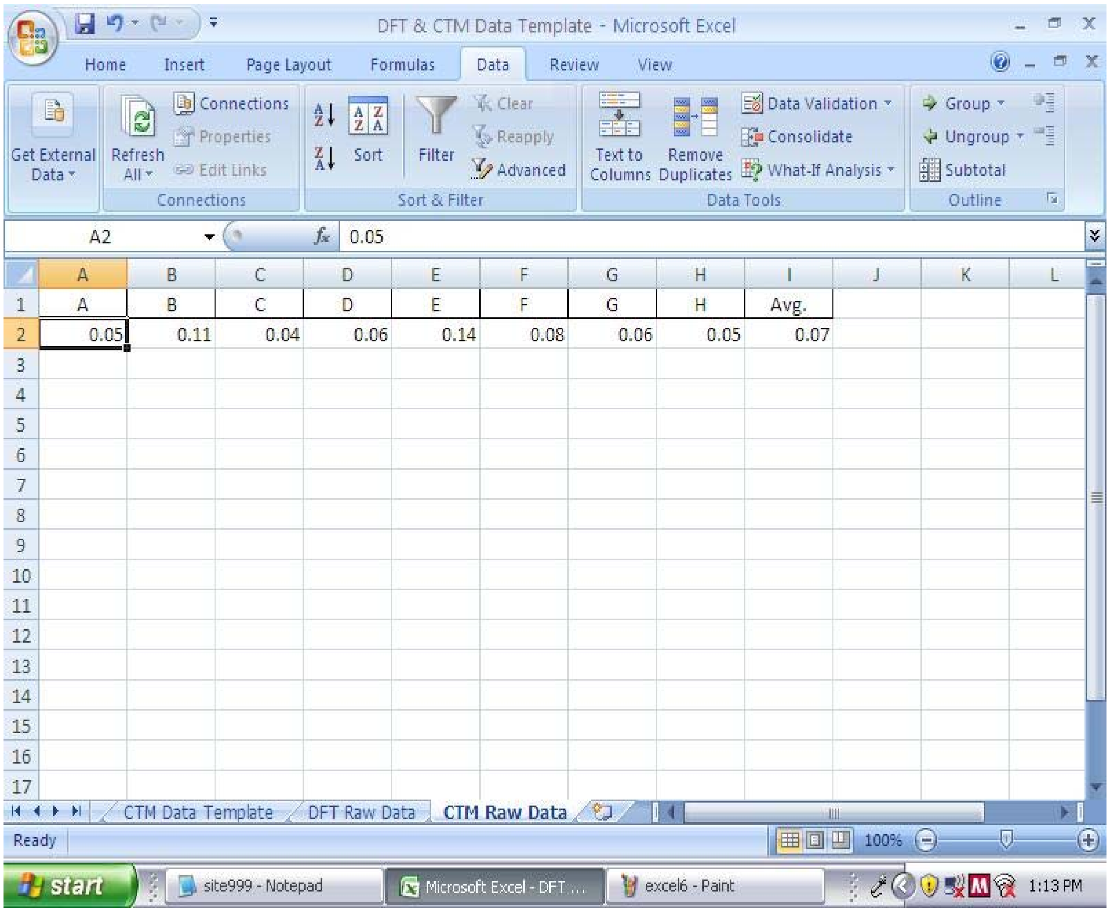
11. Choose "Delimited" and click the "Next" button.



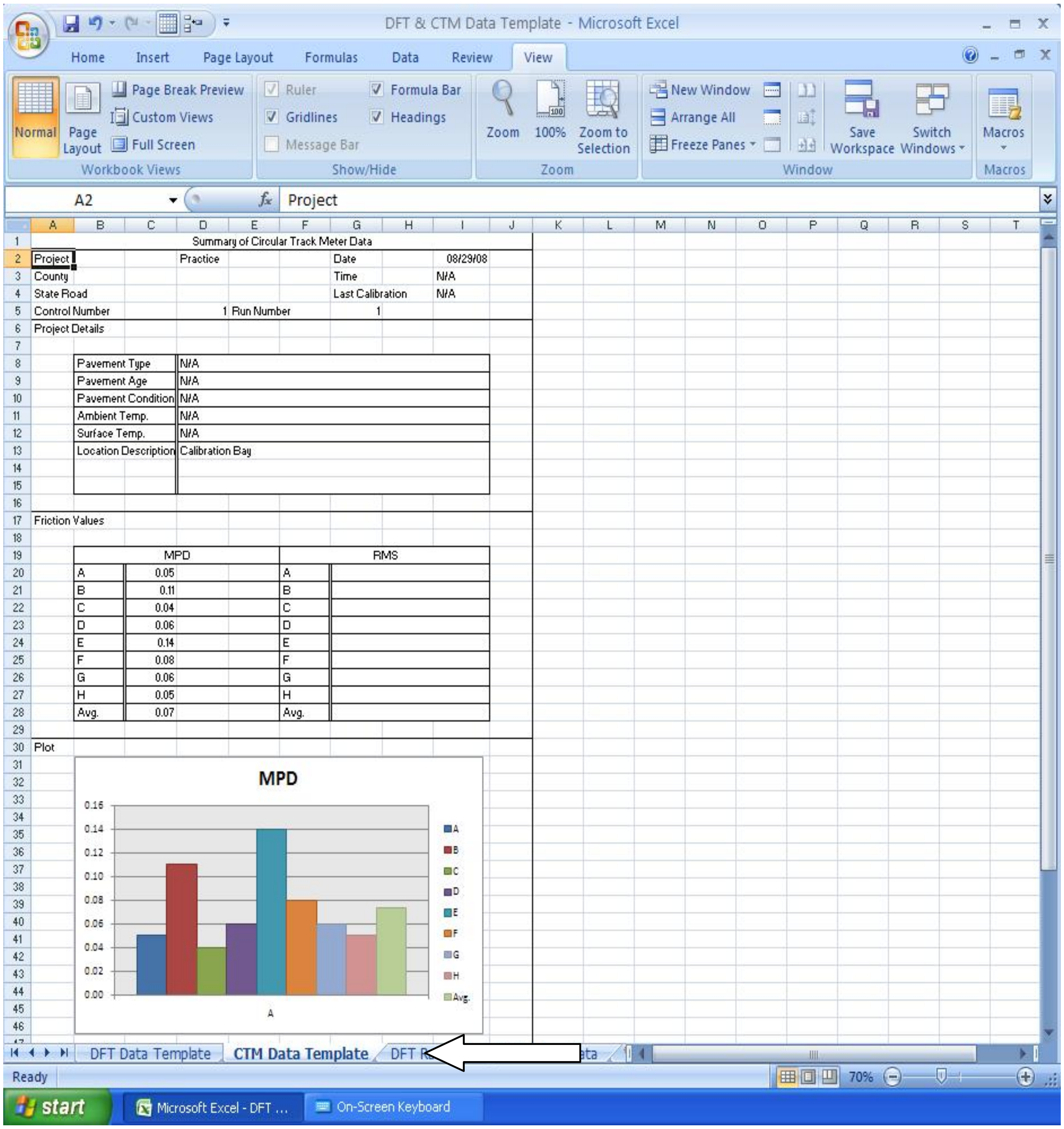
12. Check only "Comma" under Delimiters and click "Finish."



13. Each piece of data should now have its own cell, from A2 to I2, as shown below.



14. Click on the "CTM Data Template" tab. A graphical display of the CTM data for that run will be shown. Click on "File" and "Save As" to save the file to an appropriate location.

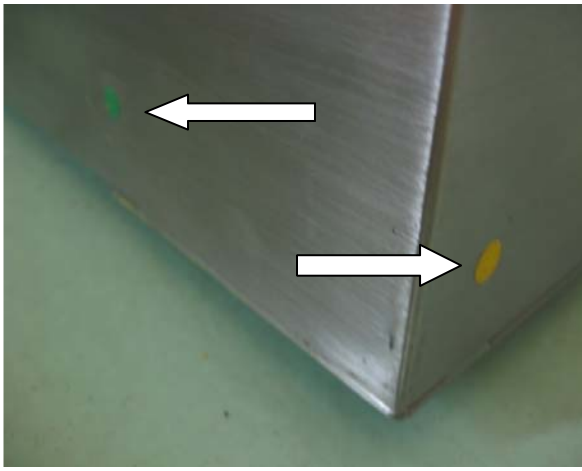


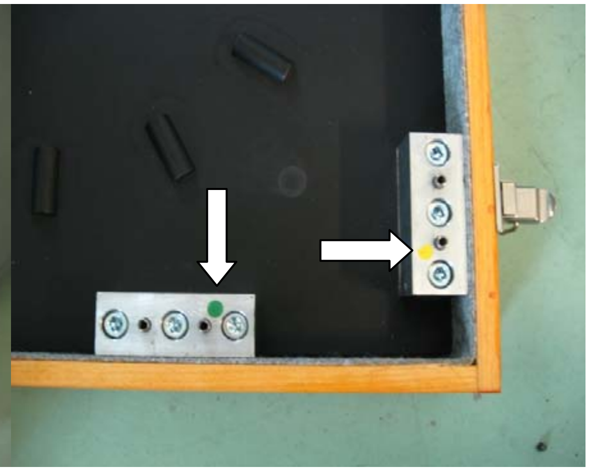
B 4 CTM CALIBRATION VERIFICATION PROCEDURES

1. Open the brown wooden Circular Track Meter box.

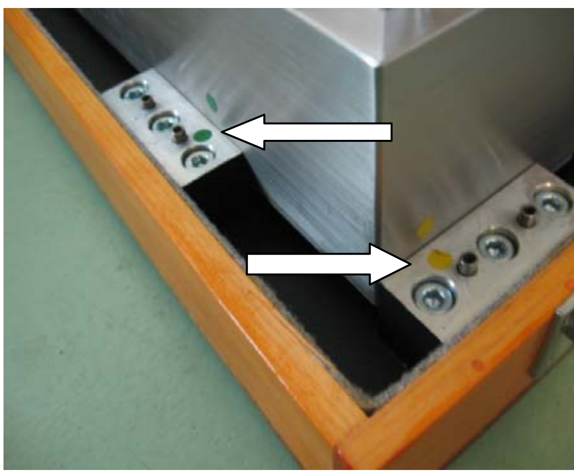
2. Carefully remove the packing peanuts and the Calibration Chart.

3. Locate the green and yellow dots on the front left corner of the CTM and on the front left corner of the CTM calibration box.





4. Carefully insert the CTM into the calibration box, making sure to align the dots, green with green, and yellow with yellow.



5. Follow the Operation Procedures to perform a CTM test. Process the data file. Compare the results with the Calibration Chart on the following page to verify the unit is operating properly and within tolerance.

Calibration of C.T.Meter (06－5028)

Caribration will be done by the manufacturer. Please contact with your local distributors for caribration if calibration is required. To determine the necessity, you are requested to check the measurement figures of the C.T.Meter using the test panel enclosed.

The procedure is as follow:

(1) Place the test panel on flat surface.

(2) Place the C.T.Meter to fit the one guide on the test panel (See Fig-1)

(3) Execute measurement in usual manner.

(4) If the average, of each measurement is within±0.05mm range of the whole averange it is considered to be normal. (See the Calculation Example)

(5) If the average of each measurement is not within the±0.05mm range ofthe whole average, it is considered to be calibrated.

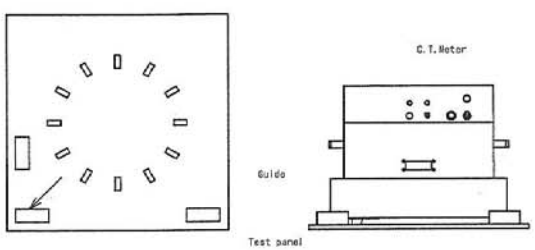


Fig-1

Test panel measurement value

Data Analysis (1024)

Without Dropout Points

[1]	A : 5. 96 (0%) [1.83]	B : 5. 38 (0%) [2.44]	C : 5. 96 (0%) [1.82]	D : 5. 33 (0%) [2.41]
[2]	A : 5. 97 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 33 (0%) [2.41]
[3]	A : 5. 96 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 33 (0%) [2.41]
[4]	A : 5. 97 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 34 (0%) [2.41]
[5]	A : 5. 96 (0%) [1.83]	B : 5. 40 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 34 (0%) [2.41]
[6]	A : 5. 96 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 34 (0%) [2.40]
[7]	A : 5. 96 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 34 (0%) [2.41]
[8]	A : 5. 96 (0%) [1.83]	B : 5. 40 (0%) [2.43]	C : 5. 95 (0%) [1.82]	D : 5. 35 (0%) [2.41]
Ave	A : 5. 96 (0%) [1.83]	B : 5. 39 (0%) [2.44]	C : 5. 95 (0%) [1.82]	D : 5. 34 (0%) [2.41]

E : 6. 02 (0%) [1.85]	F : 5. 35 (0%) [2.41]	G : 5. 97 (0%) [1.84]	H : 5. 34 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 35 (0%) [2.41]	G : 5. 97 (0%) [1.84]	H : 5. 33 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 34 (0%) [2.42]	G : 5. 98 (0%) [1.84]	H : 5. 34 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 35 (0%) [2.42]	G : 5. 98 (0%) [1.84]	H : 5. 33 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 36 (0%) [2.42]	G : 5. 98 (0%) [1.84]	H : 5. 34 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 35 (0%) [2.42]	G : 5. 96 (0%) [1.84]	H : 5. 33 (0%) [2.40]
E : 6. 03 (0%) [1.85]	F : 5. 35 (0%) [2.42]	G : 5. 98 (0%) [1.84]	H : 5. 34 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 36 (0%) [2.42]	G : 5. 97 (0%) [1.84]	H : 5. 33 (0%) [2.40]
E : 6. 02 (0%) [1.85]	F : 5. 35 (0%) [2.42]	G : 5. 97 (0%) [1.84]	H : 5. 34 (0%) [2.40]

(1Unit=0. 87mm)

Ave : 5. 66 (0%) [2.13]	Normal if within 5.62～5.72 range.
Ave : 5. 66 (0%) [2.13]	
Ave : 5. 66 (0%) [2.13]	
Ave : 5. 67 (0%) [2.13]	
Ave : 5. 67 (0%) [2.13]	
Ave : 5. 66 (0%) [2.13]	
Ave : 5. 67 (0%) [2.13]	
Ave : 5. 67 (0%) [2.13]	
Ave : 5. 67 (0%) [2.13]	±0. 05mm

UNF UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C

Florida DOT CTM Data from NCAT Test Track

(ASTM E 2157)

Appendix C Florida DOT CTM Data from NCAT Test Track

NCAT Test Section	Test Number	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
e2-48	1	1.20	1.33	0.77	1.08	0.95	1.03	1.27	1.05	1.09
e2-48	2	1.20	1.33	0.80	1.04	0.97	1.03	1.28	1.06	1.09
e2-53	1	1.21	1.23	1.08	1.06	1.09	1.38	0.76	1.02	1.10
e2-53	2	1.23	1.18	1.09	1.11	1.09	1.40	0.75	1.01	1.11
e2-109	1	0.90	0.83	0.86	1.00	1.09	0.89	1.61	0.99	1.02
e2-109	2	0.93	0.84	0.86	1.00	1.08	0.88	1.63	1.02	1.03
e2-132	1	0.80	0.74	1.21	1.47	0.78	0.78	0.93	0.82	0.94
e2-132	2	0.80	0.76	1.17	1.24	0.81	0.81	0.93	0.83	0.92
n2-51	1	0.61	0.47	0.75	0.56	0.60	0.58	0.62	0.59	0.60
n2-107	1	0.54	0.51	0.62	0.69	0.46	0.54	0.53	0.50	0.55
n2-132	1	0.42	0.53	0.44	0.50	0.58	0.53	0.46	0.64	0.51
n2-160	1	0.50	0.45	0.60	0.67	0.71	0.72	0.51	0.60	0.60
n2-160	2	0.49	0.45	0.57	0.66	0.70	0.72	0.52	0.60	0.59
n2-29	1	0.54	0.48	0.60	0.67	0.45	0.54	0.51	0.51	0.54
n2-29	2	0.54	0.51	0.62	0.69	0.46	0.54	0.53	0.50	0.55
n8-25	1	1.21	1.13	1.03	1.18	1.46	0.95	0.90	1.05	1.11
n8-25	2	1.20	1.13	1.03	1.16	1.45	0.94	0.89	1.06	1.11
n8-49	1	1.30	1.34	0.96	1.12	1.27	1.15	1.26	1.41	1.23
n8-168	1	1.02	1.25	1.13	1.36	0.89	1.08	1.47	1.28	1.18
n8-168	2	1.01	1.24	1.14	1.35	0.88	1.09	1.46	1.27	1.18
n8-188	1	1.28	0.91	1.12	1.09	1.00	1.25	0.98	1.03	1.08
n8-188	2	1.25	0.92	1.13	1.09	1.00	1.25	0.98	1.02	1.08
n9-42	1	1.37	1.16	0.82	1.24	1.12	1.12	1.08	1.28	1.15
n9-42	2	1.36	1.16	0.83	1.24	1.12	1.12	1.09	1.28	1.15
n9-53	1	0.97	1.30	1.42	1.11	0.99	0.84	0.83	1.13	1.07
n9-53	2	0.98	1.31	1.43	1.11	0.99	0.83	0.83	1.12	1.08
n9-90	1	1.14	1.03	1.32	1.30	0.87	0.96	0.99	0.95	1.07
n9-90	2	1.15	1.32	1.31	1.31	0.86	0.95	0.96	0.97	1.10
n9-102	1	1.28	0.79	0.97	1.18	1.79	1.32	1.01	1.00	1.17
n9-125	1	0.89	1.05	1.10	1.02	1.60	1.24	0.77	1.07	1.09
n9-125	2	0.89	1.04	1.10	1.02	1.59	1.23	0.77	1.06	1.09

Appendix C Florida DOT CTM Data from NCAT Test Track (Continued)

NCAT Test Section	Test Number	Segments of the Circular Track Profile (mm) A	B	C	D	E	F	G	H	Average MPD (mm)
n10-71	1	0.56	0.71	0.67	0.58	0.75	0.70	0.75	0.48	0.65
n10-79	1	0.62	0.49	0.67	0.71	0.47	0.59	0.69	0.84	0.64
n10-101	1	0.54	1.02	0.69	0.61	0.73	0.80	0.62	0.85	0.73
n10-101	2	0.55	1.03	0.70	0.62	0.74	0.81	0.63	0.84	0.74
n10-143	1	0.82	0.59	0.77	0.80	0.83	0.83	0.91	0.71	0.78
n10-143	2	0.82	0.58	0.80	0.81	0.83	0.83	0.91	0.73	0.79
n10-159	1	0.55	0.72	1.04	0.84	0.78	0.61	0.64	0.76	0.74
n10-159	2	0.55	0.72	1.02	0.63	0.77	0.61	0.64	0.73	0.71
n11-52	1	1.81	1.70	1.68	1.67	1.49	1.30	1.22	1.45	1.54
n11-52	2	1.86	1.71	1.66	1.67	1.49	1.30	1.21	1.48	1.55
n11-82	1	1.92	1.25	1.13	1.83	1.93	1.43	1.29	1.76	1.57
n11-118	1	1.17	1.51	1.64	1.85	1.84	1.53	1.82	1.61	1.62
n11-118	2	1.18	1.40	1.77	1.78	1.80	1.50	1.85	1.61	1.61
n11-132	1	2.23	1.59	1.22	1.66	1.76	1.93	1.44	1.98	1.73
n11-132	2	2.19	1.58	1.20	1.66	1.73	1.92	1.43	2.00	1.71
n13-34	1	0.95	0.96	1.10	1.13	1.08	1.04	1.21	1.20	1.08
n13-34	2	1.06	1.02	1.08	1.13	1.10	1.06	1.21	1.11	1.10
n13-74	1	1.60	1.18	1.09	1.02	0.92	1.22	1.16	1.14	1.17
n13-74	2	1.58	1.09	1.07	1.03	0.96	1.13	1.15	1.12	1.14
n13-89	1	1.24	1.27	1.38	1.33	1.14	0.92	0.95	1.47	1.21
n13-89	2	1.25	1.26	1.37	1.35	1.11	0.90	0.96	1.41	1.20
n13-135	1	1.21	1.21	1.27	1.17	1.39	1.08	1.22	1.30	1.23
n13-135	2	1.20	1.20	1.28	1.18	1.42	1.07	1.23	1.30	1.24
n13-168	1	1.20	1.37	1.09	1.35	1.13	1.45	1.28	1.30	1.27
n13-168	2	1.13	1.41	1.14	1.32	1.16	1.48	1.32	1.27	1.28

Appendix C Florida DOT CTM Data from NCAT Test Track (Continued)

NCAT Test Section	Test Number	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
s2-45	1	0.43	0.46	0.48	0.77	0.69	0.69	0.47	0.43	0.55
s2-45	2	0.51	0.48	0.49	0.77	0.69	0.69	0.46	0.43	0.57
s2-70	1	0.31	0.44	0.48	0.59	0.40	0.37	0.43	0.33	0.42
s2-70	2	0.34	0.43	0.48	0.59	0.40	0.39	0.42	0.32	0.42
s2-106	1	0.48	0.44	0.38	0.46	0.40	0.46	0.36	0.38	0.42
s2-106	2	0.48	0.44	0.40	0.46	0.40	0.47	0.36	0.38	0.42
s2-132	1	0.38	0.37	0.37	0.52	0.39	0.44	0.33	0.33	0.39
s2-132	2	0.38	0.37	0.37	0.43	0.37	0.46	0.33	0.34	0.38
s2-161	1	0.42	0.40	0.43	0.59	0.54	0.42	0.40	0.39	0.45
s2-161	2	0.44	0.41	0.43	0.60	0.56	0.41	0.40	0.40	0.46
s3-75	1	1.42	1.66	1.28	1.25	1.09	1.82	1.79	1.54	1.48
s3-75	2	1.61	1.71	1.27	1.26	1.08	1.83	1.81	1.50	1.51
s3-96	1	1.32	1.31	1.39	1.21	1.45	1.15	1.02	1.22	1.26
s3-96	2	1.33	1.29	1.42	1.19	1.45	1.16	1.03	1.20	1.26
s3-102	1	1.75	1.23	1.06	1.29	1.50	1.28	1.58	1.02	1.34
s3-102	2	1.74	1.23	1.05	1.42	1.50	1.12	1.57	1.04	1.33
s3-134	1	1.49	1.43	1.18	1.42	1.58	1.15	1.50	1.47	1.40
s3-134	2	1.46	1.44	1.19	1.36	1.56	1.14	1.46	1.46	1.38
s3-153	1	1.31	1.34	1.34	1.19	1.41	1.25	1.66	1.95	1.43
s3-153	2	1.30	1.37	1.32	1.20	1.26	1.23	1.67	1.89	1.41
w8-42	1	1.12	1.10	0.91	1.12	0.86	0.74	1.00	0.92	0.97
w8-42	2	1.12	1.09	0.91	1.13	0.85	0.74	0.99	0.92	0.97
w8-76	1	1.08	0.93	1.01	0.82	1.12	0.88	0.97	1.01	0.98
w8-76	2	1.03	0.93	1.04	0.82	1.11	0.89	0.96	1.03	0.98
w8-89	1	0.74	1.07	1.16	1.09	1.05	1.20	0.92	0.99	1.03
w8-89	2	0.75	1.10	1.16	1.10	1.05	1.20	0.93	0.99	1.04
w8-120	1	1.03	0.88	0.89	0.89	0.82	0.91	0.78	0.64	0.86
w8-158	1	1.21	0.85	1.07	1.18	1.21	0.79	1.01	0.92	1.03
w8-158	2	1.23	0.85	1.08	1.17	1.22	0.79	1.01	0.93	1.04

APPENDIX D

Florida DOT DFT Data from NCAT Test Track

(ASTM E 1911)

Appendix D Florida DOT DFT Data from NCAT Test Track

NCAT Test Section	Test Number	DFT_{20} 20 km/h (12.4 mph)	DFT_{40} 40 km/h (24.8 mph)	DFT_{60} 60 km/h (37.3 mph)
e2-48	1	0.429	0.411	0.396
e2-48	2	0.431	0.416	0.401
e2-53	1	0.435	0.417	0.400
e2-53	2	0.434	0.419	0.402
e2-109	1	0.418	0.397	0.388
e2-109	2	0.420	0.402	0.391
e2-132	1	0.453	0.430	0.410
e2-132	2	0.453	0.435	0.418
n2-51	1	0.282	0.267	0.257
n2-107	1	0.274	0.262	0.254
n2-132	1	0.282	0.267	0.254
n2-160	1	0.288	0.280	0.270
n2-160	2	0.280	0.274	0.264
n2-29	1	0.260	0.247	0.239
n2-29	2	0.267	0.254	0.240
n8-25	1	0.280	0.264	0.256
n8-25	2	0.273	0.255	0.252
n8-49	1	0.277	0.258	0.254
n8-168	1	0.319	0.290	0.280
n8-168	2	0.306	0.278	0.269
n8-188	1	0.279	0.257	0.248
n8-188	2	0.275	0.254	0.245
n9-42	1	0.294	0.269	0.257
n9-42	2	0.283	0.260	0.246
n9-53	1	0.260	0.237	0.230
n9-53	2	0.259	0.238	0.230
n9-90	1	0.274	0.256	0.242
n9-90	2	0.269	0.250	0.234
n9-102	1	0.263	0.247	0.239
n9-125	1	0.263	0.239	0.231
n9-125	2	0.254	0.234	0.226

Appendix D Florida DOT DFT Data from NCAT Test Track (Continued)

NCAT Test Section	Test Number	DFT_{20} 20 km/h (12.4 mph)	DFT_{40} 40 km/h (24.8 mph)	DFT_{60} 60 km/h (37.3 mph)
n10-71	1	0.175	0.168	0.167
n10-79	1	0.177	0.167	0.165
n10-101	1	0.178	0.173	0.176
n10-101	2	0.178	0.169	0.173
n10-143	1	0.177	0.171	0.169
n10-143	2	0.178	0.171	0.167
n10-159	1	0.181	0.174	0.172
n10-159	2	0.180	0.173	0.170
n11-52	1	0.266	0.267	0.252
n11-52	2	0.260	0.261	0.249
n11-82	1	0.269	0.267	0.258
n11-118	1	0.281	0.283	0.277
n11-118	2	0.273	0.276	0.270
n11-132	1	0.274	0.270	0.262
n11-132	2	0.272	0.272	0.264
n13-34	1	0.247	0.243	0.248
n13-34	2	0.243	0.241	0.239
n13-74	1	0.254	0.255	0.250
n13-74	2	0.249	0.249	0.242
n13-89	1	0.256	0.255	0.252
n13-89	2	0.248	0.247	0.242
n13-135	1	0.254	0.254	0.255
n13-135	2	0.247	0.247	0.248
n13-168	1	0.263	0.262	0.254
n13-168	2	0.258	0.257	0.248

Appendix D Florida DOT DFT Data from NCAT Test Track (Continued)

NCAT Test Section	Test Number	DFT_{20} 20 km/h (12.4 mph)	DFT_{40} 40 km/h (24.8 mph)	DFT_{60} 60 km/h (37.3 mph)
s2-45	1	0.255	0.237	0.226
s2-45	2	0.252	0.235	0.221
s2-70	1	0.265	0.250	0.237
s2-70	2	0.260	0.245	0.232
s2-106	1	0.251	0.235	0.221
s2-106	2	0.246	0.231	0.217
s2-132	1	0.256	0.238	0.224
s2-132	2	0.251	0.233	0.217
s2-161	1	0.259	0.240	0.229
s2-161	2	0.250	0.231	0.219
s3-75	1	0.242	0.241	0.232
s3-75	2	0.236	0.236	0.228
s3-96	1	0.244	0.230	0.228
s3-96	2	0.239	0.227	0.224
s3-102	1	0.230	0.215	0.214
s3-102	2	0.229	0.211	0.212
s3-134	1	0.243	0.226	0.227
s3-134	2	0.238	0.220	0.222
s3-153	1	0.243	0.230	0.229
s3-153	2	0.237	0.225	0.222
w8-42	1	0.186	0.186	0.186
w8-42	2	0.178	0.181	0.180
w8-76	1	0.176	0.179	0.174
w8-76	2	0.177	0.179	0.174
w8-89	1	0.152	0.155	0.152
w8-89	2	0.161	0.159	0.152
w8-120	1	0.152	0.151	0.152
w8-158	1	0.167	0.164	0.165
w8-158	2	0.164	0.161	0.161

Appendices E and F

Florida DOT Locked-Wheel Friction Test and 64 kHz Laser Texture Data from NCAT Test Track

(ASTM E 274)
(ASTM E 501)
(ASTM E 524)
(ASTM E 1845)

Appendix E Florida DOT Locked-Wheel Friction Test Data from NCAT Test Track

NCAT Test Section	Friction Number	
	FN_{40R}	FN_{40S}
E2	0.66	0.54
N2	0.45	0.33
N8	0.41	0.36
N9	0.42	0.35
N10	0.36	0.28
N11	0.47	0.45
N13	0.47	0.47
S2	0.42	0.26
S3	0.42	0.40
W8	0.30	0.28

Appendix F Florida DOT 64 kHz Laser Texture Data from NCAT Test Track

NCAT Test Section	High Speed Laser Texture, MPD (mm)		
	Texture Only Run	Ribbed Tire Test Run	Smooth Tire Test Run
E2	1.00	0.93	0.91
N2	0.54	0.51	0.54
N8	1.09	1.01	1.14
N9	0.87	0.84	0.98
N10	0.72	0.63	0.66
N11	1.64	1.39	1.48
N13	1.19	1.05	1.15
S2	0.51	0.41	0.46
S3	1.37	1.26	1.28
W8	1.02	0.93	0.90

Appendix G

CTM Data from Florida Test Sections

(ASTM E 2157)

Appendix G.1 CTM Data from Florida Test Sections, Site #1

Florida Test Site 1 October 2, 2007 Surface: FC-12.5 M Location: SR 24 Aggregate: Granite Mix Design: SPM 06-4852B Project ID: 26050000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.47	0.42	0.59	0.49	0.40	0.31	0.33	0.49	0.44
	2	0.45	0.37	0.50	0.49	0.47	0.40	0.37	0.45	0.44
	3	0.55	0.53	0.34	0.51	0.43	0.36	0.47	0.44	0.45
	4	0.47	0.33	0.43	0.48	0.39	0.45	0.42	0.39	0.42
	5	0.41	0.52	0.35	0.42	0.40	0.32	0.36	0.30	0.39
2	1	0.53	0.41	0.54	0.56	0.49	0.44	0.52	0.53	0.50
	2	0.40	0.37	0.40	0.36	0.50	0.52	0.64	0.31	0.44
	3	0.71	0.47	0.28	0.54	0.43	0.44	0.32	0.48	0.46
	4	0.38	0.44	0.49	0.54	0.57	0.39	0.49	0.44	0.47
	5	0.46	0.44	0.50	0.42	0.56	0.39	0.42	0.46	0.46
3	1	0.46	0.48	0.54	0.40	0.46	0.41	0.53	0.45	0.47
	2	0.46	0.51	0.48	0.37	0.50	0.38	0.41	0.45	0.45
	3	0.34	0.37	0.47	0.33	0.51	0.35	0.39	0.27	0.38
	4	0.33	0.45	0.48	0.30	0.29	0.33	0.37	0.38	0.37
	5	0.34	0.33	0.44	0.26	0.42	0.38	0.41	0.55	0.39
4	1	0.37	0.41	0.50	0.41	0.47	0.34	0.37	0.53	0.42
	2	0.50	0.35	0.30	0.44	0.47	0.40	0.33	0.38	0.40
	3	0.53	0.44	0.42	0.42	0.39	0.37	0.52	0.41	0.44
	4	0.42	0.35	0.39	0.52	0.36	0.38	0.69	0.54	0.46
	5	0.41	0.50	0.33	0.52	0.58	0.49	0.50	0.29	0.45
5	1	0.45	0.45	0.26	0.48	0.49	0.33	0.50	0.49	0.43
	2	0.49	0.59	0.43	0.34	0.32	0.50	0.43	0.50	0.45
	3	0.29	0.35	0.35	0.38	0.28	0.40	0.36	0.47	0.36
	4	0.51	0.36	0.50	0.36	0.40	0.48	0.45	0.38	0.43
	5	0.34	0.37	0.47	0.45	0.37	0.49	0.39	0.36	0.41

Appendix G.2 CTM Data from Florida Test Sections, Site #2

Florida Test Site 2 February 26, 2008 Surface: FC-5 Location: SR 24 Aggregate: Limestone Mix Design: QA 00-9506A Project ID: 26050000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	1.07	1.57	1.34	1.16	0.85	1.30	1.13	1.23	1.21
	2	2.26	1.82	1.72	1.10	1.40	1.03	1.43	1.18	1.49
	3	0.91	1.61	1.51	1.25	0.90	1.78	1.67	1.26	1.36
	4	1.64	1.99	1.80	2.03	1.34	1.02	1.46	1.94	1.65
	5	1.28	1.27	1.42	1.65	1.07	0.97	1.21	1.27	1.27
2	1	2.42	1.04	0.96	1.33	1.14	1.06	1.20	1.42	1.32
	2	0.97	1.04	1.44	1.03	1.14	1.35	0.85	1.02	1.10
	3	0.91	1.61	1.16	1.46	0.99	1.15	1.19	1.44	1.24
	4	1.17	0.96	0.74	0.82	1.13	1.41	1.11	1.27	1.08
	5	1.16	1.09	1.44	0.79	1.11	1.88	0.98	1.24	1.21
3	1	1.44	1.48	1.09	1.13	1.23	0.98	0.89	1.04	1.16
	2	1.38	1.23	0.92	1.28	1.52	1.29	1.13	1.33	1.26
	3	1.83	1.48	1.39	1.00	1.16	1.25	0.94	1.28	1.29
	4	1.52	1.07	1.27	1.53	1.33	0.94	1.28	1.60	1.32
	5	1.06	1.31	1.52	0.87	1.08	1.32	1.12	1.17	1.18
4	1	1.12	1.02	1.35	1.78	1.52	1.31	1.58	1.16	1.36
	2	1.30	1.13	1.75	1.13	0.99	0.79	1.47	1.34	1.24
	3	1.26	1.18	1.40	1.22	1.00	1.26	1.72	1.35	1.30
	4	1.94	0.87	1.63	0.92	1.07	1.03	1.38	1.39	1.28
	5	0.81	1.31	1.08	1.36	1.27	1.58	1.16	1.21	1.22
5	1	1.39	1.03	1.01	1.22	1.04	0.91	1.14	1.72	1.18
	2	1.23	1.17	1.04	1.23	1.05	1.43	1.43	0.96	1.19
	3	1.22	1.37	1.49	0.98	1.42	1.32	1.21	0.89	1.24
	4	1.65	0.90	1.21	1.49	1.17	1.23	1.12	0.90	1.21
	5	1.36	1.52	1.42	1.77	0.88	1.16	1.01	1.88	1.38

Appendix G.3 CTM Data from Florida Test Sections, Site #3

Florida Test Site 3 February 27, 2008 Surface: FC-5 Location: SR 24 Aggregate: Granite Mix Design: LD 02-2523A Project ID: 26050000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	2.59	2.25	1.58	1.57	1.96	1.70	1.70	1.99	1.92
	2	2.08	1.73	2.08	2.93	1.75	1.87	1.05	1.84	1.92
	3	2.14	2.09	2.28	1.99	1.50	2.28	1.50	1.69	1.93
	4	2.90	2.75	2.05	1.91	1.61	1.64	2.19	1.88	2.12
	5	2.37	1.86	1.57	1.63	1.33	2.34	1.48	2.52	1.89
2	1	1.90	2.04	1.15	1.99	1.43	1.64	1.18	1.46	1.60
	2	1.51	1.84	1.51	1.44	2.03	2.17	1.47	2.48	1.81
	3	1.54	1.65	1.28	1.45	1.88	2.02	1.84	2.17	1.73
	4	1.78	1.83	1.65	1.82	1.64	2.35	1.41	1.44	1.74
	5	1.72	2.01	1.74	1.39	1.75	1.08	1.76	1.49	1.62
3	1	2.06	2.17	1.93	1.83	1.43	1.92	1.73	3.34	2.05
	2	1.87	2.16	1.20	3.24	1.01	1.74	1.59	1.10	1.74
	3	2.79	2.17	2.56	1.58	1.75	1.55	1.94	1.24	1.95
	4	1.95	3.49	1.77	2.26	1.84	1.52	2.04	2.91	2.22
	5	1.72	1.90	2.25	1.62	1.60	2.39	2.53	2.55	2.07
4	1	2.32	1.20	1.71	1.53	1.41	1.72	2.34	1.33	1.69
	2	2.24	2.17	1.82	2.91	1.57	2.52	1.88	3.16	2.28
	3	1.93	1.58	1.52	1.76	1.26	1.46	1.50	2.46	1.68
	4	1.91	1.45	2.59	1.28	2.01	2.05	1.61	1.73	1.83
	5	2.06	1.41	1.43	2.01	1.68	2.06	2.18	1.80	1.83
5	1	2.35	1.55	1.65	1.75	1.59	2.07	1.59	1.51	1.76
	2	2.21	1.70	2.27	1.17	1.92	1.30	1.78	1.53	1.74
	3	1.51	1.85	1.41	1.36	1.25	2.80	1.86	1.64	1.71
	4	2.05	2.51	2.31	2.23	1.19	1.63	3.14	2.30	2.17
	5	2.11	1.74	1.52	1.40	2.08	1.80	2.64	2.57	1.98

Appendix G.4 CTM Data from Florida Test Sections, Site #4

Florida Test Site 4 March 10, 2008 Surface: FC-9.5 Location: SR 222 Aggregate: Granite Mix Design: SP 04-3068A Project ID: 26050000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.45	0.45	0.45	0.42	0.41	0.36	0.36	0.38	0.41
	2	0.62	0.43	0.46	0.72	0.54	0.37	0.43	0.49	0.51
	3	0.48	0.49	0.54	0.54	0.44	0.45	0.49	0.52	0.49
	4	0.38	0.49	0.41	0.35	0.47	0.46	0.53	0.47	0.45
	5	0.46	0.53	0.53	0.45	0.55	0.57	0.46	0.51	0.51
2	1	0.41	0.56	0.37	0.37	0.51	0.40	0.41	0.49	0.44
	2	0.41	0.44	0.34	0.37	0.52	0.48	0.47	0.45	0.44
	3	0.49	0.39	0.36	0.44	0.36	0.47	0.49	0.41	0.43
	4	0.45	0.39	0.53	0.42	0.53	0.32	0.50	0.48	0.45
	5	0.43	0.40	0.47	0.48	0.35	0.44	0.59	0.42	0.45
3	1	0.47	0.41	0.64	0.43	0.46	0.34	0.34	0.45	0.44
	2	0.47	0.46	0.38	0.46	0.43	0.57	0.47	0.45	0.46
	3	0.50	0.43	0.50	0.42	0.49	0.41	0.42	0.50	0.46
	4	0.39	0.34	0.44	0.41	0.49	0.38	0.42	0.33	0.40
	5	0.48	0.33	0.45	0.42	0.55	0.44	0.66	0.37	0.46
4	1	0.39	0.43	0.32	0.41	0.46	0.51	0.42	0.50	0.43
	2	0.42	0.33	0.37	0.35	0.48	0.50	0.70	0.63	0.47
	3	0.45	0.39	0.40	0.42	0.36	0.33	0.33	0.55	0.40
	4	0.51	0.42	0.39	0.64	0.35	0.65	0.48	0.39	0.48
	5	0.41	0.60	0.48	0.35	0.51	0.41	0.53	0.43	0.47
5	1	0.36	0.46	0.36	0.43	0.35	0.45	0.33	0.44	0.40
	2	0.41	0.39	0.50	0.48	0.44	0.33	0.42	0.34	0.41
	3	0.57	0.39	0.53	0.37	0.30	0.32	0.57	0.48	0.44
	4	0.52	0.41	0.41	0.28	0.42	0.47	0.33	0.46	0.41
	5	0.47	0.42	0.35	0.37	0.29	0.33	0.33	0.39	0.37

Appendix G.5 CTM Data from Florida Test Sections, Site #5

Florida Test Site 5 February 27, 2008 Surface: FC-9.5 M Location: SR 26										
Aggregate: Granite Mix Design: SPM 05-4408A Project ID: 26070000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.49	0.45	0.46	0.58	0.39	0.31	0.35	0.42	0.43
	2	0.51	0.44	0.32	0.34	0.29	0.38	0.48	0.45	0.40
	3	0.33	0.37	0.51	0.38	0.44	0.32	0.35	0.39	0.39
	4	0.41	0.37	0.35	0.37	0.41	0.38	0.36	0.37	0.38
	5	0.50	0.58	0.45	0.43	0.55	0.64	0.35	0.42	0.49
2	1	0.32	0.50	0.57	0.34	0.30	0.33	0.31	0.27	0.37
	2	0.25	0.32	0.42	0.37	0.35	0.32	0.39	0.42	0.36
	3	0.41	0.38	0.35	0.31	0.31	0.42	0.37	0.40	0.37
	4	0.44	0.39	0.37	0.36	0.43	0.30	0.32	0.37	0.37
	5	0.36	0.28	0.45	0.27	0.47	0.40	0.25	0.39	0.36
3	1	0.34	0.46	0.43	0.39	0.29	0.31	0.37	0.39	0.37
	2	0.38	0.59	0.32	0.41	0.34	0.30	0.36	0.33	0.38
	3	0.41	0.35	0.49	0.44	0.28	0.40	0.26	0.23	0.36
	4	0.43	0.36	0.44	0.40	0.44	0.38	0.33	0.30	0.39
	5	0.29	0.30	0.25	0.39	0.30	0.31	0.40	0.39	0.33
4	1	0.35	0.41	0.38	0.39	0.32	0.44	0.41	0.30	0.38
	2	0.41	0.56	0.28	0.44	0.38	0.34	0.33	0.36	0.39
	3	0.39	0.43	0.40	0.40	0.44	0.51	0.40	0.35	0.41
	4	0.46	0.35	0.38	0.32	0.34	0.32	0.37	0.50	0.38
	5	0.33	0.36	0.40	0.37	0.42	0.40	0.30	0.52	0.39
5	1	0.59	0.56	0.39	0.57	0.40	0.40	0.50	0.57	0.50
	2	0.56	0.40	0.42	0.42	0.53	0.45	0.52	0.46	0.47
	3	0.39	0.49	0.68	0.41	0.37	0.57	0.46	0.73	0.51
	4	0.51	0.38	0.25	0.49	0.46	0.60	0.50	0.52	0.46
	5	0.48	0.51	0.65	0.49	0.41	0.43	0.39	0.36	0.47

Appendix G.6 CTM Data from Florida Test Sections, Site #6

Florida Test Site 6 March 11, 2008 Surface: FC-5 M Location: US 441 Aggregate: Granite Mix Design: SPM 07-5509A Project ID: 26010000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	1.42	1.75	1.26	1.63	2.22	1.43	1.04	1.75	1.56
	2	1.70	1.73	1.68	1.38	1.60	1.64	1.60	2.17	1.69
	3	1.90	1.39	1.42	1.34	1.33	1.28	1.91	1.62	1.52
	4	1.34	2.03	2.14	1.38	1.61	1.17	1.57	2.19	1.68
	5	1.81	2.02	1.24	1.18	1.60	2.34	1.27	1.82	1.66
2	1	1.36	2.03	1.65	2.09	1.87	1.55	1.55	1.89	1.75
	2	1.52	1.74	1.52	1.42	1.75	1.34	2.19	1.31	1.60
	3	1.63	1.45	1.41	2.00	1.52	1.25	1.59	1.48	1.54
	4	1.19	2.58	1.57	1.82	1.09	1.77	1.76	1.48	1.66
	5	1.42	1.04	1.39	1.52	1.34	1.94	1.81	1.19	1.46
3	1	1.49	1.67	1.46	1.38	1.71	1.24	1.53	1.81	1.54
	2	1.75	1.66	1.77	1.32	1.53	1.29	1.47	1.99	1.60
	3	1.96	1.58	1.94	1.85	1.40	1.98	2.16	1.74	1.83
	4	2.08	1.56	1.18	1.75	1.22	1.17	1.36	1.46	1.47
	5	1.82	2.13	1.52	1.43	1.71	1.10	1.75	1.92	1.67
4	1	1.80	2.06	1.74	1.37	1.82	1.87	1.80	1.51	1.75
	2	1.97	1.33	1.46	1.74	1.54	1.52	1.95	1.45	1.62
	3	1.67	1.74	1.64	1.42	1.30	1.53	2.07	2.20	1.70
	4	1.86	2.03	1.82	1.62	1.33	1.95	1.78	3.24	1.95
	5	1.95	1.91	2.27	2.00	1.46	2.10	0.91	2.15	1.84
5	1	2.11	1.96	1.30	1.55	1.62	1.92	1.76	1.52	1.72
	2	1.27	1.58	1.80	1.49	2.09	1.71	1.54	1.93	1.68
	3	1.63	1.56	1.66	1.51	1.41	1.40	2.09	2.30	1.69
	4	1.84	1.52	1.32	1.70	1.29	1.41	1.31	1.33	1.47
	5	1.65	1.40	1.91	1.46	1.51	1.93	1.51	1.60	1.62

Appendix G.7 CTM Data from Florida Test Sections, Site #7

Florida Test Site 7 March 10, 2008 Surface: FC-12.5 Location: SR 16 Aggregate: Limestone Mix Design: SP 02-1920A Project ID: 28030001										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.19	0.31	0.38	0.40	0.29	0.37	0.36	0.31	0.33
	2	0.51	0.50	0.36	0.29	0.30	0.33	0.38	0.32	0.37
	3	0.42	0.38	0.31	0.38	0.36	0.35	0.38	0.49	0.38
	4	0.44	0.47	0.36	0.49	0.35	0.51	0.51	0.43	0.45
	5	0.45	0.45	0.43	0.47	0.36	0.41	0.48	0.41	0.43
2	1	0.42	0.53	0.62	0.53	0.46	0.48	0.47	0.51	0.50
	2	0.42	0.58	0.46	0.59	0.58	0.49	0.43	0.42	0.50
	3	0.56	0.51	0.40	0.56	0.55	0.40	0.42	0.39	0.47
	4	0.43	0.61	0.64	0.54	0.63	0.57	0.45	0.42	0.54
	5	0.43	0.49	0.43	0.69	0.47	0.58	0.42	0.58	0.51
3	1	0.71	0.47	0.46	0.41	0.46	0.50	0.48	0.56	0.51
	2	0.48	0.54	0.31	0.36	0.32	0.43	0.46	0.40	0.41
	3	0.45	0.42	0.61	0.42	0.37	0.43	0.46	0.45	0.45
	4	0.48	0.51	0.49	0.33	0.44	0.32	0.40	0.48	0.43
	5	0.48	0.43	0.44	0.26	0.45	0.35	0.35	0.28	0.38
4	1	0.41	0.42	0.41	0.36	0.51	0.62	0.44	0.32	0.44
	2	0.72	0.68	0.53	0.37	0.71	0.53	0.47	0.66	0.58
	3	0.49	0.70	0.56	0.47	0.57	0.48	0.38	0.47	0.52
	4	0.57	0.57	0.67	0.54	0.56	0.46	0.68	0.54	0.57
	5	0.53	0.78	0.67	0.51	0.47	0.53	0.51	0.58	0.57
5	1	0.59	0.60	0.31	0.38	0.34	0.34	0.55	0.45	0.45
	2	0.68	0.42	0.68	0.43	0.37	0.32	0.44	0.48	0.48
	3	0.57	0.62	0.41	0.34	0.32	0.45	0.55	0.54	0.48
	4	0.42	0.41	0.47	0.49	0.44	0.48	0.44	0.48	0.45
	5	0.59	0.51	0.43	0.47	0.53	0.44	0.53	0.42	0.49

Appendix G.8 CTM Data from Florida Test Sections, Site #8

Florida Test Site 8 June 3, 2008 Surface: FC-12.5 M Location: SR 501 Aggregate: Limestone Mix Design: SPM 06-4609C Project ID: 70011000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.49	0.46	0.33	0.39	0.38	0.52	0.33	0.51	0.43
	2	0.43	0.48	0.43	0.39	0.49	0.43	0.40	0.32	0.42
	3	0.46	0.33	0.41	0.38	0.35	0.45	0.58	0.51	0.43
	4	0.53	0.33	0.37	0.25	0.27	0.34	0.40	0.42	0.36
	5	0.49	0.44	0.41	0.40	0.41	0.37	0.46	0.49	0.43
2	1	0.75	0.61	0.52	0.60	0.58	0.34	0.53	0.77	0.59
	2	0.51	0.43	0.52	0.43	0.51	0.81	0.44	0.43	0.51
	3	0.39	0.32	0.36	0.41	0.57	0.37	0.47	0.32	0.40
	4	0.46	0.43	0.41	0.32	0.44	0.42	0.47	0.40	0.42
	5	0.54	0.41	0.53	0.35	0.43	0.32	0.51	0.43	0.44
3	1	0.45	0.42	0.59	0.44	0.41	0.34	0.31	0.43	0.42
	2	0.50	0.39	0.41	0.30	0.46	0.36	0.52	0.55	0.44
	3	0.58	0.29	0.42	0.41	0.34	0.28	0.41	0.49	0.40
	4	0.42	0.60	0.44	0.26	0.34	0.33	0.65	0.54	0.45
	5	0.53	0.62	0.63	0.32	0.38	0.29	0.45	0.59	0.48
4	1	0.45	0.62	0.41	0.28	0.35	0.35	0.44	0.29	0.40
	2	0.47	0.37	0.41	0.65	0.40	0.31	0.39	0.50	0.44
	3	0.35	0.29	0.51	0.31	0.41	0.43	0.41	0.36	0.38
	4	0.49	0.46	0.30	0.35	0.45	0.50	0.55	0.51	0.45
	5	0.54	0.54	0.58	0.31	0.52	0.50	0.50	0.48	0.50
5	1	0.62	0.56	0.45	0.39	0.36	0.45	0.52	0.59	0.49
	2	0.40	0.46	0.41	0.72	0.41	0.42	0.45	0.36	0.45
	3	0.41	0.55	0.49	0.62	0.59	0.45	0.53	0.51	0.52
	4	0.66	0.51	0.46	0.42	0.45	0.44	0.59	0.46	0.50
	5	0.43	0.38	0.36	0.70	0.35	0.37	0.49	0.68	0.47

Appendix G.9 CTM Data from Florida Test Sections, Site #9

Florida Test Site 9 May 28, 2008 Surface: Burlap Drag Location: SR 600 Material: Concrete Mix Design: 1930's Project ID: 79060000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.37	0.30	0.30	0.41	0.39	0.24	0.32	0.40	0.34
	2	0.22	0.29	0.42	0.28	0.28	0.33	0.34	0.33	0.31
	3	0.70	0.33	0.52	0.36	0.36	0.44	0.34	0.54	0.45
	4	0.32	0.28	0.28	0.36	0.52	0.23	0.27	0.29	0.32
	5	0.32	0.21	0.26	0.26	0.47	0.26	0.25	0.37	0.30
2	1	0.29	0.21	0.35	0.43	0.51	0.32	0.39	0.43	0.37
	2	0.38	0.39	0.64	0.66	0.25	0.22	0.81	0.47	0.48
	3	0.31	0.42	0.36	0.30	0.45	0.25	0.30	0.32	0.34
	4	0.26	0.35	0.24	0.33	0.59	0.38	0.58	0.46	0.40
	5	0.39	0.36	0.49	0.59	0.35	0.45	0.59	0.36	0.45
3	1	0.43	0.38	0.62	0.42	0.29	0.31	0.35	0.33	0.39
	2	0.24	0.27	0.54	0.56	0.30	0.36	0.34	0.27	0.36
	3	0.33	0.31	0.36	0.38	0.33	0.37	0.51	0.49	0.39
	4	0.38	0.49	0.27	0.39	0.23	0.48	0.35	0.40	0.37
	5	0.29	0.29	0.30	0.44	0.33	0.33	0.32	0.27	0.32
4	1	0.39	0.37	0.54	0.47	0.44	0.33	0.45	0.34	0.42
	2	0.59	0.35	0.32	0.48	0.34	0.35	0.53	0.30	0.41
	3	0.39	0.42	0.40	0.40	0.34	0.49	0.45	0.43	0.42
	4	0.41	0.41	0.52	0.43	0.37	0.33	0.64	0.25	0.42
	5	0.61	0.27	0.37	0.39	0.50	0.33	0.22	0.39	0.39
5	1	0.30	0.59	0.54	0.40	0.62	0.33	0.56	0.50	0.48
	2	0.36	0.37	0.30	0.53	0.33	0.74	0.55	0.44	0.45
	3	0.27	0.37	0.39	0.51	0.50	0.26	0.43	0.45	0.40
	4	0.65	0.59	0.47	0.68	0.49	0.36	0.64	0.31	0.52
	5	0.44	0.44	0.47	0.20	0.30	0.28	0.46	0.36	0.37

Appendix G.10 CTM Data from Florida Test Sections, Site #10

Florida Test Site 10 May 28, 2008 Surface: Long. Grind Location: SR 600 Material: Concrete Mix Design: 1930's Project ID: 79060000										
Lock-up Segment	Spot Test Location	Segments of the Circular Track Profile (mm)								Average MPD (mm)
		A	B	C	D	E	F	G	H	
1	1	0.86	0.76	0.50	0.86	0.70	0.64	0.81	0.77	0.74
	2	0.59	0.70	1.48	0.69	0.86	0.74	1.18	0.73	0.87
	3	0.65	0.78	0.92	0.74	0.54	0.66	1.25	0.85	0.80
	4	0.72	0.78	1.10	0.84	0.52	0.64	0.94	0.76	0.79
	5	0.64	0.79	1.01	0.93	0.66	1.11	0.90	0.91	0.87
2	1	0.65	0.69	0.76	0.69	0.29	0.62	0.51	0.61	0.60
	2	0.63	0.54	0.62	0.69	0.60	0.85	0.76	0.56	0.66
	3	0.44	0.70	0.91	0.91	0.70	0.85	0.76	0.69	0.75
	4	0.75	0.87	0.90	0.62	0.51	0.67	0.54	0.67	0.69
	5	0.41	0.84	0.80	0.49	0.41	0.64	1.09	0.63	0.66
3	1	0.71	0.74	0.68	0.65	0.35	0.73	0.65	0.77	0.66
	2	0.67	0.77	0.72	0.53	0.62	0.90	0.99	0.90	0.76
	3	0.67	0.82	0.59	0.68	0.39	0.56	0.68	0.72	0.64
	4	0.94	0.95	0.78	0.56	0.62	0.69	0.79	0.71	0.76
	5	0.63	0.66	0.67	0.69	0.71	0.46	0.61	0.60	0.63
4	1	0.99	0.56	0.75	0.52	0.40	0.58	0.63	0.87	0.66
	2	0.55	0.58	0.73	0.55	0.35	0.57	0.66	0.54	0.57
	3	0.54	0.62	0.64	0.44	0.24	0.31	0.71	0.66	0.52
	4	0.43	0.53	0.41	0.55	0.53	0.65	0.51	0.33	0.49
	5	0.53	0.86	0.52	0.30	0.49	0.27	0.76	0.79	0.57
5	1	0.45	0.74	0.72	0.62	0.60	0.59	0.59	0.78	0.64
	2	0.65	0.62	0.70	0.52	0.36	0.51	0.86	0.58	0.60
	3	0.63	0.81	1.02	0.53	0.49	0.54	0.72	0.56	0.66
	4	0.54	0.79	0.88	0.63	0.40	0.53	0.64	0.65	0.63
	5	0.71	0.58	0.63	0.32	0.35	0.46	0.70	0.60	0.54
	6	0.51	0.35	0.49	0.54	0.68	0.52	0.63	0.28	0.50

UNF UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix H

DFT Data from Florida Test Sections

(ASTM E 1911)

Appendix H.1 DFT Data from Florida Test Sections, Site #1

Florida Test Site 1 October 2, 2007 Surface: FC-12.5 M Location: SR 24 Aggregate: Granite Mix Design: SPM 06-4852B Project ID: 26050000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.389	0.337	0.315
	2	0.407	0.343	0.321
	3	0.412	0.365	0.343
	4	0.416	0.375	0.349
	5	0.418	0.376	0.351
2	1	0.415	0.377	0.352
	2	0.405	0.366	0.342
	3	0.405	0.367	0.341
	4	0.416	0.379	0.351
	5	0.380	0.334	0.309
3	1	0.388	0.350	0.323
	2	0.392	0.353	0.326
	3	0.398	0.357	0.327
	4	0.400	0.361	0.340
	5	0.402	0.368	0.334
4	1	0.402	0.369	0.342
	2	0.407	0.370	0.341
	3	0.400	0.365	0.338
	4	0.407	0.374	0.343
	5	0.384	0.338	0.312
5	1	0.402	0.360	0.337
	2	0.407	0.366	0.341
	3	0.406	0.367	0.339
	4	0.403	0.367	0.342
	5	0.406	0.364	0.336

Appendix H.2 DFT Data from Florida Test Sections, Site #2

Florida Test Site 2 February 26, 2008 Surface: FC-5 Location: SR 24 Aggregate: Limestone Mix Design: QA 00-9506A Project ID: 26050000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.216	0.219	0.225
	2	0.200	0.216	0.235
	3	0.247	0.253	0.244
	4	0.232	0.244	0.225
	5	0.229	0.240	0.235
2	1	0.217	0.226	0.228
	2	0.230	0.239	0.236
	3	0.221	0.230	0.237
	4	0.219	0.222	0.235
	5	0.219	0.218	0.223
3	1	0.213	0.211	0.210
	2	0.231	0.239	0.250
	3	0.236	0.237	0.240
	4	0.223	0.230	0.220
	5	0.235	0.237	0.245
4	1	0.213	0.227	0.233
	2	0.221	0.234	0.222
	3	0.230	0.239	0.238
	4	0.225	0.234	0.237
	5	0.217	0.229	0.217
5	1	0.212	0.221	0.210
	2	0.238	0.242	0.232
	3	0.228	0.225	0.225
	4			
	5			

Appendix H.3 DFT Data from Florida Test Sections, Site #3

Florida Test Site 3 February 27, 2008 Surface: FC-5 Location: SR 24 Aggregate: Granite Mix Design: LD 02-2523A Project ID: 26050000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.296	0.293	0.282
	2	0.306	0.308	0.326
	3	0.305	0.317	0.311
	4	0.320	0.332	0.346
	5	0.315	0.328	0.329
2	1	0.276	0.282	0.266
	2	0.293	0.293	0.294
	3	0.307	0.303	0.300
	4	0.317	0.312	0.300
	5	0.315	0.317	0.316
3	1	0.322	0.310	0.310
	2	0.310	0.299	0.313
	3	0.307	0.300	0.314
	4	0.315	0.319	0.298
	5	0.320	0.313	0.307
4	1	0.297	0.299	0.301
	2	0.294	0.291	0.291
	3	0.302	0.294	0.312
	4	0.294	0.289	0.288
	5	0.307	0.294	0.304
5	1	0.281	0.280	0.266
	2	0.294	0.289	0.299
	3	0.300	0.303	0.291
	4	0.300	0.294	0.287
	5	0.298	0.297	0.278

Appendix H.4 DFT Data from Florida Test Sections, Site #4

Florida Test Site 4 March 10, 2008 Surface: FC-9.5 Location: SR 222 Aggregate: Granite Mix Design: SP 04-3068A Project ID: 26050000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.387	0.357	0.335
	2	0.386	0.361	0.338
	3	0.391	0.363	0.344
	4	0.401	0.374	0.346
	5	0.388	0.367	0.344
2	1	0.329	0.303	0.279
	2	0.371	0.335	0.314
	3	0.384	0.350	0.330
	4	0.382	0.353	0.336
	5	0.395	0.363	0.345
3	1	0.385	0.354	0.332
	2	0.383	0.356	0.336
	3	0.395	0.366	0.348
	4	0.397	0.364	0.343
	5	0.394	0.364	0.349
4	1	0.329	0.295	0.275
	2	0.372	0.337	0.318
	3	0.390	0.355	0.334
	4	0.388	0.358	0.340
	5	0.394	0.360	0.344
5	1	0.380	0.348	0.328
	2	0.382	0.354	0.333
	3	0.391	0.359	0.341
	4	0.383	0.355	0.334
	5	0.381	0.354	0.336

Appendix H.5 DFT Data from Florida Test Sections, Site #5

Florida Test Site 5 February 27, 2008 Surface: FC-9.5 M Location: SR 26 Aggregate: Granite Mix Design: SPM 05-4408A Project ID: 26070000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.340	0.303	0.281
	2	0.364	0.325	0.310
	3	0.373	0.335	0.319
	4	0.375	0.336	0.319
	5	0.371	0.334	0.320
2	1	0.386	0.349	0.321
	2	0.384	0.349	0.323
	3	0.389	0.354	0.333
	4	0.389	0.357	0.332
	5	0.381	0.355	0.324
3	1	0.346	0.306	0.283
	2	0.366	0.326	0.308
	3	0.375	0.333	0.317
	4	0.380	0.341	0.317
	5	0.383	0.344	0.319
4	1	0.387	0.351	0.326
	2	0.387	0.354	0.326
	3	0.390	0.358	0.330
	4	0.386	0.357	0.333
	5	0.380	0.351	0.332
5	1	0.372	0.336	0.315
	2	0.376	0.339	0.337
	3	0.382	0.357	0.336
	4	0.384	0.359	0.336
	5	0.375	0.347	0.324

Appendix H.6 DFT Data from Florida Test Sections, Site #6

Florida Test Site 6 March 11, 2008 Surface: FC-5 M Location: US 441 Aggregate: Granite Mix Design: SPM 07-5509A Project ID: 26010000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.346	0.322	0.310
	2	0.347	0.312	0.302
	3	0.355	0.325	0.315
	4	0.355	0.326	0.321
	5	0.352	0.312	0.310
2	1	0.333	0.303	0.278
	2	0.350	0.313	0.310
	3	0.349	0.311	0.309
	4	0.357	0.320	0.315
	5	0.345	0.310	0.319
3	1	0.349	0.321	0.303
	2	0.374	0.347	0.332
	3	0.354	0.333	0.316
	4	0.362	0.325	0.313
	5	0.345	0.302	0.294
4	1	0.332	0.302	0.286
	2	0.365	0.342	0.323
	3	0.356	0.322	0.321
	4	0.355	0.319	0.320
	5	0.348	0.322	0.306
5	1	0.348	0.313	0.308
	2	0.342	0.314	0.311
	3	0.367	0.330	0.323
	4	0.364	0.323	0.317
	5	0.355	0.316	0.315

Appendix H.7 DFT Data from Florida Test Sections, Site #7

Florida Test Site 7 March 10, 2008 Surface: FC-12.5 Location: SR 16				
Aggregate: Limestone Mix Design: SP 02-1920A Project ID: 28030001				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.274	0.250	0.247
	2	0.285	0.266	0.257
	3	0.253	0.231	0.218
	4	0.280	0.256	0.282
	5	0.332	0.379	0.414
2	1	0.274	0.269	0.262
	2	0.268	0.255	0.258
	3	0.275	0.262	0.260
	4	0.287	0.277	0.275
	5	0.284	0.273	0.267
3	1	0.242	0.231	0.214
	2	0.275	0.259	0.253
	3	0.284	0.270	0.262
	4	0.300	0.282	0.280
	5	0.265	0.251	0.248
4	1	0.282	0.272	0.271
	2	0.293	0.285	0.285
	3	0.317	0.311	0.304
	4	0.311	0.308	0.298
	5	0.325	0.323	0.313
5	1	0.265	0.244	0.229
	2	0.300	0.277	0.266
	3	0.313	0.288	0.285
	4	0.308	0.289	0.279
	5	0.322	0.302	0.298

Appendix H.8 DFT Data from Florida Test Sections, Site #8

Florida Test Site 8 June 3, 2008 Surface: FC-12.5 M Location: SR 501 Aggregate: Limestone Mix Design: SPM 06-4609C Project ID: 70011000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.250	0.232	0.224
	2	0.261	0.241	0.232
	3	0.260	0.241	0.232
	4	0.256	0.239	0.232
	5	0.264	0.245	0.235
2	1	0.273	0.262	0.246
	2	0.275	0.264	0.252
	3	0.262	0.248	0.242
	4	0.266	0.246	0.237
	5	0.260	0.248	0.238
3	1	0.249	0.234	0.220
	2	0.247	0.239	0.233
	3	0.258	0.240	0.233
	4	0.254	0.239	0.234
	5	0.245	0.234	0.231
4	1	0.263	0.244	0.233
	2	0.255	0.240	0.228
	3	0.259	0.240	0.229
	4	0.269	0.249	0.237
	5	0.263	0.241	0.236
5	1	0.246	0.225	0.215
	2	0.260	0.240	0.230
	3	0.248	0.235	0.224
	4	0.255	0.239	0.232
	5	0.248	0.230	0.224

Appendix H.9 DFT Data from Florida Test Sections, Site #9

Florida Test Site 9 May 28, 2008 Surface: Burlap Drag Location: SR 600 Material: Concrete Mix Design: 1930's Project ID: 79060000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.375	0.349	0.324
	2	0.399	0.374	0.345
	3	0.399	0.374	0.345
	4	0.395	0.371	0.340
	5	0.398	0.376	0.344
2	1	0.420	0.386	0.348
	2	0.421	0.392	0.361
	3	0.420	0.392	0.364
	4	0.412	0.396	0.367
	5	0.415	0.393	0.363
3	1	0.419	0.391	0.359
	2	0.412	0.387	0.357
	3	0.421	0.389	0.355
	4	0.414	0.386	0.356
	5	0.425	0.399	0.370
4	1	0.410	0.380	0.351
	2	0.412	0.383	0.357
	3	0.419	0.399	0.376
	4	0.414	0.388	0.359
	5	0.412	0.394	0.371
5	1	0.368	0.343	0.321
	2	0.376	0.345	0.324
	3	0.387	0.366	0.347
	4	0.369	0.347	0.328
	5	0.409	0.384	0.357

Appendix H.10 DFT Data from Florida Test Sections, Site #10

Florida Test Site 10 May 28, 2008 Surface: Long. Grind Location: SR 600 Material: Concrete Mix Design: 1930's Project ID: 79060000				
Lock-up Segment	Spot Test Location	DFT 20 km/h (12.4 mph)	DFT 40 km/h (24.8 mph)	DFT 60 km/h (37.3 mph)
1	1	0.310	0.308	0.308
	2	0.299	0.297	0.304
	3	0.293	0.287	0.282
	4	0.281	0.278	0.271
	5	0.262	0.267	0.268
2	1	0.314	0.297	0.280
	2	0.305	0.290	0.287
	3	0.280	0.277	0.273
	4	0.304	0.297	0.281
	5	0.319	0.312	0.299
3	1	0.297	0.290	0.282
	2	0.300	0.300	0.286
	3	0.335	0.323	0.318
	4	0.327	0.321	0.317
	5	0.319	0.309	0.301
4	1	0.309	0.297	0.282
	2	0.302	0.291	0.285
	3	0.331	0.310	0.298
	4	0.372	0.356	0.335
	5	0.289	0.273	0.254
5	1	0.346	0.332	0.326
	2	0.320	0.314	0.307
	3	0.311	0.306	0.300
	4	0.297	0.292	0.287
	5	0.344	0.328	0.317

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix I

Locked-Wheel Friction Test Data from Florida Test Sections

(ASTM E 274)
(ASTM E 501)
(ASTM E 524)

Appendix I.1 Locked-Wheel Friction Test Data from Florida Test Sections, Site #1

October 2, 2007 Surface: FC 12.5 M Location: SR 24, by Sonny's

Aggregate: Granite Mix Design: SPM 06-4852B Project ID: 26050000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.386	0.521	0.310	0.487	0.282	0.456
2	0.439	0.488	0.374	0.478	0.302	0.449
3	0.421	0.523	0.335	0.484	0.281	0.444
4	0.399	0.528	0.335	0.480	0.302	0.467
5	0.438	0.505	0.337	0.486	0.291	0.452

Appendix I.2 Locked-Wheel Friction Test Data from Florida Test Sections, Site #2

February 26, 2008 Surface: FC 5 Location: SR 24, Austin Cary Memorial

Aggregate: Limestone Mix Design: QA 00-9506A Project ID: 26050000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.327	0.343	0.309	0.323	0.295	0.312
2	0.322	0.327	0.303	0.312	0.284	0.300
3	0.319	0.327	0.308	0.313	0.288	0.303
4	0.308	0.315	0.298	0.305	0.288	0.299
5	0.319	0.326	0.322	0.312	0.312	0.306

Appendix I.3 Locked-Wheel Friction Test Data from Florida Test Sections, Site #3

February 27, 2008 Surface: FC 5 Location: SR 24, Almost to Waldo

Aggregate: Granite Mix Design: LD 02-2523A Project ID: 26050000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.356	0.344	0.346	0.339	0.340	0.335
2	0.357	0.351	0.346	0.333	0.322	0.333
3	0.367	0.360	0.352	0.348	0.350	0.350
4	0.358	0.353	0.349	0.341	0.335	0.335
5	0.361	0.352	0.353	0.338	0.330	0.330

Appendix I.4 Locked-Wheel Friction Test Data from Florida Test Sections, Site #4

March 10, 2008 Surface: FC 9.5 Location: SR 222, 39th Ave Aggregate: Granite Mix Design: SP 04-3068A Project ID: 26050000						
Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.337	0.476	0.287	0.443	0.242	0.431
2	0.328	0.471	0.252	0.444	0.189	0.418
3	0.322	0.456	0.280	0.449	0.201	0.415
4	0.315	0.489	0.263	0.439	0.200	0.425
5	0.354	0.496	0.244	0.437	0.208	0.422

Appendix I.5 Locked-Wheel Friction Test Data from Florida Test Sections, Site #5

February 27, 2008 Surface: FC 9.5 M Location: SR 26, by Fletcher's Mill Aggregate: Granite Mix Design: SPM 05-4408A Project ID: 26070000						
Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.378	0.466	0.281	0.460	0.196	0.426
2	0.376	0.491	0.271	0.464	0.193	0.437
3	0.365	0.477	0.244	0.433	0.205	0.409
4	0.384	0.467	0.292	0.461	0.238	0.428
5	0.401	0.480	0.322	0.457	0.404	0.445

Appendix I.6 Locked-Wheel Friction Test Data from Florida Test Sections, Site #6

March 11, 2008 Surface: FC 5 M Location: US 441, Paynes Prarie Aggregate: Granite Mix Design: SPM 07-5509A Project ID: 26010000						
Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.447	0.459	0.417	0.423	0.384	0.384
2	0.435	0.447	0.407	0.411	0.387	0.393
3	0.439	0.453	0.409	0.409	0.400	0.396
4	0.427	0.449	0.372	0.423	0.408	0.388
5	0.442	0.434	0.403	0.433	0.392	0.403

Appendix I.7 Locked-Wheel Friction Test Data from Florida Test Sections, Site #7

March 10, 2008 Surface: FC 12.5 Location: SR 16

Aggregate: Limestone Mix Design: SP 02-1920A Project ID: 28030001

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.319	0.429	0.233	0.397	0.166	0.360
2	0.335	0.429	0.255	0.397	0.203	0.372
3	0.322	0.437	0.250	0.403	0.190	0.369
4	0.328	0.444	0.241	0.413	0.202	0.355
5	0.329	0.466	0.260	0.418	0.187	0.407

Appendix I.8 Locked-Wheel Friction Test Data from Florida Test Sections, Site #8

June 3, 2008 Surface: FC 12.5 M Location: SR 501, Cocoa Beach

Aggregate: Limestone Mix Design: SPM 06-4609C Project ID: 70011000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.312	0.369	0.237	0.356	0.217	0.346
2	0.329	0.376	0.245	0.369	0.195	0.351
3	0.301	0.356	0.234	0.350	0.182	0.321
4	0.302	0.377	0.258	0.363	0.220	0.331
5	0.306	0.345	0.234	0.340	0.233	0.340

Appendix I.9 Locked-Wheel Friction Test Data from Florida Test Sections, Site #9

May 28, 2008 Surface: Burlap Drag Location: SR 600 / US 92, Deland

Material: Concrete Mix Design: 1930's Project ID: 79060000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.372	0.579	0.272	0.554	0.204	0.514
2	0.385	0.591	0.289	0.570	0.237	0.535
3	0.366	0.596	0.290	0.555	0.252	0.541
4	0.379	0.586	0.322	0.567	0.269	0.535
5	0.394	0.571	0.303	0.541	0.265	0.509

Appendix I.10 Locked-Wheel Friction Test Data from Florida Test Sections, Site #10

May 28, 2008 Surface: Long. Grind Location: SR 600 / US 92 Deland

Material: Concrete Mix Design: 1930's Project ID: 79060000

Lock-up Segment	FN_{30S} 30 mph	FN_{30R} 30 mph	FN_{40S} 40 mph	FN_{40R} 40 mph	FN_{50S} 50 mph	FN_{50R} 50 mph
1	0.393	0.430	0.326	0.414	0.279	0.389
2	0.371	0.434	0.315	0.424	0.248	0.382
3	0.404	0.468	0.324	0.397	0.259	0.379
4	0.381	0.467	0.294	0.431	0.242	0.395
5	0.410	0.494	0.315	0.447	0.277	0.390

UNF UNIVERSITY of NORTH FLORIDA

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix J

64 kHz Laser Texture Test Data from Florida Test Sections

(ASTM E 1845)

Appendix J.1 64 kHz Laser Texture Data from Florida Test Sections, Site #1

October 2, 2007 Surface: FC 12.5 M Location: SR 24, by Sonny's Aggregate: Granite Mix Design: SPM 06-4852B Project ID: 26050000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.435	0.457	0.469
2	0.492	0.521	0.491
3	0.431	0.447	0.448
4	0.408	0.486	0.501
5	0.465	0.452	0.499

Appendix J.2 64 kHz Laser Texture Data from Florida Test Sections, Site #2

February 26, 2008 Surface: FC 5 Location: SR 24, Austin Cary Memorial Aggregate: Limestone Mix Design: QA 00-9506A Project ID: 26050000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	1.413	1.325	1.268
2	1.350	1.440	1.508
3	1.287	1.319	1.420
4	1.274	1.306	1.250
5	1.315	1.371	1.471

Appendix J.3 64 kHz Laser Texture Data from Florida Test Sections, Site #3

February 27, 2008 Surface: FC 5 Location: SR 24, Almost to Waldo Aggregate: Granite Mix Design: LD 02-2523A Project ID: 26050000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	1.795	1.793	1.899
2	1.871	1.823	1.724
3	2.106	1.971	1.716
4	1.807	1.651	1.787
5	1.720	1.908	1.822

Appendix J.4 64 kHz Laser Texture Data from Florida Test Sections, Site #4

March 10, 2008 Surface: FC 9.5 Location: SR 222, 39th Ave Aggregate: Granite Mix Design: SP 04-3068A Project ID: 26050000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.430	0.430	0.454
2	0.422	0.475	0.457
3	0.391	0.411	0.464
4	0.397	0.406	0.399
5	0.392	0.401	0.421

Appendix J.5 64 kHz Laser Texture Data from Florida Test Sections, Site #5

February 27, 2008 Surface: FC 9.5 M Location: SR 26, by Fletcher's Mill Aggregate: Granite Mix Design: SPM 05-4408A Project ID: 26070000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.470	0.430	0.590
2	0.480	0.310	0.510
3	0.550	0.210	0.460
4	0.450	0.550	0.490
5	0.320	0.450	0.590

Appendix J.6 64 kHz Laser Texture Data from Florida Test Sections, Site #6

March 11, 2008 Surface: FC 5 M Location: US 441, Paynes Prarie Aggregate: Granite Mix Design: SPM 07-5509A Project ID: 26010000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	1.593	1.693	1.563
2	1.809	1.713	1.620
3	1.787	1.738	1.598
4	1.661	1.696	1.544
5	1.697	1.618	1.646

Appendix J.7 64 kHz Laser Texture Data from Florida Test Sections, Site #7

March 10, 2008 Surface: FC 12.5 Location: SR 16 Aggregate: Limestone Mix Design: SP 02-1920A Project ID: 28030001			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.377	0.446	0.427
2	0.463	0.454	0.437
3	0.434	0.475	0.518
4	0.468	0.464	0.441
5	0.441	0.458	0.437

Appendix J.8 64 kHz Laser Texture Data from Florida Test Sections, Site #8

June 3, 2008 Surface: FC 12.5 M Location: SR 501, Cocoa Beach Aggregate: Limestone Mix Design: SPM 06-4609C Project ID: 70011000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.564	0.607	0.538
2	0.432	0.490	0.498
3	0.432	0.460	0.544
4	0.538	0.518	0.559
5	0.475	0.511	0.508

Appendix J.9 64 kHz Laser Texture Data from Florida Test Sections, Site #9

May 28, 2008 Surface: Burlap Drag Location: SR 600 / US 92, Deland Material: Concrete Mix Design: 1930's Project ID: 79060000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.396	0.409	0.409
2	0.391	0.411	0.455
3	0.409	0.432	0.432
4	0.498	0.500	0.480
5	0.516	0.432	0.447

Appendix J.10 64 kHz Laser Texture Data from Florida Test Sections, Site #10

May 28, 2008 Surface: Long. Grind Location: SR 600 / US 92 Deland Material: Concrete Mix Design: 1930's Project ID: 79060000			
Lock-up Segment	MPD @ 30 mph (mm)	MPD @ 40 mph (mm)	MPD @ 50 mph (mm)
1	0.333	0.447	0.439
2	0.427	0.429	0.373
3	0.338	0.391	0.439
4	0.368	0.422	0.554
5	0.401	0.424	0.498

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix K

Volumetric "Sand Patch" MTD Test Data from Florida Test Sections

(ASTM E 965)

Appendix K.1 Sand Patch (MTD) Data from Florida Test Sections, Site #1

Florida Test Site 1 October 2, 2007 Surface: FC-12.5 M Location: SR 24 Aggregate: Granite Mix Design: SPM 06-4852B Project ID: 26050000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5		Data Not Available			9.8	**0.508**
	2	1.5					9.1	**0.584**
	3	1.5					9.3	**0.558**
	4	1.5					8.9	**0.609**
	5	1.5					9.3	**0.558**
2	1	1.5		Data Not Available			9.1	**0.584**
	2	1.5					8.9	**0.609**
	3	1.5					9.3	**0.558**
	4	1.5					8.9	**0.609**
	5	1.5					8.9	**0.609**
3	1	1.5		Data Not Available			8.9	**0.609**
	2	1.5					9.3	**0.558**
	3	1.5					9.3	**0.558**
	4	1.5					9.5	**0.533**
	5	1.5					9.5	**0.533**
4	1	1.5		Data Not Available			9.3	**0.558**
	2	1.5					9.1	**0.584**
	3	1.5					9.3	**0.558**
	4	1.5					9.1	**0.584**
	5	1.5					8.7	**0.635**
5	1	1.5		Data Not Available			9.5	**0.533**
	2	1.5					9.3	**0.558**
	3	1.5					9.8	**0.508**
	4	1.5					10.0	**0.482**
	5	1.5					9.7	**0.520**

Appendix K.2 Sand Patch (MTD) Data from Florida Test Sections, Site #2

Florida Test Site 2 February 26, 2008 Surface: 5 Location: SR 24, Austin Cary Mem.

Material: Limestone Mix Design: QA 00-9506A Project ID: 26050000

Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	3.0	7.7	7.2	7.3	7.2	7.4	**1.797**
	2	3.0	7.5	7.6	7.5	7.2	7.5	**1.749**
	3	3.0	6.6	6.9	6.6	6.8	6.7	**2.146**
	4	3.0	6.7	6.5	7.0	6.8	6.8	**2.130**
	5	3.0	7.0	6.4	6.9	6.8	6.8	**2.115**
2	1	3.0	6.5	6.7	6.7	6.8	6.7	**2.179**
	2	3.0	7.0	7.3	7.2	7.5	7.3	**1.847**
	3	3.0	7.4	6.5	7.0	7.0	7.0	**1.995**
	4	3.0	7.3	7.6	7.4	7.6	7.5	**1.737**
	5	3.0	7.5	7.6	7.5	7.5	7.5	**1.714**
3	1	3.0	7.0	7.0	6.7	7.0	6.9	**2.024**
	2	3.0	7.1	7.0	7.1	7.1	7.1	**1.939**
	3	3.0	6.7	6.7	6.7	6.6	6.7	**2.179**
	4	3.0	7.1	7.3	7.3	6.9	7.2	**1.899**
	5	3.0	7.1	6.9	7.0	6.9	7.0	**1.995**
4	1	3.0	7.1	6.7	7.3	6.9	7.0	**1.981**
	2	3.0	7.7	6.6	6.7	6.9	7.0	**1.995**
	3	3.0	7.2	7.3	6.3	7.0	7.0	**2.010**
	4	3.0	7.0	7.0	7.0	7.1	7.0	**1.967**
	5	3.0	7.0	7.1	6.8	7.0	7.0	**1.995**
5	1	3.0	7.0	6.8	6.9	6.8	6.9	**2.054**
	2	3.0	7.1	6.8	6.9	6.9	6.9	**2.024**
	3	3.0	7.0	7.3	6.7	7.1	7.0	**1.967**
	4	3.0	7.2	6.8	7.3	6.8	7.0	**1.967**
	5	3.0	6.5	7.0	6.3	6.4	6.6	**2.263**

Appendix K.3 Sand Patch (MTD) Data from Florida Test Sections, Site #3

Florida Test Site 3 February 27, 2008 Surface: 5 Location: SR 24, Almost to Waldo Material: Granite Mix Design: LD 02-2523A Project ID: 26050000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	4.5	6.9	6.7	6.5	6.7	6.7	**3.240**
	2	4.5	7.5	7.0	7.2	7.4	7.3	**2.750**
	3	4.5	7.1	6.9	6.8	6.7	6.9	**3.081**
	4	4.5	7.0	6.8	6.3	7.0	6.8	**3.172**
	5	4.5	6.7	7.0	6.8	7.0	6.9	**3.081**
2	1	4.5	7.3	7.0	7.1	7.4	7.2	**2.809**
	2	4.5	7.8	7.5	7.4	7.8	7.6	**2.504**
	3	4.5	7.3	7.9	7.4	8.1	7.7	**2.472**
	4	4.5	7.3	8.0	7.2	7.4	7.5	**2.606**
	5	4.5	7.3	7.4	7.2	7.4	7.3	**2.714**
3	1	4.5	7.1	7.4	7.3	7.5	7.3	**2.714**
	2	4.5	6.9	7.0	6.8	6.7	6.9	**3.103**
	3	4.5	7.3	7.0	7.2	7.2	7.2	**2.828**
	4	4.5	7.4	6.8	7.2	7.2	7.2	**2.848**
	5	4.5	7.7	7.1	7.3	6.9	7.3	**2.770**
4	1	4.5	7.1	7.2	7.2	7.1	7.2	**2.848**
	2	4.5	6.9	7.2	7.2	6.6	7.0	**2.993**
	3	4.5	7.0	6.9	7.7	6.8	7.1	**2.888**
	4	4.5	7.5	7.1	7.3	7.2	7.3	**2.751**
	5	4.5	6.9	7.2	7.1	7.2	7.1	**2.888**
5	1	4.5	7.2	7.3	7.2	7.0	7.2	**2.828**
	2	4.5	7.5	7.1	7.5	7.3	7.4	**2.695**
	3	4.5	7.9	7.8	7.7	7.7	7.8	**2.409**
	4	4.5	7.2	7.3	7.0	7.9	7.4	**2.695**
	5	4.5	7.1	6.7	7.0	6.7	6.9	**3.081**

Appendix K.4 Sand Patch (MTD) Data from Florida Test Sections, Site #4

Florida Test Site 4 March 10, 2008 Surface: 9.5 Location: SR 222, 39th Ave Material: Granite Mix Design: SP 04-3068A Project ID: 26050000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	9.2	8.5	8.7	8.6	8.8	**0.634**
	2	1.5	8.7	7.9	8.7	8.3	8.4	**0.688**
	3	1.5	8.7	8.3	8.6	8.4	8.5	**0.672**
	4	1.5	8.1	8.1	7.9	8.5	8.2	**0.731**
	5	1.5	7.7	8.2	8.0	8.1	8.0	**0.758**
2	1	1.5	8.7	8.8	8.6	8.5	8.7	**0.649**
	2	1.5	8.3	8.4	8.4	8.8	8.5	**0.676**
	3	1.5	8.5	8.5	8.9	8.4	8.6	**0.660**
	4	1.5	8.7	8.3	8.7	8.5	8.6	**0.664**
	5	1.5	8.0	8.6	8.3	8.6	8.4	**0.692**
3	1	1.5	8.7	8.4	8.6	8.6	8.6	**0.660**
	2	1.5	8.8	7.6	7.5	8.5	8.1	**0.740**
	3	1.5	9.0	8.1	8.3	8.5	8.5	**0.676**
	4	1.5	8.5	8.6	8.1	8.6	8.5	**0.680**
	5	1.5	8.4	8.5	8.3	8.6	8.5	**0.680**
4	1	1.5	8.5	8.4	8.4	8.6	8.5	**0.676**
	2	1.5	8.4	8.5	8.1	8.4	8.4	**0.696**
	3	1.5	8.6	8.6	8.1	8.6	8.5	**0.676**
	4	1.5	8.4	8.4	8.4	8.5	8.4	**0.684**
	5	1.5	8.9	8.3	8.5	8.8	8.6	**0.652**
5	1	1.5	9.0	8.8	9.1	8.7	8.9	**0.613**
	2	1.5	9.2	8.7	8.9	9.0	9.0	**0.606**
	3	1.5	9.1	8.9	8.7	9.0	8.9	**0.609**
	4	1.5	9.0	8.9	8.8	8.8	8.9	**0.616**
	5	1.5	9.0	9.4	9.1	9.2	9.2	**0.577**

Appendix K.5 Sand Patch (MTD) Data from Florida Test Sections, Site #5

Florida Test Site 5 February 27, 2008 Surface: 9.5 M Location: SR 26, by Fletch. Mill Material: Granite Mix Design: SPM 05-4408A Project ID: 26070000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	9.2	9.3	9.5	9.2	9.3	**0.561**
	2	1.5	9.2	9.7	9.2	9.5	9.4	**0.549**
	3	1.5	8.7	9.5	8.5	9.3	9.0	**0.599**
	4	1.5	9.0	9.0	8.9	9.1	9.0	**0.599**
	5	1.5	9.0	9.3	9.1	9.5	9.2	**0.570**
2	1	1.5	9.1	8.9	9.8	9.2	9.3	**0.567**
	2	1.5	9.7	9.3	9.7	9.3	9.5	**0.538**
	3	1.5	8.6	10.2	9.9	9.3	9.5	**0.538**
	4	1.5	9.7	8.9	9.5	9.2	9.3	**0.558**
	5	1.5	9.5	9.5	9.1	9.5	9.4	**0.549**
3	1	1.5	9.0	8.8	9.5	9.0	9.1	**0.589**
	2	1.5	9.1	9.1	9.9	9.0	9.3	**0.564**
	3	1.5	9.2	9.1	9.0	9.3	9.2	**0.580**
	4	1.5	9.3	9.3	9.4	9.4	9.4	**0.555**
	5	1.5	9.0	10.0	9.1	9.2	9.3	**0.558**
4	1	1.5	9.2	9.0	8.8	9.0	9.0	**0.599**
	2	1.5	9.2	9.3	9.0	9.3	9.2	**0.573**
	3	1.5	9.1	8.8	9.0	9.1	9.0	**0.599**
	4	1.5	9.0	9.4	9.1	8.8	9.1	**0.589**
	5	1.5	9.1	9.2	9.0	9.1	9.1	**0.586**
5	1	1.5	8.2	8.3	8.4	8.3	8.3	**0.705**
	2	1.5	8.1	8.3	8.3	8.0	8.2	**0.726**
	3	1.5	8.5	8.0	8.5	8.4	8.4	**0.696**
	4	1.5	8.4	8.5	8.4	8.1	8.4	**0.696**
	5	1.5	8.3	8.6	8.2	8.9	8.5	**0.672**

Appendix K.6 Sand Patch (MTD) Data from Florida Test Sections, Site #6

Florida Test Site 6 March 11, 2008 Surface: 5 M Location: US 441, Paynes Prarie Material: Granite Mix Design: SPM 07-5509A Project ID: 26010000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	6.0	5.9	6.0	5.9	5.5	5.8	**5.722**
	2	6.0	5.7	5.7	6.0	5.6	5.8	**5.872**
	3	6.0	6.0	5.5	6.2	5.8	5.9	**5.625**
	4	6.0	6.5	5.5	5.9	5.8	5.9	**5.530**
	5	6.0	5.8	5.6	6.0	5.8	5.8	**5.771**
2	1	6.0	6.2	5.6	6.1	6.0	6.0	**5.438**
	2	6.0	6.0	6.0	5.9	5.8	5.9	**5.530**
	3	6.0	6.0	5.8	6.0	5.9	5.9	**5.530**
	4	6.0	5.4	5.8	5.6	5.4	5.6	**6.303**
	5	6.0	5.4	5.2	5.4	5.5	5.4	**6.720**
3	1	6.0	5.6	6.0	5.7	5.9	5.8	**5.771**
	2	6.0	5.6	6.0	5.6	5.3	5.6	**6.136**
	3	6.0	5.4	5.3	5.5	5.1	5.3	**6.847**
	4	6.0	5.8	5.6	5.6	5.9	5.7	**5.923**
	5	6.0	5.7	5.6	5.5	5.7	5.6	**6.136**
4	1	6.0	6.0	6.1	6.1	6.0	6.1	**5.304**
	2	6.0	5.8	5.7	5.3	5.5	5.6	**6.246**
	3	6.0	5.3	5.6	5.3	5.5	5.4	**6.597**
	4	6.0	5.3	5.7	5.2	5.2	5.4	**6.783**
	5	6.0	5.6	5.7	5.5	5.4	5.6	**6.303**
5	1	6.0	5.7	5.8	5.5	5.8	5.7	**5.975**
	2	6.0	6.0	6.1	5.8	6.0	6.0	**5.438**
	3	6.0	6.0	6.0	5.9	6.0	6.0	**5.438**
	4							
	5							

Appendix K.7 Sand Patch (MTD) Data from Florida Test Sections, Site #7

Florida Test Site 7 March 10, 2008 Surface: 12.5 Location: SR 16 Material: Limestone Mix Design: SP 02-1920A Project ID: 28030001								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	9.5	9.4	9.9	9.2	9.5	**0.538**
	2	1.5	8.8	9.5	8.5	9.8	9.2	**0.580**
	3	1.5	9.5	8.9	9.3	9.3	9.3	**0.567**
	4	1.5	8.9	9.1	8.9	9.2	9.0	**0.596**
	5	1.5	8.3	9.0	8.7	9.1	8.8	**0.630**
2	1	1.5	8.5	7.9	8.7	8.4	8.4	**0.692**
	2	1.5	9.7	7.9	9.0	8.7	8.8	**0.623**
	3	1.5	8.8	8.6	9.2	8.8	8.9	**0.620**
	4	1.5	8.6	8.5	8.5	8.8	8.6	**0.656**
	5	1.5	8.9	8.4	8.5	8.6	8.6	**0.656**
3	1	1.5	8.6	8.7	8.7	8.8	8.7	**0.641**
	2	1.5	8.5	8.6	8.8	8.8	8.7	**0.645**
	3	1.5	9.0	8.6	9.1	8.4	8.8	**0.630**
	4	1.5	8.9	9.0	9.2	9.2	9.1	**0.589**
	5	1.5	9.0	8.9	9.0	9.5	9.1	**0.586**
4	1	1.5	8.5	9.4	8.5	9.0	8.9	**0.620**
	2	1.5	8.0	7.9	8.4	7.8	8.0	**0.754**
	3	1.5	8.0	8.5	8.1	8.5	8.3	**0.709**
	4	1.5	7.9	8.5	7.9	7.7	8.0	**0.758**
	5	1.5	8.0	8.1	8.0	7.9	8.0	**0.758**
5	1	1.5	8.7	8.9	8.7	8.6	8.7	**0.638**
	2	1.5	9.1	9.0	9.4	9.0	9.1	**0.583**
	3	1.5	8.9	8.8	8.7	8.9	8.8	**0.623**
	4	1.5	9.0	8.8	8.8	9.0	8.9	**0.613**
	5	1.5	8.9	8.8	8.2	8.8	8.7	**0.645**

Appendix K.8 Sand Patch (MTD) Data from Florida Test Sections, Site #8

Florida Test Site 8 June 3, 2008 Surface: 12.5 M Location: SR 501, Cocoa Beach Material: Limestone Mix Design: SPM 06-4609C Project ID: 70011000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	9.8	9.7	9.3	9.2	9.5	**0.538**
	2	1.5	9.3	8.8	9.2	8.8	9.0	**0.596**
	3	1.5	9.0	9.8	9.2	9.6	9.4	**0.549**
	4	1.5	9.1	9.2	9.5	9.4	9.3	**0.561**
	5	1.5	9.2	9.8	9.4	10.0	9.6	**0.527**
2	1	1.5	8.3	8.5	8.4	8.3	8.4	**0.692**
	2	1.5	8.8	8.0	8.3	8.9	8.5	**0.672**
	3	1.5	9.5	9.0	9.4	9.5	9.4	**0.555**
	4	1.5	9.2	9.1	9.4	9.2	9.2	**0.570**
	5	1.5	9.0	8.6	8.4	9.2	8.8	**0.627**
3	1	1.5	9.0	9.6	8.7	9.4	9.2	**0.577**
	2	1.5	9.1	8.9	8.9	8.9	9.0	**0.606**
	3	1.5	9.5	9.0	9.0	9.5	9.3	**0.567**
	4	1.5	9.2	8.8	9.0	9.2	9.1	**0.593**
	5	1.5	9.0	8.5	8.8	9.2	8.9	**0.616**
4	1	1.5	9.0	9.4	9.1	9.5	9.3	**0.567**
	2	1.5	9.3	8.9	9.3	9.4	9.2	**0.570**
	3	1.5	9.0	8.4	8.6	8.9	8.7	**0.638**
	4	1.5	8.5	8.5	8.9	9.0	8.7	**0.638**
	5	1.5	8.2	8.5	8.5	8.2	8.4	**0.696**
5	1	1.5	8.5	8.8	8.6	8.5	8.6	**0.656**
	2	1.5	8.9	8.6	8.9	8.9	8.8	**0.623**
	3	1.5	8.6	8.5	8.6	8.5	8.6	**0.664**
	4	1.5	8.7	8.5	8.5	9.0	8.7	**0.645**
	5	1.5	9.0	9.4	9.1	9.0	9.1	**0.583**

Appendix K.9 Sand Patch (MTD) Data from Florida Test Sections, Site #9

Florida Test Site 9 May 28, 2008 Surface: Burlap Drag Location: SR 600 / US 92 Material: Concrete Mix Design: 1930's Project ID: 79060000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	9.3	9.4	9.0	8.9	9.2	**0.580**
	2	1.5	10.6	9.2	9.4	9.8	9.8	**0.511**
	3	1.5	8.7	9.0	9.0	8.8	8.9	**0.616**
	4	1.5	9.6	10.0	10.0	8.8	9.6	**0.527**
	5	1.5	9.8	9.5	9.6	10.0	9.7	**0.513**
2	1	1.5	9.0	8.8	9.1	8.8	8.9	**0.609**
	2	1.5	8.8	9.0	9.2	9.0	9.0	**0.599**
	3	1.5	9.0	10.3	9.5	10.2	9.8	**0.511**
	4	1.5	9.2	10.0	9.4	10.1	9.7	**0.519**
	5	1.5	8.6	9.0	9.1	9.3	9.0	**0.599**
3	1	1.5	8.8	8.8	8.7	9.0	8.8	**0.623**
	2	1.5	9.2	8.8	8.9	9.0	9.0	**0.603**
	3	1.5	9.4	9.4	9.5	9.0	9.3	**0.558**
	4	1.5	9.6	9.3	8.6	9.3	9.2	**0.573**
	5	1.5	9.1	9.2	9.0	9.0	9.1	**0.589**
4	1	1.5	9.1	8.9	9.0	8.7	8.9	**0.609**
	2	1.5	9.0	9.3	8.7	9.5	9.1	**0.583**
	3	1.5	8.7	8.5	9.0	8.6	8.7	**0.641**
	4	1.5	8.5	9.7	8.8	9.2	9.1	**0.593**
	5	1.5	8.9	9.1	9.1	9.0	9.0	**0.596**
5	1	1.5	9.0	8.7	8.5	8.8	8.8	**0.634**
	2	1.5	9.0	8.5	9.0	8.4	8.7	**0.638**
	3	1.5	8.7	9.0	8.5	8.9	8.8	**0.630**
	4	1.5	9.2	8.3	8.9	9.0	8.9	**0.620**
	5	1.5	9.4	9.9	9.0	9.3	9.4	**0.549**

Appendix K.10 Sand Patch (MTD) Data from Florida Test Sections, Site #10

Florida Test Site 10 May 28, 2008 Surface: Long. Grind Location: SR 600 / US 92 Material: Concrete Mix Design: 1930's Project ID: 79060000								
Lock-up Segment	Spot Test Location	Sand Vol. (cu. in.)	Dia. 1 (in.)	Dia. 2 (in.)	Dia. 3 (in.)	Dia. 4 (in.)	Mean Dia. (in.)	**MTD (mm)**
1	1	1.5	8.0	7.4	8.5	7.5	7.9	**0.788**
	2	1.5	7.8	7.3	7.7	7.1	7.5	**0.869**
	3	1.5	7.5	7.6	8.1	7.5	7.7	**0.824**
	4	1.5	7.3	7.6	7.6	7.2	7.4	**0.880**
	5	1.5	7.8	7.9	7.8	7.8	7.8	**0.793**
2	1	1.5	8.5	8.2	8.0	8.6	8.3	**0.700**
	2	1.5	7.0	8.1	7.5	8.0	7.7	**0.829**
	3	1.5	7.8	7.6	7.9	7.9	7.8	**0.798**
	4	1.5	8.3	8.4	8.4	8.5	8.4	**0.688**
	5	1.5	7.5	8.2	7.8	7.5	7.8	**0.808**
3	1	1.5	8.4	8.6	8.4	8.3	8.4	**0.684**
	2	1.5	7.8	8.2	8.1	8.1	8.1	**0.749**
	3	1.5	8.2	8.6	8.3	8.4	8.4	**0.692**
	4	1.5	8.0	8.1	8.0	7.8	8.0	**0.763**
	5	1.5	8.3	8.5	8.6	7.7	8.3	**0.709**
4	1	1.5	8.4	8.9	8.3	8.5	8.5	**0.668**
	2	1.5	8.9	9.4	9.0	8.8	9.0	**0.596**
	3	1.5	9.0	9.0	8.7	9.0	8.9	**0.609**
	4	1.5	8.1	8.1	8.5	8.0	8.2	**0.726**
	5	1.5	9.3	10.0	9.6	10.2	9.8	**0.508**
5	1	1.5	7.5	8.8	7.7	8.4	8.1	**0.740**
	2	1.5	7.8	9.2	8.5	8.5	8.5	**0.672**
	3	1.5	7.5	9.2	8.2	8.8	8.4	**0.684**
	4	1.5	8.0	8.3	8.8	8.3	8.4	**0.696**
	5	1.5	8.8	8.5	9.0	7.7	8.5	**0.672**