CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 15-018
UILU-ENG-2015-2024
ISSN: 0197-9191

EVALUATING ALL-WEATHER PAVEMENT MARKINGS IN ILLINOIS: VOLUME 1

Prepared By
Neal Hawkins
Omar Smadi
Skylar Knickerbocker
Center for Transportation Research and Education
Iowa State University

Adam Pike
Paul Carlson
Texas Transportation Institute
Texas A&M University

Research Report No. FHWA-ICT-15-018

A report of the findings of
ICT-R27-120
Evaluating All-Weather Pavement Markings and Lab Methods to Simulate Field Exposure

Illinois Center for Transportation

December 2015

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-15-018		

4. Title and Subtitle Evaluating All-Weather Pavement Markings in Illinois: Volume 1	**5. Report Date** December 2015 **6. Performing Organization Code**
7. Author(s) Neal R. Hawkins, Adam M. Pike, Omar G. Smadi, Skylar Knickerbocker, and Paul J. Carlson	**8. Performing Organization Report No.** ICT-15-018 UILU-ENG-2015-2024
9. Performing Organization Name and Address Center for Transportation Research and Education Iowa State University 2711 S. Loop Drive, Suite 4700 Ames, IA 50010-8664	**10. Work Unit No.** **11. Contract or Grant No.** R27-120
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR) Bureau of Material and Physical Research 126 East Ash Street Springfield, IL 62704	**13. Type of Report and Period Covered** 4/1/12 through 12/31/15 **14. Sponsoring Agency Code** FHWA

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Pavement markings provide critical guidance to motorists, especially under dark (non-lighted) conditions. However, the ability to see these pavement markings on a wet, rainy night is problematic given that the presence of water considerably decreases pavement marking retroreflectivity. This project evaluated the performance of several all-weather pavement marking products in an effort to provide guidance on their use on Illinois Department of Transportation (IDOT) roadways. In addition, a laboratory evaluation was completed in an effort to simulate degradation mechanisms of these pavement markings so that future all-weather materials can be evaluated in a timely manner within the lab versus public roadway.

The study found that only 15% of the all-weather products provided a retroreflectivity of 50 millicandelas per meter squared per lux (mcd/m²/lux), which is noted as (mcd) within this report, under continuous wetting conditions. The lab evaluation showed some promise for the dry retroreflectivity performance given that data variability was low and there was good correlation initially with the field data. The correlation was not as good, however, as the markings aged, and correlation in the wet conditions was not good.

17. Key Words	18. Distribution Statement
All-Weather, Pavement Marking, Wet Retroreflectivity, Field Evaluation, Laboratory Evaluation, Degradation, Continuous Wetting, Recovery	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	49	

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

ACKNOWLEDGMENTS

This publication is based on the results of **R27-120, Evaluating All-Weather Pavement Markings and Lab Methods to Simulate Field Exposure**. ICT-R27-120 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation, Division of Highways; and the U.S. Department of Transportation, Federal Highway Administration. The authors wish to acknowledge the contributions by the following Technical Review Panel members:

- Kelly Morse (TRP Chair), Illinois Department of Transportation, Bureau of Materials and Physical Research
- Thomas Schaefer, Illinois Department of Transportation District 3
- Jeff Abel, Illinois Department of Transportation District 8
- Kyle Armstrong, Illinois Department of Transportation, Operations
- Michael Fassero, Illinois Department of Transportation
- Filiberto Sotelo, Illinois Department of Transportation, Safety Engineering
- Tim Kell, Illinois Department of Transportation, Bureau of Construction
- John Benda, Illinois State Toll Highway Authority
- Brian Pfeifer, Federal Highway Administration
- Field staff from the Illinois Department of Transportation Districts 3 and 8
- Field staff from the Illinois State Toll Highway Authority

EXECUTIVE SUMMARY

Pavement markings provide critical guidance to motorists, especially in dark (non-lighted) conditions. However, the ability to see these pavement markings on a wet, rainy night is problematic given that the presence of water considerably decreases pavement marking retroreflectivity. The pavement marking industry has responded to these concerns by producing a variety of “wet reflective” (primarily referred to as all-weather retroreflective media in this report) that, when placed with the pavement markings, are designed to provide improved retroreflectivity under wet conditions.

This project evaluated the performance of several all-weather pavement marking products in an effort to recommend whether they should be considered for application on Illinois Department of Transportation (IDOT) roadways. In addition, a laboratory evaluation was completed in an effort to simulate degradation mechanisms of these pavement markings so that future all-weather materials can be evaluated in a timely manner within the lab versus public roadway.

FIELD EVALUATION

The field demonstration portion of this project included the following:

- Seeking out the range of market-ready all-weather wet reflective media available for evaluation. These media are placed on top of the liquid pavement marking upon installation and in addition to standard glass beads. This was accomplished through dialogue with representatives of the pavement marking industry and by an open-invitation, IDOT-sponsored vendor conference call.
- Determining where the selected pavement marking products would be installed in concert with the wet reflective media.
- Determining where the pavement marking test sections would be installed. The project’s Technical Review Panel (TRP) decided that the test decks would be dispersed as best as possible throughout the state on planned, contracted projects (new construction or maintenance work). This required working with both IDOT and Illinois State Toll Highway Authority staff to obtain project details, limitations, roadway surface types, pavement marking line types included (such as edge or skip line), contractor, project timing, and logistics for substituting the standard planned markings with the research materials and at a groove depth of 60 mil.
- Developing the installation detail plans to maintain consistency across sites and installation contractors.
- Working with each agency, vendor, prime contractor, and subcontractor to complete each installation.
- Developing a field evaluation methodology that defines how the evaluation will be conducted over the 2-year study.
- Conducting the study and evaluations over time and reporting the results.

LABORATORY EVALUATION

The lab evaluation portion of the research project was conducted concurrently with the field evaluation. The lab evaluation was focused on developing a method to wear pavement marking samples in a lab environment so that the quality of a pavement marking system could be determined in an accelerated fashion.

Initial lab testing was conducted to determine a suitable process for conducting the accelerated wearing of the pavement marking samples from the field test decks. The researchers needed to determine the appropriate wheels to use on the accelerated wear device, the appropriate amount of weight to place on the device, how many cycles to run between retroreflectivity tests, and how to best evaluate the retroreflectivity of the samples after accelerated wearing. The accelerated wear device used is typically used for testing the polishing properties of pavement surfaces. Several tests were conducted during the initial accelerated wear testing.

The final lab testing was conducted to evaluate the performance of the pavement marking samples from the field test decks after undergoing accelerated wear. The performance of the samples was evaluated after 0, 1000, 3000, 6000, and 10000 cycles. After the specified number of cumulative cycles had passed, the samples were removed from the accelerated wear device. The performance metrics that were evaluated were the same as in the field evaluation: dry, recovery, and continuous wetting retroreflectivity.

The research team developed an evaluation protocol to evaluate the samples initially and after the samples had received the appropriate number of accelerated wear cycles. The retroreflectivity measurements were taken with a handheld retroreflectometer. Five readings were taken and averaged for each measurement condition at each measurement interval. The measurement platform where the evaluation took place had a 2% cross-slope to facilitate drainage during the wet retroreflectivity tests. Initial performance measurements were taken on the full-size sample in the location that would receive the accelerated wear. On the basis of the initial testing, the researchers knew that the worn area was smaller than the area evaluated by the handheld retroreflectometer. The researchers evaluated the samples in a consistent place and corrected the smaller-area measurements by a factor based on testing that was conducted to determine the correction factor.

The researchers began the analysis of the lab data by summarizing the data collected during the final accelerated wear tests. At each measurement interval, data were collected for each marking sample in dry, recovery, and continuous wetting conditions. After summarizing the data, the research team corrected the data to account for the measurement area differences between the worn sample area and the area evaluated by the retroreflectometer.

The data clearly showed a decreasing trend in performance for all conditions as the number of wear cycles increase. The dry performance was far superior to either of the wet conditions. The recovery retroreflectivity levels were higher than the continuous wetting retroreflectivity levels. Many markings did not make it to the 6000-cycle or full 10000-cycle levels because of a loss of wet-reflective performance or damage. There was a drastic reduction in continuous wetting retroreflectivity from the initial to the 1000-cycle level. The markings' retroreflectivity degradation slowed after the 1000- or 3000-cycle measurement interval.

The researchers compared the performance of the pavement markings in the field with the performance of the pavement marking samples in the lab. The goal was to establish a lab technique that would correlate with the actual performance of the markings in the field. To achieve good correlation, the lab technique must be equitable across marking types, bead types, installation locations, and any other factors that might have influenced the performance of the markings in the field.

Two techniques were used to determine how well the lab technique simulated the wear that the markings received in the field. The first technique was used on a selection of samples evaluated at 250 and 500 cycles. This technique compared the field data at the 1-year measurements with the lab data collected at the various numbers of cycles. The second technique used correlation to determine how well the lab data could predict the field performance. The specific correlation value used was the coefficient of determination (R2), which compared the two sets of data based on linear regression.

Ideally, the different marking samples would have the same number of accelerated wear cycles for each of the individual field evaluation periods for each of the performance metrics. For the initial dry retroreflectivity values, the data were satisfactory. The different samples had 500, 250, 500, and 500 cycles representing the initial dry field values. Similar values indicated that the accelerated wear technique was equitable across the different markings. For many of the other scenarios, the data were not as satisfactory. The 1-year dry field readings had 10,000, 1000, 1000, and 3000 cycles as the equivalent values. Some of the wet comparisons had a similarly wide range of cycles that represented the field data. While there were some promising results for those few samples, the variability in data suggests that it is not generally possible to use the lab data to predict field performance.

FIELD EVALUATION CONCLUSIONS

The field evaluation was a significant undertaking for the research team, IDOT district staff, and Tollway staff, as well as the contractors, vendors, and suppliers. The evaluation exposed a considerable number of individuals to traffic over the course of the 2-year study, but it was an ideal way to understand how these all-weather products perform on Illinois roadways.

The research team provided the TRP with threshold values as a means to contrast product performance in terms of dry, recovery, and continuous wetting retroreflectivity. These thresholds were conservatively set at 100 millicandelas per meter squared per lux (mcd/m²/lux) which is noted as (mcd) within this report for both dry and recovery, and 50 mcd for continuous wetting or wet conditions.

Using these thresholds, the following conclusions can be made:

- Dry retroreflectivity: Every product was able to perform at or above 100 mcd for each measurement interval (initial, 1 year, and 2 year)
- Recovery retroreflectivity: Only three product combinations were able to exceed 100 mcd after 2 years (3M 380AW, 3M AWP yellow with polyurea, and 3M AWP yellow with urethane)
- Wet retroreflectivity: Only four product combinations were able to exceed 50 mcd after 2 years—3M 380AW, 3M AWP yellow with polyurea, 3M AWP yellow with urethane, and Epoplex VISIMAX (yellow). The Epoplex material did not meet the 50 mcd threshold at either the initial or 1 year reading but was found to exceed that value at the 2-year reading.
- Wet retroreflectivity overall: Given that the focus of this effort was to understand product performance under wet conditions, this evaluation showed that of the 27 possible product combinations installed, the following was found:
    - Initial conditions: 12 out of a possible 27 (44%) product combinations measured at or above 50 mcd (less than half of the markings).
    - After 1 year: Five out of a possible 27 (18%) product combinations measured at or above 50 mcd.
    - After 2 years: Four out of a possible 27 (15%) product combinations measured at or above 50 mcd.

LABORATORY EVALUATION CONCLUSIONS

The lab evaluation had positive and negative aspects. There were some promising results for the dry retroreflectivity performance. The data variability was low and there was good correlation initially with the field data. The correlation was not as good as the markings aged, and correlation in the wet conditions was not good. The lab testing did yield useful degradation curves for the materials, which could be helpful in future product comparisons in a lab environment.

There were several drawbacks to the lab testing technique used. The researchers had to use available equipment and modify it to work for the research. The system was not able to wear a sufficiently large area of the markings to fully cover the measurement area of the handheld retroreflectometer. This required the researchers to develop correction factors, which is not ideal because doing so adds an extra step and increases variability and uncertainty with the measurements. The correction factor proved to be a consistent measurement for the dry evaluations but was more variable under the wet conditions.

CONTENTS

FIGURES

TABLES

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Pavement markings provide critical guidance to motorists especially under dark (non-lighted) conditions. However, the ability to see these pavement markings on a wet rainy night is problematic given that the presence of water considerably decreases pavement marking retroreflectivity. Driving under these conditions can cause both stress and fatigue to motorists, especially elderly drivers who are becoming an increasing percentage of the driving population.

The pavement marking industry has responded to these concerns by producing a variety of "wet reflective" (primarily referred to as all-weather retroreflective media in this report) that, when placed with the pavement markings, are designed to provide improved retroreflectivity under wet conditions.

1.2 OBJECTIVE

This project evaluates the performance of several all-weather pavement marking products in an effort to recommend whether they should be considered for application on Illinois Department of Transportation (IDOT) roadways.

1.3 SCOPE

The primary research efforts included the following:

- Conducting a multi-season field evaluation of different all-weather pavement markings on Illinois roadways under live traffic conditions and winter operational practices.
- Developing a laboratory technique to simulate degradation mechanisms of these pavement markings so that future all-weather materials can be evaluated in a timely manner.

CHAPTER 2: STUDY METHODOLOGY

2.1 PRODUCT SELECTION

The field demonstration portion of this project focused on evaluating all-weather pavement marking products on Illinois roadways, given IDOT's desire to determine whether these products are an option for enhancing motorist safety. To accomplish this objective, and in light of a late contractual start date for the research project, the research team worked with the TRP to select products for evaluation and to identify projects for which the products could be installed in an expedited manner. The primary activities are summarized below.

2.1.1. Wet Reflective Media

The TRP was interested in seeking out the range of market-ready all-weather wet reflective media available for evaluation in this research project. The research team initiated dialogue with the pavement marking industry and ultimately decided to hold an open-invitation, IDOT-sponsored vendor conference call. This call provided each vendor with an overview of the research objectives in addition to information specific to their participation. The vendor call meeting information provided is noted below, and Figure 2.1 shows the vendor participation and products.

1. Installation: This work will be added to existing IDOT or Tollway pavement marking contracts. Traffic control, installation equipment, crew, etc. will be managed by others. All installations will be placed within a 60 mil groove. Anticipate a minimum 1000-foot section to install each unique wet reflective product (whether liquid or tape) using lines to be marked per the existing roadway contract (which can vary by project). IDOT-approved pavement marking products and standard beads will not be modified. Vendors will provide their all-weather wet reflective media to be added/applied in different marking materials (urethane, polyurea, epoxy, thermo, etc.) as a supplement to standard IDOT beads.
2. Location: Multiple locations (within Districts 3 and 8).
3. Expected vendor participation: Provide sample material and documentation to IDOT in advance for review. Provide the installation contractor with the necessary wet reflective media/tape. Coordinate with IDOT and be onsite to assist with and make sure you are satisfied with the bead calibration and coverage for your test section (work with contractor for a smooth and efficient installation).
4. Evaluation: Products will be evaluated by the research team in terms of wet/dry/recovery retroreflectivity after one or up to two winters.

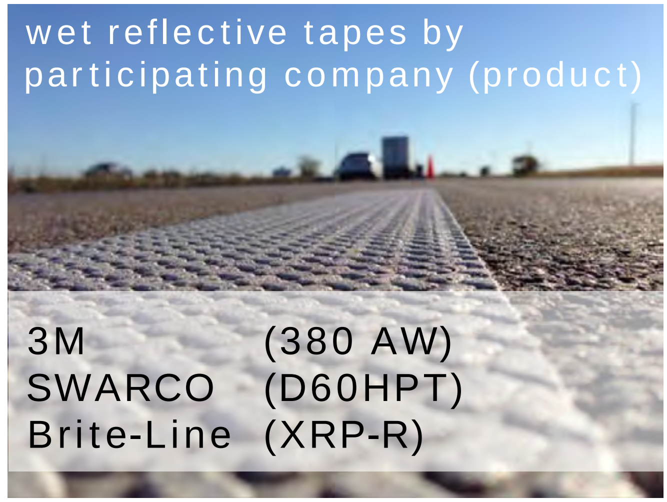

Figure 2.1 Vendor participation and all-weather media and tape products.

2.1.2. Pavement Markings

Given that the research work was going to be added to current IDOT contracted projects and maintenance work, the TRP directed that all of the pavement marking materials used, as a part of this research, be from the current IDOT-approved marking materials list as shown in Table 2.1.

Table 2.1 Approved IDOT Marking Materials List

Material	Specification	Link
Traffic Paint		
Epoxy Paint	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.04	1095.04
Latex Paint	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.02	1095.02
Black Latex Paint	Materials Spec for Fast Dry Black SN M135-05	M135-05
Modified Urethane	BDE Special Provision for Modified Urethane Pavement Marking 4/1/12	BDE Mod Urethane
Polyurea	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.08	1095.08
Type A-A2886(Acetone)	A-A2886B October 19,2004	A-A2886B
Preformed Plastic Tape		
Type 1	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.06	1095.06
Type 3	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.06	1095.06
Type B	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.03	1095.03
Type IV (Wet Reflective)	BDE Special Provision for Pavement Marking Tape Type IV 4/1/12	BDE Type IV
Type D (Wet Reflective)	BDE Special Provision for Preformed Plastic Pavement Marking Type D-Inlaid 4/1/12	BDE Type D
Theromplastic	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.01	1095.01
Wet Reflective Thermoplastic	BDE Special Provision for Wet Reflective Thermoplastic Pavement 4/1/12	BDE Wet Thermoplastic
Preformed Thermoplastic	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.01 and 1095.05	1095.05
Beads		
Type B	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.07	1095.07
Epoxy	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1095.04	1095.04
Miscellaneous		
Raised Pavement Marker	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1096.01	1096.01
Type VI Replacement Delineater	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1096.01	1096.01
Reflectors/ Delineators	Standard Specifications for Roads and Bridge Construction 1/1/12: Article 1097	1097.01

Based on consideration of project locations, described in Section 2.2 of this report, the selected marking materials (four liquid materials and tape) included in the evaluation are identified in Figure 2.2. The figure also shows a photograph of the paint truck applying the materials (traveling right to left). The material is delivered via paint gun followed by the all-weather media gun, and then the standard IDOT bead gun (typical for each installation).

The wet reflective media were delivered to the line prior to the standard IDOT beads, as shown in the photo above. All liquid marking products were placed within a 60 mil groove with the exception of thermoplastic which was installed within a 125 mil groove. The liquid pavement marking products were placed on several types of roadway surfaces (PCC and ACC).

Figure 2.2 Marking materials and bead gun arrangement.

2.2 FIELD TESTING

2.2.1 Identifying Field Test Locations

The TRP decided that the test decks would be spread as best as possible throughout the state on planned, contracted projects (new construction or maintenance work). Specific project locations were finalized by working with both IDOT and Tollway staff, taking into consideration the project details, limits, roadway surface types, pavement marking line types included (such as edge or skip line), contractor, project timing, and logistics for substituting the standard planned markings with the research materials and at a groove depth of 60 mil.

Each IDOT district provided a list of contracted work, and the research team worked with the roadway contractors and pavement marking vendors to determine each test deck location. This included test decks on I-80, I-55, I-355, and I-57. Figure 2.3 shows the general project locations on a map along with the year installed and number of test decks for the corresponding roadway.

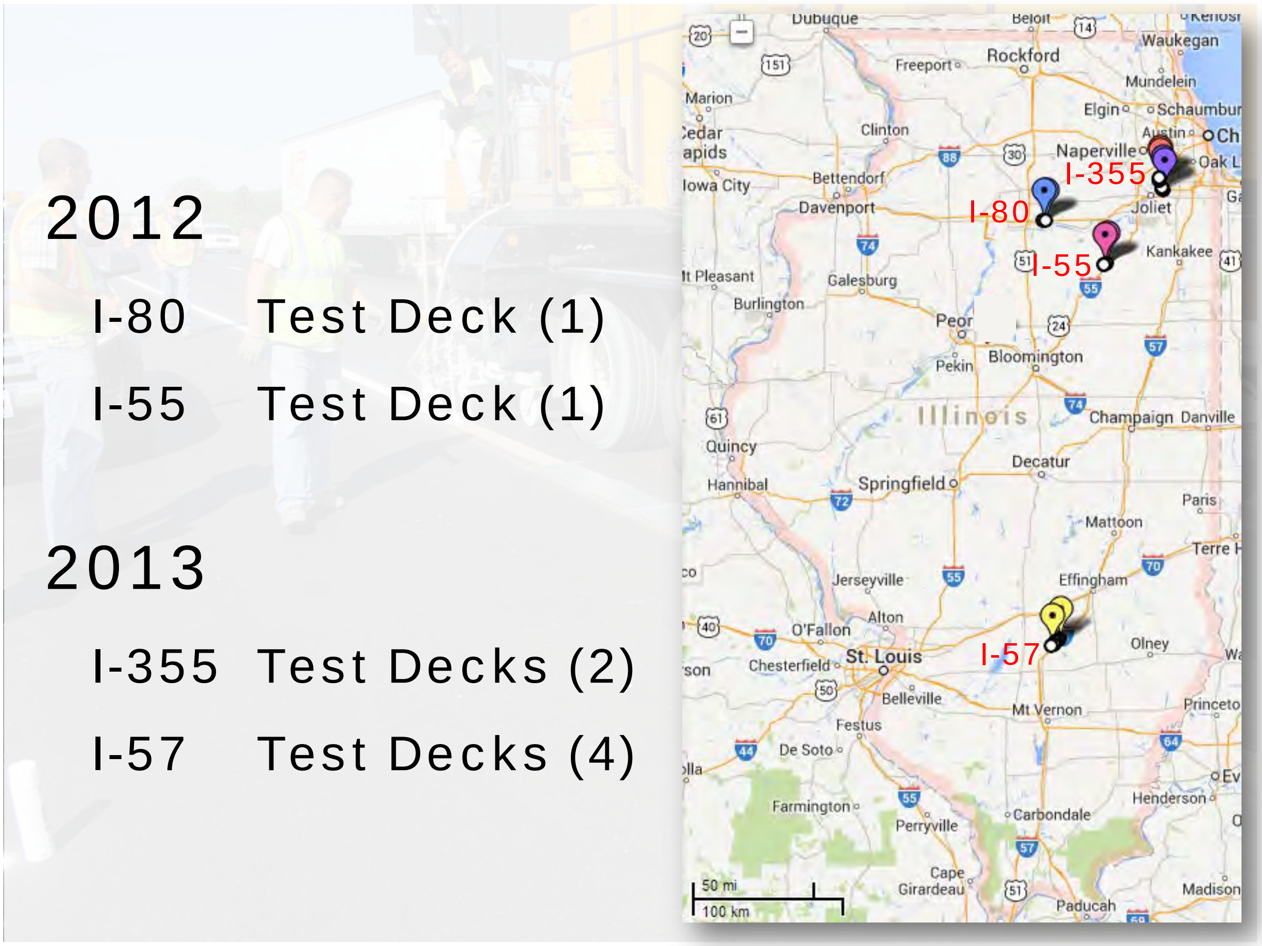

Figure 2.3 All-weather pavement marking test deck locations by year of installation.

Figure 2.4 is a summary matrix for the all-weather test segments by material, type of roadway surface, roadway surface age, and roadway name.

	Urethane	Polyurea	Epoxy	Thermo	Tape
ACC	New I-80 Existing I-57	Existing I-57	Existing I-57	Existing I-57	New I-80
PCC	Existing I-55	Existing I-355	Existing I-355		

"New": Installed on a new Roadway Surface
"Existing": Installed on an "Existing" Roadway Surface

Figure 2.4 All-weather test deck matrix by product, surface type, and roadway.

2.2.2 Installation Plans

The research team developed specific installation plan details by product, line type, and vendor for each test deck segment on each roadway as described below.

I-80 and I-55

Figure 2.5 provides a map and photos showing the test sections and direction of travel for both sections receiving the all-weather markings for both I-80 and I-55. Figure 2.6 provides the details specific to the location where each test product was placed, by line type and test deck segment.

The I-80 test deck was part of a major resurfacing effort and included three different wet reflective tape products on the white skip line and three different all-weather products on the white edge line. The yellow edge line was not included because of issues with contractor staging. The segment lengths per product varied because this project had to be completed under construction staging conditions.

The I-55 test deck was installed on the existing Portland cement concrete (PCC) surface and included all-weather markings for the yellow edge, white skip, and white edge lines with equal one-third-mile segments for each product.

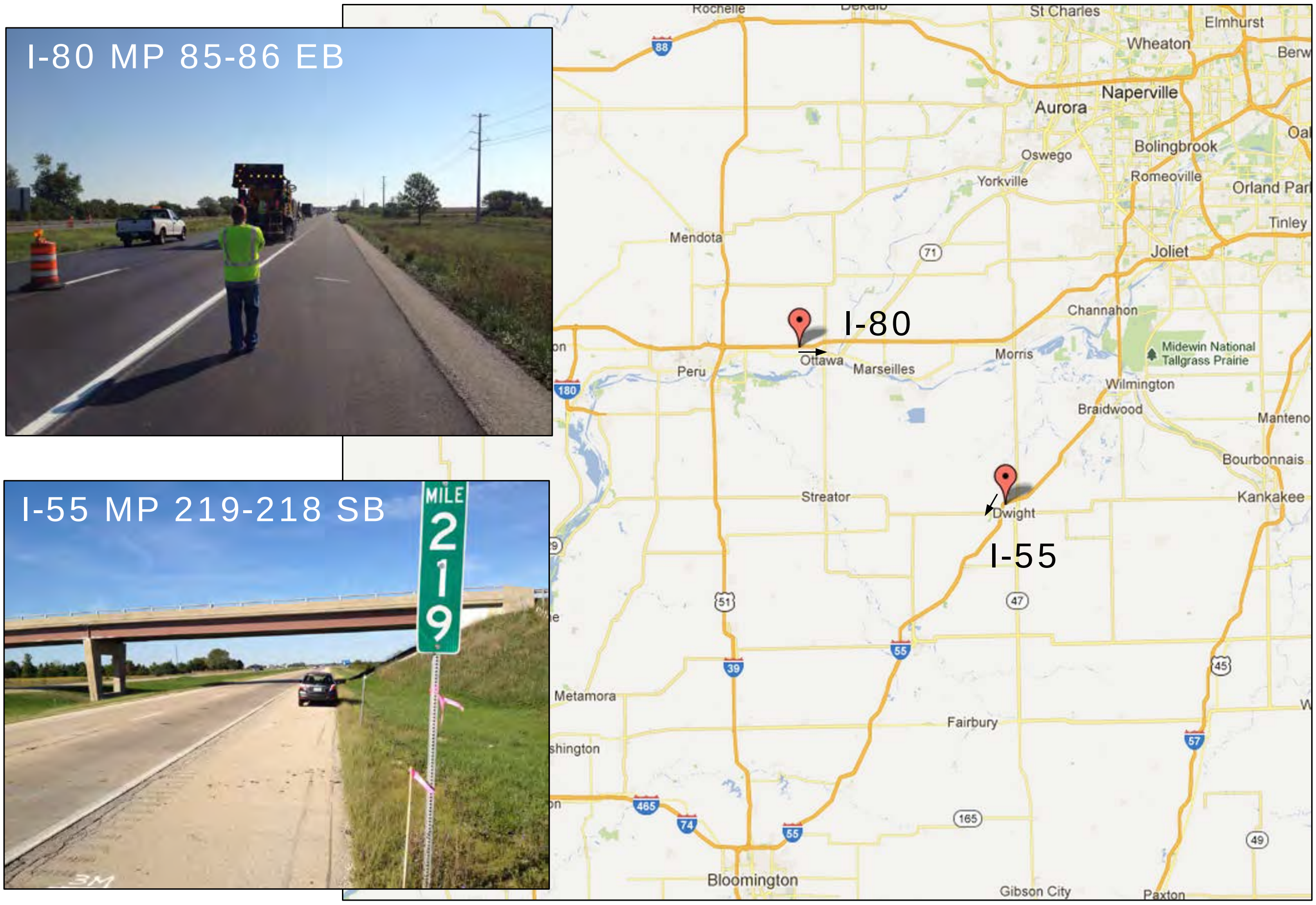

Figure 2.5 Test deck installation photo and locations for I-80 and I-55.

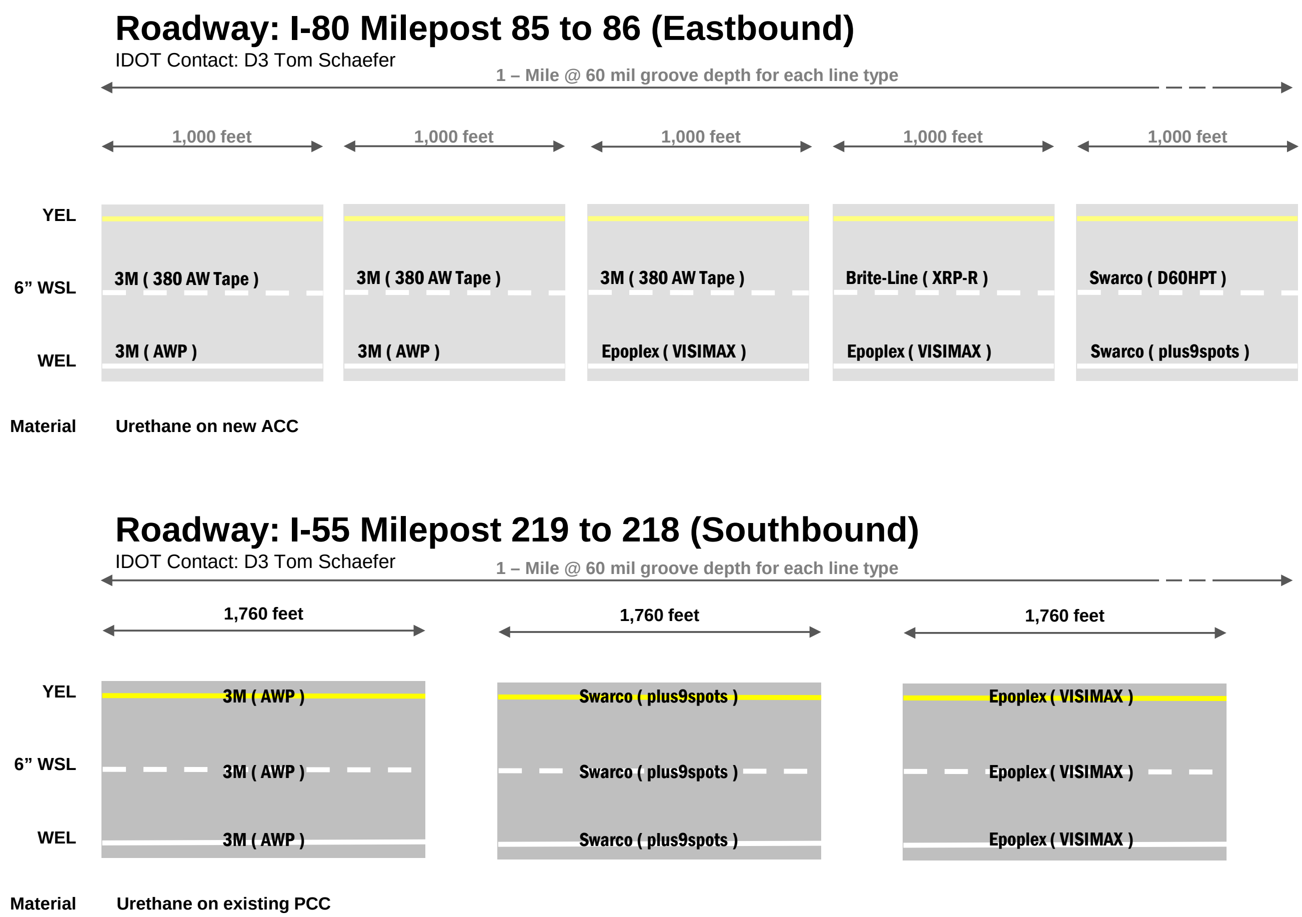

Figure 2.6 Test deck installation details for I-80 and I-55.

I-355

Figure 2.7 provides a map and photos showing the test sections and direction of travel for both sections receiving the all-weather markings along the I-355 tollway. Figure 2.8 provides the details specific to the location where each test product was placed, by line type and test deck segment.

The I-355 test deck markings were placed over an existing PCC roadway; however, the grooving operation was already completed for this project. The polyurea and epoxy decks were laid out in the same manner, by product and line type. This included test materials for the white edge line, the adjacent white skip line, and the yellow edge line. To minimize installation time, and given that there are two white skip lines on this four-lane road, the white skip line adjacent to the yellow edge line was not striped as a part of this study. Because of traffic demands, the materials were installed at night.

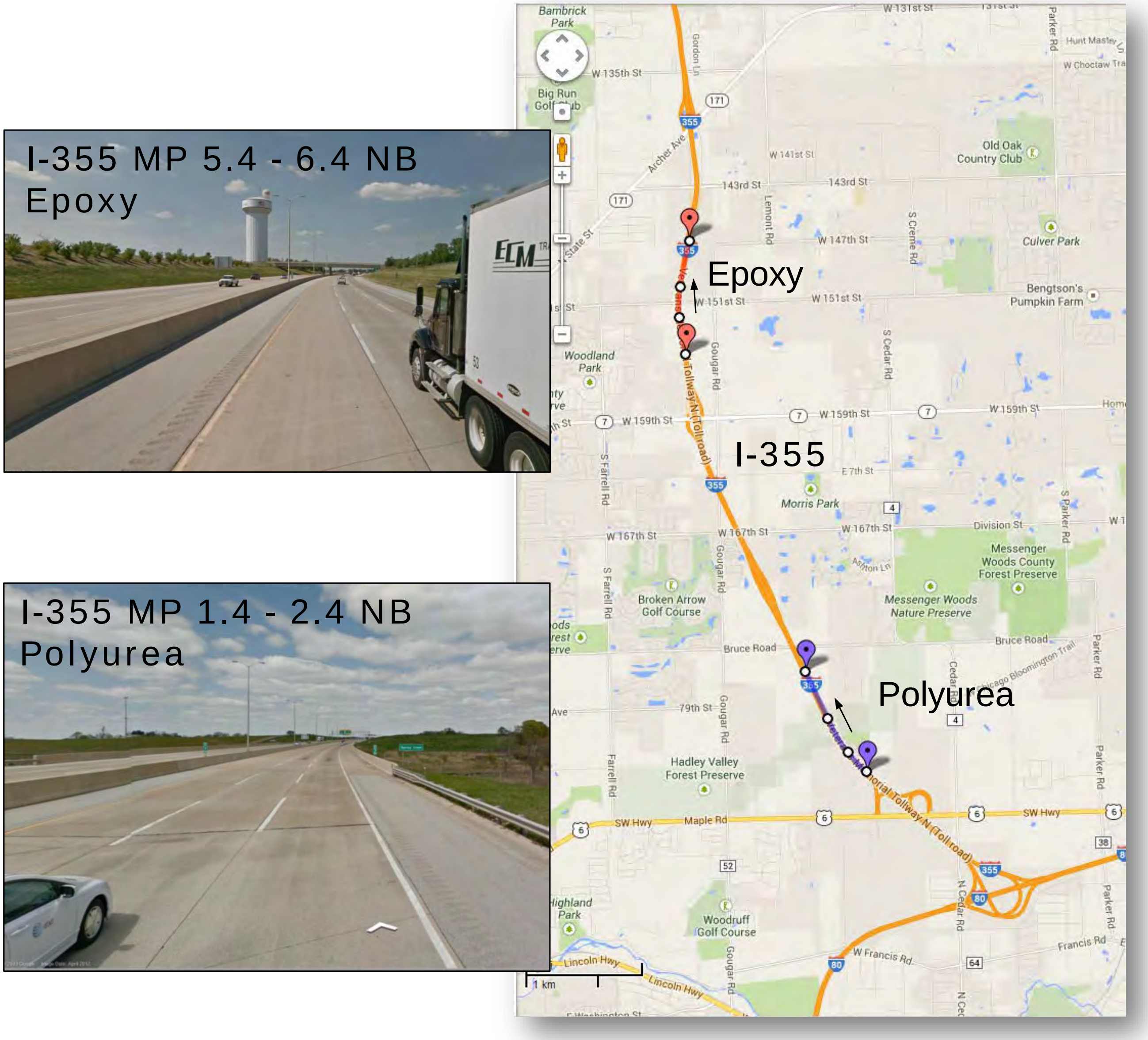

Figure 2.7 Test deck installation photo and locations for the I-355 tollway.

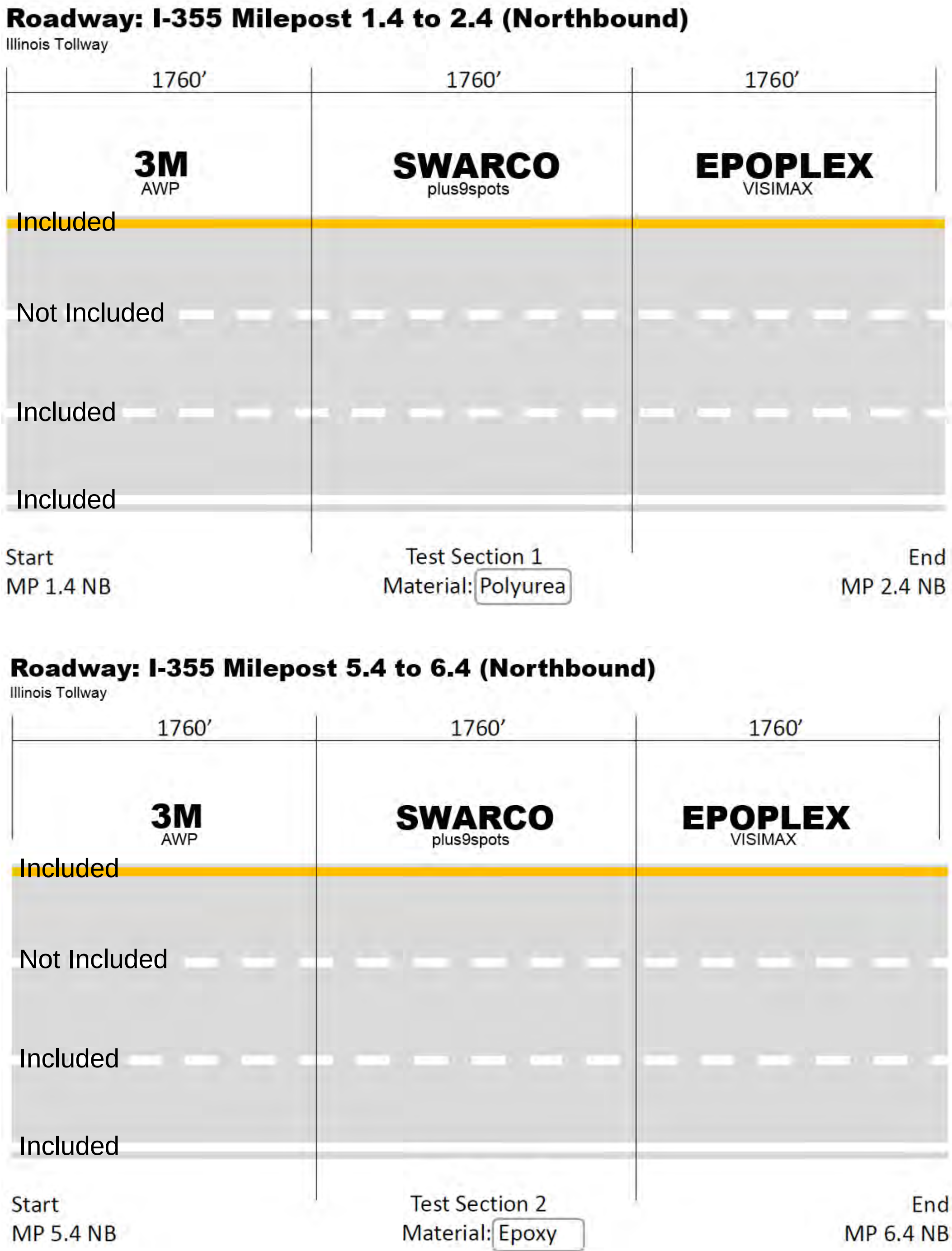

Figure 2.8 Test deck installation details for the I-355 tollway.

I-57

Figure 2.9 provides a map and photos showing the test sections and direction of travel for the sections receiving the all-weather markings along I-57. Figure 2.10 provides the details specific to the location where each test product was placed, by line type and test deck segment.

The I-57 test deck was installed on the existing asphalt cement concrete (ACC) surface and included all-weather markings for the yellow edge and white edge lines only. The 24000-foot-long project included four material test sections, each with 2000-foot segments by product. This test deck was farthest south within the state, at roughly 230 miles south of the I-355 test area.

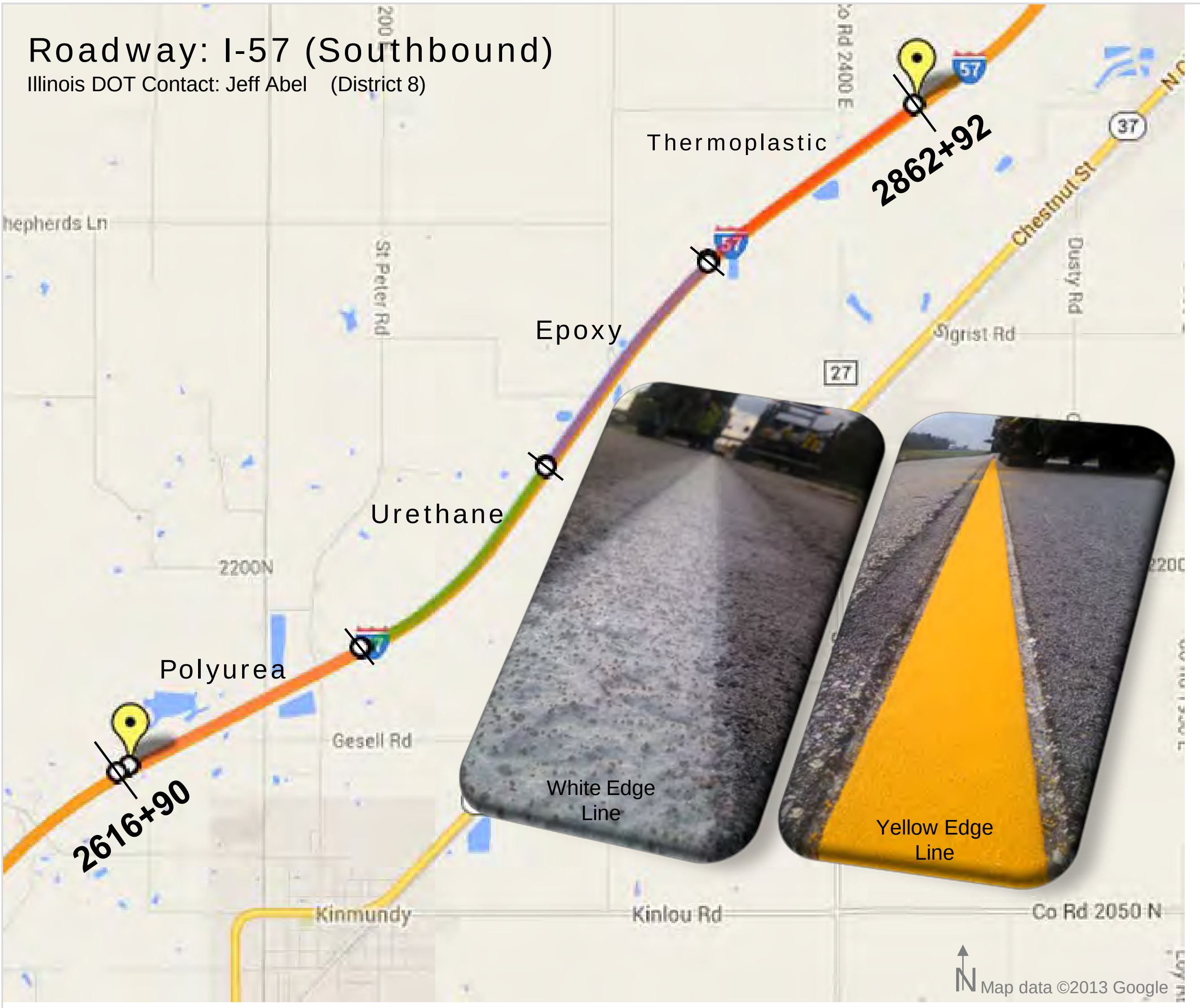

Figure 2.9 Test deck installation photo and locations for I-57.

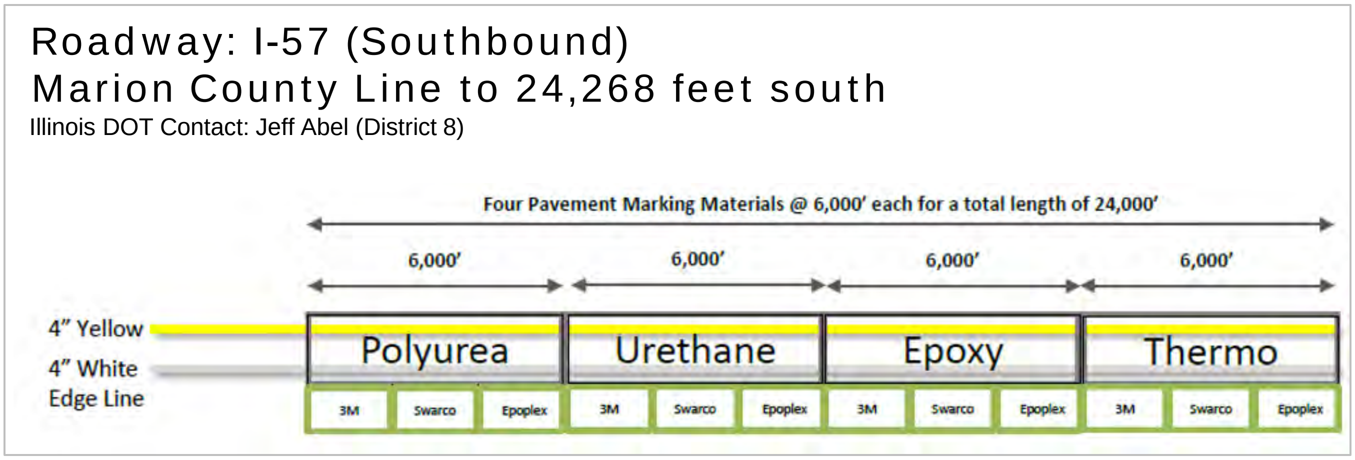

Figure 2.10 Test deck installation details for I-57.

2.3 EVALUATION

2.3.1 Field Evaluation

Measurement Method

Based on input from the TRP, a field evaluation methodology was developed and applied, to each of the test deck and line types using a hand-held retroreflectometer. The methodology is described below and is shown in Figure 2.11.

- Point A. Identify the beginning location of the test segment and for each line type conduct the following tests:
    1. Dry retroreflectivity readings (ASTM 1710)
    2. Wet recovery retroreflectivity readings (ASTM 2177)
    3. Continuous wetting retroreflectivity readings (ASTM E2832-12)
- Section B. Moving in the direction of traffic along the line, over the next 400 feet obtain 20 dry retroreflectivity readings (evenly spaced).
- Point C. Roughly, 400 feet downstream from Point A, repeat measurements 1 through 3 exactly as at Point A.

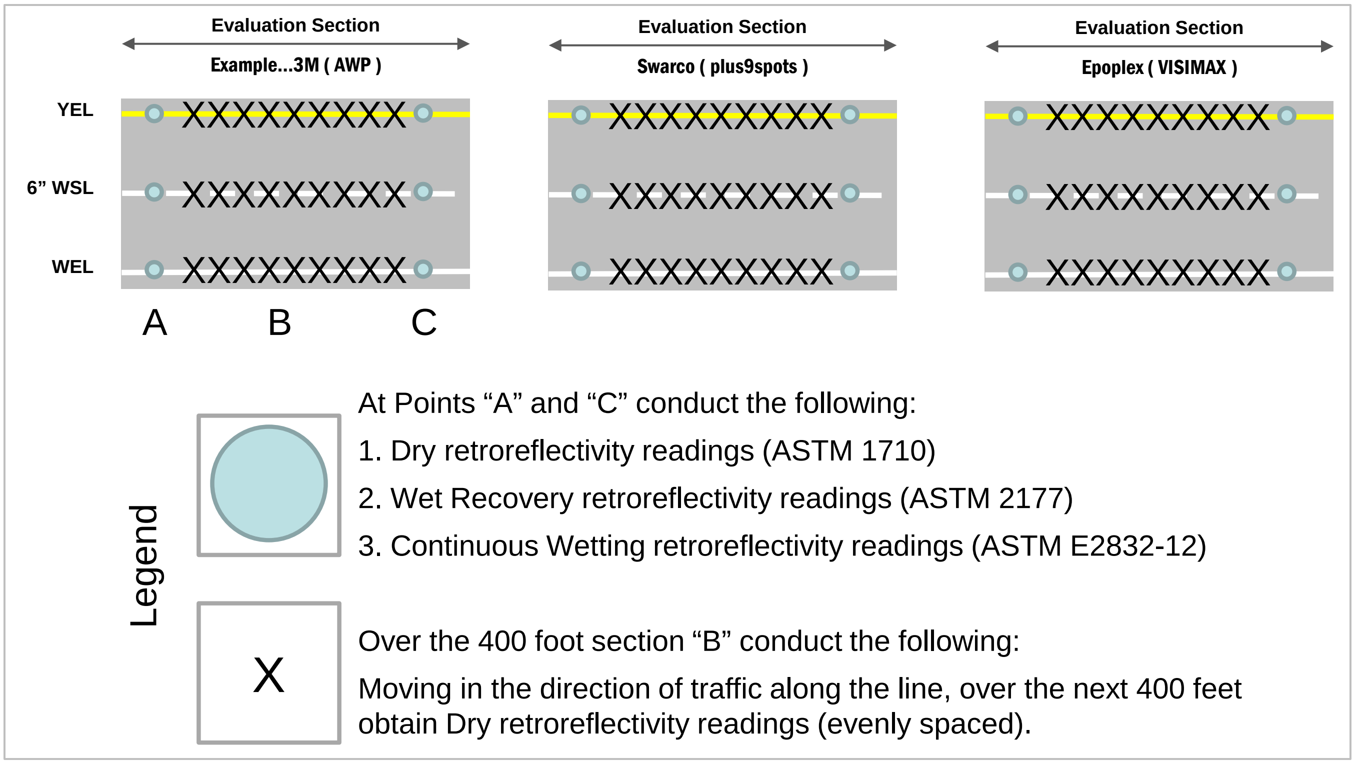

Figure 2.11 Field measurement methodology

Measurement Frequency

Each test segment and line type was measured as follows:

- Initially: At a time less than 1 month, or at most 2 months, after installation
- One year: After one winter and approximately 1 year after installation
- Two years: After two winters and approximately 2 years after installation

2.3.2 Laboratory Evaluation

The lab evaluation portion of the research project was conducted concurrently with the field evaluation. The lab evaluation focused on developing a method to wear pavement marking samples in a lab environment so that the quality of a pavement marking system could be determined in an accelerated fashion. Pavement marking test decks in the field may take years to wear to failure. The accelerated wear in a laboratory environment could evaluate the quality of pavement markings in a much shorter timeframe.

The testing device used was a circular track polishing machine that is typiclly used to evaluate the polishing properties of road surfaces. The circular testing device is similar to other accelerated pavement marking testing systems such as the German Federal Highway Research Institute (BASt) simulator and the Association for the Development of Technologies for Road Equipment (AETEC) simulator in Spain. These pavement marking wear simulators have diameters of over 20 feet. The circular track polishing machine used in this study has a diameter of approximately 12 inches. The circular track polishing machine had an initial cost of approximately $20,000. An additional $700 was spent on steel wheels that had an 8-inch diameter and were 3 inches wide.

The pavement marking samples used during the final lab evaluation were collected from the field evaluation test sites. This allowed the researchers to compare the field results with the accelerated lab testing technique. After various intervals of accelerated wear, the pavement marking samples were characterized for performance. The performance metrics were the same as in the field evaluation: dry, recovery, and continuous wetting retroreflectivity.

CHAPTER 3: TEST DECK EVALUATION

3.1 MEASUREMENTS

Field measurements of retroreflectivity were completed for each test deck as outlined in Section 2.3.1 of this report. The specific dates for each measurement are provided along with the field data in Section 3.2. Additional field data collected for each roadway, but not presented below, were pavement marking photos, installation temperature, grade, and cross-slope. Some supplemental comments and selected images per test deck follow.

I-80

District 3 staff provided traffic control while the white edge and white skip lines were being measured. Initial measurements were completed in November 2012. Additional measurements were made in October 2013 (1 year) and June 2014 (2-year reading, or after two winters). Scheduling for all readings was a major effort and subject to district staff availability and traffic conditions. Figure 3.1 includes a few images from one of the measurement activities.

Figure 3.1 Taking a retroreflectivity (continuous wetting, left) reading on I-80 along with marking presence images for the white edge line (center) and centerline skip (right).

I-55

District 3 staff also provided traffic control for measuring the white edge, white skip, and yellow edge lines. This roadway was measured at the same times as I-80. Figure 3.2 includes a few images from one of those measurement activities.

Figure 3.2 Taking a retroreflectivity (recovery, left) reading on I-55 along with marking presence images for the yellow edge line (center) and white edge line (right).

I-355

The Tollway's contractor provided traffic control while the two test decks on I-355 (all at night) were being measured. The white edge, white skip, and yellow edge lines were each measured. Initial measurements were completed in October 2013 followed by September 2014 (1 year). No additional measurements were taken beyond the 1-year time period because of the costs associated with obtaining the measurements and the wet retroreflective performance observed. Figure 3.3 includes a few images from one of the measurements.

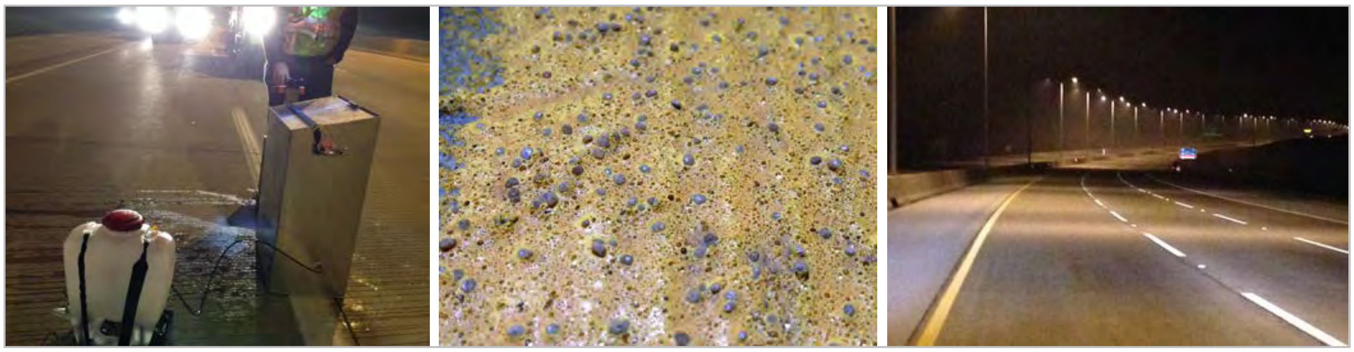

Figure 3.3 Taking a retroreflectivity (continuous wetting, left) reading on I-355 along with marking presence images for the yellow edge line (center) and general photo of all lines (right).

I-57

District 8 staff provided traffic control while the white and yellow edge lines were measured. Initial measurements were completed in November 2013 followed by readings in June 2014 (1 year) and June 2015 (2 year). Scheduling for all readings was a major effort and subject to district staff availability and traffic conditions. Figure 3.4 includes a few images from the initial installation of these markings.

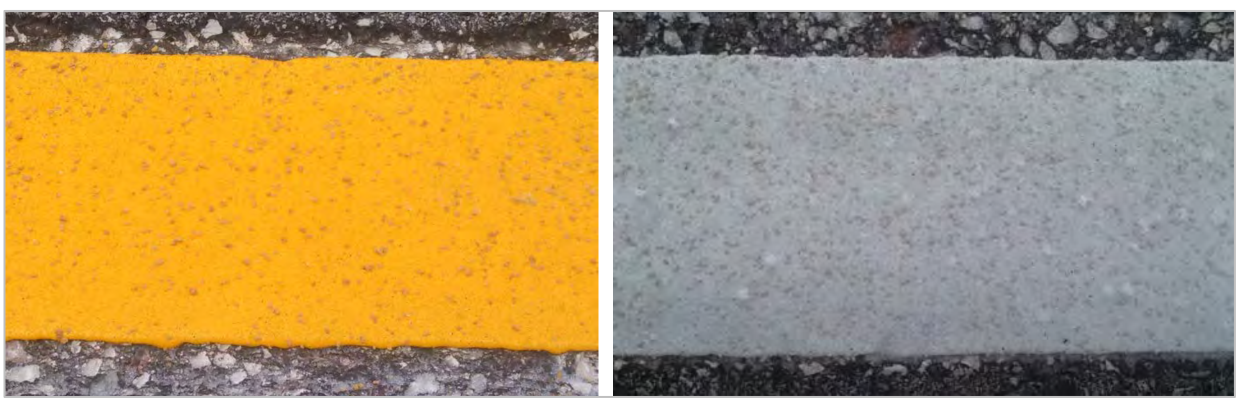

Figure 3.4 Initial installation images on I-57 for yellow edge line (left) and white edge line (right).

3.2 EVALUATION

Measurement data obtained from each of the retroreflectivity readings are presented below. These data are shown by roadway, road surface type, pavement marking product, manufacturer of the wet reflective media, trade name for the media, line type, date measured, timeline reference, and retroreflectivity (dry, recovery, and continuous wet) in millicandelas per meter squared per lux (mcd). The retroreflectivity readings are averages. The below definitions apply to Tables 3.1 to 3.9:

AWP: All Weather Paint (3M trade name)
Visi: Abbreviation for VISIMAX (Epoplex trade name)
Plus9: Abbreviation for Plus9Spots (Swarco trade name)
WEL: White Edge Line
WSL: White Skip Line
YEL: Yellow Edge Line
Avg_Dry: Averaged dry retroreflectivity value (mcd)
Avg_Recovery: Averaged wet recovery retroreflectivity value (mcd)
Avg_Wet: Averaged continuous wetting retroreflectivity value (mcd)

I-80

Table 3.1 presents the averaged retroreflectivity readings for the urethane white edge line by product and over time. Table 3.2 presents the averaged retroreflectivity readings for the tape white skip line by product and over time.

I-55

Table 3.3 presents the averaged retroreflectivity readings for the urethane markings by line type, product, and time.

I-355

Table 3.4 presents the averaged retroreflectivity readings for the polyurea markings by line type, product, and time. Table 3.5 presents the averaged retroreflectivity readings for the epoxy markings by line type, product, and time.

I-57

Tables 3.6, 3.7, 3.8, and 3.9 present the averaged retroreflectivity readings for the thermoplastic, epoxy, urethane, and polyurea markings, respectively, by line type, product, and time.

Table 3.1 Retroreflectivity Readings for the I-80 Urethane White Edge Line by Product and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-80	New ACC	Urethane	3M	AWP	WEL	11/1/2012	Initial	309	133	39
I-80	New ACC	Urethane	Epoplex	Visi	WEL	11/1/2012	Initial	314	12	16
I-80	New ACC	Urethane	Swarco	plus9	WEL	11/1/2012	Initial	250	15	13
I-80	New ACC	Urethane	3M	AWP	WEL	10/8/2013	After 1 year	176	20	14
I-80	New ACC	Urethane	Epoplex	Visi	WEL	10/8/2013	After 1 year	152	17	13
I-80	New ACC	Urethane	Swarco	plus9	WEL	10/8/2013	After 1 year	163	5	12
I-80	New ACC	Urethane	3M	AWP	WEL	6/17/2014	After 2 years	169	26	14
I-80	New ACC	Urethane	Epoplex	Visi	WEL	6/17/2014	After 2 years	178	20	12
I-80	New ACC	Urethane	Swarco	plus9	WEL	6/17/2014	After 2 years	164	9	13

Table 3.2 Retroreflectivity Readings for the I-80 Tape White Skip Line by Product and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-80	New ACC	Tape	3M	AWTape	WSL	11/1/2012	Initial	963	489	346
I-80	New ACC	Tape	Brite-Line	XRP-R	WSL	11/1/2012	Initial	628	157	93
I-80	New ACC	Tape	Swarco	D60H	WSL	11/1/2012	Initial	1001	82	16
I-80	New ACC	Tape	3M	AWTape	WSL	10/8/2013	After 1 year	732	222	175
I-80	New ACC	Tape	Brite-Line	XRP-R	WSL	10/8/2013	After 1 year	298	53	35
I-80	New ACC	Tape	Swarco	D60H	WSL	10/8/2013	After 1 year	845	13	13
I-80	New ACC	Tape	3M	AWTape	WSL	6/17/2014	After 2 years	926	224	162
I-80	New ACC	Tape	Brite-Line	XRP-R	WSL	6/17/2014	After 2 years	324	50	25
I-80	New ACC	Tape	Swarco	D60H	WSL	6/17/2014	After 2 years	845	13	13

Table 3.3 Retroreflectivity Readings for I-55 Urethane by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-55	Existing PCC	Urethane	3M	AWP	WEL	11/1/2012	Initial	704	87	35
I-55	Existing PCC	Urethane	3M	AWP	WSL	11/1/2012	Initial	917	117	90
I-55	Existing PCC	Urethane	3M	AWP	YEL	11/1/2012	Initial	567	124	81
I-55	Existing PCC	Urethane	Swarco	plus9	WEL	11/1/2012	Initial	327	32	20
I-55	Existing PCC	Urethane	Swarco	plus9	WSL	11/1/2012	Initial	462	42	21
I-55	Existing PCC	Urethane	Swarco	plus9	YEL	11/1/2012	Initial	138	18	11
I-55	Existing PCC	Urethane	Epoplex	Visi	WEL	11/1/2012	Initial	425	47	21
I-55	Existing PCC	Urethane	Epoplex	Visi	WSL	11/1/2012	Initial	490	64	37
I-55	Existing PCC	Urethane	Epoplex	Visi	YEL	11/1/2012	Initial	512	59	39
I-55	Existing PCC	Urethane	3M	AWP	WEL	10/8/2013	After 1 year	369	51	25
I-55	Existing PCC	Urethane	3M	AWP	WSL	10/8/2013	After 1 year	588	83	33
I-55	Existing PCC	Urethane	3M	AWP	YEL	10/8/2013	After 1 year	468	121	82
I-55	Existing PCC	Urethane	Swarco	plus9	WEL	10/8/2013	After 1 year	183	17	15
I-55	Existing PCC	Urethane	Swarco	plus9	WSL	10/8/2013	After 1 year	291	26	14
I-55	Existing PCC	Urethane	Swarco	plus9	YEL	10/8/2013	After 1 year	108	9	9
I-55	Existing PCC	Urethane	Epoplex	Visi	WEL	10/8/2013	After 1 year	232	59	48
I-55	Existing PCC	Urethane	Epoplex	Visi	WSL	10/8/2013	After 1 year	260	72	58
I-55	Existing PCC	Urethane	Epoplex	Visi	YEL	10/8/2013	After 1 year	308	43	33
I-55	Existing PCC	Urethane	3M	AWP	WEL	6/17/2014	After 2 years	255	46	15
I-55	Existing PCC	Urethane	3M	AWP	WSL	6/17/2014	After 2 years	397	30	12
I-55	Existing PCC	Urethane	3M	AWP	YEL	6/17/2014	After 2 years	437	88	21
I-55	Existing PCC	Urethane	Swarco	plus9	WEL	6/17/2014	After 2 years	215	18	11
I-55	Existing PCC	Urethane	Swarco	plus9	WSL	6/17/2014	After 2 years	260	24	15
I-55	Existing PCC	Urethane	Swarco	plus9	YEL	6/17/2014	After 2 years	147	18	15
I-55	Existing PCC	Urethane	Epoplex	Visi	WEL	6/17/2014	After 2 years	271	88	65
I-55	Existing PCC	Urethane	Epoplex	Visi	WSL	6/17/2014	After 2 years	305	136	75
I-55	Existing PCC	Urethane	Epoplex	Visi	YEL	6/17/2014	After 2 years	305	138	79

Table 3.4 Retroreflectivity Readings for I-355 Polyurea by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-355	Existing PCC	Polyurea	3M	AWP	WEL	10/29/2013	Initial	1045	251	115
I-355	Existing PCC	Polyurea	3M	AWP	WSL	10/29/2013	Initial	1391	353	240
I-355	Existing PCC	Polyurea	3M	AWP	YEL	10/29/2013	Initial	509	345	173
I-355	Existing PCC	Polyurea	Swarco	plus9	WEL	10/29/2013	Initial	400	82	31
I-355	Existing PCC	Polyurea	Swarco	plus9	WSL	10/29/2013	Initial	422	65	35
I-355	Existing PCC	Polyurea	Swarco	plus9	YEL	10/29/2013	Initial	194	29	18
I-355	Existing PCC	Polyurea	Epoplex	Visi	WEL	10/29/2013	Initial	316	88	54
I-355	Existing PCC	Polyurea	Epoplex	Visi	WSL	10/29/2013	Initial	373	77	41
I-355	Existing PCC	Polyurea	Epoplex	Visi	YEL	10/29/2013	Initial	435	51	30
I-355	Existing PCC	Polyurea	3M	AWP	WEL	9/17/2014	After 1 year	472	38	29
I-355	Existing PCC	Polyurea	3M	AWP	WSL	9/17/2014	After 1 year	463	30	21
I-355	Existing PCC	Polyurea	3M	AWP	YEL	9/17/2014	After 1 year	424	180	97
I-355	Existing PCC	Polyurea	Swarco	plus9	WEL	9/17/2014	After 1 year	207	49	28
I-355	Existing PCC	Polyurea	Swarco	plus9	WSL	9/17/2014	After 1 year	220	12	11
I-355	Existing PCC	Polyurea	Swarco	plus9	YEL	9/17/2014	After 1 year	167	24	15
I-355	Existing PCC	Polyurea	Epoplex	Visi	WEL	9/17/2014	After 1 year	245	40	31
I-355	Existing PCC	Polyurea	Epoplex	Visi	WSL	9/17/2014	After 1 year	227	22	18
I-355	Existing PCC	Polyurea	Epoplex	Visi	YEL	9/17/2014	After 1 year	316	47	43

Table 3.5 Retroreflectivity Readings for I-355 Epoxy by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-355	Existing PCC	Epoxy	3M	AWP	WEL	10/29/2013	Initial	493	80	36
I-355	Existing PCC	Epoxy	3M	AWP	WSL	10/29/2013	Initial	729	219	129
I-355	Existing PCC	Epoxy	3M	AWP	YEL	10/29/2013	Initial	428	202	139
I-355	Existing PCC	Epoxy	Swarco	plus9	WEL	10/29/2013	Initial	378	103	61
I-355	Existing PCC	Epoxy	Swarco	plus9	WSL	10/29/2013	Initial	693	242	149
I-355	Existing PCC	Epoxy	Swarco	plus9	YEL	10/29/2013	Initial	212	69	32
I-355	Existing PCC	Epoxy	Epoplex	Visi	WEL	10/29/2013	Initial	338	56	37
I-355	Existing PCC	Epoxy	Epoplex	Visi	WSL	10/29/2013	Initial	423	90	44
I-355	Existing PCC	Epoxy	Epoplex	Visi	YEL	10/29/2013	Initial	416	101	60
I-355	Existing PCC	Epoxy	3M	AWP	WEL	9/17/2014	After 1 year	303	16	15
I-355	Existing PCC	Epoxy	3M	AWP	WSL	9/17/2014	After 1 year	362	35	27
I-355	Existing PCC	Epoxy	3M	AWP	YEL	9/17/2014	After 1 year	381	126	71
I-355	Existing PCC	Epoxy	Swarco	plus9	WEL	9/17/2014	After 1 year	294	24	16
I-355	Existing PCC	Epoxy	Swarco	plus9	WSL	9/17/2014	After 1 year	378	54	43
I-355	Existing PCC	Epoxy	Swarco	plus9	YEL	9/17/2014	After 1 year	224	42	29
I-355	Existing PCC	Epoxy	Epoplex	Visi	WEL	9/17/2014	After 1 year	359	53	51
I-355	Existing PCC	Epoxy	Epoplex	Visi	WSL	9/17/2014	After 1 year	358	40	37
I-355	Existing PCC	Epoxy	Epoplex	Visi	YEL	9/17/2014	After 1 year	361	94	79

Table 3.6 Retroreflectivity Readings for I-57 Thermoplastic by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-57	Existing ACC	Thermo	3M	AWP	WEL	11/20/2013	Initial	514	121	58
I-57	Existing ACC	Thermo	3M	AWP	YEL	11/20/2013	Initial	431	93	58
I-57	Existing ACC	Thermo	Swarco	plus9	WEL	11/20/2013	Initial	691	61	40
I-57	Existing ACC	Thermo	Swarco	plus9	YEL	11/20/2013	Initial	377	58	27
I-57	Existing ACC	Thermo	Epoplex	Visi	WEL	11/20/2013	Initial	609	46	33
I-57	Existing ACC	Thermo	Epoplex	Visi	YEL	11/20/2013	Initial	672	58	28
I-57	Existing ACC	Thermo	3M	AWP	WEL	6/25/2014	After 1 year	554	25	16
I-57	Existing ACC	Thermo	3M	AWP	YEL	6/25/2014	After 1 year	439	147	73
I-57	Existing ACC	Thermo	Swarco	plus9	WEL	6/25/2014	After 1 year	646	48	20
I-57	Existing ACC	Thermo	Swarco	plus9	YEL	6/25/2014	After 1 year	365	36	21
I-57	Existing ACC	Thermo	Epoplex	Visi	WEL	6/25/2014	After 1 year	464	47	24
I-57	Existing ACC	Thermo	Epoplex	Visi	YEL	6/25/2014	After 1 year	584	44	19
I-57	Existing ACC	Thermo	3M	AWP	WEL	6/2/2015	After 2 years	433	15	14
I-57	Existing ACC	Thermo	3M	AWP	YEL	6/2/2015	After 2 years	316	65	49
I-57	Existing ACC	Thermo	Swarco	plus9	WEL	6/2/2015	After 2 years	514	35	25
I-57	Existing ACC	Thermo	Swarco	plus9	YEL	6/2/2015	After 2 years	230	10	10
I-57	Existing ACC	Thermo	Epoplex	Visi	WEL	6/2/2015	After 2 years	281	26	17
I-57	Existing ACC	Thermo	Epoplex	Visi	YEL	6/2/2015	After 2 years	403	58	34

Table 3.7 Retroreflectivity Readings for I-57 Epoxy by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-57	Existing ACC	Epoxy	3M	AWP	WEL	11/20/2013	Initial	608	24	14
I-57	Existing ACC	Epoxy	3M	AWP	YEL	11/20/2013	Initial	528	59	27
I-57	Existing ACC	Epoxy	Swarco	plus9	WEL	11/20/2013	Initial	499	52	43
I-57	Existing ACC	Epoxy	Swarco	plus9	YEL	11/20/2013	Initial	299	34	21
I-57	Existing ACC	Epoxy	Epoplex	Visi	WEL	11/20/2013	Initial	617	49	35
I-57	Existing ACC	Epoxy	Epoplex	Visi	YEL	11/20/2013	Initial	580	64	44
I-57	Existing ACC	Epoxy	3M	AWP	WEL	6/25/2014	After 1 year	290	66	33
I-57	Existing ACC	Epoxy	3M	AWP	YEL	6/25/2014	After 1 year	406	41	11
I-57	Existing ACC	Epoxy	Swarco	plus9	WEL	6/25/2014	After 1 year	252	27	19
I-57	Existing ACC	Epoxy	Swarco	plus9	YEL	6/25/2014	After 1 year	196	19	15
I-57	Existing ACC	Epoxy	Epoplex	Visi	WEL	6/25/2014	After 1 year	280	59	46
I-57	Existing ACC	Epoxy	Epoplex	Visi	YEL	6/25/2014	After 1 year	493	56	40
I-57	Existing ACC	Epoxy	3M	AWP	WEL	6/2/2015	After 2 years	216	12	24
I-57	Existing ACC	Epoxy	3M	AWP	YEL	6/2/2015	After 2 years	354	32	21
I-57	Existing ACC	Epoxy	Swarco	plus9	WEL	6/2/2015	After 2 years	209	20	22
I-57	Existing ACC	Epoxy	Swarco	plus9	YEL	6/2/2015	After 2 years	193	13	10
I-57	Existing ACC	Epoxy	Epoplex	Visi	WEL	6/2/2015	After 2 years	217	35	16
I-57	Existing ACC	Epoxy	Epoplex	Visi	YEL	6/2/2015	After 2 years	396	57	43

Table 3.8 Retroreflectivity Readings for I-57 Urethane by Line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-57	Existing ACC	Urethane	3M	AWP	WEL	11/20/2013	Initial	613	299	163
I-57	Existing ACC	Urethane	3M	AWP	YEL	11/20/2013	Initial	627	178	103
I-57	Existing ACC	Urethane	Swarco	plus9	WEL	11/20/2013	Initial	503	67	46
I-57	Existing ACC	Urethane	Swarco	plus9	YEL	11/20/2013	Initial	196	19	12
I-57	Existing ACC	Urethane	Epoplex	Visi	WEL	11/20/2013	Initial	544	40	21
I-57	Existing ACC	Urethane	Epoplex	Visi	YEL	11/20/2013	Initial	478	50	28
I-57	Existing ACC	Urethane	3M	AWP	WEL	6/25/2014	After 1 year	298	51	22
I-57	Existing ACC	Urethane	3M	AWP	YEL	6/25/2014	After 1 year	548	134	34
I-57	Existing ACC	Urethane	Swarco	plus9	WEL	6/25/2014	After 1 year	206	19	13
I-57	Existing ACC	Urethane	Swarco	plus9	YEL	6/25/2014	After 1 year	171	16	7
I-57	Existing ACC	Urethane	Epoplex	Visi	WEL	6/25/2014	After 1 year	276	55	29
I-57	Existing ACC	Urethane	Epoplex	Visi	YEL	6/25/2014	After 1 year	342	63	33
I-57	Existing ACC	Urethane	3M	AWP	WEL	6/2/2015	After 2 years	193	23	16
I-57	Existing ACC	Urethane	3M	AWP	YEL	6/2/2015	After 2 years	510	131	85
I-57	Existing ACC	Urethane	Swarco	plus9	WEL	6/2/2015	After 2 years	167	15	10
I-57	Existing ACC	Urethane	Swarco	plus9	YEL	6/2/2015	After 2 years	181	9	14
I-57	Existing ACC	Urethane	Epoplex	Visi	WEL	6/2/2015	After 2 years	231	56	62
I-57	Existing ACC	Urethane	Epoplex	Visi	YEL	6/2/2015	After 2 years	273	43	44

Table 3.9 Retroreflectivity Readings for I-57 Polyurea by line Type, Product, and Time

Roadway	Road Surface	Marking Product	Wet Refl Manufacturer	Wet Reflective Media	Line Type	Date Measured	Measurement Timeline	Avg_Dry	Avg Recovery	Avg_Wet
I-57	Existing ACC	Polyurea 5000	3M	AWP	WEL	11/20/2013	Initial	591	392	207
I-57	Existing ACC	Polyurea 5000	3M	AWP	YEL	11/20/2013	Initial	551	303	165
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	WEL	11/20/2013	Initial	433	61	30
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	YEL	11/20/2013	Initial	359	56	37
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	WEL	11/20/2013	Initial	453	64	39
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	YEL	11/20/2013	Initial	394	43	30
I-57	Existing ACC	Polyurea 5000	3M	AWP	WEL	6/25/2014	After 1 year	326	114	56
I-57	Existing ACC	Polyurea 5000	3M	AWP	YEL	6/25/2014	After 1 year	384	177	116
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	WEL	6/25/2014	After 1 year	163	15	9
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	YEL	6/25/2014	After 1 year	198	22	12
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	WEL	6/25/2014	After 1 year	164	28	18
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	YEL	6/25/2014	After 1 year	188	40	27
I-57	Existing ACC	Polyurea 5000	3M	AWP	WEL	6/2/2015	After 2 years	240	31	20
I-57	Existing ACC	Polyurea 5000	3M	AWP	YEL	6/2/2015	After 2 years	320	113	64
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	WEL	6/2/2015	After 2 years	164	19	12
I-57	Existing ACC	Polyurea 5000	Swarco	plus9	YEL	6/2/2015	After 2 years	191	14	7
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	WEL	6/2/2015	After 2 years	136	18	14
I-57	Existing ACC	Polyurea 5000	Epoplex	Visi	YEL	6/2/2015	After 2 years	158	33	14

CHAPTER 4: LAB EVALUATION

The lab evaluation consisted of pavement marking sample preparation, two sets of accelerated wear testing, and development of a performance evaluation protocol to account for the unique requirements of the retroreflectivity performance characterization. The various aspects of conducting the lab evaluation are described in this chapter.

4.1 INITIAL LAB TESTING

Very little research has previously been conducted on developing a small-scale lab-based accelerated pavement marking evaluation technique. The researchers used past experience in evaluating pavement markings and equipment that is used to polish pavement surfaces to develop an accelerated pavement marking wearing technique. The initial lab testing was conducted to determine a suitable process for conducting accelerated wear testing of the pavement markings.

4.1.1 Pavement Marking Samples

To conduct the initial lab testing, the researchers first needed to produce pavement marking samples. The researchers produced pavement marking sample substrates out of typical roadway materials. These materials were cast concrete and asphalt made with a kneading compactor (Figure 4.1).

Figure 4.1 Linear kneading compactor for preparing asphalt slabs.

The researchers striped over the substrate slabs with a material similar to what was installed on the field test decks. The markings were white and yellow Epoplex LS50 epoxy with a double drop of AASHTO M-247 Type I and Type IV beads. Three stripes were put on each slab to allow for more flexibility in conducting the initial accelerated wear testing. Figure 4.2 provides an image of the slabs being striped and of the four striped slabs.

Figure 4.2 Pavement marking samples.

4.1.2 Initial Accelerated Wear Tests

The initial lab testing was undertaken to identify a suitable process for conducting the accelerated wearing of the pavement marking samples from the field test decks. The researchers needed to determine the appropriate wheels to use on the accelerated wear device, the appropriate amount of weight to place on the device, how many cycles to run between testing the retroreflectivity, and how to best evaluate the retroreflectivity of the samples after accelerated wearing. The accelerated wear device is shown in Figure 4.3, with pneumatic wheels on the left and steel wheels on the right.

The accelerated wear device is used for testing the polishing properties of pavement surfaces. The device has three wheels that make contact with the marking during each cycle (i.e., one cycle equals three wheel hits). The device has a watering system that keeps the samples from heating and helps to flush away worn materials. Several tests were conducted during the initial accelerated wear testing.

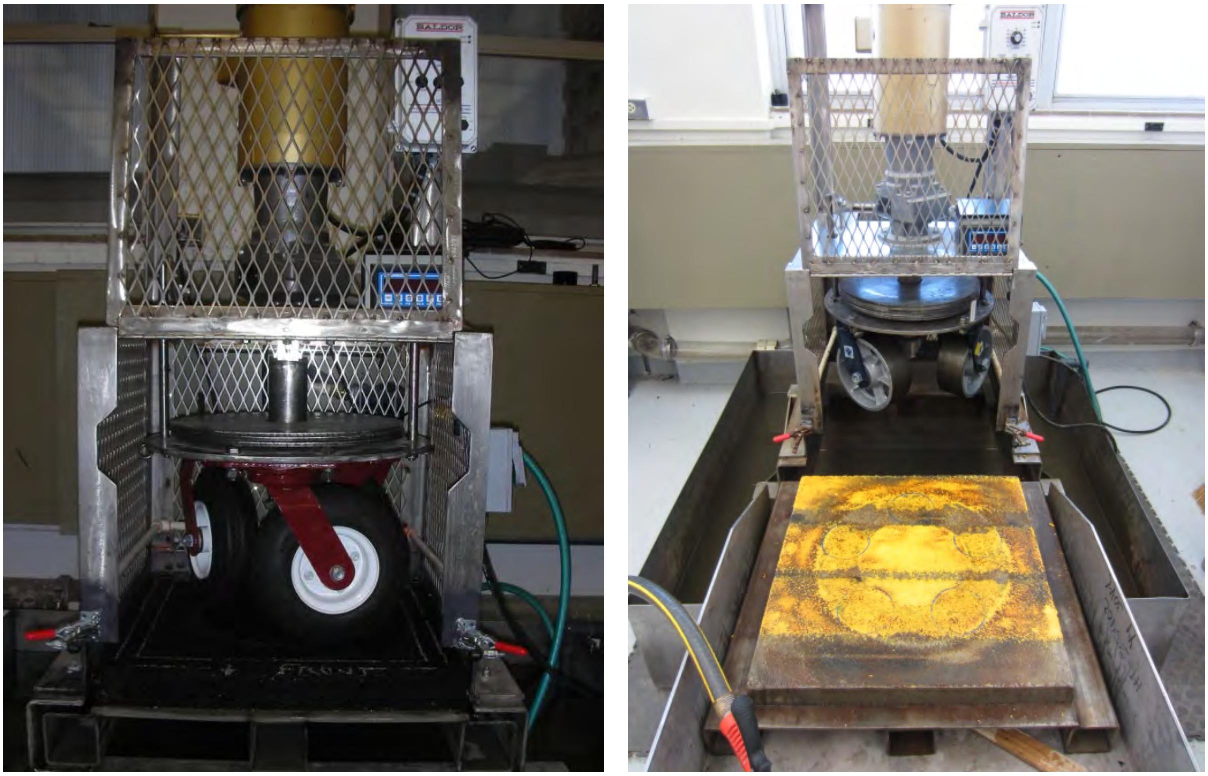

Figure 4.3 Accelerated wear wheel testing (pneumatic wheels, left; steel wheels, right).

The first test was to determine how much wear the standard pneumatic wheels would produce on the pavement marking samples that were applied to the concrete and asphalt slabs. The performance of the samples was evaluated after 0, 5000, 25000, 75000, and 165000 cycles. The evaluation was a visual observation of the impact of the wearing on the pavement marking binder and beads. Neither sample showed much wear of the pavement marking binder. Figure 4.4 (left photo) shows the results of the pneumatic wheel testing. The samples did show some bead loss, but many beads still remained within the wear path. The researchers believed that the level of wear for the time required to conduct the test was not sufficient. The system runs at approximately 2700 cycles per hour, which meant more than 60 hours were required to achieve 165000 cycles.

To increase the wear, the researchers had the option of increasing the weight on the system or using a different wheel. The researchers chose to use a steel wheel with the same amount of weight as used in the pneumatic wheel testing. It was apparent that the steel wheels were wearing the marking at a much faster rate than the pneumatic wheels. The steel wheels were evaluated after 0, 5000, and 11000 cycles. Figure 4.4 (right photo) shows the results of the pneumatic wheel testing. The steel wheels crushed and dislodged some beads and wore some of the binder around the edge portion of the marking. The wear at 11000 cycles with the steel wheels was greater than at 165000 cycles for the pneumatic wheels.

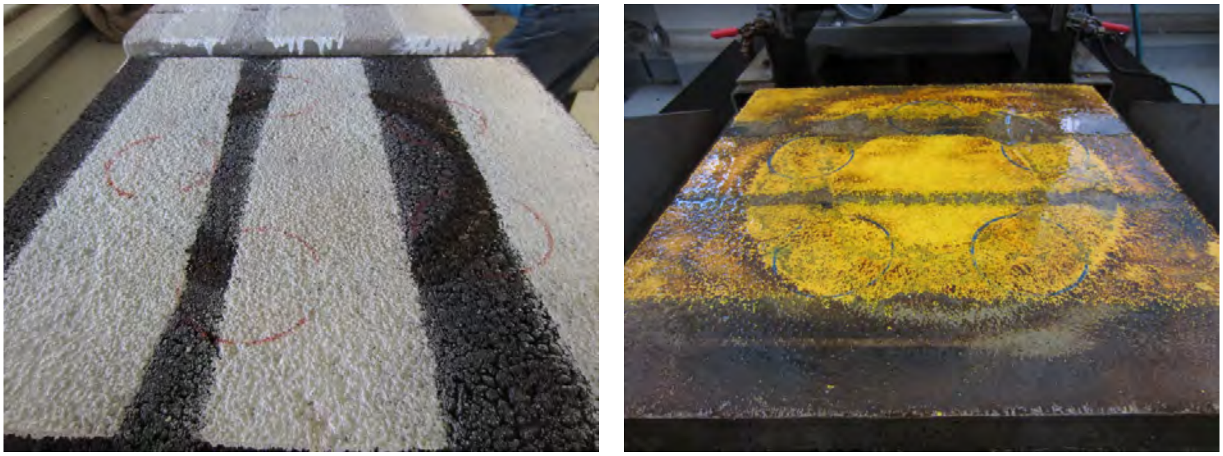

Figure 4.4 Samples after partial wear testing (pneumatic wheels, left; steel wheels, right).

4.2 FINAL LAB TESTING

On the basis of the initial lab testing, the researchers developed a plan for full-scale testing of the field pavement marking samples. The following sections describe the process of conducting the accelerated lab testing on the field pavement marking samples.

4.2.1 Sample Selection and Preparation

The research team collected 46 pavement marking samples from the field test deck installations. All of the samples were on aluminum sign substrate material. The samples were shipped to the Texas A&M Transportation Institute for testing. The researchers selected 24 of the samples for the final accelerated wear testing. The markings were selected from each of the field test decks and were a representative sample of the marking binder type (urethane, epoxy, polyurea) and wet-reflective bead type (3M, Epoplex, Swarco). The markings tested consisted of 20 white samples and four yellow samples. Information on the selected samples is provided in Table 4.1.

Although care was taken in packing and shipping the thermoplastic samples, all six of the samples were destroyed in transit and could not be evaluated. Thermoplastic is a relatively brittle material and does not form a strong bond with the aluminum. This resulted in the thermoplastic breaking away from the aluminum and crumbling. A different substrate material that allows the thermoplastic to form a better bond—while remaining durable enough to withstand any anticipated testing—should be considered in a future study. Using slab substrates similar to those used in the initial lab testing is not practical for collecting samples in the field because of the size and weight of the substrate materials.

Table 4.1 Pavement Marking Samples Selected for Testing

Panel #	Road	Road Surface	Marking Type	Wet-Reflective Type	Line Type
1	I-80	New ACC	Urethane	3M	WEL
2	I-80	New ACC	Urethane	Epoplex	WEL
3	I-80	New ACC	Urethane	Swarco	WEL
4	I-55	Existing PCC	Urethane	3M	WEL
6	I-55	Existing PCC	Urethane	Epoplex	WEL
8	I-55	Existing PCC	Urethane	Swarco	WEL
11	I-355	Existing PCC	Epoxy	3M	WEL
13	I-355	Existing PCC	Polyurea	3M	WEL
14	I-355	Existing PCC	Polyurea	3M	YEL
15	I-355	Existing PCC	Epoxy	Epoplex	WEL
17	I-355	Existing PCC	Polyurea	Epoplex	WEL
18	I-355	Existing PCC	Polyurea	Epoplex	YEL
21	I-355	Existing PCC	Polyurea	Swarco	WEL
22	I-355	Existing PCC	Polyurea	Swarco	YEL
23	I-57	Existing ACC	Urethane	3M	WEL
25	I-57	Existing ACC	Polyurea	3M	WEL
27	I-57	Existing ACC	Epoxy	3M	WEL
31	I-57	Existing ACC	Urethane	Epoplex	WEL
33	I-57	Existing ACC	Polyurea	Epoplex	WEL
35	I-57	Existing ACC	Epoxy	Epoplex	WEL
39	I-57	Existing ACC	Urethane	Swarco	WEL
41	I-57	Existing ACC	Polyurea	Swarco	WEL
43	I-57	Existing ACC	Epoxy	Swarco	WEL
44	I-57	Existing ACC	Epoxy	Swarco	YEL

WEL = White edge line

YEL = Yellow edge line

The pavement marking samples were cut using a band saw so that they would fit into the testing jig that was placed in the circular track polishing machine. Two samples were placed into the jig at the same time. The samples were marked with arrows to indicate the installation direction of the markings in the field. The markings were placed into the jig so that the wearing would occur in the direction that the markings were striped, which would be the same way they would be worn in the field by traffic. Not all of the markings were applied to the center of the substrate material. To account for the different positions, additional aluminum spacer strips were placed between the two samples in the jig. These spacers were used so that the markings were always in the same position under the accelerated wear device. This resulted in the marking samples all receiving wear centered along the marking sample. Figure 4.5 shows two marking samples on the test jig after testing. The wear path of the wheels is well defined on the sample.

Figure 4.5 Aluminum sample plates during testing.

4.2.2 Final Accelerated Wear Tests

The final lab testing was conducted to evaluate the performance of the pavement marking samples from the field test decks after undergoing accelerated wearing. The researchers used the steel wheels with three weights on the system. The device was set to turn at approximately 45 revolutions per minute. The water spray apparatus was set to “on” to keep the samples cool and to remove any loose debris. Two pavement marking samples were placed in the test jig and positioned under the testing device. Figure 4.6 shows two images from the testing. The top image shows the cage closed during the testing while the steel wheels rotate on the pavement marking samples. The bottom image shows how the steel wheel rolls over the center portion of the pavement marking sample.

The performance of the samples was evaluated after 0, 1000, 3000, 6000, and 10000 cycles. After the specified number of cumulative cycles had passed, the samples were removed from the accelerated wear device. The samples were cleaned with water and a light brush to remove any debris that may have been on the samples after the accelerated wearing. After the samples were allowed to dry, they were evaluated. The performance metrics that were evaluated were the same as in the field evaluation: dry, recovery, and continuous wetting retroreflectivity. The process of conducting these measurements is described in the next section. Once a sample’s retroreflectivity in the recovery condition fell below 20 $mcd/m^2/lux$, it was removed from testing because of poor performance. Markings were also removed from the evaluation if they became damaged.

A second set of data was collected after comparing the accelerated wearing data to the initial field data. The researchers found that for some of the materials, the performance data for the markings in the initial and 1000-cycle accelerated wear testing did not match up very well with the initial data from the field. This prompted the researchers to collect additional accelerated wear data at a lower number of cycles to determine whether the initial degradation of the markings could be more accurately represented with the accelerated wear testing. The researchers selected four of the previously tested panels (#1, #13, #23, and #27) to include in the additional testing. The researchers used the remaining portion of the field samples for the markings that had not yet received the accelerated wearing. The performance of the samples was evaluated after 0, 250, and 500 cycles.

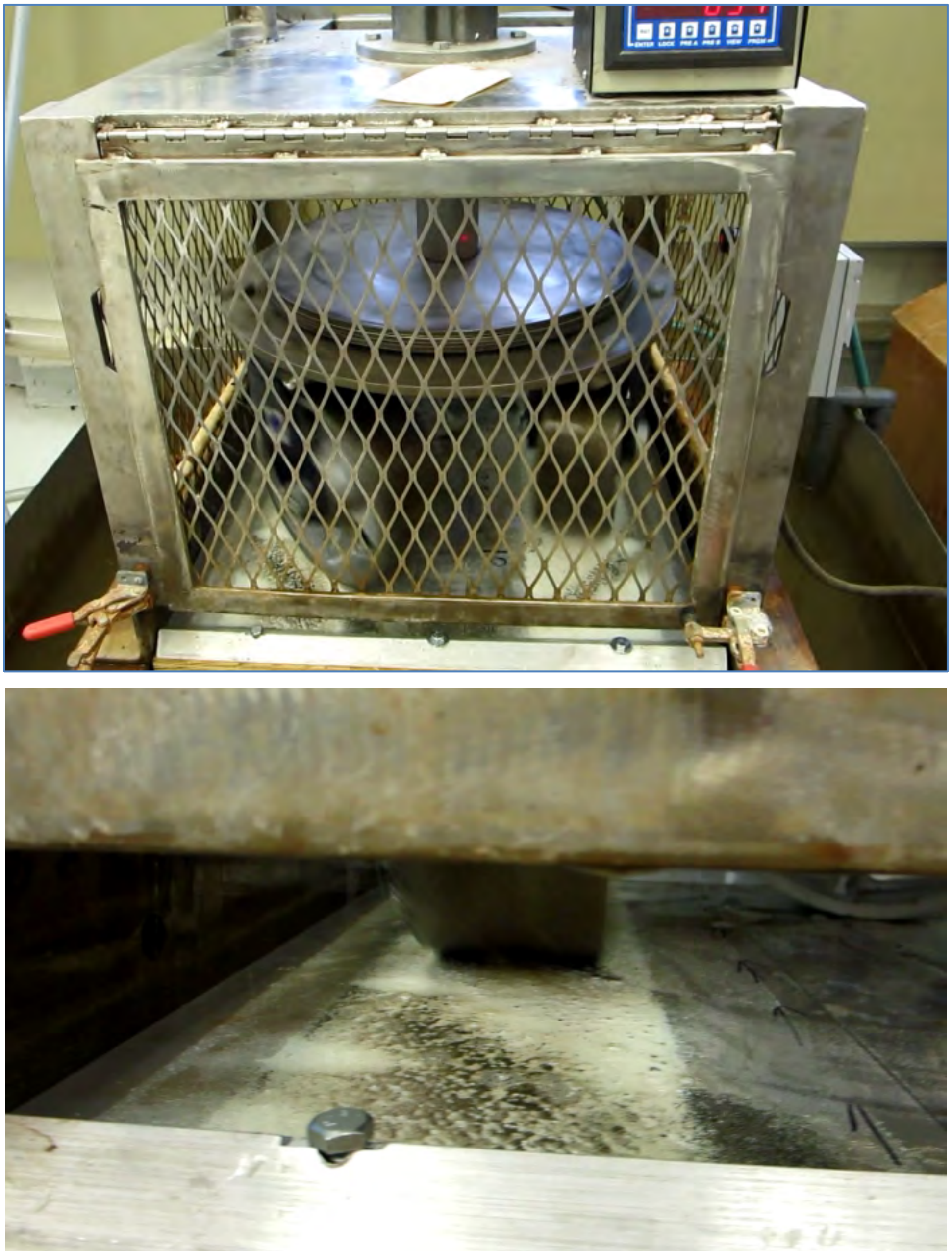

Figure 4.6 Accelerated wearing of samples from test deck.

4.3 PERFORMANCE EVALUATION

The performance metric of interest to the research team was the retroreflectivity performance of the pavement marking samples. The research team developed a protocol to evaluate the samples initially and after the samples had received the appropriate number of accelerated wear cycles.

During the initial lab testing, the research team evaluated two quantitative methods that could be used to evaluate the performance of the samples during the final lab testing. These two methods were a reduced measurement area evaluation using a handheld retroreflectometer, and an evaluation using a charge-coupled device (CCD) camera. The worn samples from the initial lab testing were taped and evaluated using the CCD photometer. Figure 4.7 is an image of the taped samples. The areas exposed were the areas worn during the initial testing.

Figure 4.8 is an image of the CCD photometer setup used to evaluate the samples. The CCD photometer was placed in a coplanar geometry with the light source. The height of the light source and camera and the distance to the marking samples were the proper scale to represent the standard 30-meter geometry used to evaluate the retroreflectivity of pavement markings. The CCD photometer captured an image of the marking, allowing the researchers to evaluate the luminance of the marking samples. The luminance coupled with the measured illuminance falling on the marking from the light source allowed the researchers to calculate the retroreflectivity of the samples.

A CCD photometer is not a typical device owned by a DOT, whereas a DOT typically owns a handheld retroreflectometer. Therefore, the researchers elected to focus all future measurements on the reduced area measurements of the samples using a handheld retroreflectometer. The reduced area measurements are not ideal because a correction factor is necessary to relate the retroreflectivity readings to what would be obtained if the worn area was large enough to fill the entire measurement area of the retroreflectometer. The development of the reduced area correction factors is explained later in this report.

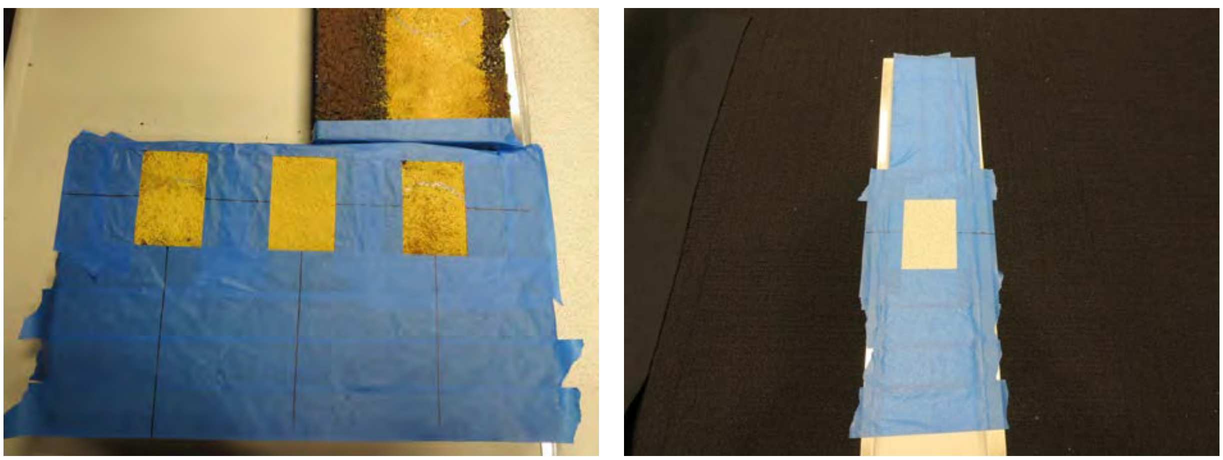

Figure 4.7 Reduced area samples.

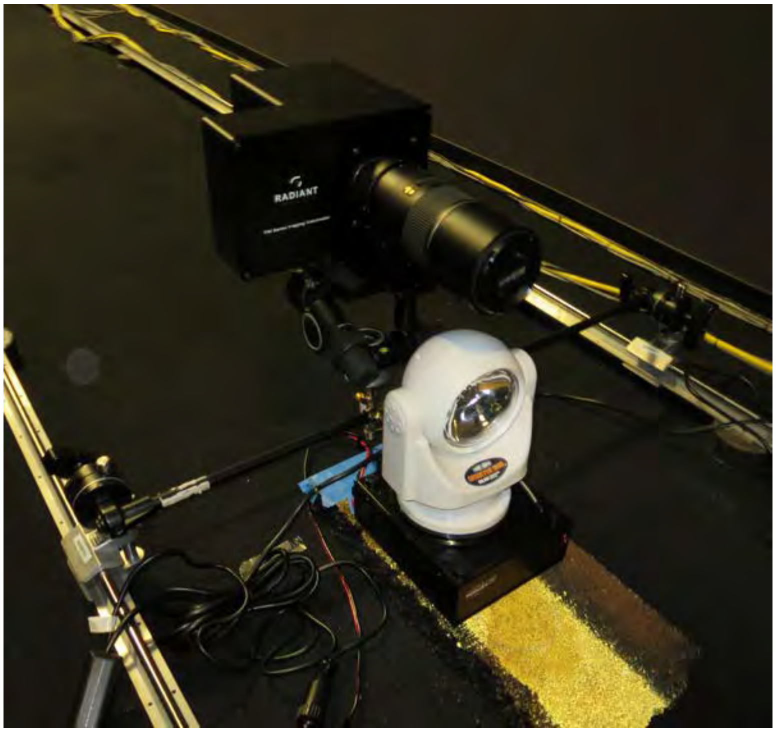

Figure 4.8 Initial reduced area evaluation equipment.

The performance of the samples during the final lab testing was regularly evaluated so that degradation curves of the retroreflectivity performance of the samples could be generated as the markings received additional wear. Most samples were evaluated at 0, 1000, 3000, 6000, and 10000 cycles. Four samples were also evaluated at 250 and 500 cycles. The performance metrics that were evaluated were the same as in the field evaluation: dry, recovery, and continuous wetting retroreflectivity.

The retroreflectivity measurements were taken with a handheld retroreflectometer. Five readings were taken and averaged for each measurement condition at each measurement interval. The measurement platform where the evaluation took place had a 2% cross-slope to facilitate drainage during the wet retroreflectivity tests.

Initial performance measurements were taken on the full-size sample in the location that would receive the accelerated wear. Based on the initial testing, the researchers knew that the worn area was smaller than the area evaluated by the handheld retroreflectometer. The researchers evaluated the samples in a consistent place and corrected the smaller-area measurements by a factor based on testing that was conducted to determine the correction factor.

Figure 4.9 an image of the evaluation area for the reduced measurement size. The evaluation area is completely within the worn area. Figure 4.10 is an image of the retroreflectivity testing. The area outside of the evaluation area was taped off with non-reflective tape so that unworn areas would not influence the retroreflectivity readings.

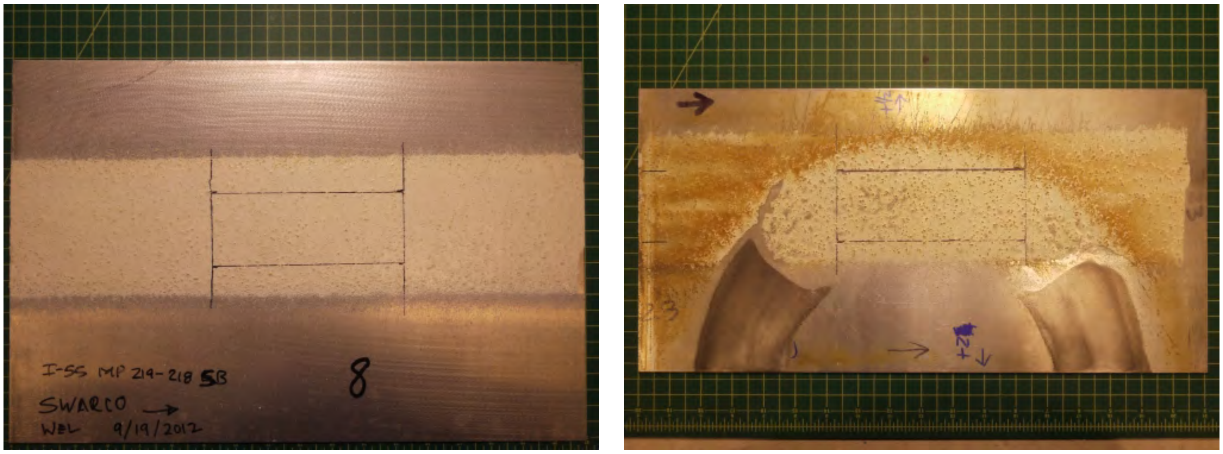

Figure 4.9 Reduced area aluminum substrate marking samples.

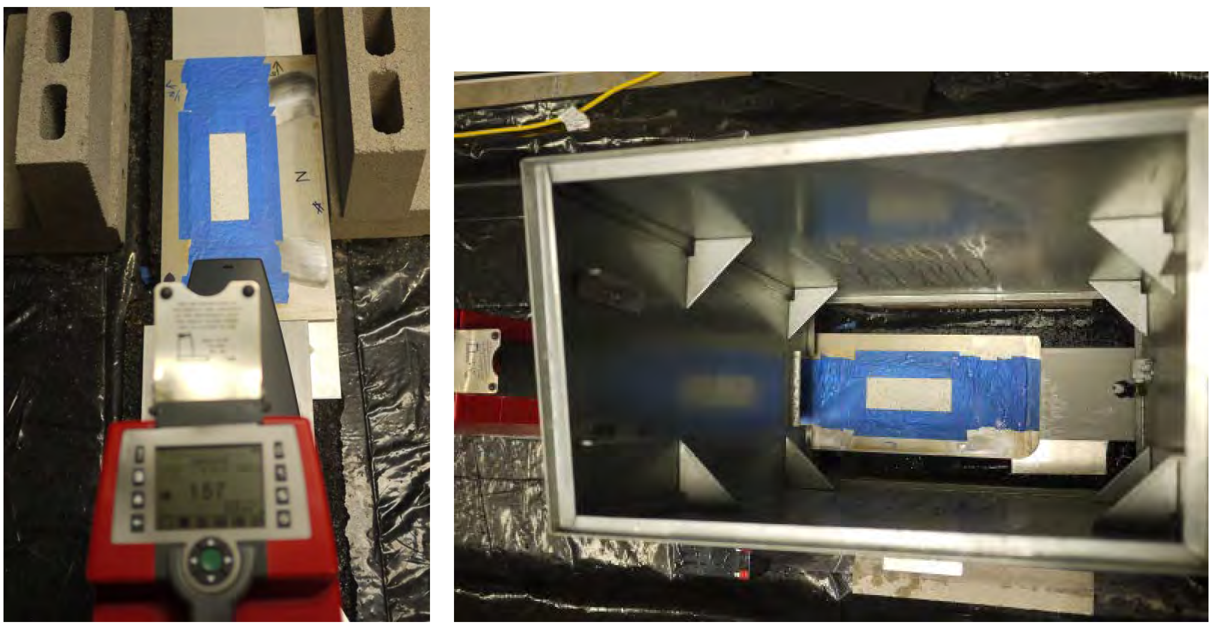

Figure 4.10 Reduced area aluminum substrate marking retroreflectivity evaluations.

To determine the reduced area correction factor, the researchers evaluated the unworn samples with a full-size measurement (i.e., no tape was added to the sample). The researchers then evaluated the sample in the same location but taped off everything except the specific reduced measurement area that would be worn. Two sets of data were collected on eight samples. The data are presented in Table 4.2 and are the average of five measurements for each condition on each sample. Four panels were evaluated in the dry condition only. Four other panels were evaluated in all three measurement conditions. The wet condition measurements exhibited higher variability than the dry measurements.

Table 4.2 Reduced Measurement Area Correction Factor

Measurement Type	Panel Number	Unmasked Average	Masked Average	Percent Reduction	Average Percent Reduction	Correction Factor
DRY	8	601	490	18.5	19.2	1.192
	17	605	476	21.4		
	3	337	270	19.8		
	25	1186	983	17.1		
DRY	1	381	312	18.0	20.8	1.208
	13	1395	1059	24.1		
	23	816	695	14.9		
	27	895	660	26.3		
RECOVERY	1	266	178	32.9	18.2	1.182
	13	359	366	–1.9		
	23	412	345	16.4		
	27	405	301	25.5		
CONTINUOUS WETTING	1	224	111	50.4	28.3	1.283
	13	311	233	24.9		
	23	341	307	9.9		
	27	326	235	27.8		

CHAPTER 5: DATA ANALYSIS

5.1 FIELD EVALUATION

The research team provided the TRP with an analysis of the field results by location, line type, and product. The performance over time for each wet reflective media type and pavement marking product are noted below. As a point of reference, the research team used the value of 100 mcd as a threshold for both dry and recovery retroreflectivity and 50 mcd for wet retroreflectivity (any value above the threshold shows up as a green circle, otherwise red). Tables 5.1 through 5.7 provide a summary of these results.

Table 5.1 Performance of Tape Products Over Time

Tape (white)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
3M	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Brite-Line	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Swarco	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴

Table 5.2 Performance of 3M AWP (White) Over Time by Marking Material

3M AWP (white)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Polyurea	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Thermo	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Urethane	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴

Table 5.3 Performance of 3M AWP (Yellow) Over Time by Marking Material

3M AWP (yellow)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Polyurea	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Thermo	🟢	🟢	🟢	🔴	🟢	🔴	🟢	🟢	🔴
Urethane	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢

Table 5.4 Performance of Swarco (White) Over Time by Marking Material

Swarco plus9spots (white)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🟢	🔴	🔴	🟢	🔴	🔴
Polyurea	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Thermo	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Urethane	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴

Table 5.5 Performance of Swarco (Yellow) Over Time by Marking Material

Swarco plus9spots (yellow)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Polyurea	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Thermo	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Urethane	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴

Table 5.6 Performance of Epoplex VISIMAX (White) Over Time by Marking Material

Epoplex VISIMAX (white)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Polyurea	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Thermo	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Urethane	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴

Table 5.7 Performance of Epoplex VISIMAX (Yellow) Over Time by Marking Material

Epoplex VISIMAX (yellow)

	Dry Retroreflectivity > 100 mcd?			Recovery Retroreflectivity > 100			Wet Retroreflectivity > 50 mcd?		
	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years	Initial	After 1 year	After 2 years
Epoxy	🟢	🟢	🟢	🔴	🔴	🔴	🟢	🟢	🔴
Polyurea	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Thermo	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴
Urethane	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🟢

5.2 LABORATORY EVALUATION

The researchers began the analysis of the lab data by summarizing the data collected during the final accelerated wear tests. At each measurement interval, data were collected for each marking sample in dry, recovery, and continuous wetting conditions. After summarizing the data, the research team had to correct the data to account for the measurement area differences between the worn sample area and the area evaluated by the retroreflectometer. The researchers used the average correction factors from Table 4.2 to correct the data. For the dry measurements, a factor of 1.20 was used because it was an average of the two separate dry tests.

The average data for each data collection interval for each sample in each measurement condition are provided in the following tables. Table 5.8 contains the dry retroreflectivity data, Table 5.9 contains the recovery retroreflectivity data, and Table 5.10 contains the continuous wetting retroreflectivity data. The rows highlighted yellow are the yellow pavement markings. The rows highlighted light blue are the samples that received additional wear, which is described later. The light gray cells indicate that no data were collected because of poor performance and the sample being pulled from additional accelerated wear or because the marking was damaged.

The data clearly show a decreasing trend in performance for all conditions as the number of wear cycles increases. The dry performance is far superior to either of the wet conditions. The recovery retroreflectivity levels are higher than the continuous wetting retroreflectivity levels. Many markings did not make it to the 6000-cycle or full 10000-cycle levels because of a loss of wet-reflective performance or damage. There was a drastic reduction in continuous wetting retroreflectivity from the initial to the 1000-cycle level.

Figure 5.1 shows Sample 1 after each of the accelerated wear test intervals. Figure 5.2 shows Sample 18 after each of the accelerated wear test intervals. As the markings were worn, the beads would become crushed or dislodged. The marking binder would begin to smooth out from the loss of beads and start to wear. With a lack of beads on a marking sample, the retroreflectivity performance of the marking declines.

Table 5.8 Average Dry Retroreflectivity of Worn Samples

Sample Information						Average Dry Retroreflectivity				
Panel #	Road	Surface	Marking	Wet-Reflective Manufacturer	Line Type	Initial	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	435	226	204	176	158
2	I-80	New ACC	Urethane	Epoplex	WEL	405	248	216	202	178
3	I-80	New ACC	Urethane	Swarco	WEL	307	143	143	104	85
4	I-55	Existing PCC	Urethane	3M	WEL	894	583	312	236	174
6	I-55	Existing PCC	Urethane	Epoplex	WEL	209	170	157	156	110
8	I-55	Existing PCC	Urethane	Swarco	WEL	507	113	65	48	
11	I-355	Existing PCC	Epoxy	3M	WEL	543	374	276	254	199
13	I-355	Existing PCC	Polyurea	3M	WEL	1466	701	205	174	132
14	I-355	Existing PCC	Polyurea	3M	YEL	399	116			
15	I-355	Existing PCC	Epoxy	Epoplex	WEL	316	156	177	150	123
17	I-355	Existing PCC	Polyurea	Epoplex	WEL	558	238	169	140	109
18	I-355	Existing PCC	Polyurea	Epoplex	YEL	495	185	79	98	73
21	I-355	Existing PCC	Polyurea	Swarco	WEL	572	212	113	140	135
22	I-355	Existing PCC	Polyurea	Swarco	YEL	316	81	67	57	
23	I-57	Existing ACC	Urethane	3M	WEL	836	254	195	137	121
25	I-57	Existing ACC	Polyurea	3M	WEL	1099	114			
27	I-57	Existing ACC	Epoxy	3M	WEL	844	292	199	153	149
31	I-57	Existing ACC	Urethane	Epoplex	WEL	753	308			
33	I-57	Existing ACC	Polyurea	Epoplex	WEL	764	403			
35	I-57	Existing ACC	Epoxy	Epoplex	WEL	615	350	295	201	
39	I-57	Existing ACC	Urethane	Swarco	WEL	560	187	169		
41	I-57	Existing ACC	Polyurea	Swarco	WEL	642	187	85		
43	I-57	Existing ACC	Epoxy	Swarco	WEL	590	185	164	139	117
44	I-57	Existing ACC	Epoxy	Swarco	YEL	193	96	79	61	

Table 5.9 Average Recovery Retroreflectivity of Worn Samples

Sample Information						Average Recovery Retroreflectivity				
Panel #	Road	Surface	Marking	Wet-Reflective Manufacturer	Line Type	Initial	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	448	106	102	79	50
2	I-80	New ACC	Urethane	Epoplex	WEL	84	31	15		
3	I-80	New ACC	Urethane	Swarco	WEL	42	13			
4	I-55	Existing PCC	Urethane	3M	WEL	307	104	42	50	20
6	I-55	Existing PCC	Urethane	Epoplex	WEL	62	20	20		
8	I-55	Existing PCC	Urethane	Swarco	WEL	56	9			
11	I-355	Existing PCC	Epoxy	3M	WEL	239	94	84	67	62
13	I-355	Existing PCC	Polyurea	3M	WEL	415	223	20		
14	I-355	Existing PCC	Polyurea	3M	YEL	196	19			
15	I-355	Existing PCC	Epoxy	Epoplex	WEL	132	31	34	38	25
17	I-355	Existing PCC	Polyurea	Epoplex	WEL	176	28	13		
18	I-355	Existing PCC	Polyurea	Epoplex	YEL	106	20	10		
21	I-355	Existing PCC	Polyurea	Swarco	WEL	101	22	11		
22	I-355	Existing PCC	Polyurea	Swarco	YEL	44	11			
23	I-57	Existing ACC	Urethane	3M	WEL	382	31	21		
25	I-57	Existing ACC	Polyurea	3M	WEL	632	32			
27	I-57	Existing ACC	Epoxy	3M	WEL	495	58	28	17	
31	I-57	Existing ACC	Urethane	Epoplex	WEL	115	39			
33	I-57	Existing ACC	Polyurea	Epoplex	WEL	192	68			
35	I-57	Existing ACC	Epoxy	Epoplex	WEL	117	47	34	12	
39	I-57	Existing ACC	Urethane	Swarco	WEL	163	19	15		
41	I-57	Existing ACC	Polyurea	Swarco	WEL	183	28	18		
43	I-57	Existing ACC	Epoxy	Swarco	WEL	170	22	11		
44	I-57	Existing ACC	Epoxy	Swarco	YEL	28	12			

Table 5.10 Average Continuous Wetting Retroreflectivity of Worn Samples

Sample Information						Average Continuous Wetting Retroreflectivity				
Panel #	Road	Surface	Marking	Wet-Reflective Manufacturer	Line Type	Initial	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	345	29	35	38	19
2	I-80	New ACC	Urethane	Epoplex	WEL	54	18	10		
3	I-80	New ACC	Urethane	Swarco	WEL	35	11			
4	I-55	Existing PCC	Urethane	3M	WEL	223	48	20	14	14
6	I-55	Existing PCC	Urethane	Epoplex	WEL	48	11	8		
8	I-55	Existing PCC	Urethane	Swarco	WEL	42	9			
11	I-355	Existing PCC	Epoxy	3M	WEL	208	22	31	28	15
13	I-355	Existing PCC	Polyurea	3M	WEL	332	61	11		
14	I-355	Existing PCC	Polyurea	3M	YEL	174	11			
15	I-355	Existing PCC	Epoxy	Epoplex	WEL	117	16	11	16	8
17	I-355	Existing PCC	Polyurea	Epoplex	WEL	125	13	9		
18	I-355	Existing PCC	Polyurea	Epoplex	YEL	87	11	7		
21	I-355	Existing PCC	Polyurea	Swarco	WEL	89	12	9		
22	I-355	Existing PCC	Polyurea	Swarco	YEL	35	10			
23	I-57	Existing ACC	Urethane	3M	WEL	315	16	13		
25	I-57	Existing ACC	Polyurea	3M	WEL	512	25			
27	I-57	Existing ACC	Epoxy	3M	WEL	394	18	12	13	
31	I-57	Existing ACC	Urethane	Epoplex	WEL	93	18			
33	I-57	Existing ACC	Polyurea	Epoplex	WEL	155	33			
35	I-57	Existing ACC	Epoxy	Epoplex	WEL	98	18	12	11	
39	I-57	Existing ACC	Urethane	Swarco	WEL	133	12	9		
41	I-57	Existing ACC	Polyurea	Swarco	WEL	120	16	11		
43	I-57	Existing ACC	Epoxy	Swarco	WEL	133	11	7		
44	I-57	Existing ACC	Epoxy	Swarco	YEL	20	9			

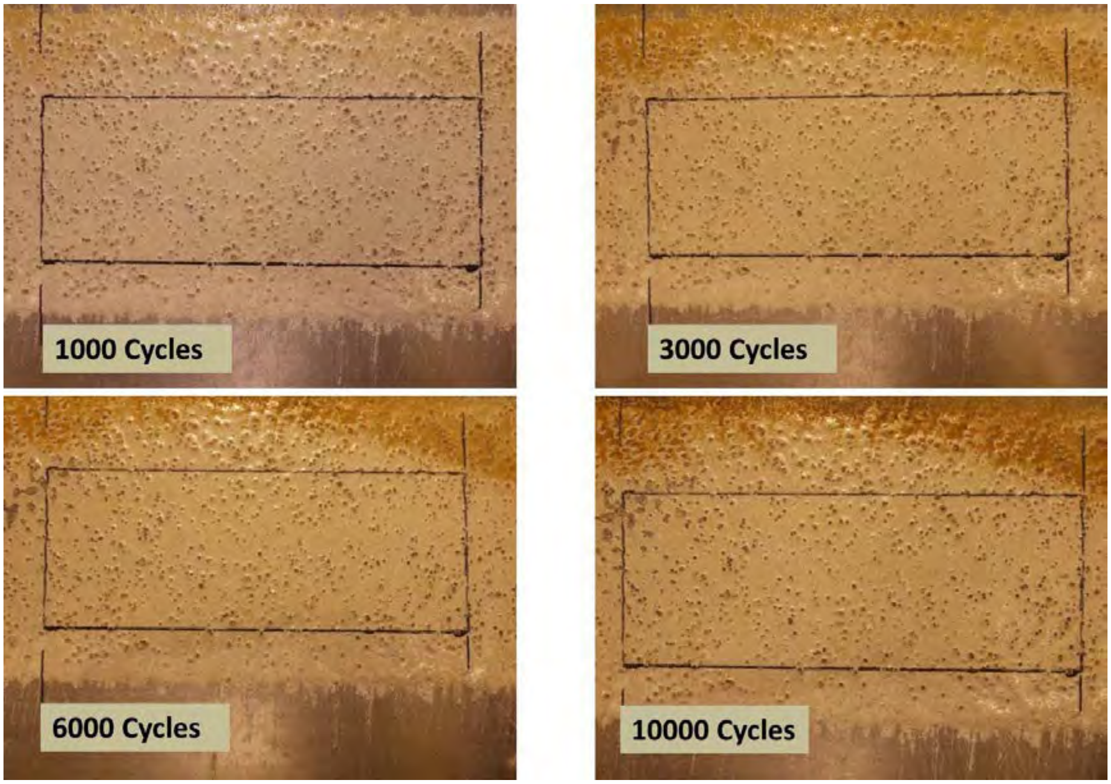

Figure 5.1 Sample 1 after accelerated wear testing.

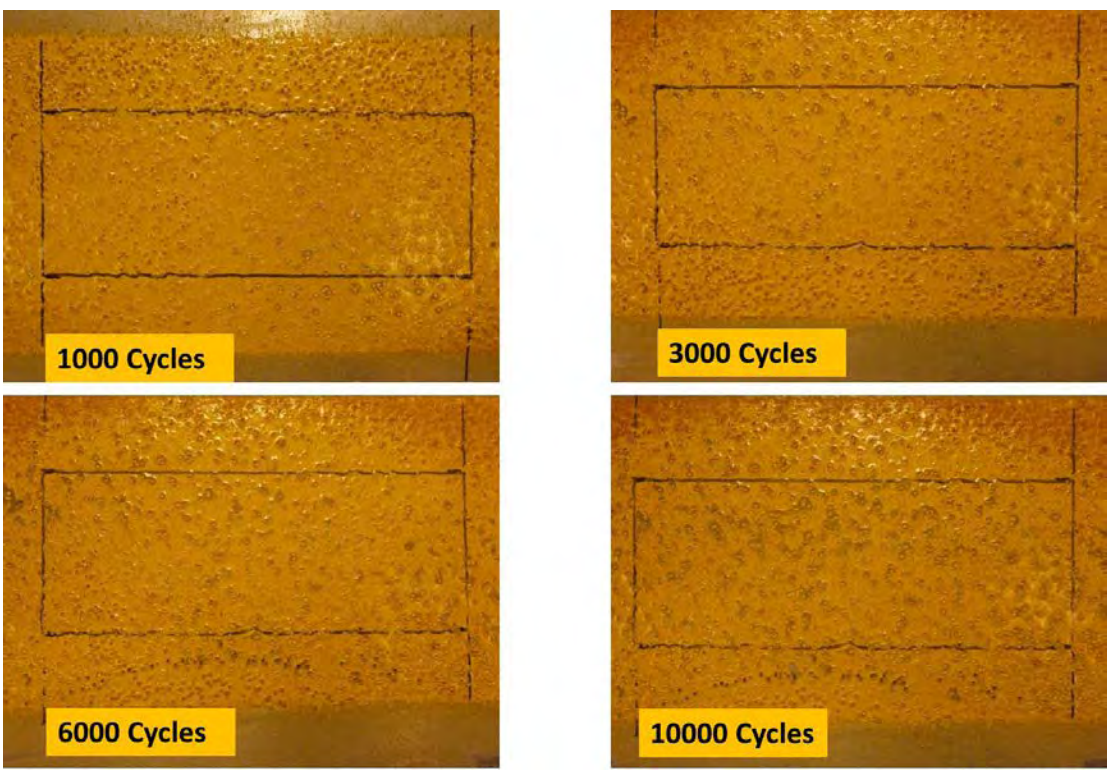

Figure 5.2 Sample 18 after accelerated wear testing.

A sample of additional data was collected by the researchers because of the large decrease in performance of some samples from the initial values to the 1000-cycle value, coupled with initial field values that were lower than the initial lab values. The additional data collection required two correction factors. In addition to the reduced measurement area correction factor, the researchers had to normalize the additional data collected on the four samples at 0, 250, and 500 cycles. The initial 0-cycle data for the samples tested during the first set of data collection were not the same as the initial 0-cycle data for the samples tested during the additional data collection, even though the samples were the same marking type. The same marking sample (an area that had not been previously worn) was used, but owing to the variable nature of pavement markings, the initial values may differ.

The difference in performance of the same marking type in a different location on a sample is more noticeable for specialty retroreflective optics such as wet-weather markings. The researchers developed a normalization correction factor for each of the four samples for each of the three measurement conditions. This factor was applied to the data collected at the 250- and 500-cycle intervals. The correction factors to normalize the data ranged from 0.94 to 1.14 for dry, 0.93 to 1.68 for recovery, and 0.92 to 1.54 for continuous wetting. The majority of the correction factors were less than 20%; the two larger values clearly indicate a marking that had variable performance. Similar to the measurement area correction factor, the wet condition measurements exhibited higher variability than the dry measurements.

Figure 5.3 shows the dry retroreflectivity degradation curves of the four markings that received the additional accelerated wear. Figure 5.4 shows the recovery retroreflectivity degradation curves of the four markings that received the additional accelerated wear. Figure 5.5 shows the continuous wetting retroreflectivity degradation curves of the four markings that received the additional accelerated wear. The data plotted in the three figures are summarized in Table 5.11. The data clearly show a rapid decrease in retroreflectivity as the markings are worn. The markings' retroreflectivity degradation slows after the 1000- or 3000-cycle measurement interval.

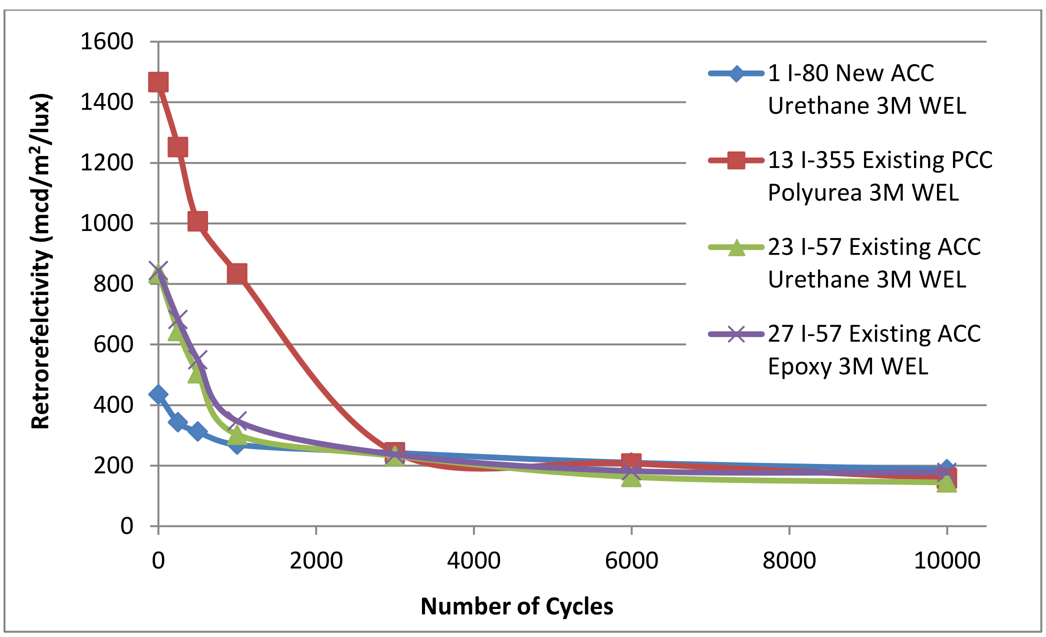

Figure 5.3 Average dry retroreflectivity of samples after additional wear.

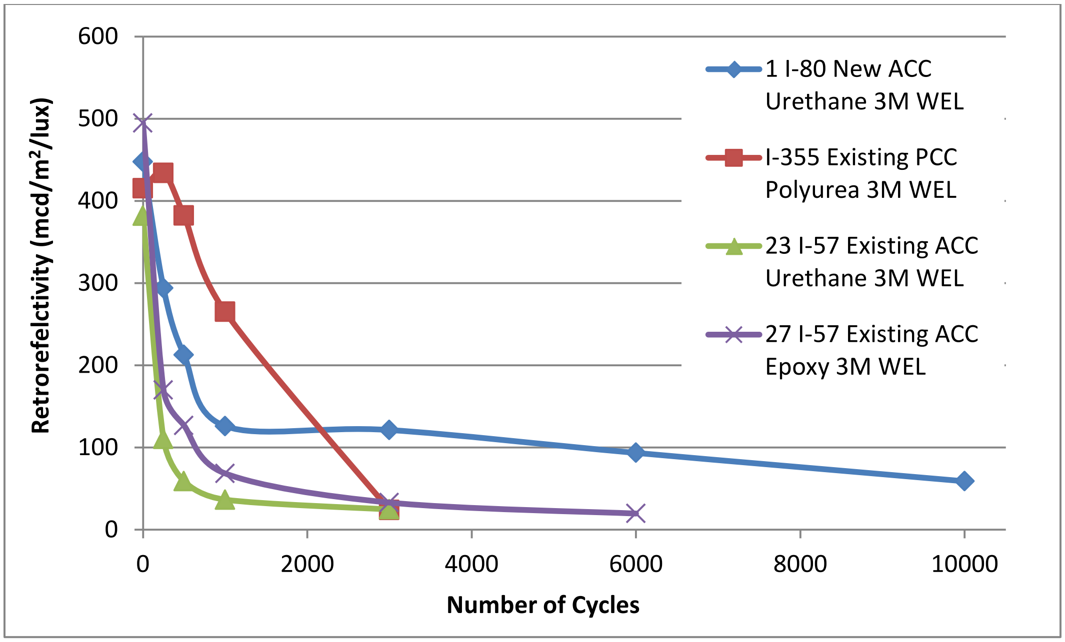

Figure 5.4 Average recovery retroreflectivity of samples after additional wear.

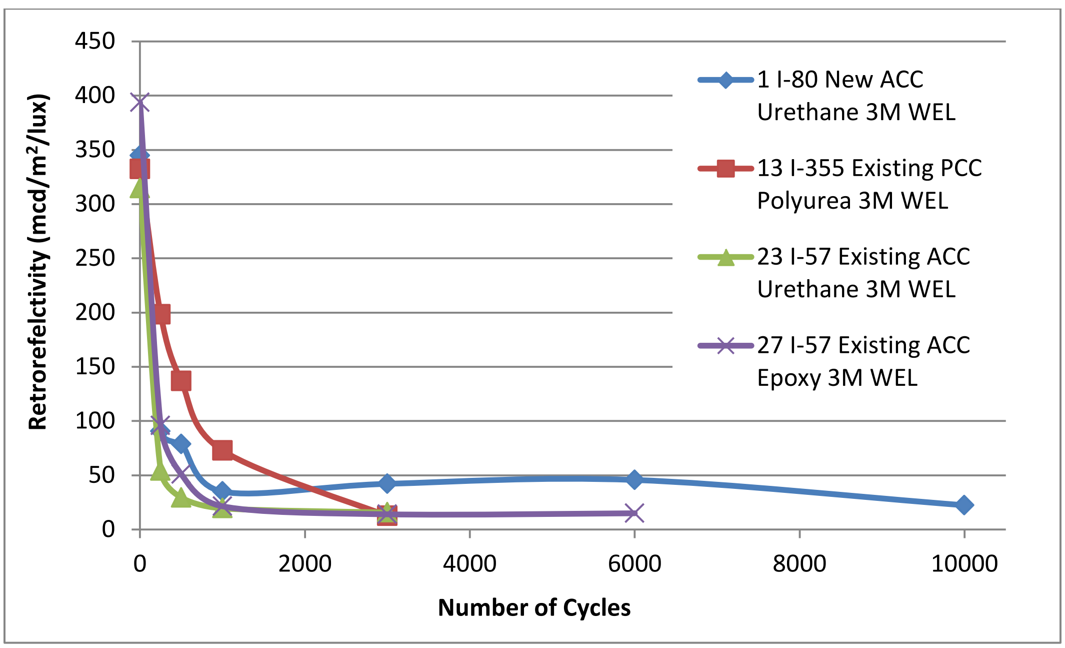

Figure 5.5 Average continuous wetting retroreflectivity of samples after additional wear.

Table 5.11 Average Retroreflectivity Values of Samples After Additional Wear

Sample Information						Average Dry Retroreflectivity						
Panel #	Road	Surface	Marking	Wet-Reflective Type	Line Type	Initial	250	500	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	435	344	312	226	204	176	158
13	I-355	Existing PCC	Polyurea	3M	WEL	1466	1252	1006	701	205	174	132
23	I-57	Existing ACC	Urethane	3M	WEL	836	645	505	254	195	137	121
27	I-57	Existing ACC	Epoxy	3M	WEL	844	682	549	292	199	153	149

Sample Information						Average Recovery Retroreflectivity						
Panel #	Road	Surface	Marking	Wet-Reflective Type	Line Type	Initial	250	500	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	448	294	213	106	102	79	50
13	I-355	Existing PCC	Polyurea	3M	WEL	415	434	382	223	20		
23	I-57	Existing ACC	Urethane	3M	WEL	382	111	59	31	21		
27	I-57	Existing ACC	Epoxy	3M	WEL	495	170	127	58	28	17	

Sample Information						Average Continuous Wetting Retroreflectivity						
Panel #	Road	Surface	Marking	Wet-Reflective Type	Line Type	Initial	250	500	1000	3000	6000	10000
1	I-80	New ACC	Urethane	3M	WEL	345	91	79	29	35	38	19
13	I-355	Existing PCC	Polyurea	3M	WEL	332	198	137	61	11		
23	I-57	Existing ACC	Urethane	3M	WEL	315	54	30	16	13		
27	I-57	Existing ACC	Epoxy	3M	WEL	394	96	51	18	12	13	

5.3 FIELD VERSUS LAB COMPARISON

The researchers compared the performance of the pavement markings in the field with the performance of the pavement marking samples in the lab. The goal is to develop a lab technique that will correlate with the actual performance of the marking in the field. For good correlation, the lab technique would have to be equitable across marking types, bead types, installation locations, and any other factors that may influence the performance of the markings in the field.

Two techniques were used to determine how well the lab technique was able to simulate the wear that the markings received in the field. The first technique was used on the samples that received the additional wear at the low cycles. This technique compared the field data with the lab data collected at the various numbers of cycles. The second technique used correlation to determine how well the lab data could predict field performance. The specific correlation value used is the coefficient of determination (R^2), which compared the two sets of data based on linear regression.

If the accelerated wear technique provided a similar level of wear on the markings compared with the field test decks, then a similar number of cycles for each sample should equate to the data collected in the field. The researchers used the field data and compared them with the accelerated wear data for all three performance metrics. The researchers used the average retroreflectivity value from the field test deck and found the number of cycles of accelerated wear that yielded the lab retroreflectivity value that most closely matched the field value, see Table 5.12.

Table 5.12 Number of Accelerated Wear Cycles to Match Field Data

4 Panels Selected for Additional Testing						Closest # Cycles to Match Field Data		
Panel #	Roadway	Surface	Marking	Year	Measurement Period (days)	Dry	Recovery	Continuous Wet
1	I-80	New ACC	Urethane	2012	Initial (56)	500	1000	1000
	I-80	New ACC	Urethane	2013	1 (397)	10000	10000	10000
	I-80	New ACC	Urethane	2014	2 (649)	10000	10000	10000
23	I-55	Existing PCC	Urethane	2012	Initial (43)	250	250	500
	I-55	Existing PCC	Urethane	2013	1 (384)	1000	500	1000
	I-55	Existing PCC	Urethane	2014	2 (636)	3000	1000	3000
27	I-57	Existing ACC	Epoxy	2013	Initial (18)	500	6000	3000
	I-57	Existing ACC	Epoxy	2014	1 (235)	1000	1000	1000
	I-57	Existing ACC	Epoxy	2015	2 (577)	3000	6000	1000
13	I-355	Existing PCC	Polyurea	2013	Initial (34)	500	1000	500
	I-355	Existing PCC	Polyurea	2014	1 (357)	3000	3000	3000

Ideally, the different marking samples would have the same number of accelerated wear cycles for each of the individual field evaluation periods for each of the performance metrics. For the initial dry retroreflectivity values, the data were promising. The different samples had 500, 250, 500, and 500 cycles representing the initial dry field values. Values that are similar indicate that the accelerated wear technique is equitable across the different markings. Unfortunately, for many of the other scenarios the data were not as promising. The 1-year dry field readings had 10000, 1000, 1000, and 3000 cycles as the equivalent values. Some of the wet comparisons had a similarly wide range of cycles that represented the field data. While there appeared to be some promise for these few samples, the variability in the data suggests that it would not generally be possible to use the lab data to predict field performance.

The researchers also looked at the correlation of the lab and field data by determining the coefficient of determination (R^2) for a linear regression line representing the trend of the data. An R^2 value is somewhere between 0 and 1 (1 represents perfect correlation; 0 represents no correlation). The slope of the regression line determines whether the relationship between the two values is positive or negative. A positive regression line indicates that the field and lab data trend in the same direction (i.e., as the field data decrease, the lab data decrease). A negative regression line means the two sets of data trend in opposite directions. Because the goal is to use lab values to predict field values, a negative regression line means the accelerated wear test is not suitable for that purpose.

Table 5.13 provides the correlation values for the field and lab data based on marking binder types.

Table 5.14 provides the correlation values for the field and lab data based on the road surface type of the field test decks. The correlation values are based on the 1-year data collected at the field sites. The 1-year field site data are compared with the accelerated wear data at several levels to determine whether any of the accelerated wear levels could predict the 1-year field performance. Many of the regression lines have a negative slope, which is not good. Many of the positive-sloped regression lines have a low R^2 value, which also is not good. One encouraging aspect is that the regression lines are all positively sloped for the dry evaluations.

Figures 5.6, 5.7, 5.8, and 5.9 are graphs of the correlation testing. For the wet testing, the 6000- and 10000-cycle levels were not evaluated because the data were limited.

Table 5.13 Correlation of Lab and Field Data Based on Binder Type (1-Year Field Data)

Measurement Condition	Number of Cycles	Epoxy Binders		Polyurea Binders		Urethane Binders	
		Regression Line Slope	R^2	Regression Line Slope	R^2	Regression Line Slope	R^2
Dry	1000	+	0.1209	+	0.1528	+	0.6544
	3000	+	0.2678	+	0.5225	+	0.4006
	6000	+	0.3405	+	0.4494	+	0.01953
Recovery	1000	+	0.0000	–	0.0370	+	0.0433
	3000	–	0.2398	–	0.4809	–	0.1640
Continuous Wetting	1000	+	0.0658	–	0.0297	+	0.0006
	3000	–	0.2293	–	0.8028	–	0.0954

Table 5.14 Correlation of Lab and Field Data Based on Road Surface (1-Year Field Data)

Measurement Condition	Number of Cycles	ACC Road Surfaces		PCC Road Surfaces	
		Regression Line Slope	R^2	Regression Line Slope	R^2
Dry	1000	+	0.0044	+	0.3796
	3000	+	0.2195	+	0.3871
	6000	+	0.0108	+	0.3458
Recovery	1000	+	0.0107	–	0.0319
	3000	–	0.0054	–	0.4718
Continuous Wetting	1000	+	0.0694	–	0.0426
	3000	–	0.0198	–	0.5116

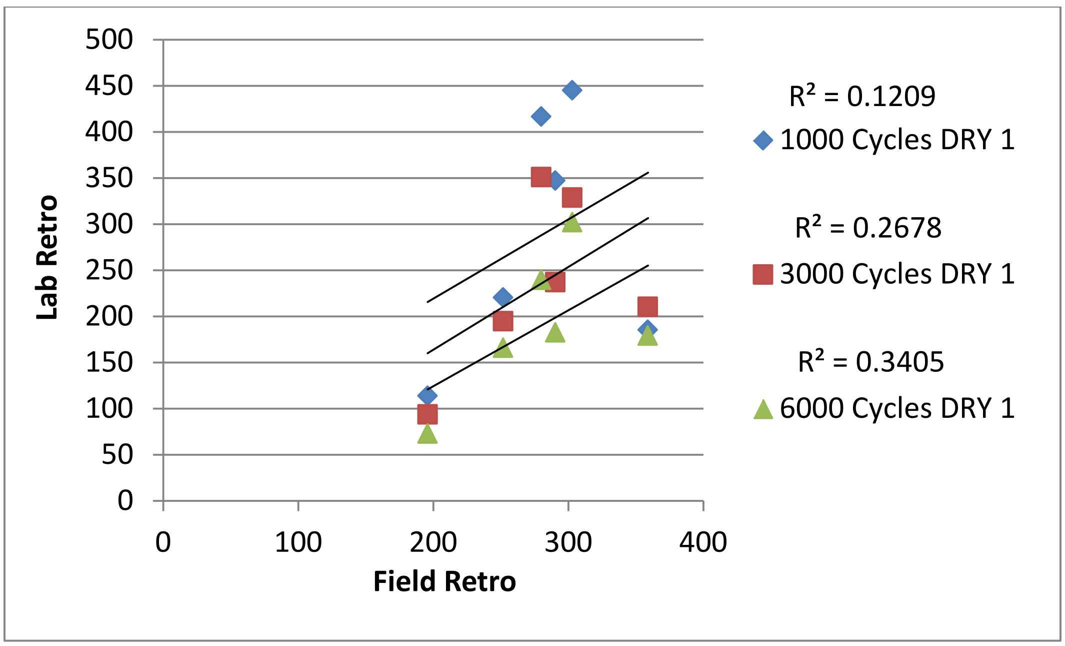

Figure 5.6 Comparison of lab and field retroreflectivity (dry, year 1) for epoxy markings.

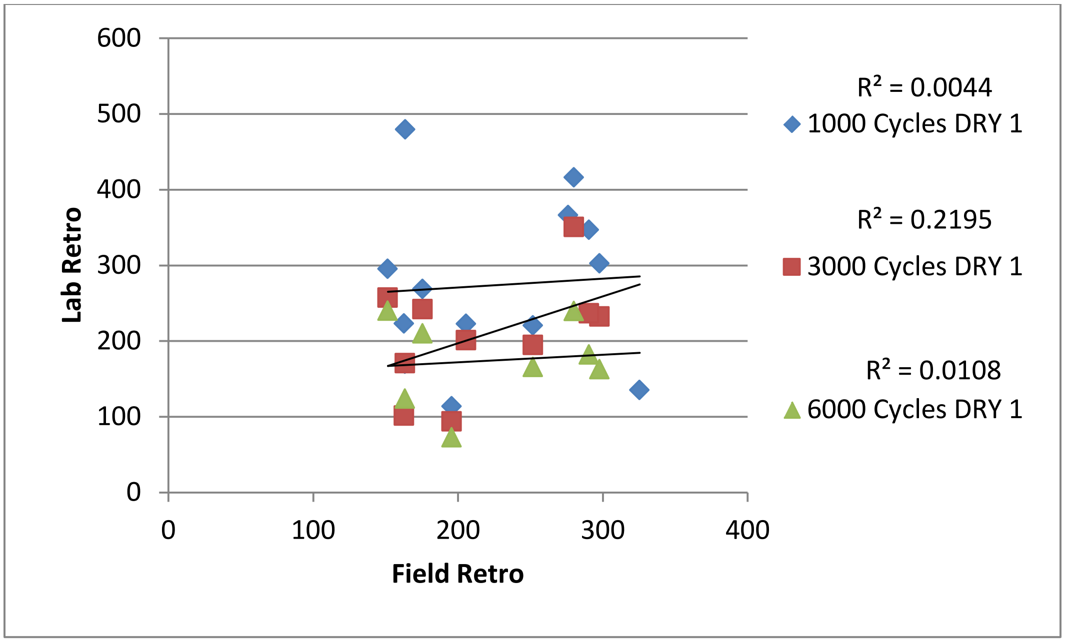

Figure 5.7 Comparison of lab and field retroreflectivity (dry, year 1) for markings on ACC surfaces.

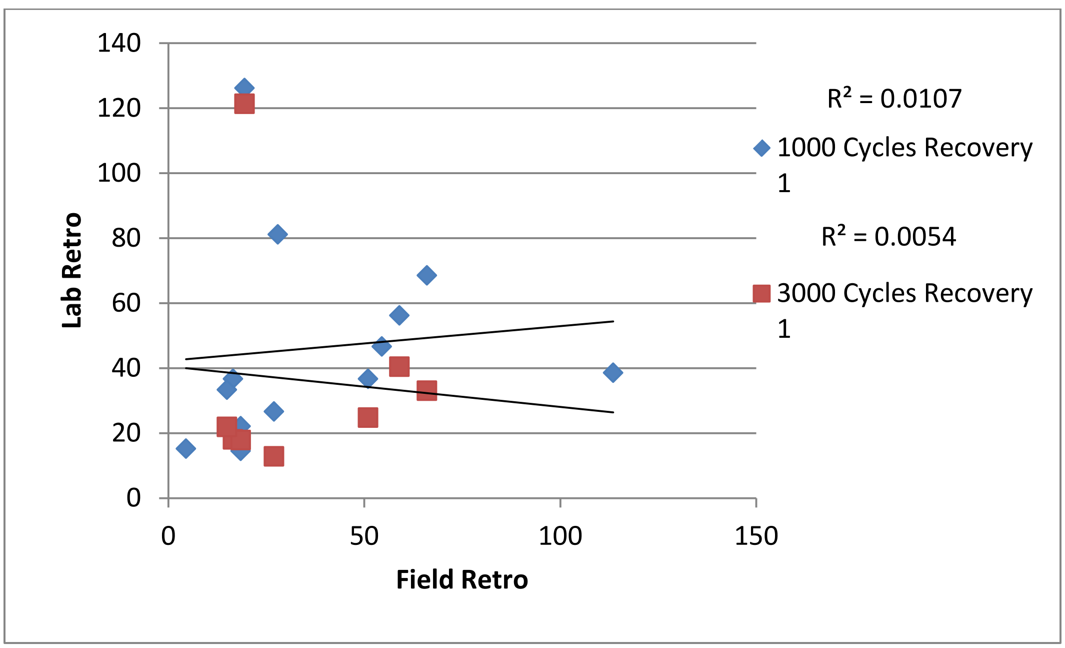

Figure 5.8 Comparison of lab and field retroreflectivity (recovery, year 1) for markings on ACC surfaces.

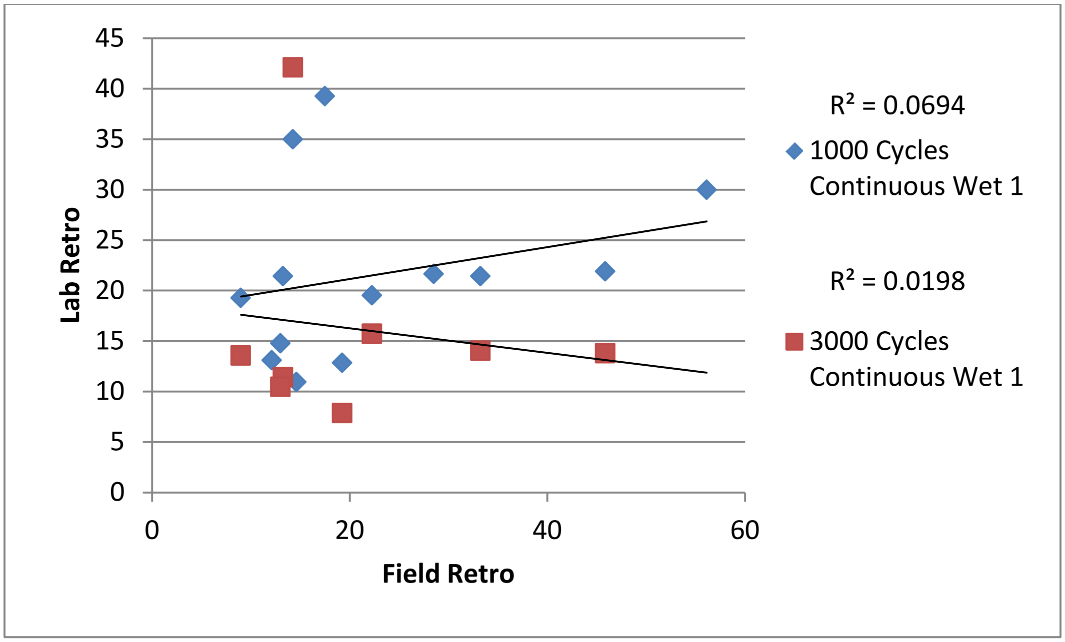

Figure 5.9 Comparison of lab and field retroreflectivity (continuous wetting, year 1) for markings on ACC surfaces.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 FIELD EVALUATION

The field evaluation was a significant undertaking for the research team, IDOT district staff, and Tollway staff, as well as the contractors, vendors, and suppliers. The evaluation exposed a considerable number of individuals to traffic over the course of the 2-year study, but it was an ideal way to understand how these all-weather products perform on Illinois roadways.

The research team provided the TRP with threshold values as a means to contrast product performance in terms of dry, recovery, and continuous wetting retroreflectivity. These thresholds were conservatively set at 100 (mcd) for both dry and recovery, and 50 mcd for continuous wetting or wet conditions.

Using these thresholds, the following conclusions can be made:

- Dry retroreflectivity: Every product measured at or above 100 mcd for each measurement interval (initial, 1 year, and 2 year)
- Recovery retroreflectivity: Only three product combinations exceeded 100 mcd after 2 years (3M 380AW, 3M AWP yellow with polyurea, and 3M AWP yellow with urethane)
- Wet retroreflectivity: Only four product combinations exceeded 50 mcd after 2 years—3M 380AW, 3M AWP yellow with polyurea, 3M AWP yellow with urethane, and Epoplex VISIMAX (yellow). The Epoplex material did not meet the 50 mcd threshold at either the initial or 1 year reading but was found to exceed that value at the 2-year reading.
- Wet retroreflectivity overall: Given that the focus of this effort was to understand product performance under wet conditions, this evaluation showed that of the 27 possible product combinations installed, the following was found:
    - Initial conditions: 12 out of a possible 27 (44%) product combinations measured at or above 50 mcd (less than half of the markings).
    - After 1 year: Five out of a possible 27 (18%) product combinations measured at or above 50 mcd.
    - After 2 years: Four out of a possible 27 (15%) product combinations measured at or above 50 mcd.

6.2 LAB EVALUATION

The lab evaluation had positive and negative aspects. There were some promising results for the dry retroreflectivity performance. The data variability was low and there was good correlation initially with the field data. The correlation was not as good as the markings aged, and correlation in the wet conditions was not good. The lab testing did yield useful degradation curves for the materials, which could be helpful in future product comparisons in a lab environment.

There were several drawbacks to the lab testing technique used. The researchers had to use available equipment and modify it to work for the research. The system was not able to wear a sufficiently large area of the markings to fully cover the measurement area of the handheld retroreflectometer. This required the researchers to develop correction factors, which is not ideal because doing so adds an extra step and increases variability and uncertainty with the measurements. The correction factor proved to be a consistent measurement for the dry evaluations but was more variable under the wet conditions.

The current lab evaluation method used was not able to produce data that correlated equitably across the various factors included in the evaluation (marking type, road surface type, wet-reflective manufacturer). The frequency of the field evaluations, the variable nature of wet-reflective evaluations, and a lab setup that was not ideally suited for this type of testing are possible reasons for the lack correlation between the lab and field data.

6.3 FUTURE TESTING

The research team has several recommendations for future testing to build on this research project. Several drawbacks of the current lab methodology were explained in Section 6.2. A future research project could focus on addressing those shortcomings.

Building a testing device specifically for creating accelerated wear on pavement markings would alleviate several disadvantages of the current method. The device would need to be large enough to use standard tires and have a large enough diameter to wear at least one longitudinal foot of the pavement marking samples. A standard tire would be preferred, but some form of steel wheel for low numbers of cycles could be beneficial in simulating the additional wear caused by snowplow blades.

A major drawback of the current test was that all the marking samples were collected on aluminum sign substrate. This is a common practice, but aluminum is not the best substrate on which to perform accelerated wear. Developing or finding a substrate material that will allow the thermoplastic to form a better bond and be durable enough to withstand any anticipated testing should be considered. Ideally, typical road surface materials would be used, but the weight and strength of the substrates must be taken into consideration.

To more accurately compare lab and field data, more frequent field evaluations should take place to create better degradation curves. Many of the marking materials included in this project lost most of their wet retroreflective properties more quickly than expected. With annual evaluations, it was not possible to generate a degradation curve with enough detail. However, from a time, safety, and monetary standpoint, conducting field evaluations more frequently may be difficult. A way to reduce the impact of taking additional field readings would be to evaluate fewer pavement marking test sections.

Illinois Department of Transportation

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN