Texas A&M Transportation Institute
Proving Ground

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Development of Delineator Material/Impact Testing Specific to Managed Lane Use for Optimization of Service Life

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

Exhibit DA-6

Technical Report Documentation Page

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Project Title: Development of Delineator Material/Impact Testing Specific to Managed Lane Use for Optimization of Service Life

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16. Abstract

The durability of delineators should be considered when selecting a product. Looking at the data gathered in this project, there was a considerable gap between the quality of the top three delineators tested and the other four. This led the researchers to recommend minimum average numbers of 150 tire impacts and 45 bumper impacts resisted as a pass/fail criterion for managed lane marker durability. This criterion would serve as a reasonable requirement ensuring that quality products meet a minimum threshold of performance. As the values are based on product testing, it ensures the criterion is an obtainable value for companies who intend to market their product for this application.

The researchers developed a minimum requirement specification to ensure compliance according to the recommendations found within this report. This specification will help to ensure that the proper and more durable product is selected to be placed on Florida Department of Transportation roadways.

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EXECUTIVE SUMMARY

The durability of delineators should be considered when selecting a product. Looking at the data gathered in this project, there was a considerable gap between the quality of the top three delineators tested and the other four. This led the researchers to recommend minimum average numbers of 150 tire impacts and 45 bumper impacts resisted as a pass/fail criterion for managed lane marker durability. This criterion would serve as a reasonable requirement ensuring that quality products meet a minimum threshold of performance. As the values are based on product testing, it ensures the criterion is an obtainable value for companies who intend to market their product for this application.

The researchers developed the following minimum requirement specification to ensure compliance according to the recommendations found within this report. This specification will help to ensure that the proper and more durable product is selected to be placed on FDOT roadways:

1. **PURPOSE**
   To define a set of standards (a minimum requirement) that products must meet in order to be considered for use by FDOT.
2. **BACKGROUND**
   This standard was developed to provide an obtainable requirement for companies who are marketing their product to be considered by FDOT.
3. **MINIMUM REQUIREMENT**
   These specifications are necessary to increase the performance of delineator products and save resources for FDOT.
   - 3.1 Tire Impact Requirement
     Delineator posts must be able to withstand a minimum of 150 impacts from the tire of the vehicle.
   - 3.2 Bumper Impact Requirement
     Delineator posts must be able to withstand a minimum of 45 impacts from the front bumper of the vehicle.
   - 3.3 Pass Criteria
     Delineator posts must meet both requirements mentioned above to be considered for use.

Delineators under consideration must be installed on a concrete pavement surface at a laboratory listed on FHWA's list of "Laboratories Accredited to Crash Test Roadside Safety Hardware." Each test deck should consist of eight samples installed in two parallel lines with four samples in each line. A max of 200 vehicle impacts per sample should be performed. A tire impact should be performed by the vehicle impacting the sample with the centerline of the sample aligned with the centerline of the vehicle tire. A bumper impact should be performed by the vehicle impacting the sample with the front bumper at the ⅓-point of the vehicle. To pass the testing criteria, the delineators must meet two minimum requirements for the average number of tire and bumper impacts withstood. The delineators must be able to withstand 150 tire impacts and 45 bumper impacts. Additional testing must be performed to develop a minimum requirement for delineators tested on an asphalt surface.

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CHAPTER 1. INTRODUCTION

1.1. DOCUMENT DELINEATOR FAILURE MODES

1.1.1 Delineator Components

Delineators have four main parts: the retroreflective sheeting (required for nighttime use), the post (can be various colors), the mechanism that connects the post and the base (typically a proprietary component), and the base. Figure 1 shows these parts that compose one delineator.

Figure 1. Delineator Parts

When installed, there are two additional parts to consider: the epoxy (which connects the base to the pavement) and the pavement itself. Any of these parts may fail when the delineator is struck. Based on past efforts, the researchers developed a list of failure modes, which are described below:

Sheeting failure: The retroreflective sheeting is damaged from abrasions or tearing and is not providing sufficient retroreflectivity at night.

Post failure to restore: The post is kinked or ruptured above the connection to the mechanism. This usually occurs around vehicle bumper height.

Post failure at connection: The post is fractured near the bottom where it connects to the mechanism. This includes failures where the post is completely missing from the mechanism.

Mechanism failure: The proprietary connection has failed and no longer keeps the post erect.

Base failure: The base (or mechanism housing) may potentially become fractured. While conceivable, this type of failure has not been seen in past research efforts.

Epoxy failure: The epoxy has become completely separated from either the base or the pavement.

Pavement failure: The entire delineator is missing and a portion of the pavement is also missing.

1.1.2 Data Collection

The researchers traveled to south Florida to see two delineator installations and document the failure modes found there. The delineator installations were both located on Interstate 95 (I-95).

Phase 1 (the south segment) was located between NW 29th Street in Miami and the Golden Glades Park & Ride exit ramp gore in North Miami Beach. The length of this segment is approximately 7.8 miles. Within Phase 1, there is currently a rigid pavement rehabilitation contract extending from NW 103rd Street to the Biscayne Canal (a distance of approximately 3.3 miles). The pavement contractor is required to maintain the delineators during the rehabilitation project.

Phase 2 (the north segment) was located from the Golden Glades Park & Ride entrance ramp gore to near Broward Boulevard in Fort Lauderdale. In this segment, the I-95 express lane construction contract is nearing completion and consists of 3.9 miles in Miami-Dade County and 7.7 miles in Broward County (a total of 11.6 miles).

In each phase, the type of delineator product used was documented. The researchers then prepared an estimate of the number of delineators in each phase. Table 1 shows these data.

Table 1. Delineator Installations on I-95.

Phase	Delineator Product	Segment Length	Approx # of Delineators[3]
1	Flexstake 754TM (42-in)[1]	7.8 mi (41,184 ft)	8,240
2	Flexstake 754TM (36-in)[2] with connection bolt	11.6 mi (61,248 ft)	12,250

[1]with one 12-in white retroreflective stripe.
[2]with two 4-in orange and two 4-in white retroreflective stripes.
[3]Calculated assuming delineators are at 10-ft spacing and located in both directions.

While both phases have the same product class (same product number) installed, the product used in Phase 2 has been modified to include these enhancements:

- shorter height,
- different retroreflective sheeting pattern,
- a bolt through the connection between the post and the mechanism,
- proprietary mechanism shape changed from rectangular to cylindrical, and
- base diameter increase.

In Phase 1, the researchers followed a two man crew tasked with repairing and/or replacing failed (damaged) delineators in the northbound direction of I-95 at night. The researchers followed the crew while they replaced 100 delineators. For each delineator, the failure mode was noted. There were no data available to identify the type of impact(s) (i.e., vehicle tire or bumper) that likely caused each failure. The time required for the crew to repair or replace the delineator was documented for a sampling of the failures. Figure 2 shows the distribution of failure modes seen in Phase 1. Notice that no base failures were documented in the field.

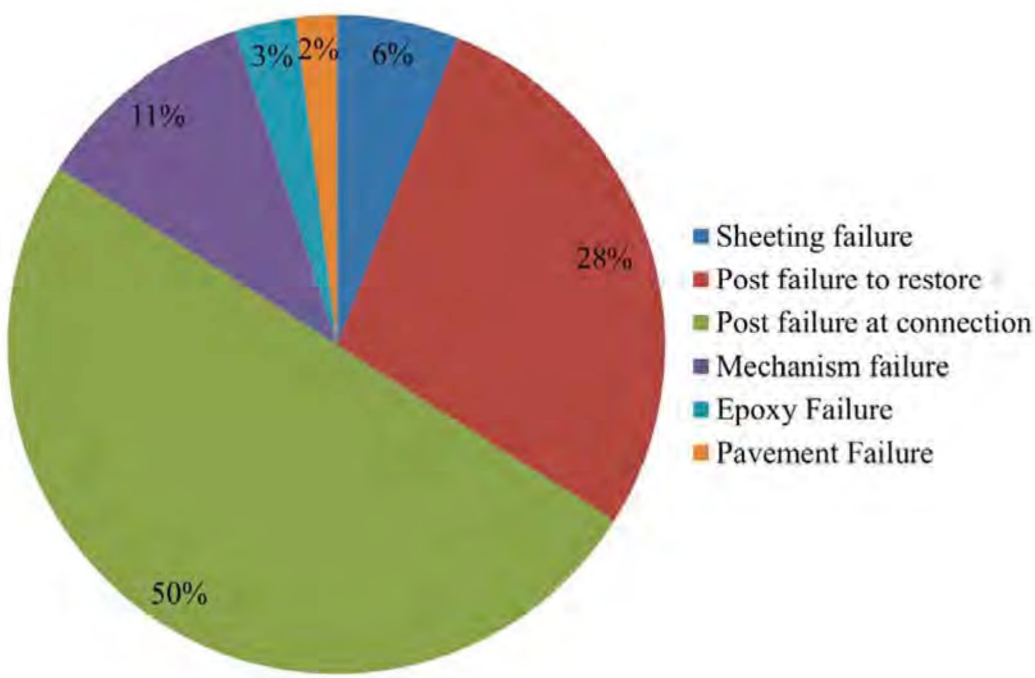

Figure 2. Distribution of Failure Modes in Phase 1 of I-95 Express Lanes.

The first three failure modes (sheeting failure, post failure to restore, and post failure at connection) comprised 84 percent of the repair/replace activities witnessed in Phase 1. All of these failures required replacement of the post to correct. The workers used a cutting tool to remove any portions of the failed posts (as shown in Figure 3) and attached the new post by shoving it down onto the connector. Each of these repairs took about 15 seconds for one worker to perform.

Figure 3. Sheeting Failure and Post Failure Replacement.

When the mechanism failed (as shown in Figure 4), the worker removed it by hammering the pin out from one side, pulling the mechanism out, cleaning debris from inside the base, inserting a new mechanism, and hammering the pin back into place. A new post was installed as well. Each of these repairs took about 90 seconds for one worker to perform.

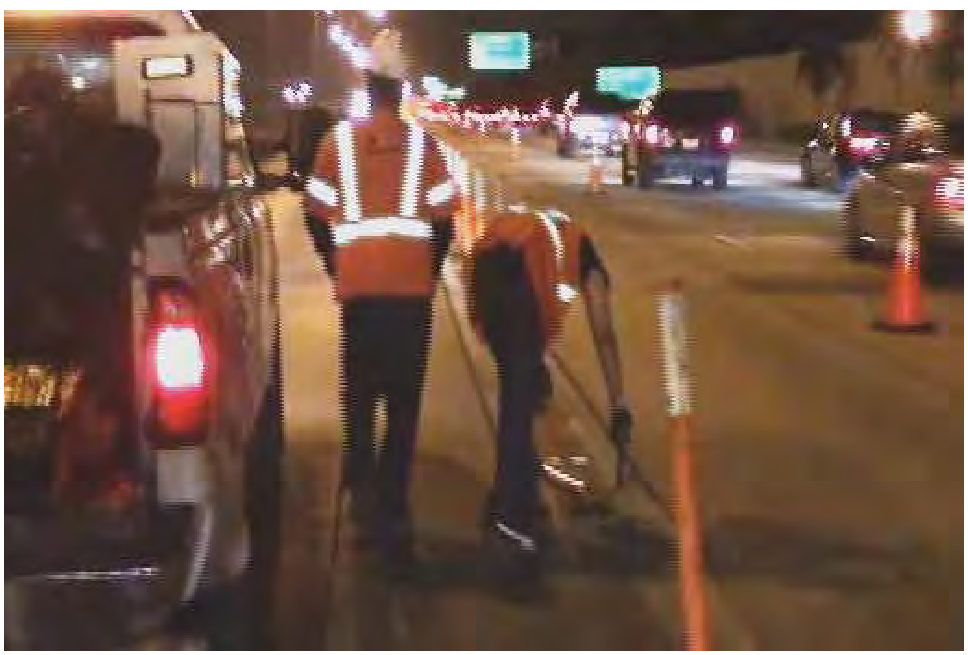

Figure 4. Mechanism Failure Replacement.

When the epoxy or the pavement has failed, a new delineator was installed. The workers swept a small area of the pavement by hand and mixed a small batch of two-part epoxy directly on the pavement (as shown in Figure 5). A new delineator was placed and the workers set the delineator by rotating it in the wet epoxy, checking for proper alignment, and stepping on the top of the base to force the epoxy up into the pockets in the bottom of the base. This process took about 4 minutes for two workers to perform.

Figure 5. Epoxy Failure and Pavement Failure Replacement.

The Phase 1 observation period began at station 110+00 and ended at station 263+00. Total distance was approximately 15,300 ft (or 2.9 miles). Assuming a 10-ft spacing, this segment would contain 1,530 delineators. Of those 1,530 delineators, there were 100 repairs or replacements. The researchers calculated a 6.5 percent replacement rate. The last time that delineator failures in this segment were corrected was 5 nights prior. The researchers calculated a 30-day (monthly) replacement rate of 39 percent and a 365-day (annual) replacement rate of 475 percent. Table 1 shows approximately 8,240 delineators in Phase 1. Assuming that the replacements documented along the observed segment represents the same proportion of replacements made along the entire length of the delineator installation, the researchers computed a total of 39,140 delineator repairs or replacements per year in Phase 1.

The Phase 1 observation period began at 11:26 p.m. and ended at 12:45 a.m. Total observation duration was 79 minutes for two workers to make 100 repairs or replacements. With 39,140 delineator repairs or replacements per year, the researchers calculated an annual worker exposure time of 515 hours per worker (1,030 for a two man crew).

Other data estimates obtained from the contractor performing the Phase 1 pavement rehabilitation work indicated that approximately 333 posts were replaced per night for each night of delineator maintenance. The rehab project consists of 3.3 miles in each direction. Using similar calculations, replacement rates were estimated to be 9.6 percent per night of delineator maintenance. The contractor noted that 80 percent of the replacements were post replacements, while the remaining 20 percent were entire unit replacements. In addition, the contractor estimated 48 man-hours of worker time per night of maintenance (3,500 hours per year).

Phase 2 delineator maintenance observation data were not available because the contractor was not replacing delineators during the week of data collection. The delineators were relatively new and had very few failures in the segments where the researchers drove. The contractor reported that they replace delineators only twice per month and have very few failures.

1.2. INITIAL TESTING OF DELINEATOR PRODUCTS

1.2.1 Test Installation and Method

The test facility consisted of a segmented concrete apron. Each concrete segment was approximately 12.5 ft wide by 15 ft long and approximately 6 inches thick. The surface had previously been treated with a low friction seal coat (20+ years ago) that subsequently has been worn off by environment and traffic. The surface, while optimal for mechanical anchors in concrete, may not be optimal for testing epoxy adhesion. Researchers will be evaluating the need for resurfacing this facility. Many of the surfaces that resulted in failures in field inspections were in locations where milling or resurfacing had occurred. This is possibly due to the epoxy not being able to bond to the smoother surface.

The products currently installed in the I-95 corridor were tested according to the procedure established in Texas A&M Transportation Institute (TTI)/Texas Department of Transportation (TxDOT) Research report 0-6772-1, which is based on the existing National Transportation Product Evaluation Program (NTPEP) Temporary Traffic Control Devices (TTCD) evaluation standard (*1*). Figure 6 shows the products installed at the TTI testing facility.

(a) Phase 1 delineator (42-in Flexstake TM754)

(b) Phase 2 delineator (36-in Flexstake TM754)

Figure 6. Products Tested during Task 1.

Figure 7 shows the layout of the entire test installation. A total of eight samples of each product were installed in two rows or four each. Each row of four samples had two samples installed with the locking pin parallel to the impact direction (or test vehicle travel path) while the remaining two samples were rotated 25° to simulate an angled impact. The spacing between the rows was such that four of each product (indicated by a T in post number) would be impacted by the vehicle tire, and the remaining four (indicated by a B in post number) would be impacted by the vehicle bumper near the 1/3 point opposite the impacting wheel. All 16 samples were impacted each time the test vehicle passed through the installation at 70 mph. The vehicle utilized during testing was a 2011 Kia Rio, shown in the impact position in Figure 8. All testing was performed at an ambient temperature greater than 65°F to be consistent with previous Florida Department of Transportation (FDOT) requirements.

The vehicle impacts caused damage to the delineators. This damage is typically measured in terms of list, lean, and failure. List and lean occur when the delineator post is no longer perpendicular to the installation surface. List occurs when the top of the delineator post deviates from perpendicular left or right compared to the test vehicle travel path. Lean occurs when the top of the delineator deviates from perpendicular forward or back compared to the test vehicle travel path. List and lean were measured from the base of the delineator to the top edge of the delineator (as shown in Figure 9) using a digital level. During testing, list and lean were measured prior to any impacts and after the 1st, 5th, 10th, and 50th impacts. A delineator is considered to have failed once the delineator deviates more than 15° from perpendicular in any direction.

Delineator failure was defined as failing to restore within 15° of vertical (perpendicular to the installation surface) in any direction. Additionally, the testing was halted anytime a sample failed. When a sample failed, the failure mode was documented using photographs and the sample was then removed from the installation. Testing then resumed until all samples had failed. All impacts were documented through standard speed video (30 frames per second). Photos of the test vehicle, the installation, and the individual test samples were taken periodically throughout the testing (at the established number of impacts and when failure occurred). Due to the conditions under which nighttime luminance of retroreflective material is measured and the lack of thresholds for acceptance, sheeting retroreflectivity was not measured during testing.

1.2.2 Test Results

The testing was performed on September 24, 2015. Table 2 summarizes the test results, including the measured list and lean, number of impacts to failure, and failure mode. For reference, photographs taken at failure for each of the 16 samples are provided in Appendix A.

The results show that the delineators rarely had any significant listing. For the Phase 2 delineators, significant leaning did not occur until well after 10 impacts. Several of the Phase 1 delineators began to have significant impacts after as few as five impacts. The cells highlighted in red indicate samples that leaned more than 5° (which would not meet the current FDOT requirement in the Technical Special Provisions for High-Performance Surface-Mounted Delineators).

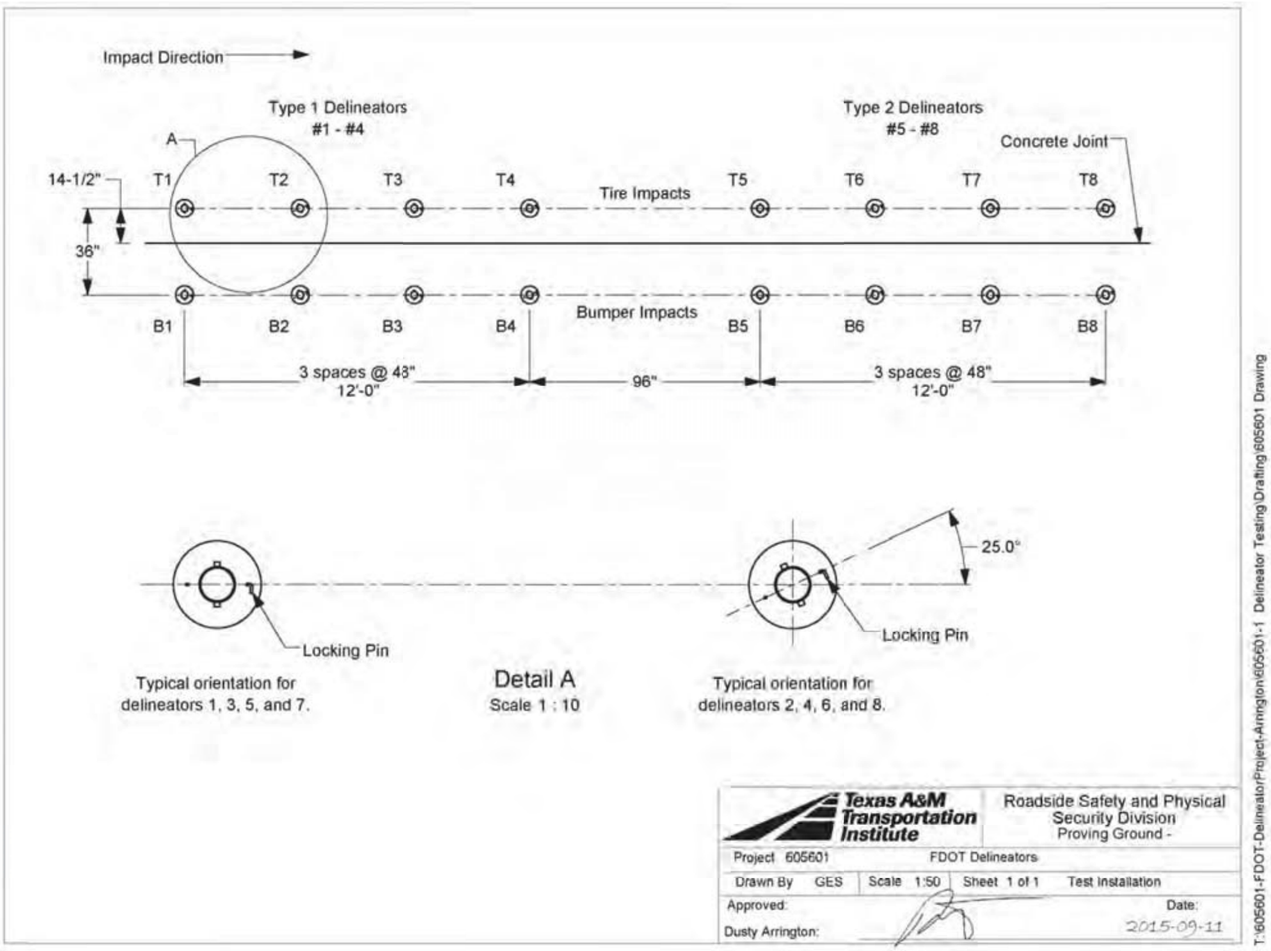

Figure 7. Diagram of Test Installation.

Figure 8. Test Vehicle in Impact Position prior to Testing.

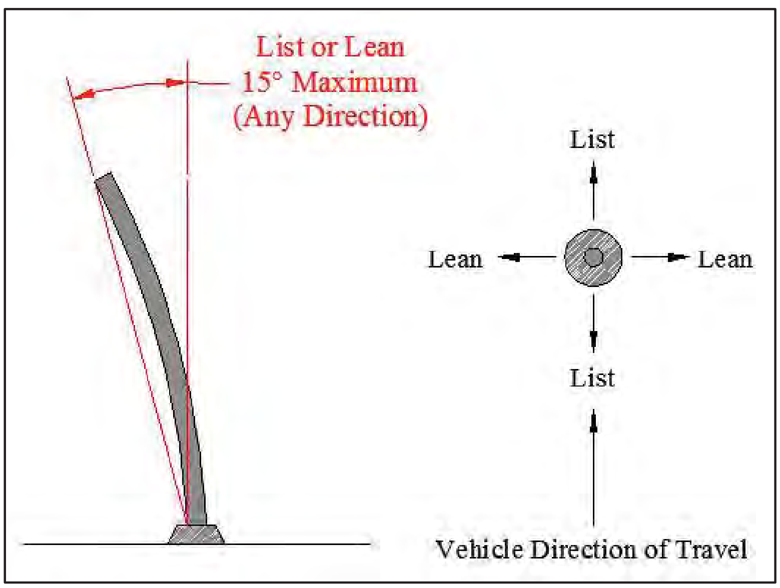

Figure 9. Measurement of List/Lean.

Table 2. Table of List and Lean Measurements.

FDOT I-95 Phase	Test Post Number	Before Testing		After 1st Impact		After 5th Impact		After 10th Impact		After 50th Impact		Failure	
		List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Impact #	Mode
2	1T	89.5	89.5	89	89	90	88	90	90	90	84	53	Post failure at connection
	1B	90	89	90	89	89	88	88	89			27	Post failure at connection (loss of post)
	2T	90	88	88	88	88	89	88	89	89	90	66	Post failure to restore and Post failure at connection
	2B	89	89	89	88	89	88	90	88			44	Mechanism failure
	3T	88.5	88.5	89	88	90	88	90	87	90	89	71	Post failure to restore and Post failure at connection
	3B	90	88.5	90	88	89	89	89	90			28	Post failure at connection (loss of post)
	4T	88.5	90	90	89	89	89	90	88	88	85	56	Post failure at connection (loss of post)
	4B	90	90	89	90	89	89	89	89			42	Post failure at connection (loss of post)
1	5T	89.5	88	89	90	89	89	90	90			32	Post failure to restore (40°)
	5B	89	88	89	86	88	84	89	85			21	Post failure at connection (loss of post)
	6T	89.5	89	89	89	89	87	87	85			25	Post failure to restore (64°)
	6B	89	88	89	86	87	84	89	83			29	Post failure at connection (loss of post)
	7T	89	89.5	89	88	89	87	89	88			29	Post failure at connection (loss of post)
	7B	89.5	88	90	89	88	88	88	89			18	Post failure at connection (loss of post)
	8T	89	89	90	90	89	87					6	Post failure to restore (43°)
	8B	88	89	89	89	89	87	88	87			26	Post failure at connection (loss of post)

For the Phase 2 delineators, all of the samples receiving tire impacts survived more than 50 impacts. Those with bumper impacts tended to fail between 27 and 44 impacts. Overall, the Phase 1 delineator samples failed much earlier. Samples with tire impacts failed between 6 and 32 impacts, while samples with bumper impacts failed between 18 and 29 impacts. Regardless of type of impact, the Phase 2 delineators lasted longer than the Phase 1 delineators. This is likely due the design improvements already mentioned earlier in this report.

Three different failure modes were witnessed during the testing: post failure to restore, post failure at connection, and mechanism failure. Post failure at connection was the most prevalent failure mode documented in the test results. This was also the most frequently occurring failure mode from the field data (observations during the I-95 installation visits). Post failure to restore was also evident in significant proportions in the test results and in the field data. One mechanism failure occurred during testing (which is not out of proportion with field data). In the field, the post is replaced when it fails, but the base mechanism is typically reused. It is possible that mechanism failures seen in the field data may have first been post failures followed by repeated vehicle impacts directly to the mechanism, but no evidence of that remained at the time of the observations (thus, they were recorded as mechanism failures).

Failure of the delineator base was not seen in the field data nor in the testing results. Therefore, no further consideration will be given to base failures.

There were no epoxy failures witnessed during testing of the samples. While these samples were installed according to the manufacturer's instructions, the method by which the epoxy is mixed in the field may not be as precise. In addition, epoxy failures in the field may also be caused by the presence of dirt and dust on the roadway surface or smoothness of the surface (due to milling) when the base is glued down.

And finally, no pavement failures were documented in the testing. This is likely because the delineators would fail for other reasons long before the base would receive enough impacts to create this type of failure.

1.3. INITIAL CONCLUSIONS

Based on the information obtained to date, the researchers found that two versions of the same product are being used in the express lane marker application. This product is likely being selected because it is the least expensive of the products shown on the FDOT Approved Products List (APL). With replacement rates estimated at almost five times per year in Phase 1, the initial purchase and installation costs are insignificant compared to the maintenance cost. In addition, thousands of hours of worker time during delineator maintenance activities represents unnecessary worker exposure to traffic.

The testing procedure utilized was developed in previous TTI/TxDOT research and is detailed in TTI/TxDOT Research Report 0-6772-1. The method appears to accurately produce the failure modes found on the I-95 express lanes. The results indicate that no further modifications are required to the method at this time.

CHAPTER 2. IMPACT TESTING PROCEDURE

Upon completion of Phase 1 testing, TTI researchers proceeded with developing a final testing procedure and product specification. Below you will find the procedure developed and utilized in later testing under this project.

2.1 PURPOSE

To define standard method for evaluating a managed lane marker's impact performance with the intention of qualifying products that will minimize long-term maintenance costs.

2.2 AUTHORITY

Section xxx.xxx(x), Florida Statutes.

2.3 SCOPE

Primary offices affected by this procedure include the State Materials Office (SMO), State Construction Office (SCO), District Construction Offices (DCO), District Materials Offices (DMO), and Resident Construction Offices (RCO).

2.4 BACKGROUND

This standard was developed to provide a fair, efficient, and repeatable method of evaluating the impact performance of a Managed Lane Marker.

2.4.1 I-95 Managed Lane Installation Study

The standard was developed to produce failure modes witnessed in FDOT's managed lane applications in Districts (4 and 6). The initial products installed on the I-95 managed lanes in District 6 were being replaced approximately 5 times per year. This has led to high maintenance and replacement costs.

2.4.2 Previous TxDOT Research

TxDOT project number 0-6772 focused on developing a new method of evaluating delineator impact performance that exceeds the standard method developed by the NTPEP TTCD Technical Committee. The method includes various impact severities based on the specific applications in which the delineators would be utilized.

Under this project, the researchers investigated delineator failure modes and, with TxDOT guidance, developed a test method for reproducing those failure modes in an efficient and repeatable manner. The researchers then performed testing on several different products to evaluate the effectiveness and repeatability of the procedure.

This project resulted in proposed impact testing standards for three applications of delineators. The first application, named Low Durability Side of Roadway Applications, is an updated version of the NTPEP TTCD Technical Committee's method, which utilizes only 10 impacts at 55 mph. The proposed standard defined the test vehicle specifications and allowable vehicle modifications to resist impacts of test samples. The second application, named High Durability Metropolitan Delineator Applications, increases the maximum number of impacts to 200 but still maintain an impact speed of 55 mph. The third application, named High Speed High Durability Application, utilizes a maximum of 200 impacts and an impact speed of 70 mph.

2.4.3 FDOT Research Study

Understanding the elevated durability requirements associated with managed lane marker applications, FDOT wanted to develop a durability standard to evaluate products in this application. The research was intended to build upon the high speed high durability application test method documented in TxDOT 0-6772-1 project report, titled *Development of Delineator Testing Standard*. Under the FDOT project BDR74 977-06, the researchers documented failure modes and replacement rates associated with managed lane marker applications and performed impact testing on the products. The results showed that the recommended procedures adequately reproduced the failure modes found in the managed lane marker installations. This test method is the result of those findings.

2.5 MANAGED LANE MARKER SPECIFICATIONS

These specifications are necessary to unify critical design and aesthetic properties of the managed lane markers.

2.5.1 Dimension Requirements

The post shall have a minimum width of 2 inches perpendicular to traffic flow and of such length to generally provide a height of 36 inches above the pavement surface.

2.5.2 Color Requirements

The post shall be opaque white. The yellowness index shall not exceed 12 when tested in accordance with ASTM D1925 or ASTM E313. The daylight 45°, 0° luminous directional reflectance shall be a minimum of 70 when tested in accordance with ASTM E1347.

2.5.3 Reflective Sheeting Requirements

The reflective sheeting shall be Types IV or V and meet the requirements of Section 994. The reflective sheeting shall have a minimum width of 3 inches and have a minimum projected area of 18 square inches.

2.5.4 Attachment Method

Attachment methods are not restricted. Each attachment method and product will be individually considered, tested, and qualified.

2.6 IMPACT TESTING

All products shall be individually tested and qualified at an approved testing facility. All products must be tested using the same post, base, attachment method, hardware, and epoxy that will be used in the field. Testing facilities will follow testing methodology described herein.

2.6.1 Approved Testing Facilities

Testing shall be performed by a laboratory listed on Federal Highway Administration's (FHWA's) list of "Laboratories Accredited to Crash Test Roadside Safety Hardware." A full list of approved labs can be found on FHWA's website at: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/laboratories/.

2.6.2 Samples

A minimum number of 9 samples will be randomly selected and submitted to the selected lab for evaluation. One sample will be used for dimensional verification and material properties testing. Generic drawings and material specifications will be submitted along with samples.

2.6.3 Drawings

Generic drawings shall be provided. The generic drawings of the product shall include the following minimum dimensions: overall height, post wall thickness, post diameter, attachment method, base diameter, and base height.

2.6.4 Verification of Material and Dimensional Properties

One sample will be randomly selected for additional destructive lab testing to verify/document material and dimensional properties.

2.6.4.1 Dimensional Verification

One sample will be utilized to verify that the product is constructed according to drawings provided and to gather additional dimensional information that may not have been provided in generic drawings.

2.6.4.2 Material Property Testing

The same sample used for dimensional verification will be utilized for destructive testing to document material and physical properties of post. Below is a list of laboratory tests to be performed:

Test Name	ASTM Number	Criteria
ASH Test	D5630	Documentation Only
Density and Specific Gravity	D792	Documentation Only
Tensile Strength and Elongation	D638-08	Documentation Only
Accelerated Weathering	G154-06	Documentation Only
Yellowness Index	D1925 of E313	See Section 1.5.2
Daylight Luminance	E1347	See Section 1.5.2

2.6.4.3 Attachment Methods

All attachment methods/products shall be evaluated for impact performance. The evaluation is product specific, and equivalencies are not permitted. A minimum of four samples of each product shall be impact tested.

2.6.4.4 Reflective Sheeting

All reflective sheeting shall be evaluated for impact performance. The evaluation is product specific, and equivalencies are not permitted. A minimum of four samples of each sheeting material shall be impact tested.

2.6.5 Installation

This section describes how the test installation shall be constructed. Samples should be grouped together by product model, attachment method, and by sheeting type to ease evaluation.

2.6.5.1 Vertical Installation Tolerance

All samples shall be installed to within 1° of vertical prior to first impact.

2.6.5.2 Wheel-over Impacts

Half of the samples shall be installed such that the impact vehicle's front tire will traverse the base as the vehicle passes.

2.6.5.3 Bumper Impacts

Half of the samples shall be installed such that the impacting vehicle's bumper will contact the post as the vehicle passes over without the base or post coming in contact with the tire.

2.6.5.4 Orientation of Samples

Manufacturer has the option of defining the front face (0°) of the sample. If the manufacturer does not define the front face, then the lab will use reasonable judgement to determine the front face. Half of the Bumper and half of the Wheel Over impact samples will be installed with the front face perpendicular to the path of the impacting vehicle (0°). The remaining samples will be rotated 25°. The testing lab will determine which direction of rotation (clockwise or counterclockwise) is more critical. Impact testing will be performed on the more critical direction of rotation. The lab will evaluate the effect of bumper interaction with the post and base. The samples will be installed such that the more critical orientation is tested. The more critical orientation is one that potentially induces more interaction with the vehicle and presents the higher risk of sample failure during testing.

2.6.5.5 Multiple Configurations of Samples

If multiple configurations of the same product are tested (i.e., different attachment methods or sheeting), an equal number of bumper and wheel over samples shall be installed for each configuration. Additionally, an equal number of 0° and 25° samples shall be installed for each configuration.

2.6.5.6 Spacing of Samples

Samples will be installed in two parallel lines. One line will correspond to bumper impacts and the other will correspond to Wheel Over impacts. The spacing of these lines will be determined by testing laboratory and shall ensure no interaction between any two samples on the test deck.

2.6.6 Test Vehicle

The test vehicle should meet 1100C requirements set in current American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) with the following exceptions. The vehicle model year shall be within 10 model years of the date the test is performed. No vehicle instrumentation is required. Vehicle modifications described in TTI/TxDOT Report 0-6772-1 shall be followed. Additional modifications are allowed if it can be reasonably demonstrated that they will not adversely impact the results of the testing.

2.6.7 Impact Conditions

For repeatability and for unification of impact conditions across multiple products, all testing shall be performed under the following conditions.

2.6.7.1 Temperature

All impacts shall occur at an ambient temperature at or above 65°F.

2.6.7.2 Impact Speed

All impacts shall occur at a target impact speed of 70 mph ±5 mph. A test sequence that has 60 percent or more of impacts less than 70 mph should be considered invalid.

2.6.7.3 Evaluation Criteria

The lab monitor and document list/lean, damage to post/base, damage to reflective sheeting, and failure to restore to an upright position.

2.6.7.4 Sample Failure Criteria

A sample shall be considered failed should it fail to restore to within 15° of vertical in **any direction**. The sample should also be considered failed should the sample rupture (>50 percent of cross section) or should it become detached from the test surface (partially or fully). The lab shall observe the performance of the samples during testing and shall halt testing should a sample appear to not restore to within 15° of vertical. Samples are allowed up to 5 minutes after the last impact to fully restore. Testing shall be postponed until all samples are deemed within 15° of vertical or the suspect sample is deemed failed.

2.6.7.5 Sheeting

While there is no specific requirement for sheeting performance, the performance and abrasion resistance shall be documented through photos as described in Section 1.6.9.

2.6.8 Documentation

The following categories define the minimum amount of documentation required to be provided as part of the report or in addition to the report. Additional information can be provided should the manufacturer or testing laboratory desire to do so. Samples should be numbered such that a reviewer can easily determine which product is being reviewed and whether the product is being impacted by the vehicle bumper or tire. All sample components should be labeled using this numbering method to aid in identifying samples after testing is completed (should further study be required).

2.6.8.1 Material Classification

Generic material properties provided by manufacturer shall be included in the report.

2.6.8.2 Drawings

Generic drawings as described in Section 2.6.3 shall be included in the report.

2.6.8.3 Material Property Testing Results

All material property testing reports shall be included in the report.

2.6.8.4 Video Documentation

Standard rate video shall be provided to document each impact performed. The impact number shall appear within view of the camera and shall not be added to the view after testing has been completed using video editing techniques. Failure to comply with this requirement will invalidate the testing results.

2.6.8.5 Photo Documentation

Extensive photo documentation shall be performed during testing. This includes documentation of the test installation, test vehicle, and test samples after the following impact numbers:

Prior to 1st impact
After 1st impact
After 5th impact
After 10th impact
After 50th impact
After 100th impact
After 150th impact
After 200th impact

Upon failure of any test sample, testing shall stop and the condition of the sample at the time of failure shall be documented. When documenting each sample, the following photos should be taken: photo of identifying label for test sample, frontal face of sample, any newly observed damaged to sample, and a close up image of the reflective sheeting to document sheeting loss or damage.

2.6.8.6 Photo Table

A table of photos shall be included in the report for each sample tested. Each table should include an image of the frontal face of the sample, any newly discovered damage to the sample, and a close up image of the reflective sheeting. This table shall have an entry for each of the impacts described in Section 2.6.8.5 of this standard.

2.6.8.7 Written Documentation

A written test log should be maintained documenting the progression of the testing and documenting any failures.

2.6.8.7.1 List/Lean

A log of list and lean shall be maintained for inclusion in test report. List/lean shall be measured as shown in Figure 10. List and lean shall be documented after the following impacts:

Prior to 1st impact
After 1st impact
After 10th impact
After 100th impact
After 200th impact

2.6.8.7.2 Damage to Test Sample

A log of damage to samples should be maintained and shall include the impact number when the failure occurred and a description of the failure mode.

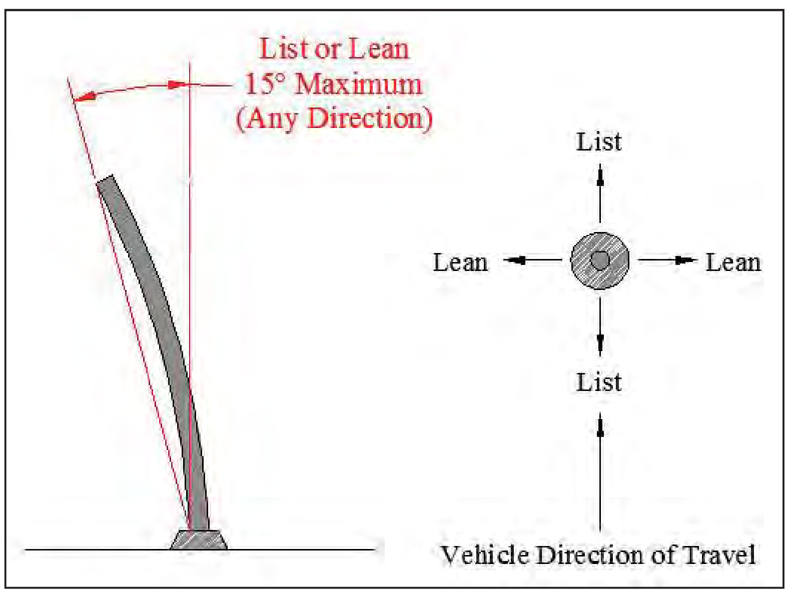

Figure 10. Measurement of List/Lean.

2.6.8.8 Average Number of Impacts Resisted

The testing lab shall calculate an average number of impacts resisted for: all samples, bumper impacts only, and wheel over impacts only. The resulting numbers shall be included in the final report.

2.7 REEVALUATION

Should impact testing result in product performance that the lab or manufacturer feels is a not a fair representation of the product’s actual performance; the manufacturer has the option of resubmitting the product for reevaluation. The product can be reevaluated only one time without a significant change to address failures modes witnessed in previous testing. When reevaluating impact performance of a product, a minimum of nine samples of each attachment method and sheeting, shall be evaluated.

2.8 REQUALIFICATION

As impact durability of managed lane markers is directly tied to the profile and design of the impacting vehicle’s bumper, it is recommended that products be requalified every 10 years.

CHAPTER 3. IMPACT DURABILITY TESTS

3.1 TEST FACILITY

Between March 22 and 30, researchers at TTI performed five impact durability tests, 605601-2 through 605601-6, using the TTI Riverside Test Facility. Figure 11 shows the overhead view of the facility. The yellow line in Figure 11 represents the vehicle test path (approximately 0.8-mile loop). The blue, red, and green lines represent various locations used for sample testing. All test samples for this task were installed in the areas with blue outlines (Concrete Surface Testing Area).

3.2 TEST INSTALLATION AND CONDITIONS

All tests for this task were installed on a concrete surface. Each test deck consisted of eight samples installed in two parallel lines with four samples in each line. One line of samples was positioned to receive bumper impacts. The second line of samples was positioned to receive tire impacts. A total of 200 vehicle impacts per sample were to be performed. A tire impact consisted of the vehicle impacting the sample with the centerline of the sample aligned with the centerline of the vehicle tire. During a tire impact, the vehicle tire traverses over the sample. A bumper impact consisted of the vehicle impacting the sample with the front bumper at the one-third distance of the vehicle width (⅓-point of the vehicle). The bumper and tire impacts were performed simultaneously in a single pass of the vehicle. The vehicle was traveling at a nominal speed of 70 mph when impacting the samples and at an ambient temperature greater than or equal to 65°F. Photographs and list/lean measurements were taken according to proposed testing procedures. These procedures were detailed under Task 2 of this project and can be found in Appendix B for your convenience.

3.3 TTI IMPACT DURABILITY TEST #605601-2

3.3.1 Pexco Surface Mount City Post Sample – Mechanically Anchored

Test #605601-2, performed on March 22, was an impact durability test performed on 36¾-inch tall Pexco Surface Mount City Post samples secured with Hilti ⅜-inch HCA Coil Anchor Bolts. Detailed diagrams of the test samples and test layout can be found in Figure 12. Figure 13 shows images of the test sample setup and impact vehicle at the beginning of testing. Figure 14 shows the test setup and impact vehicle after testing was completed. Each sample was secured with four bolts, fastening one bolt in each corner of the base. Samples 1T, 1B, 3T, and 3B were positioned with the centerline of the sample parallel to the impact vehicle path. Samples 2T, 2B, 4T, and 4B were positioned with the centerline of the sample turned 25° clockwise from the line parallel to the impact vehicle path.

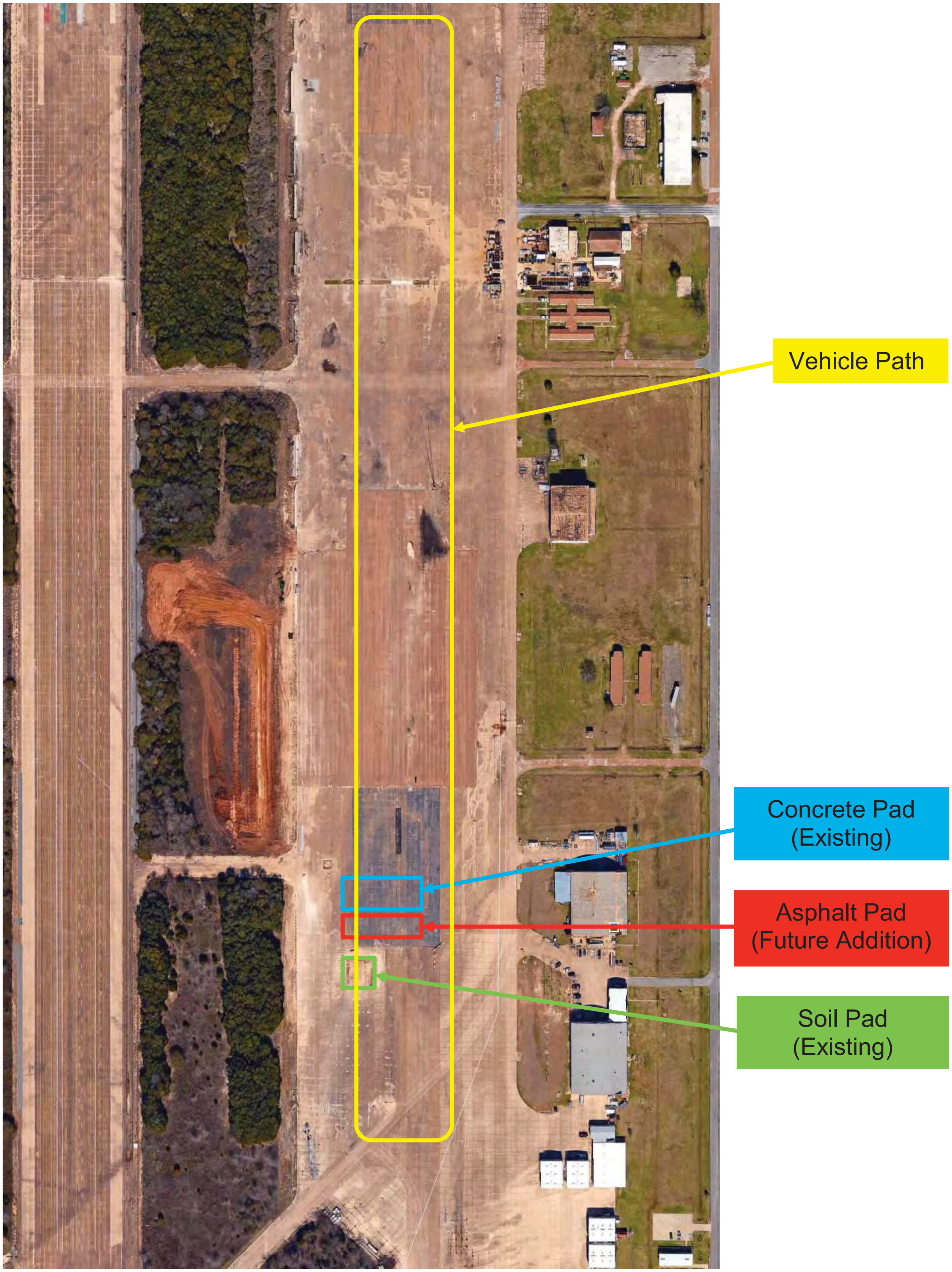

Figure 11. TTI Test Facility.

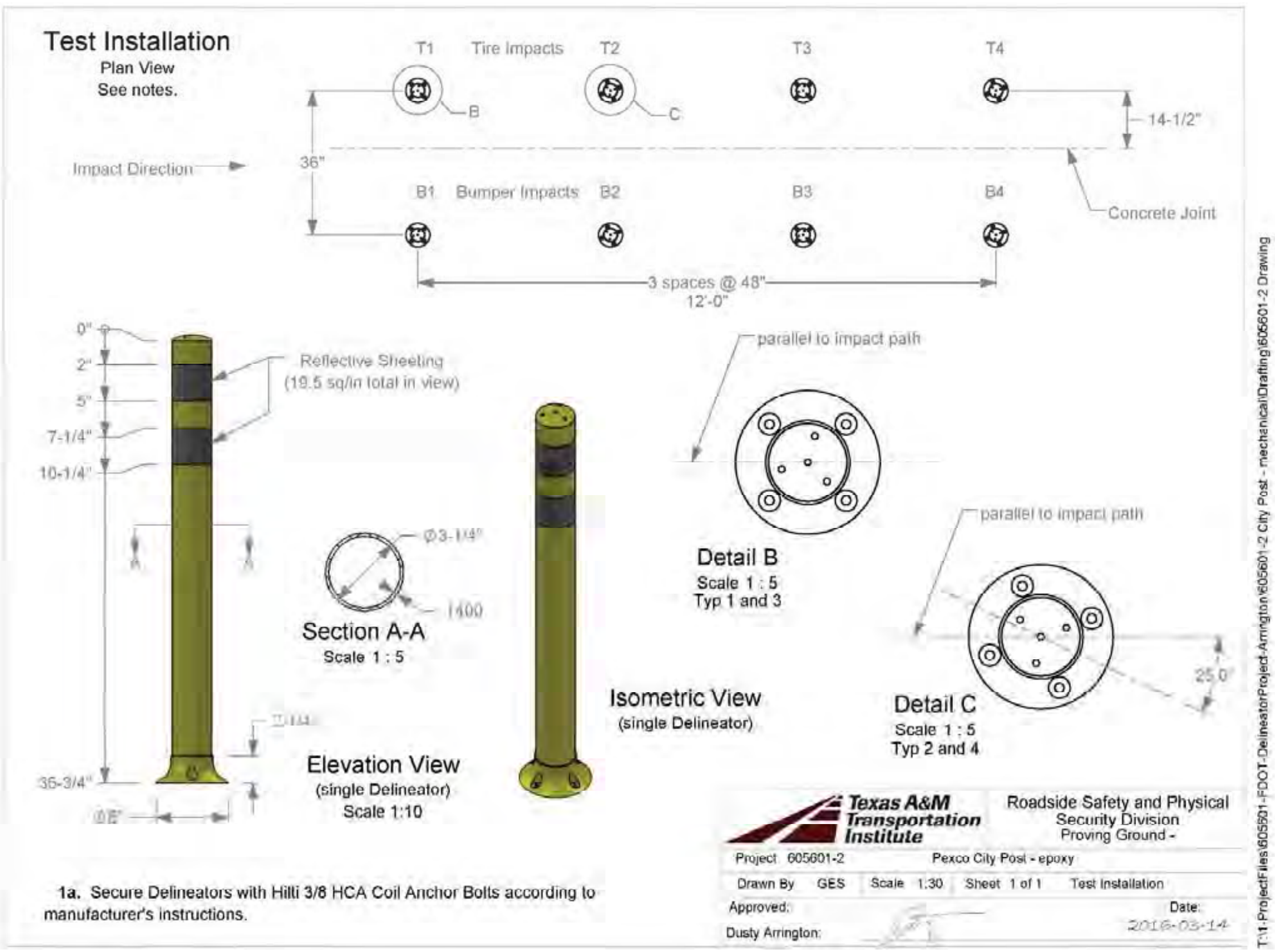

Figure 12. 605601-2 Test Setup and Sample Details.

Figure 13. 605601-2 before Testing.

Figure 14. 605601-2 after Testing.

3.3.2 Impact Performance

Test #605601-2 yielded the results shown in Table 3. For the Pexco Surface Mount City Post Sample, all samples impacted by the bumper failed to resist 200 bumper impacts. Seventy-five percent of the samples impacted by the tire withstood all 200 runs. The primary mode of failure was anchorage failure. In this case, the anchorage washer deformed and was pulled through the base of the sample. The maximum list recorded was 4°, and the maximum lean recorded was 8°.

Table 3. 605601-2 List/Lean Values.

#	Before		Run #1		Run #10		Run #100		Run #200		Failure	
	List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Run #	Mode
1T	90	89	89	88	89	88	88	88	86	82	119	Fractured ≈ 12" From Top
1B	89	90	89	88	89	87	90	86	x	x	163	Failure to Restore
2T	89	89	89	88	90	88	90	88	88	88	x	x
2B	89	89	89	89	90	88	89	86	x	x	134	Anchorage Failure
3T	90	89	90	89	89	88	89	88	88	88	x	x
3B	90	89	89	88	89	86	x	x	x	x	96	Anchorage Failure
4T	89	89	89	88	90	88	90	88	89	88	x	x
4B	90	89	89	88	89	87	90	86	x	x	120	Anchorage Failure
5T												
5B												
6T												
6B												
7T												
7B												
8T												
8B												

3.4 TTI IMPACT DURABILITY TEST RUN #605601-3

3.4.1 FG300 Sample

Test #605601-3, performed on March 23, was an impact durability test performed on 36½-inch tall FG300 secured with two different adhesives. Detailed diagrams of the test samples and test layout can be found in Figure 15. Figure 16 shows images of the test sample setup and impact vehicle at the beginning of testing. Figure 17 shows the test setup and impact vehicle after testing was completed. The first four samples were secured with FIRMmarker™ #18M900C20 2-part epoxy adhesive, and the second four samples were secured with Crafco Hot-Applied Bituminous Marker Adhesive #34269. Samples 1T, 1B, 3T, and 3B were positioned with the centerline of the sample parallel to the impact vehicle path. Samples 2T, 2B, 4T, and 4B were positioned with the centerline of the sample turned 25° clockwise from the line parallel to the impact vehicle path.

3.4.2 Impact Performance

Table 4 documents the list/lean and failure modes witnessed under Test #605601-3. All FG300 samples resisted less than 200 impacts. The primary mode of failure was rupture of the post at the retention pin holes. The maximum list recorded was 4°, and the maximum lean recorded was 3° prior to failure.

3.5 TTI IMPACT DURABILITY TEST RUN #605601-4

3.5.1 Pexco Surface Mount City Post Sample – Epoxy Anchored

Test #605601-4, performed on March 28, was an impact durability test performed on 36¾-inch Pexco Surface Mount City Post Samples secured with FIRMmarker™ #18M900C20 2-part epoxy adhesive. Detailed diagrams of the test samples and test layout can be found in Figure 18. Figure 19 shows images of the test sample setup and impact vehicle at the beginning of testing. Figure 20 shows the test setup and impact vehicle after testing was completed. Each sample was secured with the epoxy adhesive previously mentioned. Samples 1T, 1B, 3T, and 3B were positioned with the centerline of the sample parallel to the impact vehicle path. Samples 2T, 2B, 4T, and 4B were positioned with the centerline of the sample turned 25° clockwise from the line parallel to the impact vehicle path.

3.5.2 Impact Performance

Table 5 documents the list/lean and failure modes witnessed under Test #605601-4. All samples that were impacted by the bumper of the vehicle failed to resist 200 impacts. Fifty percent of samples that were impacted by the tire resisted all 200 impacts. The primary mode of failure was rupturing of the samples at the base. The maximum list recorded prior to failure was 3°, and the maximum lean recorded prior to failure was 4°.

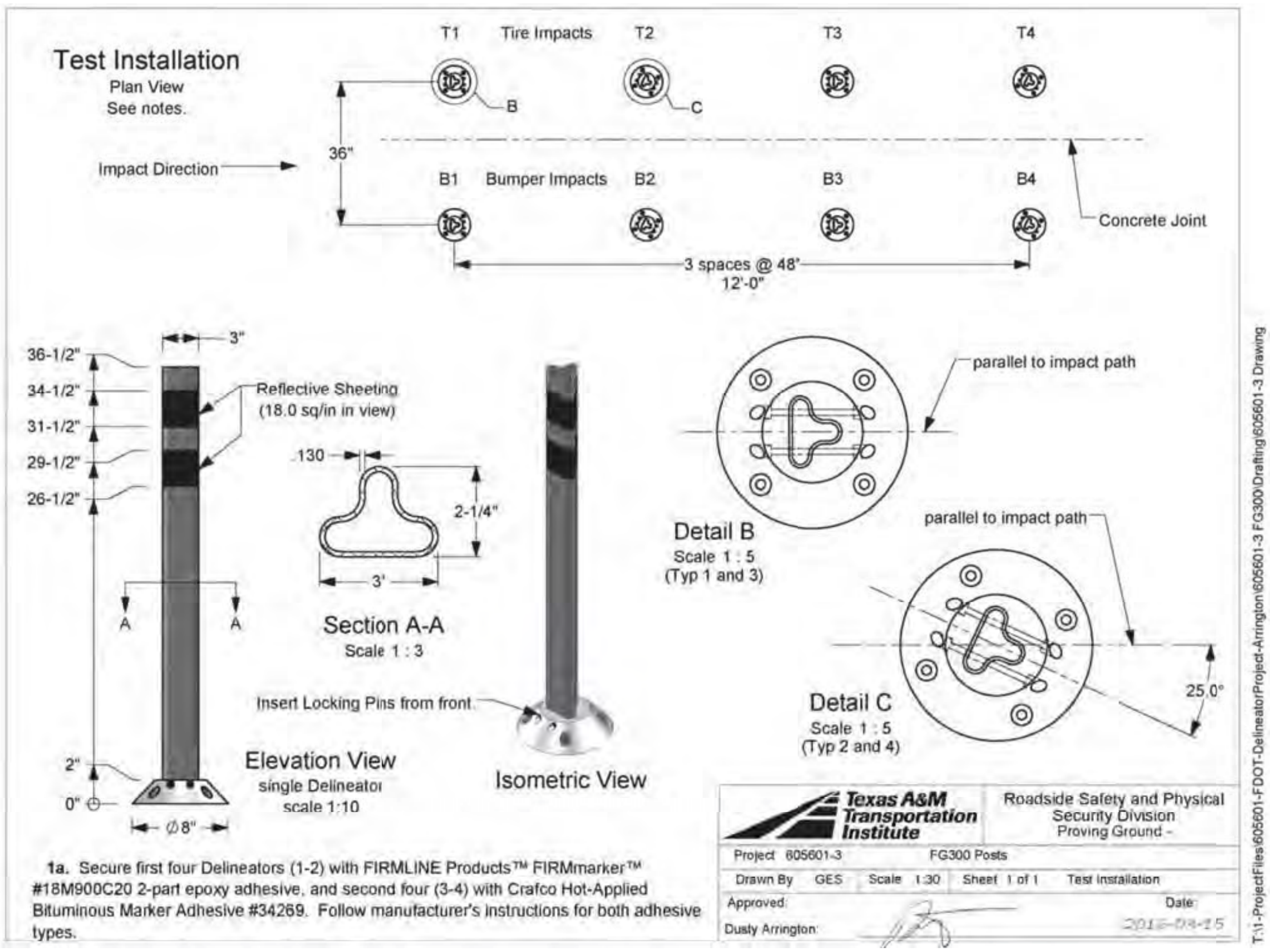

Figure 15. 605601-3 Test Setup and Sample Details.

Figure 16. 605601-3 before Testing.

Figure 17. 605601-3 after Testing.

Table 4. 605601-3 List/Lean Values.

#	Before		Run #1		Run #10		Run #100		Run #200		Failure	
	List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Run #	Mode
1T	90	90	90	89	89	88	x	x	x	x	45	Failed at Pin Holes; 81°
1B	89	90	90	89	90	90	x	x	x	x	17	Failed at Pin Holes
2T	89	90	89	90	89	90	87	89	x	x	185	Failed at Pin Holes
2B	90	90	90	89	88	87	x	x	x	x	12	Failed at Pin Holes
3T	90	90	90	88	88	88	x	x	x	x	30	75° and Turn
3B	89	90	90	89	x	x	x	x	x	x	10	Failed at Pin Holes
4T	90	89	89	88	88	89	86	89	x	x	120	Failed at Pin Holes
4B	89	89	90	88	89	86	x	x	x	x	15	71°
5T												
5B												
6T												
6B												
7T												
7B												
8T												
8B												

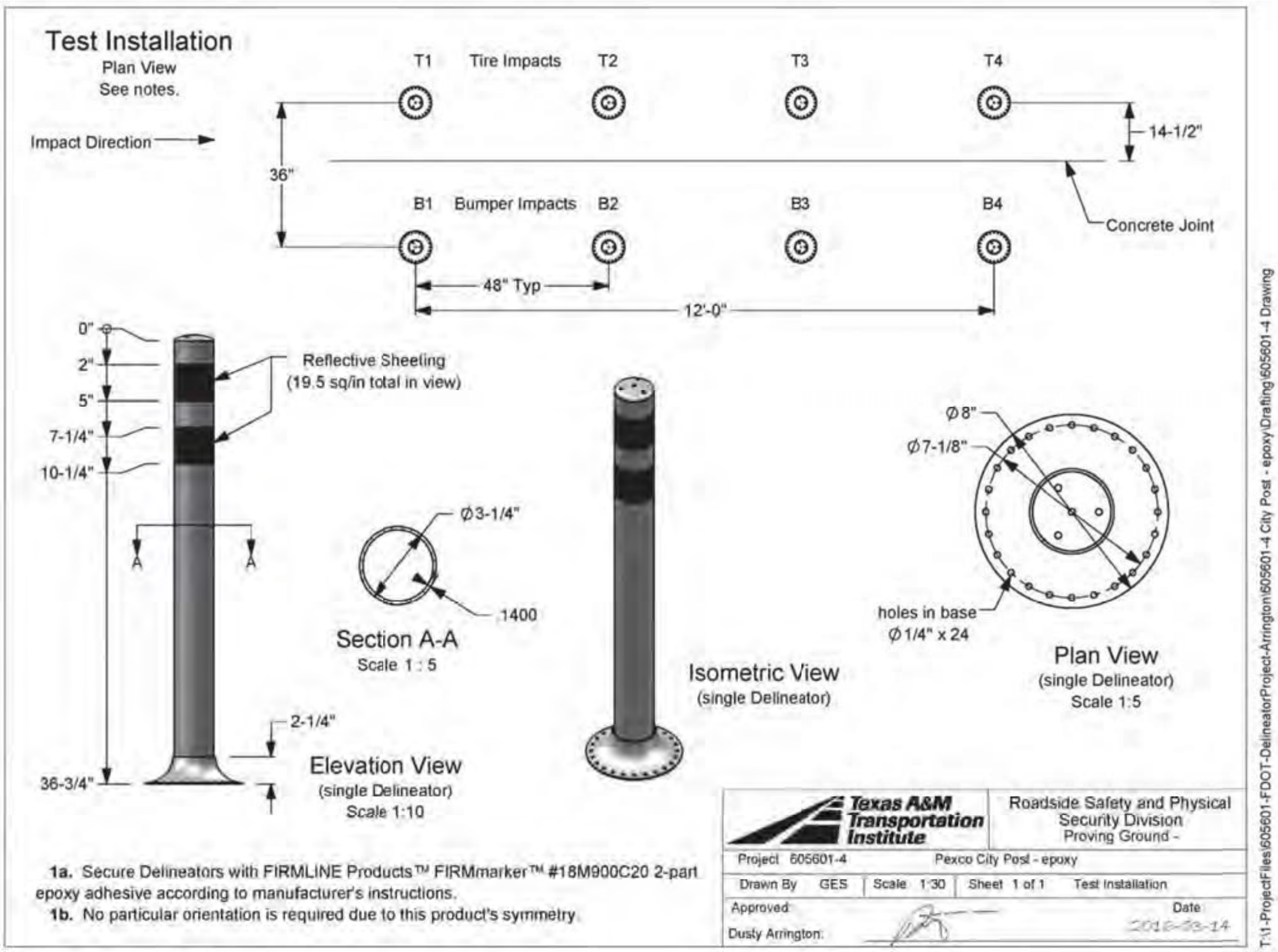

Figure 18. 605601-4 Test Setup and Sample Details.

Figure 19. 605601-4 before Testing.

Figure 20. 605601-4 after Testing.

Table 5. 605601-4 List/Lean Values.

#	Before		Run #1		Run #10		Run #100		Run #200		Failure	
	List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Run #	Mode
1T	90	89	88	90	88	89	87	89	x	x	177	ruptured ≈12" above grade
1B	90	90	90	88	90	87	88	86	x	x	199	70°
2T	90	90	89	89	89	89	88	89	87	88	x	x
2B	90	90	90	88	90	87	89	86	x	x	136	ruptured ≈12" above grade
3T	89	89	89	89	88	88	87	88	x	x	136	caught on concrete, failed to return
3B	90	90	90	88	89	87	88	86	x	x	150	adhesive failure
4T	90	90	90	89	89	89	88	88	87	88	x	x
4B	90	89	90	88	90	87	x	x	x	x	70	failed at base
5T												
5B												
6T												
6B												
7T												
7B												
8T												
8B												

3.6 TTI IMPACT DURABILITY TEST RUN #605601-5

3.6.1 Dura-Post Sample

Test #605601-5, performed on March 29, was an impact durability test performed on Dura-Post Samples secured by both epoxy and mechanical methods. Detailed diagrams of the test samples and test layout can be found in Figure 21. Figure 22 shows images of the test sample setup and impact vehicle at the beginning of testing. Figure 23 shows the test setup and impact vehicle after testing was completed. The first four samples were secured with SHEPX-13-K1 epoxy, and the second four samples were secured with 20 mm × 90 mm plastic anchor sleeves and ⅜-inch × 4-inch lag screws. Samples 1T, 1B, 3T, and 3B were positioned with the centerline of the sample parallel to the impact vehicle path. Samples 2T, 2B, 4T, and 4B were positioned with the centerline of the sample turned 25° clockwise from the line parallel to the impact vehicle path.

3.6.2 Impact Performance

Table 6 documents the list/lean and failure modes witnessed under Test #605601-5. All Dura-Post samples that were impacted by the bumper of the vehicle failed to resist 200 impacts. All of the samples that were impacted by the tire resisted all 200 impacts. The primary mode of failure was exceeding the maximum allowable degree of list/lean. The maximum list recorded was 4°, and the maximum lean recorded was 20°. In each case, the samples failed to restore due to the retention pin tearing through the bottom of the post.

3.7 TTI IMPACT DURABILITY TEST RUN #605601-6

3.7.1 Shur-Flex Surface Mount Sample

Test #605601-6, performed on March 30, was an impact durability test performed on Shur-Flex Surface Mount samples secured by both adhesive and mechanical methods. Detailed diagrams of the test samples and test layout can be found in Figure 24. Figure 25 shows images of the test sample setup and impact vehicle at the beginning of testing. Figure 26 shows the test setup and impact vehicle after testing was completed. The first four samples were secured with Henry HE913 Dot Stick Adhesive, and the second four samples were secured with ½-inch × 3-inch Shur-Tite Nylon Plugs and ½-inch × 3½-inch lag screws (with USS flat washers) in four corner holes. Samples 1T, 1B, 3T, and 3B were positioned with the centerline of the sample parallel to the impact vehicle path. Samples 2T, 2B, 4T, and 4B were positioned with the centerline of the sample turned 25° clockwise from the line parallel to the impact vehicle path.

3.7.2 Impact Performance

Table 7 documents the list/lean and failure modes witnessed under Test #605601-6. For the Shur-Flex Surface Mount sample, all samples failed to resist 200 impacts. The primary mode of failure was exceeding the maximum allowable degree of lean/lean. The maximum list recorded was 4°, and the maximum lean recorded was 50°.

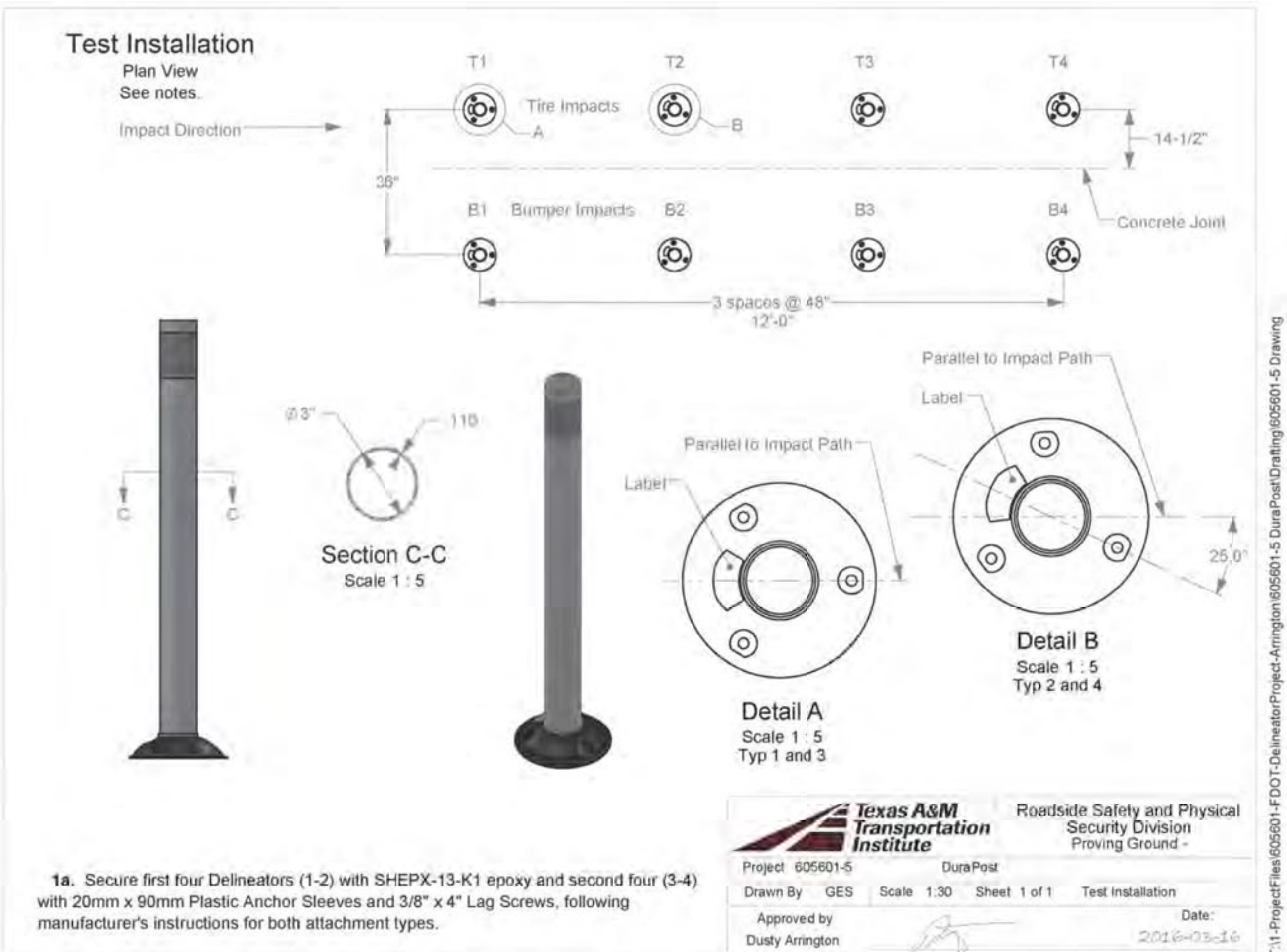

Figure 21. 605601-5 Test Setup and Sample Details.

Figure 22. 605601-5 before Testing.

Figure 23. 605601-5 after Testing.

Table 6. 605601-5 List/Lean Values.

#	Before		Run #1		Run #10		Run #100		Run #200		Failure	
	List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Run #	Mode
1T	90	89	88	87	88	85	87	85	88	85	x	x
1B	90	89	89	87	90	87	88	85	x	x	113	failed at base
2T	89	90	90	90	90	87	89	86	89	87	x	x
2B	90	89	89	88	90	87	x	x	x	x	58	74 deg lean
3T	90	90	89	88	89	87	88	86	87	86	x	x
3B	89	89	89	87	89	89	x	x	x	x	96	70 deg lean
4T	89	90	88	89	87	87	86	86	86	86	x	x
4B	89	90	89	88	89	88	x	x	x	x	57	70 deg lean
5T												
5B												
6T												
6B												
7T												
7B												
8T												
8B												

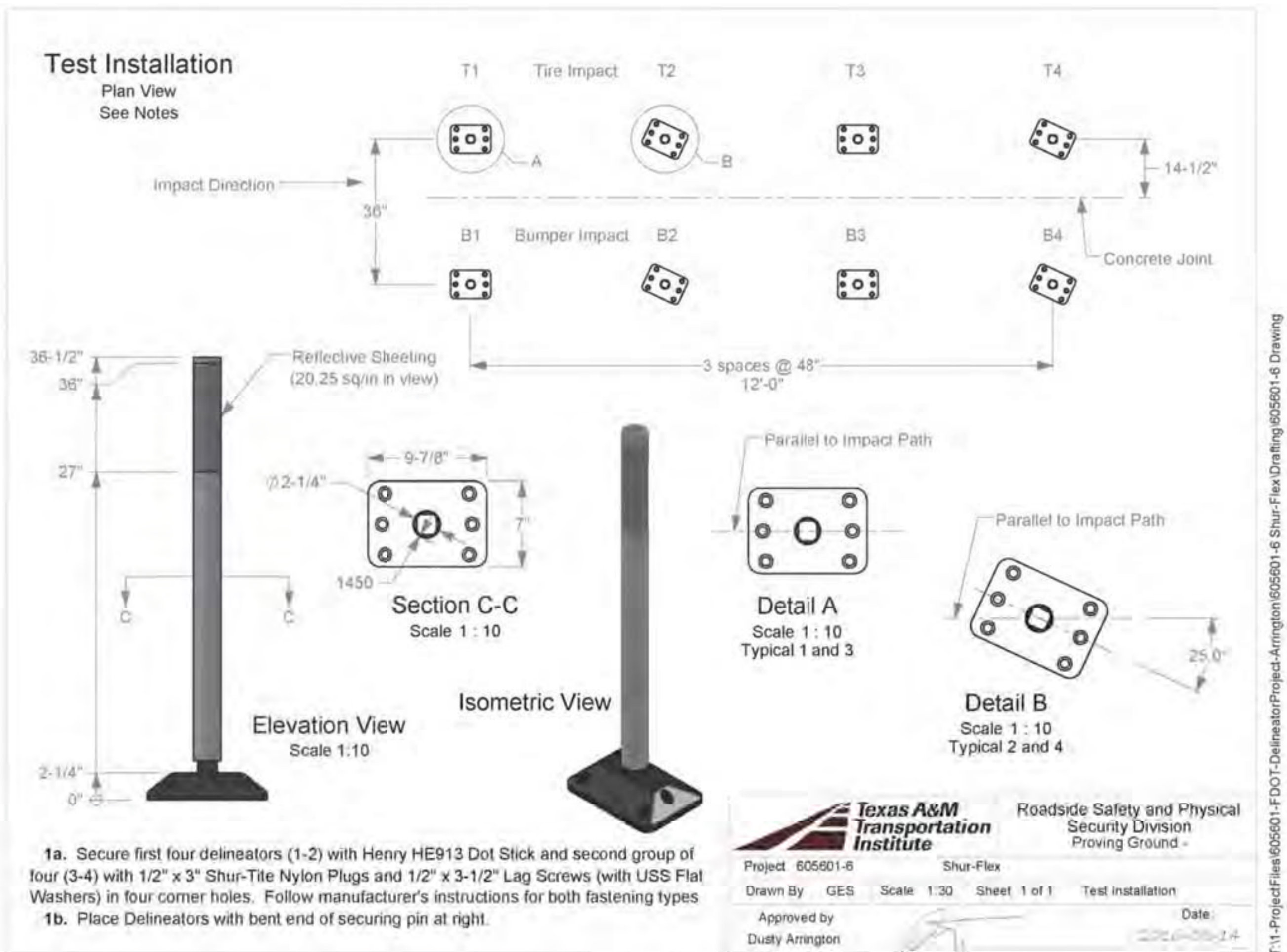

Figure 24. 605601-6 Test Setup and Sample Details.

Figure 25. 605601-6 before Testing.

Figure 26. 605601-6 after Testing.

Table 7. 605601-6 List/Lean Values.

#	Before		Run #1		Run #10		Run #100		Run #200		Failure	
	List	Lean	List	Lean	List	Lean	List	Lean	List	Lean	Run #	Mode
1T	90	89	89	89	87	87	x	x	x	x	69	73 deg lean
1B	90	90	90	88	90	87	x	x	x	x	40	44 deg lean
2T	90	90	89	89	86	88	x	x	x	x	63	40 deg lean
2B	90	90	89	88	89	86	x	x	x	x	29	45 deg lean
3T	89	90	89	89	87	80	x	x	x	x	29	74 deg lean
3B	89	90	x	x	x	x	x	x	x	x	1	base fractured
4T	90	90	89	90	87	87	x	x	x	x	49	74 deg lean
4B	90	89	89	88	89	86	x	x	x	x	33	47 deg lean
5T												
5B												
6T												
6B												
7T												
7B												
8T												
8B												

3.8 SUMMARY OF IMPACT PERFORMANCE

3.8.1 Impact Durability Test #605601-2

Test #605601-2, performed on March 22, was an impact durability test performed on 36¾-inch tall Pexco Surface Mount City Post samples secured with Hilti 3/8 inch HCA Coil Anchor Bolts as shown in Figure 27. The product resisted an average of 180 tire impacts. The product resisted an average of 128 bumper impacts. The product resisted a combined average of 154 tire and bumper impacts. Table 8 shows a summary of the results. The primary failure mode of the sample was anchorage failure.

Figure 27. 605601-2 Product Sample.

Table 8. 605601-2 Summary Table.

City Post Mechanical Anchor		
	T	B
1	119	163
2	200	134
3	200	96
4	200	120
Average	180	128
Overall	154	

3.8.2 Impact Durability Test #605601-3

Test #605601-3, performed on March 23, was an impact durability test performed on FG300 samples secured with two different epoxy adhesives as shown in Figure 28. The first four samples were secured with FIRMmarker™ #18M900C20 2-part epoxy adhesive, and the second four samples were secured with Crafco Hot-Applied Bituminous Marker Adhesive #34269. The product resisted an average of 95 tire impacts. The product resisted an average of 14 bumper impacts. The product resisted a combined average of 54 tire and bumper impacts. Table 9 shows a summary of the results. The primary failure mode of the sample was failure at retention pin holes.

Figure 28. 605601-3 Sample.

Table 9. 605601-3 Summary Table.

FG300		
	T	B
1	45	17
2	185	12
3	30	10
4	120	15
Average	95	14
Overall	54	

3.8.3 Impact Durability Test #605601-4

Test #605601-4, performed on March 28, was an impact durability test performed on 36¾-inch Pexco Surface Mount City Post samples secured with FIRMmarker™ #18M900C20 2-part epoxy adhesive as shown in Figure 29. The product resisted an average of 178 tire impacts. The product resisted an average of 145 bumper impacts. The product resisted a combined average of 161 tire and bumper impacts. Table 10 shows a summary of the results. The primary failure mode of the sample was rupturing of the samples near the base.

Figure 29. 605601-4 Sample.

Table 10. 605601-4 Summary Table.

City Post Epoxy		
	T	B
1	177	199
2	200	159
3	136	150
4	200	70
Average	178	145
Overall	161	

3.8.4 Impact Durability Test #605601-5

Test #605601-5, performed on March 29, was an impact durability test performed on Dura-Post samples secured by both epoxy and mechanical methods. The first four samples were secured with SHEPX-13-K1 epoxy, and the second four samples were secured with 20 mm × 90 mm plastic anchor sleeves and ⅜-inch × 4-inch lag screws as shown in Figure 30. The product resisted an average of 200 tire impacts. The product resisted an average of 81 bumper impacts. The product resisted a combined average of 141 tire and bumper impacts. Table 11 shows a summary of the results. The primary failure mode of the sample was exceeding the maximum allowable degree of lean.

Figure 30. 605601-5 Sample.

Table 11. 605601-5 Summary Table.

Dura-Post		
	T	B
1	200	113
2	200	58
3	200	96
4	200	57
Average	200	81
Overall	141	

3.8.5 Impact Durability Test #605601-6

Test #605601-6, performed on March 30, was an impact durability test performed on Shur-Flex Surface Mount samples secured by both adhesive and mechanical methods. The first four samples were secured with Henry HE913 Dot Stick Adhesive, and the second four samples were secured with ½-inch × 3-inch Shur-Tite Nylon Plugs and ½-inch × 3½-inch lag screws (with USS flat washers) in four corner holes as shown in Figure 31. The product resisted an average of 53 tire impacts. The product resisted an average of 26 bumper impacts. The product resisted a combined average of 39 tire and bumper impacts. Table 12 shows a summary of the results. The primary failure mode of the sample was exceeding the maximum allowable degree of lean.

Figure 31. 605601-6 Sample.

Table 12. 605601-6 Sample.

Shur-Flex		
	T	B
1	69	40
2	63	29
3	29	1
4	49	33
Average	53	26
Overall	39	

3.9 RESULTS

Table 13 shows the average number of impacts resisted by the tire, the average number of impacts resisted by the bumper, and the overall combined average number of tire and bumper impacts resisted for each sample. From the results shown in Table 13, the five samples tested should be ranked as follows:

1. Pexco Surface Mount City Post Sample – Epoxy Anchored.
2. Pexco Surface Mount City Post Sample – Mechanically Anchored.
3. Dura-Post Sample.
4. FG300 Sample.
5. Shur-Flex Surface Mount Sample.

The data show that both Pexco Surface Mount City Post samples (epoxy secured and mechanically secured) resisted the most overall and bumper impacts. The next highest performing product was the Dura-Post. The FG300 and Shur-Flex Surface Mount samples performed at a level significantly lower than the other three samples.

Table 13. Average Number of Impacts Resisted Summary Table.

Delineator	City Post - Mechanical	FG300	City Post - Epoxy	Dura-Post	Shur-Flex
Average (T)	180	95	178	200	53
Average (B)	128	14	145	81	26
Average (O)	154	54	161	141	39

CHAPTER 4. RECOMMENDATIONS

4.1. IMPACT DURABILITY TEST DATA

Recent impact testing under this project has produced data indicating the current durability of many top performing delineator products. The data include durability with respect to both a vehicle's tire and front bumper. A total of seven different delineators have been evaluated. Two of these products were preliminarily evaluated under Task 1 of the study and only represent a reasonable approximation of their performance. Figure 32 and Figure 33 compare the average number of tire impacts resisted, the average number of bumper impacts resisted, and the combined overall average number of tire and bumper impacts resisted for each delineator. Figure 32 shows a summary of the average number of impacts resisted for the delineators that were evaluated under Task 3. Figure 33 shows a summary of the average number of impacts resisted for the two delineators that were evaluate under Task 1.

4.2 PROPOSAL OF MINIMUM PERFORMANCE LIMITS

Under previous projects such as TTI/TxDOT 0-6772 (*1*), a minimum performance level was not set. The intent was to determine a normalized cost per impact by dividing the average number of impacts resisted into the combined material and installation cost of the product. This could allow for a cheaper, reasonably durable product to compete with a higher cost, more durable product. However, for the managed lane marker applications, it is advantageous to utilize higher durability products as it helps to reduce life cycle costs. Managed lane marker applications have a higher durability requirement due to the generally higher average daily traffic (ADT) and its reduced offset distance to high speed traffic. Additionally, these same attributes generally lead to higher risk to workers while repairing long installations of managed lane markers. For all the reasons previously mentioned, FDOT has requested that a requirement be developed to ensure that a minimum durability level is met in addition to the requirements mentioned in the testing standard proposed under Task 2.

To address this issue, TTI researchers have proposed setting a minimum limit on the average number of impacts resisted. The researchers propose a separate limit for both impact conditions: tire and bumper. The researchers recommend this as the performance of each is critical and want to ensure each is addressed. Additionally, it would be redundant to set a minimum limit on the overall average impact performance. While this value is important from a cost comparison standpoint, it would not provide additional evaluation of the product that is not already provided.

After an extensive evaluation of the data, the researchers recommend setting a minimum average of 150 tire impacts and a minimum average of 45 bumper impacts resisted. These minimum values would serve as an additional requirement that a product must meet in order to be considered for a managed lane marker application. These recommended values come directly from the data obtained while testing the products under Task 3 and represent the state of the possible.

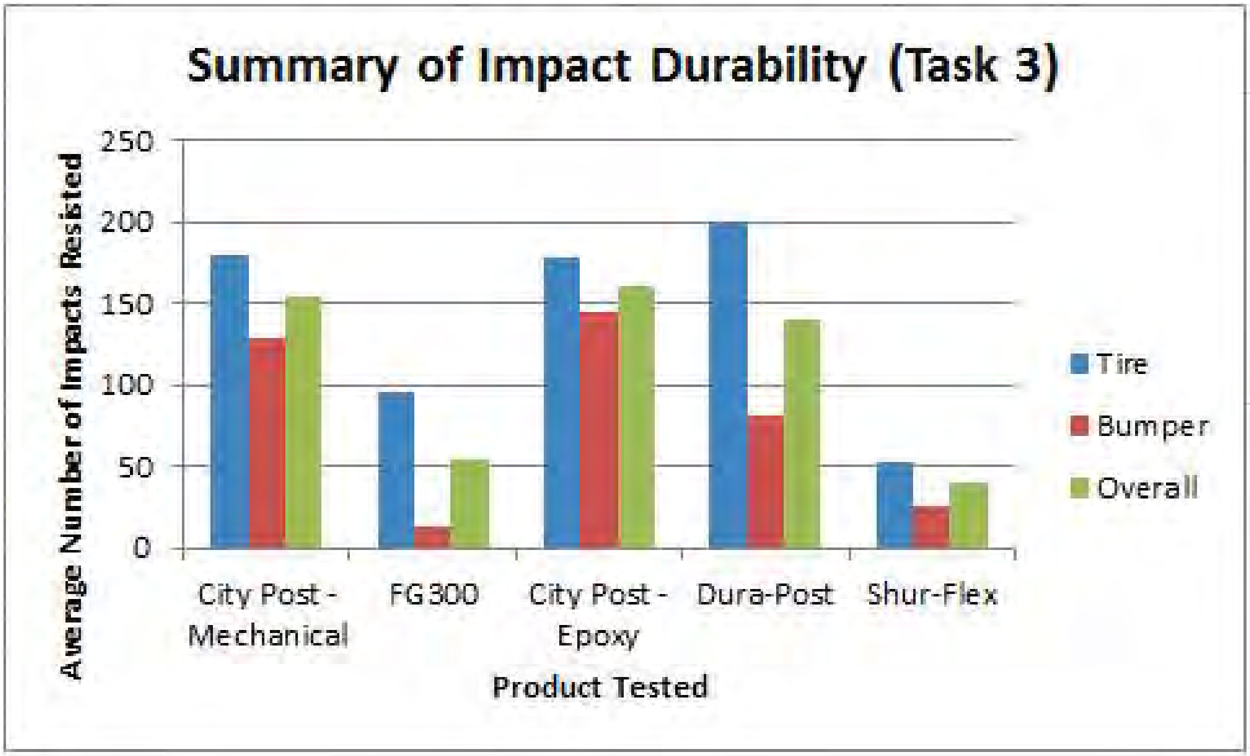

Figure 32. Summary of Impact Durability (Task 3).

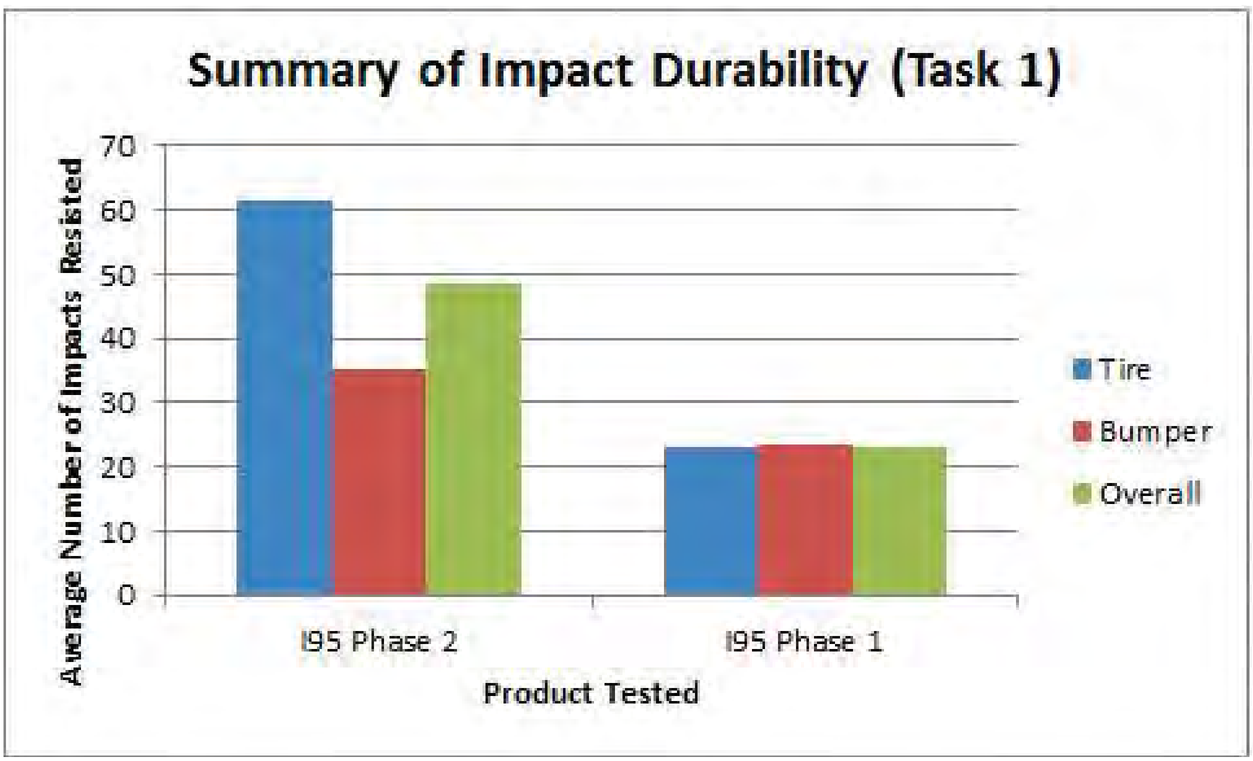

Figure 33. Summary of Impact Durability (Task 1).

When determining the minimum average number of tire impacts, the researchers looked at the performance of the test samples under Task 1 and Task 3. After looking at the data, there was a large gap between product performances. This created a reasonable and scientific reason to set a minimum performance level for tire impacts that separates the two performance levels. The researchers recommend that a minimum value of 150 impacts be used as a minimum average number of impacts to be resisted by an impacting vehicle tire. Figure 34 shows the average number of tire impacts resisted for each delineator compared to the recommended minimum value. The City Post (mechanically anchored), City Post (epoxy anchored), and Dura-Post (epoxy and mechanically anchored) samples all meet the minimum. The FG300, Shur-Flex, I95 Phase 1, and I95 Phase 2 products do not meet the minimum requirement.

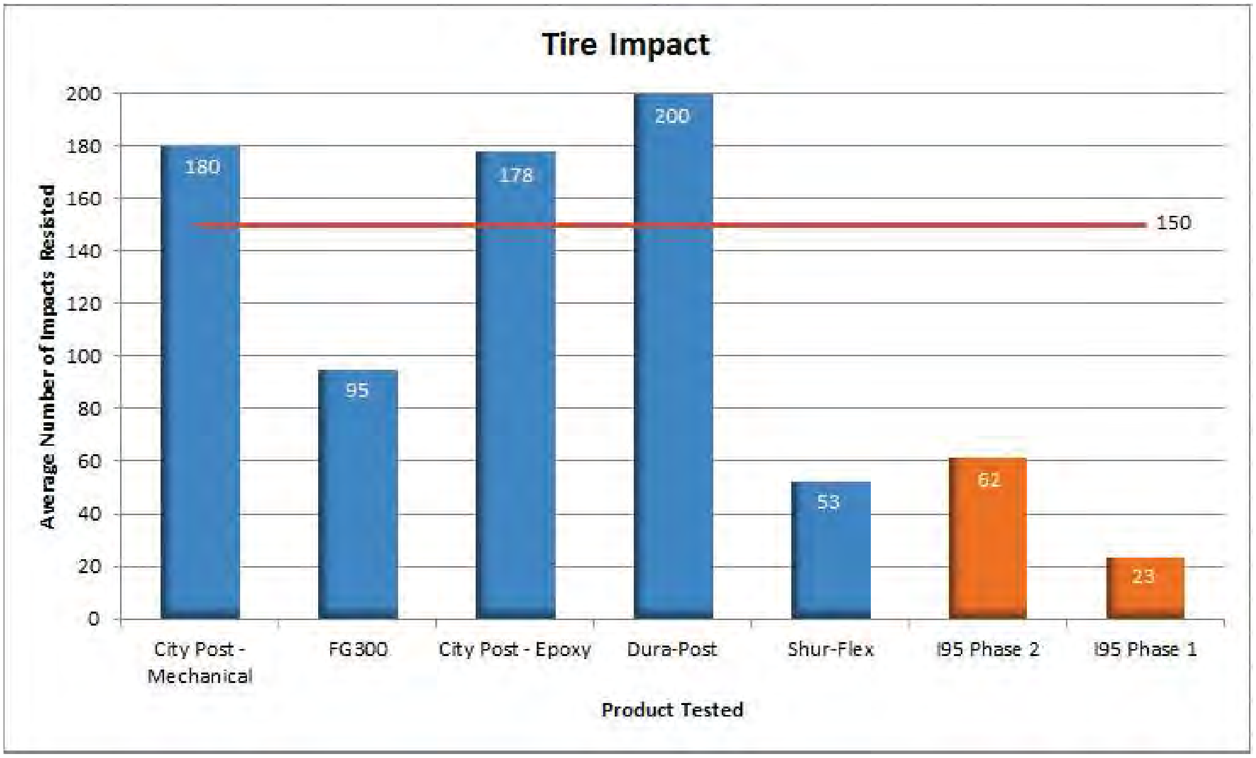

Figure 34. Average Number of Tire Impacts Resisted.

When evaluating impacts with the front bumper, a trend was witnessed. This time three rather than two groups of product performance were noticed. The best performing group included two products from Pexco and had a minimum impact performance of 128 impacts resisted. The third lowest performing group included the FG300, Shur-Flex, and I95 Phase 1 and 2 products. The third and final group was comprised by only 1 product, the Dura-Post. While the product did perform significantly better than the products found in the third group, it did not perform as well as the City-Post products.

During the process of evaluating the results, FDOT expressed a need to have a minimum of two manufactures products that meet the minimum performance level to maintain competitive bids. To address FDOT's requirements, the researchers recommend that a minimum average of 45 bumper impacts be used. Figure 35 shows the average number of bumper impacts resisted by each product compared to the recommended minimum value. Again the City Post (mechanically anchored), City Post (epoxy anchored), and Dura-Post (epoxy and mechanically anchored) samples all meet the minimum requirement. The FG300, Shur-Flex, I95 Phase 1, and I95 Phase 2 products do not meet the minimum requirement.

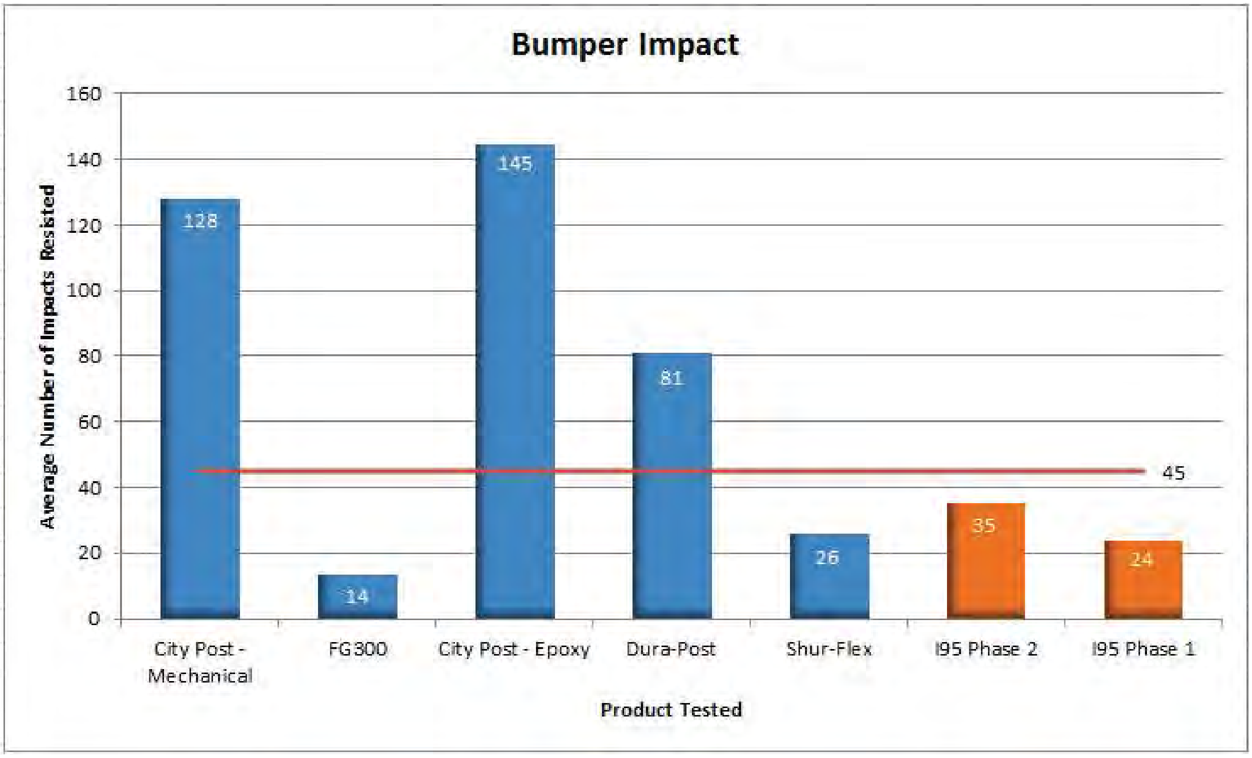

Figure 35. Average Number of Bumper Impacts Resisted.

Finally, the average overall impact performance of the delineator should exceed 98 impacts resisted. This value represents the average of the tire (150) and bumper (45) impacts resisted. Figure 36 shows the overall average number of impacts resisted for each product compared to the secondary limit of 98 impacts. As expected the City Post (mechanically anchored), City Post (epoxy anchored), and Dura-Post (epoxy and mechanically anchored) samples all meet the secondary limit. The FG300, Shur-Flex, I95 Phase 1, and I95 Phase 2 products do not meet the secondary limit.

The three minimum requirements previously mentioned (150 – tire, 45 – bumper, 98 – overall) are recommended by the researchers for testing completed on a concrete pavement surface. Further testing will need to be performed on an asphalt surface in order to establish a minimum number of tire, bumper, and overall impacts for delineators installed on an asphalt surfaces.

One major requirement of this standard of testing is repeatability. Researchers previously tested the Dura-Post delineator during summer 2013 and 2014 under TTI/TxDOT Project #0-6772 (*1*). These tests maintained the exact same conditions as the 2016 test with two exceptions. The first exception is that the testing performed in summer of 2013 was completed with only four samples. This is only half the number of samples required under the current method. The second exception is that the temperatures at the time of testing varied significantly when compared to the testing performed in 2016. During the 2013 and 2014 tests, the temperature was in excess of 85°F; however, the ambient temperature was at or just above 65°F through the duration of the testing performed in 2016.

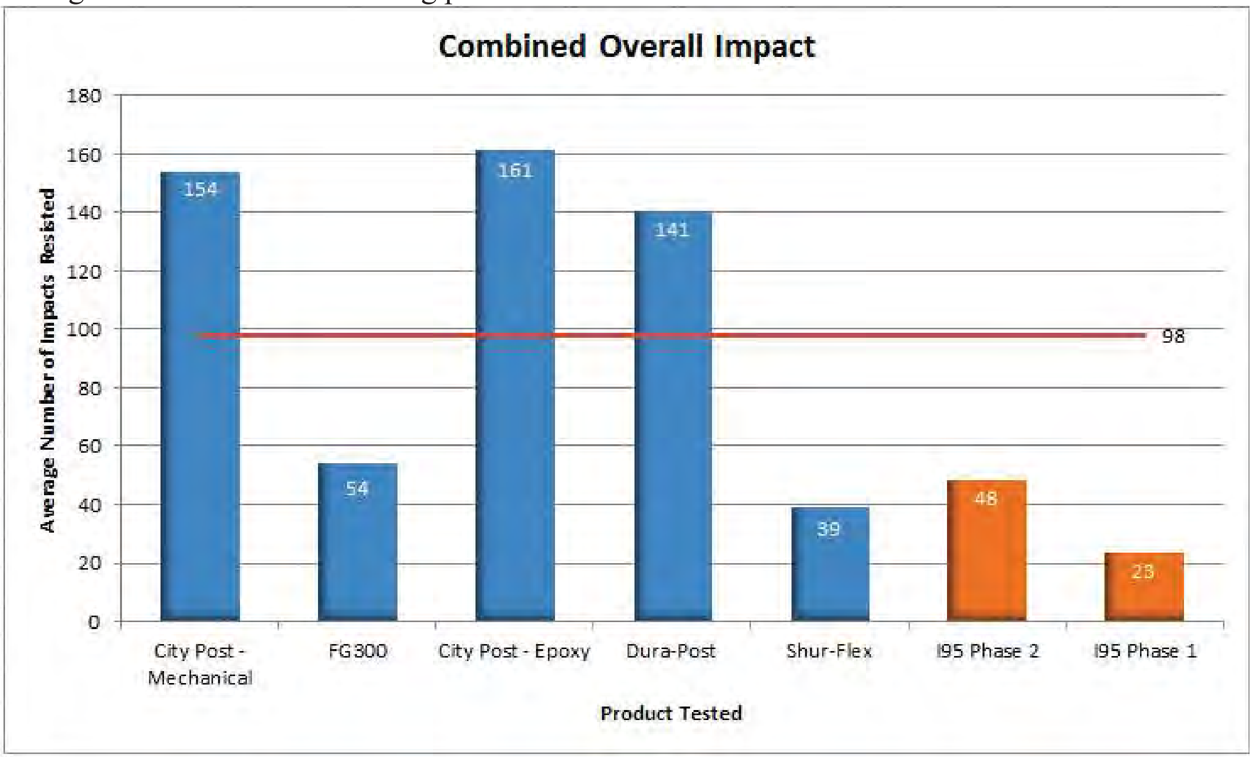

Figure 36. Combined Overall Average Number of Impacts Resisted.

4.3 REPEATABILITY AND TEMPERATURE EFFECTS

Figure 37 through Figure 39 show the average number of tire, bumper, and overall impacts resisted by the Dura-Post during each of these tests. It is shown that the number of impacts resisted in the 2013 and 2014 tests are significantly lower than the number of impacts resisted in the 2016 test. This shows variability in the performance of the products tested based on ambient temperature that has to be considered.

To address this inherent variability, the minimum average number of impacts resisted was shifted lower to accommodate the variability in testing conditions. Figure 37 through Figure 39 indicate how the minimum values were selected to ensure that the Dura-Post and City-Post meet the minimum requirement within a reasonable temperature range for testing under this standard. Additionally, Figure 39 indicates why the minimum value for the average number of bumper impacts resisted is recommended to be much lower than the values witnessed in the 2016 testing.

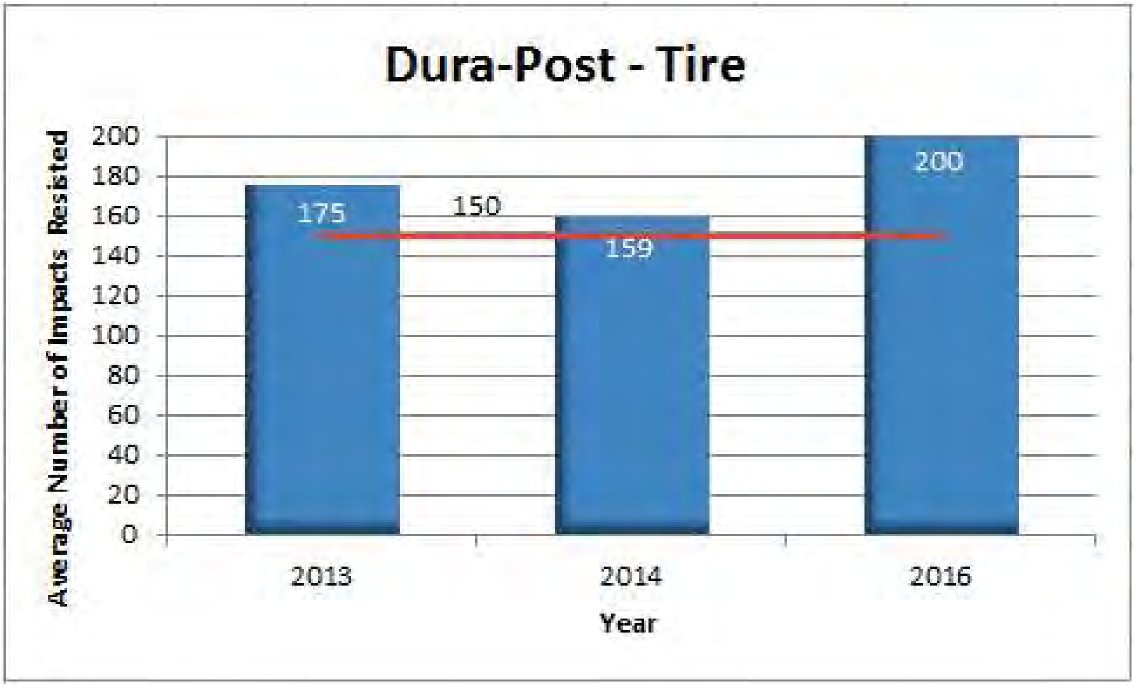

Figure 37. Average Number of Tire Impacts Resisted.

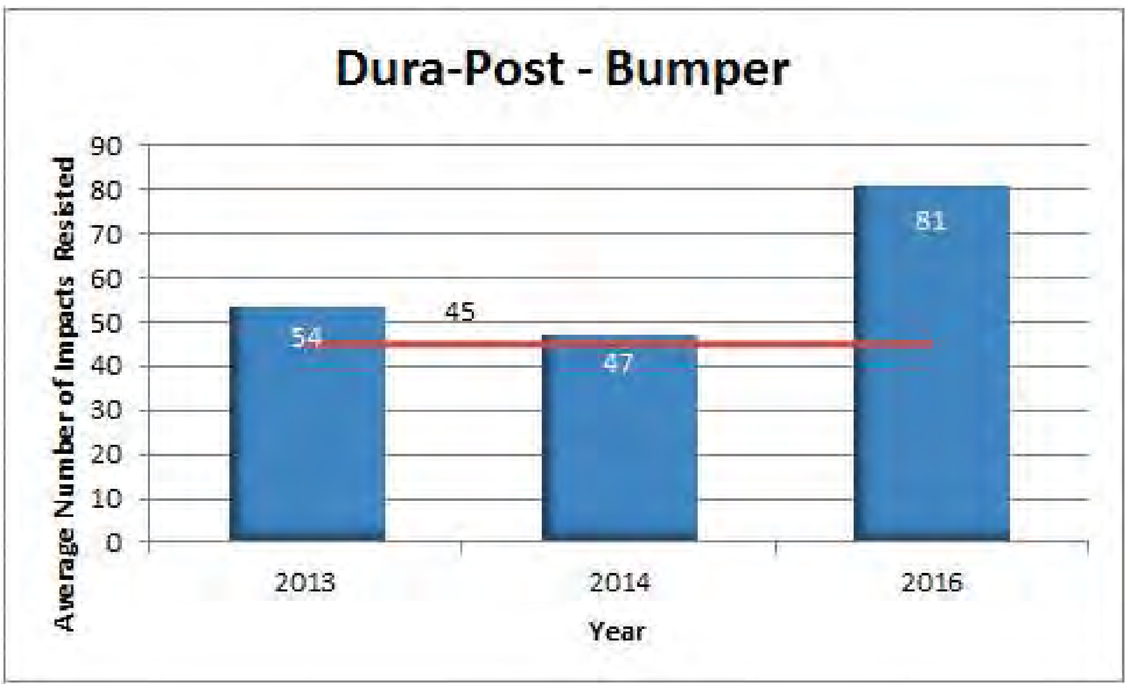

Figure 38. Average Number of Bumper Impacts Resisted.

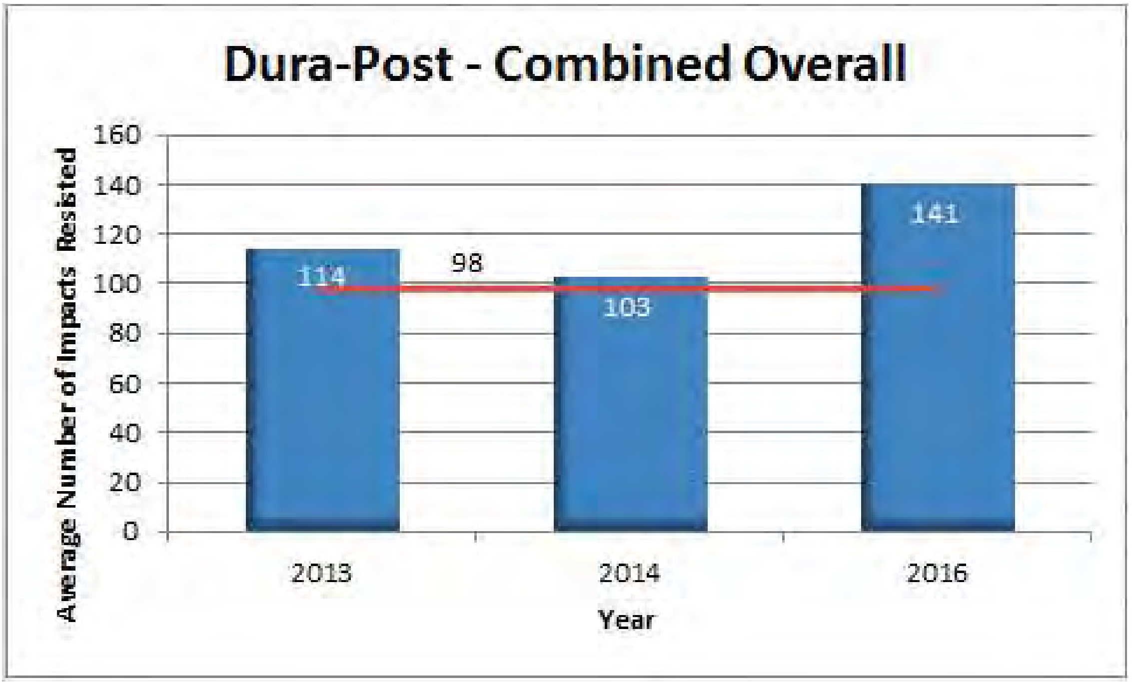

Figure 39. Combined Overall Average Number of Impacts Resisted.

4.4 IMPORTANCE OF TIRE versus BUMPER IMPACT PERFORMANCE

When comparing the results of one product to another the researchers recommend an order of importance. The most important measure of durability is the average number of front bumper impacts resisted. This is due to the nature of how the delineators will be impacted in real world application. These managed lane markers will be used to separate the managed lane from the unmanaged lanes. Many of these managed lanes carry a toll for their use. Traditionally a driver will impact a managed lane marker for one of the following reasons, listed in perceived frequency of occurrence given results of Task 1 inspection of I-95 installation:

1. A driver will be in the toll lane and decide to cross over to the unmanaged lane in order to avoid paying the toll. While this can occur anywhere along the length of the installation, it is generally localized to the beginning of the tolled facility and in advance of a toll reader.
2. A driver will be in the unmanaged lane and decide to cross over in order to get on to the toll facility. This is generally to escape congestion. While this can occur anywhere along the length of the installation, it is generally localized to the beginning of the tolled facility and downstream of a toll reader.
3. A driver, as they approach the beginning of the managed lane facility or an interchange location, will make a last second decision to either leave or enter the facility. There are many causes of this type of impact: driver inattentiveness, driver confusion, traffic volume, and/or lack of sufficient notice or information for driver to make a lane choice.
4. A driver will be in one of the lanes (either managed or unmanaged) and begin to drift toward the managed lane markers. After impacting the delineators with one side of

the vehicle, the driver will correct their course and continue driving in their respective lane.

The front bumper of the car makes up the majority of the front end of the impacting vehicle. As the front of the vehicle is the primary portion of the car that interacts with the managed lane markers, it would be reasonable to expect that the bumper impacts could make up a significantly higher number of impacts resisted in the field. In the first three scenarios, the bumper would be very likely to interact with the managed lane marker as it transitions from one side to the other. In the fourth scenario, it is more likely that the tire will constitute the majority of impacts, but there is still a chance that the bumper will be impacted depending on the degree of interaction with the installation. Considering these four cases, there is a higher probability that managed lane markers interact with the front bumper of the impacting vehicle.

To compound the situation, the average number for bumper impacts resisted is almost always significantly lower than average number of tire impacts resisted. This disparity in impact performance is directly related to the way that the managed lane markers interact with the vehicle. Modern vehicles have slightly curved front bumpers. The curvature is generally more pronounced near either side of the vehicle (tire impact locations). The curvature of the bumper causes an impacted managed lane marker to deflect away from the vehicle, rather than wrap around the bumper and stick to the hood. The act of wrapping around and sticking to the hood causes the managed lane marker to be pulled against its base and anchorage connections. This effect is lessened significantly during a tire impact as the managed lane marker is deflected away from these areas. This additional tension stress on the post, base connection, and anchorage leads to a premature failure when compared to a tire impact.

Since the bumper impact is considered generally more severe and has a higher probability of occurrence, it leads the researchers to consider it the most important evaluation criteria of a managed lane marker's durability. The second most important measure of durability to consider is the overall average number of impacts resisted, as it accounts for both. The least important to consider, is the average number of tire impacts resisted as it proportionally constitutes a lower proportion of real world impacts. Additionally, as many of the products have successfully resisted 200 tire impacts, it is not truly known how many current designs can resist. For this reason, a reasonable comparison of tire impact durability cannot be made as the true durability is unknown.

4.5 DURABILITY OF DELINEATORS

The durability of delineators should be considered when selecting a product. Table 14 shows data from three different projects where Pexco delineators were installed on various tollways. The data was taken from presentations provided by Pexco to FDOT district management. TTI did not request similar data from other manufactures as this was not a primary focus of the research tasks. Results may vary depending on product design, cost, and location of installation. Table 14 compares the replacement rate (calculated by dividing the number of posts replaced per year by the total number of posts installed) and the average annual cost to replace damaged delineators. As the number of posts needed to be replaced increases, the annual cost to replace damaged delineators increases as well. Figure 40 shows the replacement rate compared to the average number of tire impacts, bumper impacts, and overall average number of impacts resisted. As the replacement rate increases, the number of impacts withstood decreases, further supporting the correlation seen in Table 14.

4.6 SUMMARY OF RESULTS

Looking at the data shown in Figure 34 through Figure 39, there is a considerable gap between the quality of the top three delineators and the other four. This led the researchers to recommend a minimum average number of 150 tire impacts and 45 bumper impacts resisted as a pass fail criteria for managed lane marker durability requirements. These requirements will serve as a reasonable minimum requirement ensuring that quality products meet a minimum threshold of performance. As the values are based on product testing, it ensures the requirements are an obtainable value for companies who intend to market their product for this application.

To implement this requirement, the minimum values would first need to be established based on the recommendation of the researchers. Companies whose delineators are being considered would have to be tested according to the proposed test method in Task 2 and meet these two additional impact performance requirements. With the data provided from this testing, FDOT can make a more informed decision on which product should be selected for install.

4.7 MINIMUM DURABILITY REQUIREMENT SPECIFICATION

The researchers developed the following minimum requirement specification to ensure compliance according to the recommendations found within this report. This specification will help to ensure that the proper and more durable product is selected to be placed on FDOT roadways:

4. **PURPOSE**
   To define a set of standards (a minimum requirement) that products must meet in order to be considered for use by FDOT.
5. **BACKGROUND**
   This standard was developed to provide an obtainable requirement for companies who are marketing their product to be considered by FDOT.
6. **MINIMUM REQUIREMENT**
   These specifications are necessary to increase the performance of delineator products and save resources for FDOT.
   - 3.8 Tire Impact Requirement
     Delineator posts must be able to withstand a minimum of 150 impacts from the tire of the vehicle.
   - 3.9 Bumper Impact Requirement
     Delineator posts must be able to withstand a minimum of 45 impacts from the front bumper of the vehicle.
   - 3.10 Pass Criteria
     Delineator posts must meet both requirements mentioned above to be considered for use.

Table 14. Durability of Posts and Speed Limit.

Product	Distance of Installation (miles)	Total Number of Posts Installed	Spacing (feet)	Average Number of Posts Replaced	Average Annual Cost to Replace	365-Day (Annual) Replacement Rate (%)	Speed Limit (MPH)
Pexco FG300 UR 36"	9	15840	6	1667	$75,000.00	10.5	65
Pexco EFX 36"	10	13200	8	750	$65,000.00	5.7	65
Pexco City Post Surface Mount	0.5	405	10	0	$0.00	0.0	70

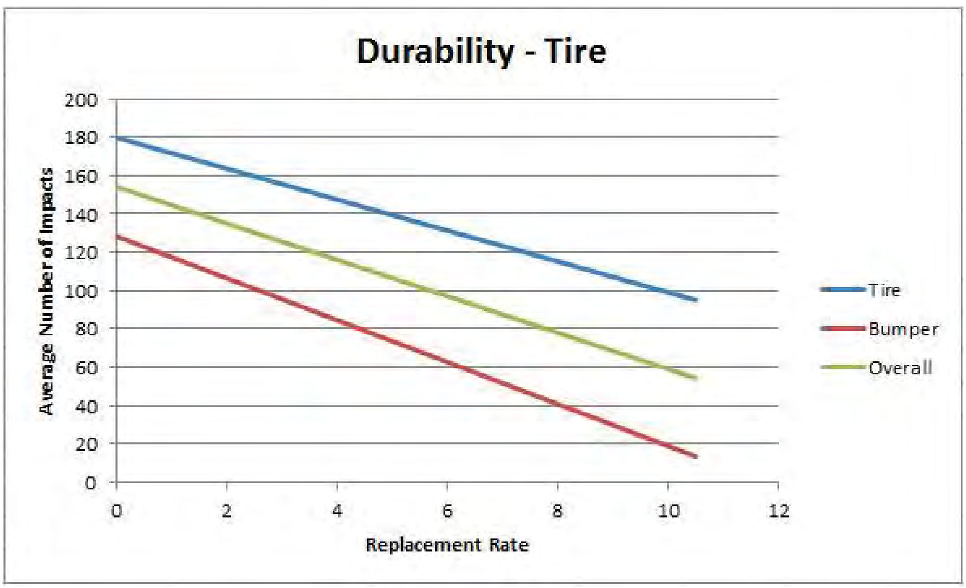

Figure 40. Durability of Delineators.

4.8 SUMMARY OF STANDARD TESTING PROCEDURE

Delineators under consideration must be installed on a concrete pavement surface at a laboratory listed on FHWA's list of "Laboratories Accredited to Crash Test Roadside Safety Hardware." Each test deck should consist of eight samples installed in two parallel lines with four samples in each line. A max of 200 vehicle impacts per sample should be performed. A tire impact should be performed by the vehicle impacting the sample with the centerline of the sample aligned with the centerline of the vehicle tire. A bumper impact should be performed by the vehicle impacting the sample with the front bumper at the ⅓-point of the vehicle. To pass the testing criteria, the delineators must meet two minimum requirements for the average number of tire and bumper impacts withstood. The delineators must be able to withstand 150 tire impacts and 45 bumper impacts. Additional testing must be performed to develop a minimum requirement for delineators tested on an asphalt surface.

4.9 RECOMMENDATIONS FOR SELECTION OF PRODUCT

After developing a list of products that meet the minimum requirements stated above, FDOT will be tasked with selecting which of these products to install in individual installations. The researchers recommend choosing a delineator that has the highest average number of tire and overall (tire and bumper) impacts resisted. Again, when selecting a product one could use the normalized cost formula specified by equation 4.1.

$$\frac{Product\ Cost + Install\ cost}{Average\ Overall\ Impacts\ Resisted} = Normalized\ Cost\ per\ Impact \qquad (4.1)$$

4.10 FUTURE CHANGES TO MINIMUM REQUIREMENTS

As discussed previously, the City-Post performed noticeably better than the Dura-Post when impacted by the vehicle bumper. As stated before, it is the researcher's opinion that the bumper impact is the more critical of the two impact evaluations. As previously discussed, it was FDOT's desire to have more than one manufacture that meets the minimum requirements to maintain a competitive bid situation. That being said, there is room for improvement as shown by the performance of the City-Post system. To give emphasis on the need to improve the performance of the product, it is the recommendation that the minimum average number of bumper impacts resisted be increased to 100 impacts after a period of 3 years after this report is released (increase by August 2019). This will give other manufactures ample time to develop and test new or revised products to meet the increased performance requirement. Additionally the tire and bumper impact performance requirements should be revaluated on a regular basis to determine if the requirement should be further increased as product performance improves.

REFERENCES

1. D. R. Arrington, L. Theiss, R. A. Zimmer, and W. L. Menges. *Development of Delineator Testing Standard*. Report No. 0-6772-1, Texas A&M Transportation Institute, College Station, TX, February 2015.

APPENDIX A. PHOTO DOCUMENTATION FOR INITIAL TESTING

Figure A-1 through Figure A-16 show each delineator sample at failure.

Figure A-1. Sample 1T Failure at 53 Impacts.

Figure A-2. Sample 1B Failure at 27 Impacts.

Figure A-3. Sample 2T Failure at 66 Impacts.

Figure A-4. Sample 2B Failure at 44 Impacts.

Figure A-5. Sample 3T Failure at 71 Impacts.

Figure A-6. Sample 3B Failure at 28 Impacts.

Figure A-7. Sample 4T Failure at 56 Impacts.

Figure A-8. Sample 4B Failure at 42 Impacts.

Figure A-9. Sample 5T Failure at 32 Impacts.

Figure A-10. Sample 5B Failure at 21 Impacts.

Figure A-11. Sample 6T Failure at 25 Impacts.

Figure A-12. Sample 6B Failure at 29 Impacts.

Figure A-13. Sample 7T Failure at 29 Impacts.

Figure A-14. Sample 7B Failure at 18 Impacts.

Figure A-15. Sample 8T Failure at 6 Impacts.

Figure A-16. Sample 8B Failure at 28 Impacts.

APPENDIX B. IMPACT TESTING OF MANAGED LANE MARKERS

1.1 PURPOSE

To define standard method for evaluating a managed lane marker's impact performance with the intention of qualifying products that will minimize long-term maintenance costs.

1.2 AUTHORITY

Section xxx.xxx(x), Florida Statutes

1.3 SCOPE

Primary offices affected by this procedure include the State Materials Office (SMO), State Construction Office (SCO), District Construction Offices (DCO), District Materials Offices (DMO), and Resident Construction Offices (RCO).

1.4 BACKGROUND

This standard was developed to provide a fair, efficient, and repeatable method of evaluating the impact performance of a Managed Lane Marker.

1.4.1 I-95 Managed Lane Installation Study

The standard was developed to produce failure modes witnessed in Florida Department of Transportation's (FDOT) managed lane applications in Districts (4 and 6). The initial products installed on the I-95managed lanes in District 6 were being replaced approximately 5 times per year. This has led to high maintenance and replacement costs.

1.4.2 Previous Texas Department of Transportation (TxDOT) Research

TxDOT project number 0-6772 focused on developing a new method of evaluating delineator impact performance which exceeds the standard method developed by the National Transportation Product Evaluation Program (NTPEP) Temporary Traffic Control Devices (TTCD) Technical Committee. The method includes various impact severities based on the specific applications in which the delineators would be utilized.

Under this project, the researchers investigated delineator failure modes and, with TxDOT guidance, developed a test method for reproducing those failure modes in an efficient and repeatable manner. The researchers then performed testing on several different products to evaluate the effectiveness and repeatability of the procedure.

This project resulted in proposed impact testing standards for three applications of delineators. The first application, named Low Durability Side of Roadway Applications, is an updated version of the NTPEP TTCD Technical Committee's method which utilizes only 10 impacts at 55 mph. The proposed standard defined the test vehicle specifications and allowable vehicle modifications to resist impacts of test samples. The second application, named High Durability Metropolitan Delineator Applications, increases the maximum number of impacts to 200 but still maintain an impact speed of 55 mph. The third application, named High Speed High Durability Application, utilizes a maximum of 200 impacts and an impact speed of 70 mph.

1.4.3 FDOT Research Study

Understanding the elevated durability requirements associated with Managed Lane Marker applications, FDOT wanted to develop a durability standard to evaluate products in this application. The research was intended to build upon the High Speed High Durability Application test method documented in TxDOT 0-6772-1 project report, titled Development of Delineator Testing Standard. Under the FDOT project BDR74 977-06, the researchers documented failure modes and replacement rates associated with managed lane marker applications and performed impact testing on the products. The results showed that the recommended procedures adequately reproduced the failure modes found in the managed lane marker installations. This test method is the result of those findings.

1.5 Managed Lane Marker Specifications

These specifications are necessary to unify critical design and aesthetic properties of the managed lane markers.

1.5.1 Dimension Requirements

The post shall have a minimum width of 2 inches perpendicular to traffic flow and of such length to generally provide a height of 36 inches above the pavement surface.

1.5.2 Color Requirements

The post shall be opaque white. The yellowness index shall not exceed 12 when tested in accordance with ASTM D1925 or ASTM E313. The daylight 45 degree, 0 degree luminous directional reflectance shall be a minimum of 70 when tested in accordance with ASTM E1347.

1.5.3 Reflective Sheeting Requirements

The reflective sheeting shall be Types IV or V and meet the requirements of Section 994 and shall be constructed of a reboundable material as defined in ASTM D4956 S2. The reflective sheeting shall have a minimum width of 3 inches and have a minimum projected area of 18 square inches.

1.5.4 Attachment Method

Attachment methods are not restricted. Each attachment method and product will be individually considered, tested, and qualified.

1.6 Impact Testing

All products shall be individually tested and qualified at an approved testing facility. All products must be tested using the same post, base, attachment method, hardware, and epoxy that will be used in the field. Testing facilities will follow testing methodology described herein.

1.6.1 Approved Testing Facilities

Testing shall be performed by a laboratory listed on FHWA's list of "Laboratories Accredited to Crash Test Roadside Safety Hardware." A full list of approved labs can be found on FHWA's website at: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/laboratories/.

1.6.2 Samples

A minimum number of 9 samples will be randomly selected and submitted to the selected lab for evaluation. One sample will be used for dimensional verification and material properties testing. Generic drawings and material specifications will be submitted along with samples.

1.6.3 Drawings

Generic drawings shall be provided. The generic drawings of the product shall include the following minimum dimensions: overall height, post wall thickness, post diameter, attachment method, base diameter, and base height.

1.6.4 Verification of Material and Dimensional Properties

One sample will be randomly selected for additional destructive lab testing to verify/document material and dimensional properties.

1.6.4.1 Dimensional Verification

One sample will be utilized to verify that the product is constructed according to drawings provided and to gather additional dimensional information that may not have been provided in generic drawings.

1.6.4.2 Material Property Testing

The same sample used for dimensional verification will be utilized for destructive testing to document material and physical properties of post. Below is a list of laboratory tests to be performed:

Test Name	ASTM Number	Criteria
ASH Test	D5630	Documentation Only
Density and Specific Gravity	D792	Documentation Only
Tensile Strength & Elongation	D638-08	Documentation Only
Accelerated Weathering	G154-06	Documentation Only
Yellowness Index	D1925 or E313	See Section 1.5.2
Daylight Luminance	E1347	See Section 1.5.2

1.6.4.3 Attachment Methods

All attachment methods/products shall be evaluated for impact performance. The evaluation is product specific and equivalencies are not permitted. A minimum of 4 samples of each product shall be impact tested.

1.6.4.4 Reflective Sheeting

All reflective sheeting shall be evaluated for impact performance. The evaluation is product specific and equivalencies are not permitted. A minimum of 4 samples of each sheeting material shall be impact tested.

1.6.5 Installation

This section describes how the test installation shall be constructed. Samples should be grouped together by product model, attachment method, and by sheeting type to ease evaluation.

1.6.5.1 Vertical Installation Tolerance

All samples shall be installed to within 1 degree of vertical prior to first impact.

1.6.5.2 Wheel Over Impacts

Half of the samples shall be installed such that the impact vehicle's front tire will traverse the base as the vehicle passes.

1.6.5.3 Bumper Impacts

Half of the samples shall be installed such that the impacting vehicle's bumper will contact the post as the vehicle passes over without the base or post coming in contact with the tire.

1.6.5.4 Orientation of Samples

Manufacturer has the option of defining the front face (0 deg) of the sample. If the manufacturer does not define the front face, then the lab will use reasonable judgement to determine the front face. Half of the Bumper and half of the Wheel Over impact samples will be installed with the front face perpendicular to the path of the impacting vehicle (0 deg). The remaining samples will be rotated 25 degrees. The testing lab will determine which direction of rotation (clockwise or counterclockwise) is more critical. Impact testing will be performed on the more critical direction of rotation. The lab will evaluate the effect of bumper interaction with the post and base. The samples will be installed such that the more critical orientation is tested. The more critical orientation is one that potentially induces more interaction with the vehicle and presents the higher risk of sample failure during testing.

1.6.5.5 Multiple Configurations of Samples

If multiple configurations of the same product are tested (i.e. different attachment methods or sheeting,) an equal number of bumper and wheel over samples shall be installed for each configuration. Additionally, an equal number of 0 deg and 25deg samples shall be installed for each configuration.

1.6.5.6 Spacing of Samples

Samples will be installed in two parallel lines. One line will correspond to bumper impacts and the other will correspond to Wheel Over impacts. The spacing of these lines will be determined by testing laboratory and shall ensure no interaction between any two samples on the test deck.

1.6.6 Test Vehicle

The test vehicle should meet 1100C requirements set in current Manual for Assessing Safety Hardware (MASH) with the following exceptions. The vehicle model year shall be within 10 model years of the date the test is performed. No vehicle instrumentation is required. Vehicle modifications described in TxDOT Report 0-6772-1 shall be followed. Additional modifications are allowed if it can be reasonably demonstrated that they will not adversely impact the results of the testing.

1.6.7 Impact Conditions

For repeatability and for unification of impact conditions across multiple products, all testing shall be performed under the following conditions.

1.6.7.1 Temperature

All impacts shall occur at an ambient temperature at or above 65 degrees Fahrenheit.

1.6.7.2 Impact speed

All impacts shall occur at a target impact speed of 70 mph ± 5 mph. A test sequence that has 60% or more of impacts less than 70 miles per hour should be considered invalid.

1.6.7.3 Evaluation Criteria

The lab monitor and document list/lean, damage to post/base, damage to reflective sheeting, and failure to restore to an upright position.

1.6.7.4 Sample Failure Criteria

A sample shall be considered failed should it fail to restore to within 15 degrees of vertical in **any direction**. The sample should also be considered failed should the sample rupture (>50% of cross section) or should it become detached from the test surface (partially or fully). The lab shall observe the performance of the samples during testing and shall halt testing should a sample appear to not restore to within 15 degrees of vertical. Samples are allowed up to 5 minutes after the last impact to fully restore. Testing shall be postponed until all samples are deemed within 15 degrees of vertical or the suspect sample is deemed failed.

1.6.7.5 Sheeting

While there is no specific requirement for sheeting performance, the performance and abrasion resistance shall be documented through photos as described in Section 1.6.9.

1.6.8 Documentation

The following categories define the minimum amount of documentation required to be provided as part of the report or in addition to the report. Additional information can be provided should the manufacturer or testing laboratory desire to do so. Samples should be numbered such that a reviewer can easily determine which product is being reviewed and whether the product is being impacted by the vehicle bumper or tire. All sample components should be labeled using this numbering method to aid in identifying samples after testing is completed (should further study be required).

1.6.8.1 Material Classification

Generic material properties provided by manufacturer shall be included in the report.

1.6.8.2 Drawings

Generic drawings as described in Section 1.6.3 shall be included in the report.

1.6.8.3 Material Property Testing Results

All material property testing reports shall be included in the report.

1.6.8.4 Video Documentation

Standard rate video shall be provided to document each impact performed. The impact number shall appear within view of the camera and shall not be added to the view after testing has been completed using video editing techniques. Failure to comply with this requirement will invalidate the testing results.

1.6.8.5 Photo Documentation

Extensive photo documentation shall be performed during testing. This includes documentation of the test installation, test vehicle, and test samples after the following impact numbers:

Prior to 1st impact
After 1st impact
After 5th impact
After 10th impact
After 50th impact
After100th impact
After150th impact
After200th impact

Upon failure of any test sample, testing shall stop and the condition of the sample at the time of failure shall be documented. When documenting each sample the following photos should be taken: photo of identifying label for test sample, frontal face of sample, any newly observed damaged to sample, and a close up image of the reflective sheeting to document sheeting loss or damage.

1.6.8.6 Photo Table

A table of photos shall be included in the report for each sample tested. Each table should include an image of the frontal face of the sample, any newly discovered damage to the sample, and a close up image of the reflective sheeting. This table shall have an entry for each of the impacts described in Section 1.6.9.5 of this standard.

1.6.8.7 Written Documentation

A written test log should be maintained documenting the progression of the testing and documenting any failures.

1.6.8.7.1 List/Lean

A log of list and lean shall be maintained for inclusion in test report. List/lean shall be measured as shown in Figure B1 below. List and lean shall be documented after the following impacts:

- Prior to 1st impact
- After 1st impact
- After 10th impact
- After 100th impact
- After 200th impact

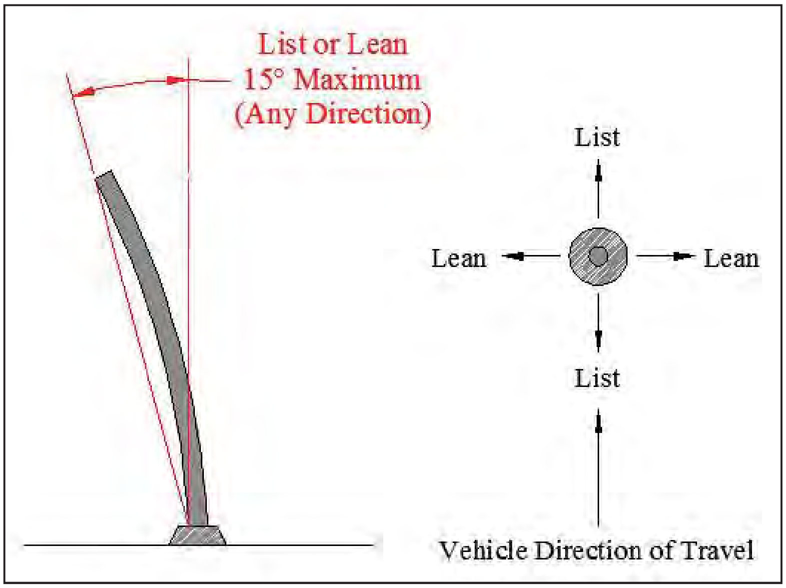

Figure B41. Measurement of List/Lean.

1.6.8.7.2 Damage to Test Sample

A log of damage to samples should be maintained and shall include the impact number when the failure occurred and a description of the failure mode.

1.6.8.8 Average Number of Impacts Resisted

The testing lab shall calculate an average number of impacts resisted for: all samples, bumper impacts only, and wheel over impacts only. The resulting numbers shall be included in the final report.

1.7 Reevaluation

Should impact testing result in product performance that the lab or manufacturer feels is a not a fair representation of the product's actual performance; the manufacturer has the option of resubmitting the product for reevaluation. The product can be reevaluated only one time without a significant change to address failures modes witnessed in previous testing. When reevaluating impact performance of a product, a minimum of 9 samples of each attachment method and sheeting, shall be evaluated.

1.8 Requalification

As impact durability of managed lane markers is directly tied to the profile and design of the impacting vehicle's bumper, it is recommended that products be requalified every 10 years.