IMPLEMENTATION AND EVALUATION OF TRAFFIC MARKING RECESSES FOR APPLICATION OF THERMOPLASTIC PAVEMENT MARKINGS ON MODIFIED OPEN GRADED FRICTION COURSE

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16. Abstract

Snow plow blade abrasion is the most noticeable mechanism of damage to all types of pavement marking materials, with the worst effect occurring with thermoplastic skip stripes on open graded friction course (OGFC). Unfortunately, the thermoplastic markings are extruded onto the OGFC at a 1/8 inch thickness, which becomes a substantial target for snow plow blade damage during the winter maintenance season. In some cases the scraping action of the snow plow blades shear off the thermoplastic markings or pull out pieces of the OGFC layers, penetrated by the thermoplastic.

If thermoplastic markings are applied to a constructed recess in the pavement surface, the snow plow blades would pass over without damaging either the marking and/or the pavement surface. Therefore, this study explored the best means of creating traffic marking recesses on modified OGFC mixes and the cost effectiveness of this method.

A trial field installation of this method was carried out with the cooperation of a contractor. Detailed construction specifications were developed and included application methods and equipment, for use by any state highway agency (SHA). The installation consisted of a 1,000 ft tangent section, a 500 ft exit ramp section, and a 500 ft curved section. Three types of recesses and a non recessed control section were constructed within each test section. A new pavement marking product, permanent inlaid tape, used by the RIDOT just outside the limits of the three test sections was also incorporated into the present study.

17. Key Words
Recessed Pavement Markings, Thermoplastic, Open Graded Friction Course, Retroreflectivity

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Preface

This is the final report of the research project, entitled "Implementation and Evaluation of Traffic Marking Recesses for the Application of Thermoplastic Pavement Markings on Modified Open Graded Mixes." The goal was to explore the best means of creating traffic marking recesses on modified OGFC mixes, install and evaluate test sections of the traffic marking recesses, and evaluated the cost and cost effectiveness of this new method of pavement marking.

This research project was conducted by the Department of Civil and Environmental Engineering at the University of Rhode Island (URI) in conjunction with Cardi Corporation. The work presented herein was accomplished by a team including Dr. K. Wayne Lee, Mr. Stephen A. Cardi, II, and Mr. Sean Corrigan. We would also like to acknowledge the assistance provided by the faculty, staff and students in the Department of Civil and Environmental Engineering at URI.

The development of this project could not have occurred without the cooperation and encouragement the members of the technical committee, particularly the chairperson, Ms. Despina Metakos. Dr. Charles E. Dougan, Mr. Colin A. Franco and Mr. Gerald M. McCarthy also provided essential continuing support and assistance throughout the program.

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CHAPTER 1. INTRODUCTION

1.1 Problem Statement

Snow plow blade abrasion is the most noticeable mechanism of damage to all types of pavement marking materials, with the worst effect occurring with thermoplastic skip stripes on open graded friction course (OGFC). Thermoplastic is applied as a hot liquid (400°F-440°F) to the porous OGFC and easily penetrates the asphalt material. The thermoplastic then cools and solidifies to form a deep, strong bond with the asphalt pavement surface. Unfortunately, the thermoplastic markings are extruded onto the OGFC at a 1/8 inch thickness, which becomes a substantial target for snow plow blade damage during the winter maintenance season. In some cases the scraping action of the snow plow blades shear off the thermoplastic markings or pull out pieces of the OGFC layers, penetrated by the thermoplastic. This problem has been well documented as illustrated in Appendix A by the Providence Journal-Bulletin article entitled, "Material Shows It's True Stripes as Asphalt Foe".

If thermoplastic markings are applied to a constructed recess in the pavement surface, the snow plow blades would pass over without damaging either the marking and/or the pavement surface.

1.2 Significance of the Study

Roadway delineation is essential for the safe, effective guidance of the driver. Pavement markings used on high speed roads with heavy traffic volume, must be highly durable and reflective to enhance traffic control, safety, and driving comfort. Thermoplastic has proven to be extremely cost effective in the Southern areas of the country, because it provides a long service life and a sustained level of reflectivity throughout the service life. However, the thickness of the applied markings deters highway agencies in the snow-belt region from using durable and reflective thermoplastic markings, due to the effect of snow plow damage.

There have been many documented attempts to find a traffic marking system which minimizes the effect of snow plow damage. These studies include recessed raised pavement markers (RPMs), snow plowable RPMs, and inlaid preformed marking tape, but have obtained mixed results. Furthermore, there have been no attempts to study the effectiveness of recessed thermoplastic markings on modified OGFC mixes in reducing snow plow damage. The present study explored a new method of traffic marking application, which reduces the snow plow damage to the traffic marking system.

1.3 Objectives

This study determined the best means of creating traffic marking recesses on modified OGFC mixes and the cost effectiveness of this method. A trial field installation of this method was carried out with the cooperation of a contractor. Detailed construction specifications were developed and included application methods and equipment, for use by other highway agencies. The installation consisted of a 1,000 ft tangent section, a 500 ft exit ramp section, and a 500 ft curved section. Each test section included three types of recesses and a non-recessed control.

After estsblishing three control sections, the durability and retroreflectivity of the recessed markings have been monitored two times over the winter maintenance season. The durability was evaluated by a subjective rating method, and the retroreflectivity was measured by a retroreflectometer. The results of the retroreflective readings taken along the recessed section were statistically (t-test) compared with the retroreflective readings taken along the non recessed sections. The results of this statistical analysis were used to examine the hypotheses for the present study.

The cost effectiveness of traffic marking recesses was determined. Specifically, the cost of the equipment used to produce the recesses, and how labor intensive it would be to create the recesses in the OGFC. A life cycle cost analysis was also performed.

CHAPTER 2. CURRENT STATUS OF KNOWLEDGE

2.1 Introduction

Roadway delineation is essential for the effective guidance of the driver. This guidance enhances traffic flow, driving comfort, and safety. Delineation is defined as one, or a combination of devices (excluding guide signs), that regulate, warn, or provide tracking information and guidance to the driver ("Roadway" 1994). Painted markings, thermoplastic and other durable markings, raised pavement markers (RPM), and post-mounted delineators are used as delineation materials.

2.2 Retroreflection

Retroreflection is the phenomenon of light rays striking a surface and being redirected directly back to the source of light. A perfect retroreflector would just reflect the light back into the headlights of the automobile. Fortunately, retroreflectors are not perfect, and some light is absorbed by the reflector, and there is a scattering of light intensity in directions around that of the source. It is this cone of imperfectly retroreflected light which returns to the drivers eyes (Figure 2-1) and allows retroreflection to be useful for pavement marking ("Roadway" 1994).

Retroreflectivity is vital for a delineation system to be effective at night. During the day, visual information is indirectly available from roadway features and surrounding terrain. At night, this information is lost and the driver must rely on pavement markings to perceive a safe route of travel. Nighttime visibility of pavement markings is almost directly proportional to the retroreflectivity of the pavement markings. According to the

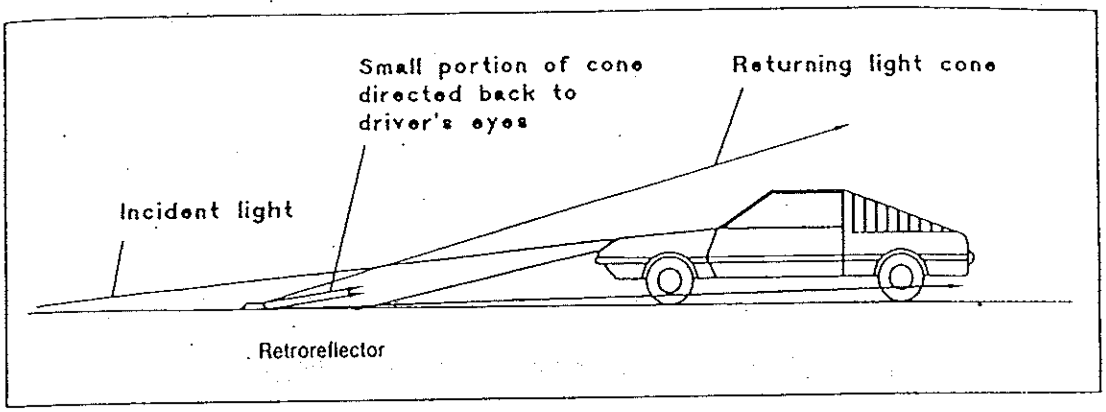


Figure 2-1. Light Returned by Pavement Markings

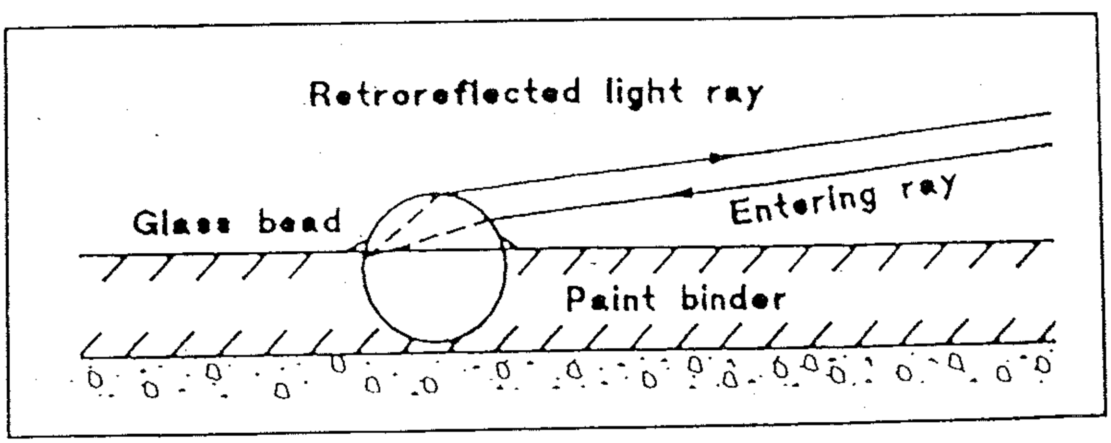


Figure 2-2. Glass Bead Retroreflection

Manual on Uniform Traffic Control Devices (MUTCD), markings that must be visible at night should be retroreflective unless ambient illumination assures adequate visibility ("Manual"1988).

2.2.1 Glass Beads

Glass beads are small glass spheres used in highway signs and pavement markings to provide the necessary retroreflectivity. The beads can be applied to the pavement marking in one of the following three ways: they can be dropped on, premixed in the marking materials before application, or a portion of the beads can be dropped onto premixed materials. For beads to retroreflect light, two bead properties are necessary: transparency and roundness. Glass beads have both of these properties.

The need for transparency and roundness can be explained by examining the path of the light as it enters a glass bead embedded in a painted marking. As the light enters the transparent bead, it is bent (refracted) downward by the rounded surface of the bead to a point below where the bead is embedded in the paint. Light striking the back of the paint-coated bead surface is reflected back toward the point of entry as shown in Figure 2-2 ("Roadway" 1994). The light that the glass beads retroreflect is a function of three variables: index of refraction; bead shape, size and embedment; and the number of beads present and exposed to the light rays. The refractive index (RI) is a function of the chemical makeup of the beads. The higher the RI, the more light is retroreflected. Beads used in traffic paint commonly have an RI of 1.50. There are some 1.65 RI beads used in thermoplastic. Beads with a RI of 1.90 are often used in retroreflective airport markings.

Each glass sphere works like a light-focusing lens. Each has a definite focal point outside the back of the bead. The closer the focal point is to the back of the sphere, the brighter the return. For example, as shown in Figure 2-3, the 1.5 RI bead has a focal point further behind the back of the bead than does the 1.65 RI bead ("Roadway" 1994).

Since the light is actually focused outside the back of the sphere, the light that is incident on the back of the bead is in the shape of a semicircular bright "spot." As a direct result of the glass bead's optical characteristics, the bright spot on the back of the bead turns out to be about 60 percent of the diameters's distance from the top. Accordingly, the bead's retroreflectivity should rise sharply at about 60 percent embedment, as the bright spot must strike the binder and undergo diffuse reflection for the beads proper functioning (Figure 2-4)("Roadway" 1994).

Large glass beads (40 mesh or greater) enhance a markings retroreflectivity. When used with an appropriate binder system, they can be quite durable as well. Figure 2-5 shows large versus standard bead performance in thermoplastic pavement markings as measured with a Mirolux retroreflectometer (Kalchbrenner 1989).

2.2.2 Wet pavement/nighttime retroreflectivity

Driving decisions are based 90 percent on visual cues (Allen 1970). The roadway environment must provide clear and informational messages to support those decisions. Rain, fog, and darkness can obscure vital visual communication from the road. Approximately 54 percent of fatal crashes occur at night; 14 percent occur when the road

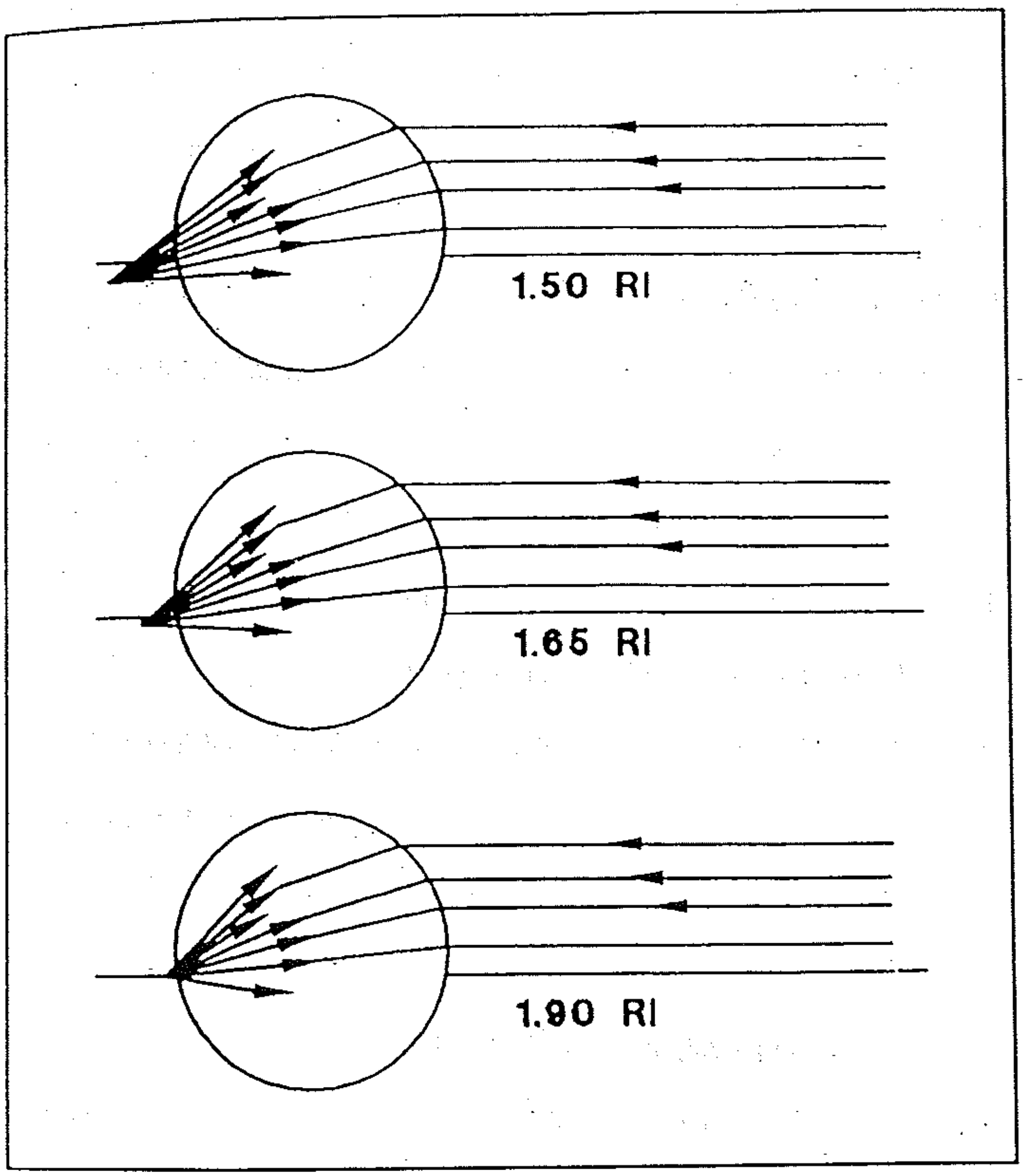


Figure 2-3. Effect of Refractive Index on Glass Bead Retroreflection

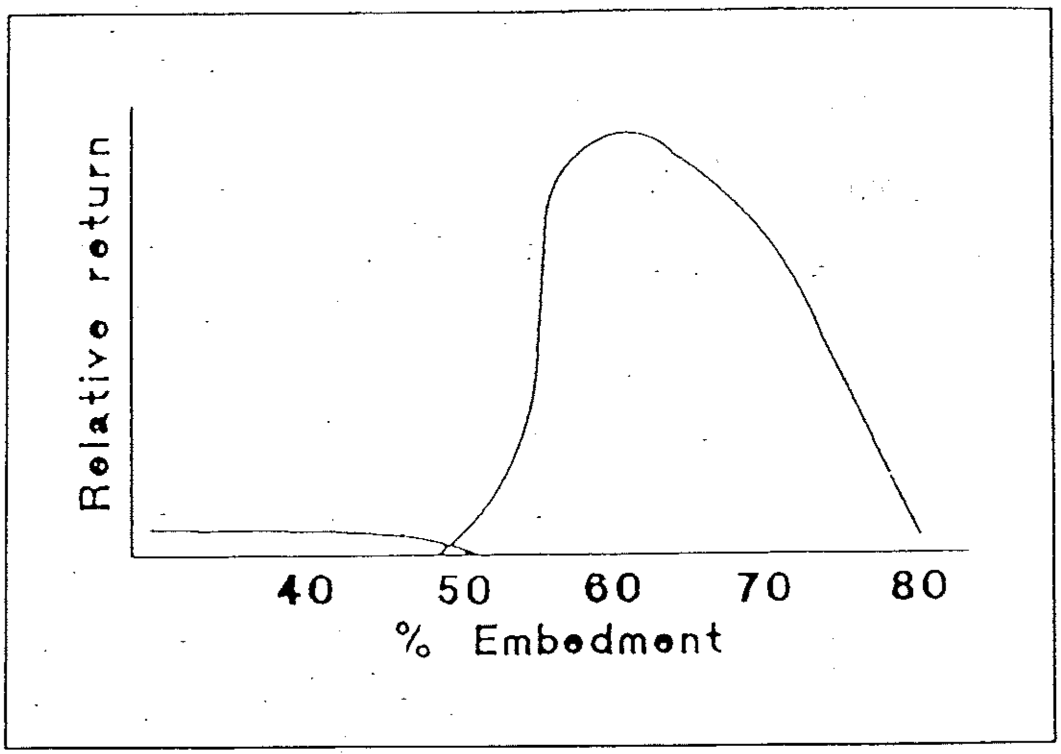


Figure 2-4. Optimum Glass Bead Embedment

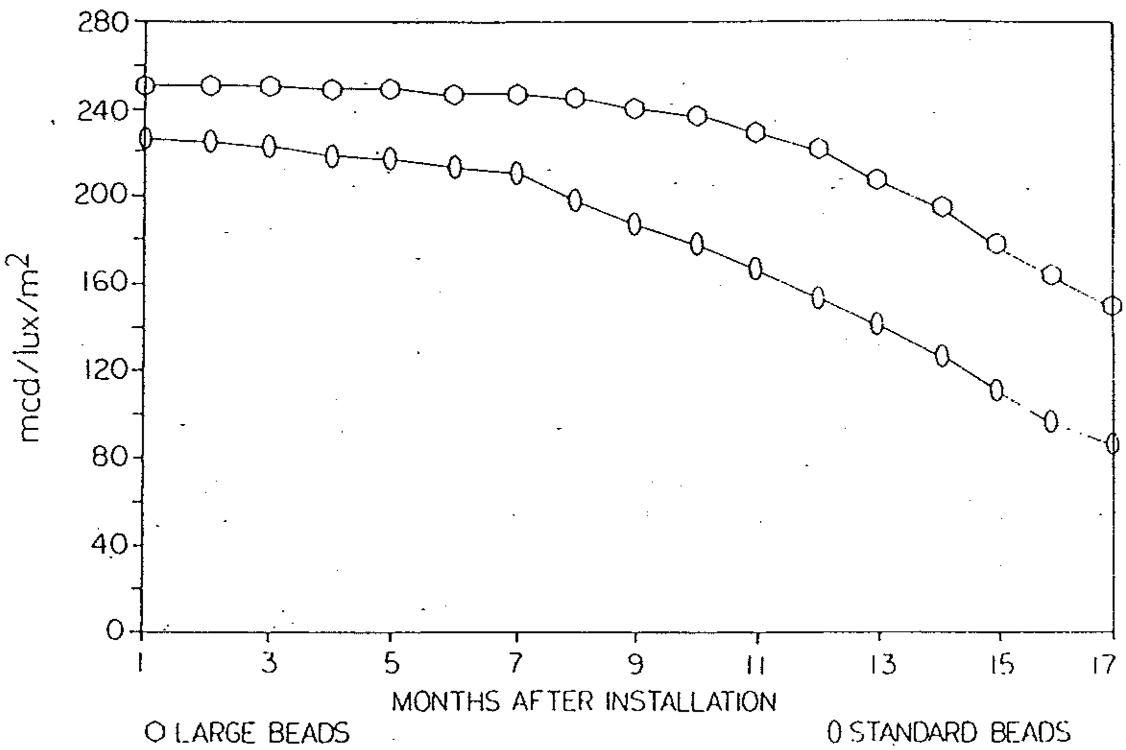
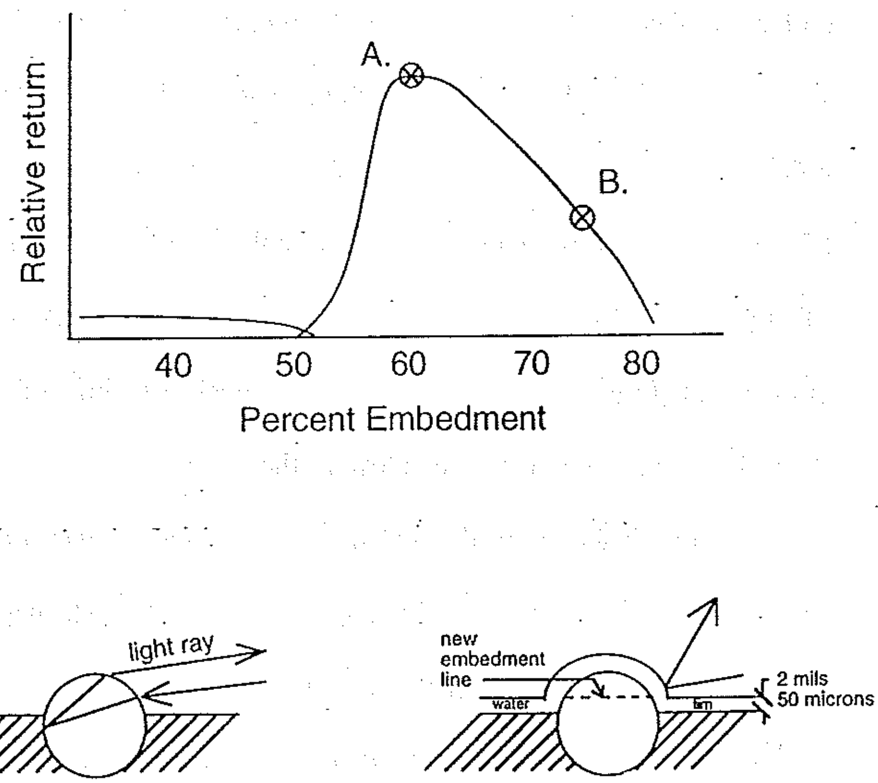


Figure 2-5. Retroreflectivity: Large Beads vs. Standard in Thermoplastic

is wet ("Fatal" 1985), even though there is relatively less driving under those conditions. Reflectorized pavement markings provide drivers valuable continuous information about the roadway and its characteristics. Unfortunately, pavement markings can lose their reflectivity, and thus their visibility, on dark rainy nights just when drivers are more apt to actively look to them for guidance. Much research has been devoted to the issue of wet-night visibility.

Laboratory studies have shown that as rainfall occurs, a thin film of water spreads uniformly over a stripe containing glass beads (Kalchbrenner 1989). As the water film builds, surface tension forces are overcome, and gravity causes water to flow down the side of the beads (Kalchbrenner 1989). The equilibrium water film depth is about 50 microns (2 mils) and is not strongly influenced by the rainfall rate or bead size (Kalchbrenner 1989). This thin film not only prevents the collection and retroreflection of light, but also changes the optical embedment without changing the apparent embedment (Figure 2-6). This increase in optical embedment decreases the proportion of the reflected cone that is returned toward the driver.

After different bead sizes had been tested, it was determined that properly embedded beads within the size range of 10 to 20 mesh, depending on binder, could overcome the water film effect and reflect light back even in rainfall rates of ½ in./hr. Calculations show the greater the diameter of the bead, the less effect the film of water has on the optical embedment. Results of laboratory studies measuring wet reflectivity of large beads versus standard beads are shown in Figure 2-7 for a typical thermoplastic system (Kalchbrenner 1989).



A. Dry head at optium 60% optical embedment

B. Bead with water film preventing collection of light and increasing the optical embedment to 75%

Figure 2-6. Water Film's Effect on Retroreflectivity

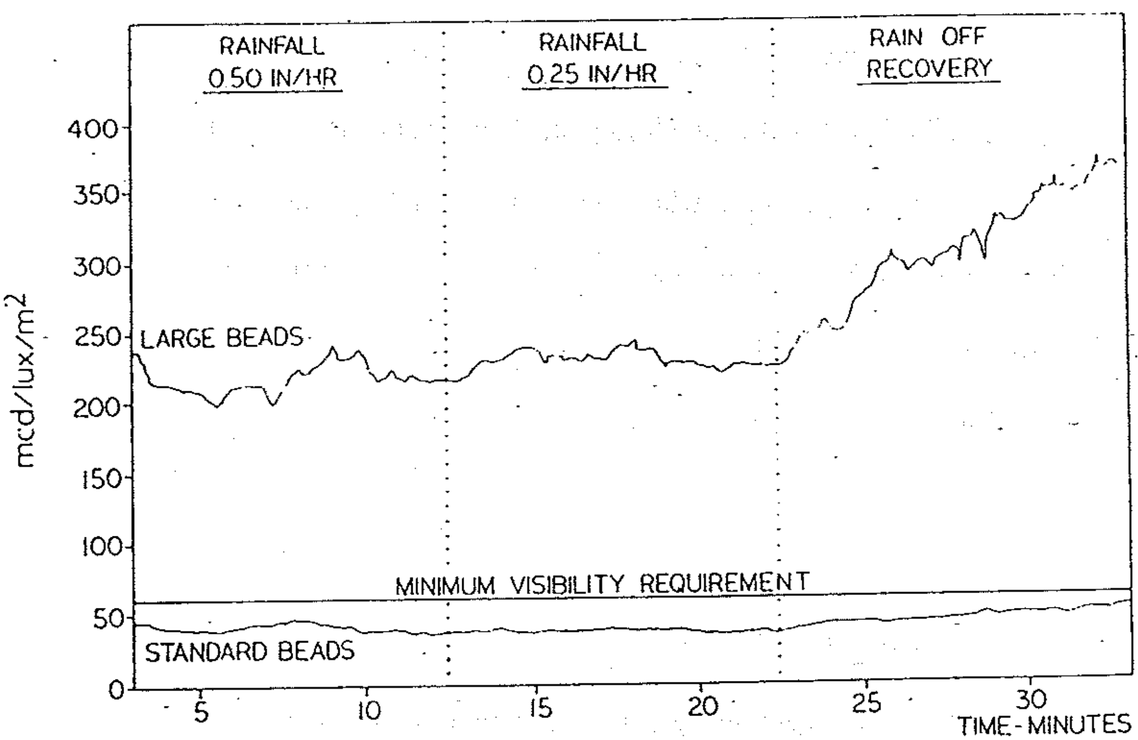


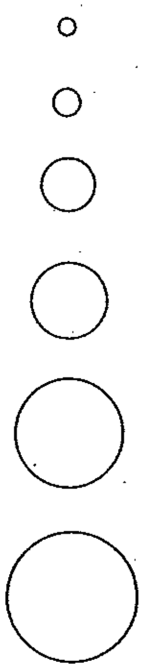
Figure 2-7. Large Beads vs. Standard in Thermoplastic (Wet Conditions)

As the graph indicates, the large-bead pavement marking system provides retroreflectivity levels 3 to 4 times higher than the minimum visibility requirements in rainfall rates up to ½ in./hr considered by meteorologists to be heavy precipitation. When the rain stops, the large-bead pavement markings recover quickly to extremely high retroreflectivity values. By comparison, standard highway beads in the same pavement marking binder fall well below the target of 60 mcd/lux/m² in rainfall (Kalchbrenner 1989). Figure 2-8 shows relative sizes of large beads versus standard beads and the change in optical embedment due to the water film effect.

Rhode Island's thermoplastic specifications call for a standard bead gradation shown in Table 2-1. In the previously mentioned study by Potters Industries, used a dual-drop application system, in which two separate bead gradation drops are used with the large beads (Table 2-2) are applied first, immediately followed by the standard beads shown in Table 2-3. The recommended application rate for this dual-drop system is 12 lbs of the large beads plus 12 lbs of the standard beads per 100 square feet (Kalchbrenner 1989).

2.3 Pavement Marking Systems

Pavement marking systems are comprised of three material components: the pavement material, the marking material, and the retroreflective material. One of the best known ways to improve capacity and safety on the highways is to provide cost effective pavement marking systems. A very durable pavement marking material with a long service life per unit of cost, must also have acceptable retroreflectivity throughout the



U.S. SIEVE	MICRONS	INCHES	% CHANGE IN OPTICAL EMBEDMENT DUE TO THE WATER FILM EFFECT	
80	180	.0070	27.8%	TYPICAL HIGWAY GRADATION
50	300	.0117	16.7%	
30	600	.0234	8.3%	
20	1180	.0331	4.2%	RECOMMENDED LARGE BEAD GRADATION FOR THERMOPLASTICS WITHIN THE NORTHEAST
16	1400	.0469	3.6%	
14	1700	.0555	2.9%	

Figure 2-8. Bead Size Comparison

Table 2-1. Rhode Island's specified bead gradation

Sieve Size	Percent Passing
#20	100%
#30	75-95%
#50	15-35%
#80	0-5%

Table 2-2. Gradation for Thick Film Binders (Thermoplastics)

Sieve Size	Percent On
#12	0-5%
#14	5-20%
#16	40-80%
#18	10-40%
#20	0-5%
PAN	0-2%

Table 2-3. Gradation of Standard Beads for Dual-Drop Application

Sieve Size	Percent On
#20	0-5%
#30	5-20%
#50	30-75%
#80	9-32%
#100	0-5%
PAN	0-2%

service life of the pavement marking material in order have an effective pavement marking system. Additionally, the pavement marking system should be visible at night during times of adverse weather conditions, when the driver is most dependent on the pavement markings for visual cues of the upcoming sections of the highway.

2.3.1 Traffic Paint

Traffic paints have been the most widely used pavement markings since the dirt road gave way to the paved road. They can be classified in several ways: retroreflective vs. non-retroreflective; cold-applied or hot-applied; and most commonly by the drying time. The categories of paint based on drying time are as follows:

(1) **Conventional:** Cold-applied paints with a standard value of viscosity. They require more than 7 minutes to dry.

(2) **Fast Dry:** Hot-applied paints that dry to a no-track condition within 2 to 7 minutes.

(3) **Quick Dry:** Hot-applied paints that dry to a no-track condition within 30 to 120 seconds.

(4) **Instant Dry:** Hot-applied, heavy-bodied paints that dry in less than 30 seconds.

The main components of traffic paint are the binder (base material), pigment (color), solvent, and glass beads. Before application, paint maintains it's liquid form due to the solvents. When the paint is applied to the pavement surface, the solvent evaporates, leaving a hard thin film. The different types of traffic paints, classified by the type of base material found in the paints composition, are summarized below.

2.3.1.1 Types of Traffic Paint

Alkyd and Modified Alkyd Paint

The alkyd and modified alkyd paints are the preferred marking materials of most states, due to the fast drying time and the low material and application cost. One of the drawbacks of this formulation is it's lack of durability (three months in harsh conditions), which makes frequent reapplication a necessity. The fast drying time which makes this paint so popular with many states is attributed to the type of solvents found in the paint's composition. These solvents release volatile organic compounds (VOCs) into the atmosphere when they are applied to the pavement surface. Current Environmental Protection Agency regulations will virtually eliminate solvent based paints in the future (Colburn 1995).

Chlorinated-Rubber Paint

Chlorinated-Rubber paint was an experiment into varying the base materials for traffic paints in order to increase their durability. Although the service life of 9 to 12 months was achieved by this formulation, the solvents used in this type of paint will also eliminate the future use of this paint.

Water-based Latex Paints

Due to the environmental concerns mentioned above, State highway agencies are mandating the use of VOC-free paint, such as latex formulations, on their highways. Following this trend the paint manufactures are also switching from solvent based paints to water based latex paints. These paints use water as the solvent, thus eliminating the harmful release of VOCs into the atmosphere.

Water based paints are applied at the same wet thickness as solvent based paints (15 mil), but where solvent based paints when dry will have a (8-10 mil) thickness, the Water based products will dry to a (10-12 mil) thickness. This has resulted in some increased durability for the product, however, paint is still not a multi-year product.

The negative aspects of using water based paints include sensitivity to temperature and humidity during application, longer drying times in humid weather, solvent based equipment must be converted to stainless steel for application, and a slightly higher cost per linear foot.

2.3.1.2 Performance

The estimated service life of paint is a function of numerous site-specific variables, such as, roadway geometry, weather and climate, traffic volume and composition, and the substrate material. Average daily traffic is the most commonly used variable to determine the service life of traffic paint. The relationship between average daily traffic and the service life of painted markings is shown in Figure 2-9 ("Roadway" 1994). On the average, traffic paint has a service life of 6 to 12 months under normal conditions.

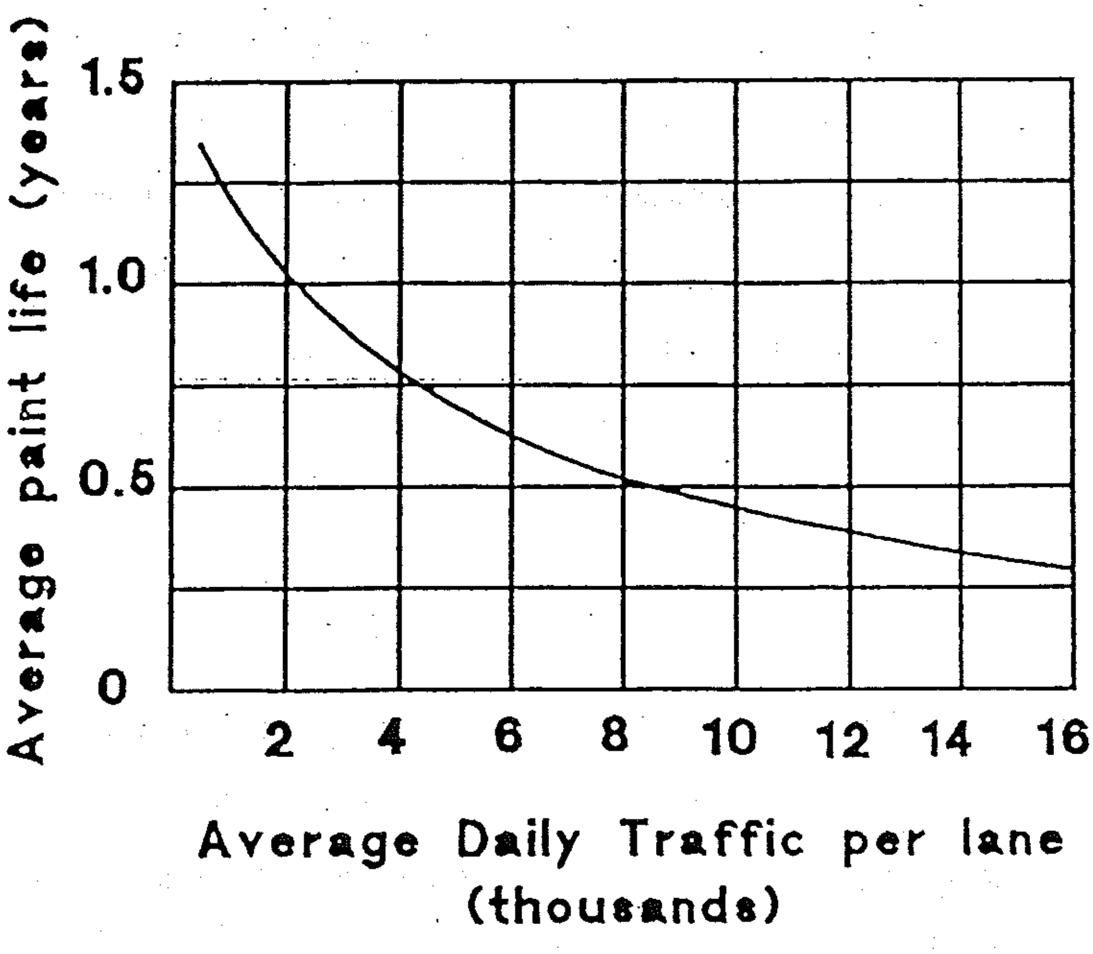


Figure 2-9 Average Paint Life vs. Average Daily Traffic

Weather and climate also influence the durability of traffic paint. Increased wear on the traffic paint by snowplow activity, studded tires, chemicals and deicing salts, along with bond failures (chipping) due to free-thaw cycles can drastically reduce the service life of the markings in cold weather.

2.3.1.3 Summary

The relatively low initial cost, well-established technology, ease of installation, and the readily available application equipment ensure the continued widespread use of traffic paints. Due to environmental concerns, highway agencies will have to upgrade their equipment in order to make the transition to water-based VOC free paints in the near future.

However, traffic paints are not very cost effective in the northeast, due to the harsh winter conditions, particularly on high volume roadways. The combination of high volume and severe winter conditions can make it necessary to reapply traffic paint bi-annually on many highways. This is a serious safety issue for many state highway agencies, due to the frequent exposure of striping crews to heavy traffic on high volume roadways. Also, some states cannot afford to stripe their highways twice a year and often ignore the inadequate night visibility, which accompanies highly worn traffic paint, due to loss of the glass beads.

Another traffic safety concern which is often overlooked by state agencies is inadequate wet-night visibility. Many agencies are still using a standard gradation (small) of glass beads in their traffic paint formulation. These beads are quickly submerged under a film of water during adverse weather conditions. This film prevents the collection of light and also decreases the amount of light reflected back to the driver. As mentioned earlier, the use of larger glass bead gradations (VISIBEADS, Potters Industries) in conjunction with standard bead gradations can overcome this problem. In the past, the use of these large glass beads has been restricted to materials with strong binders and resins, such as thermoplastics, epoxy, and polyester. Potters Industries has formulated a line of VISIBEADs for use with latex traffic paint, which has been very successful in field tests.

2.3.2 Thermoplastic

Hot-applied thermoplastic pavement marking materials have been the answer to the search for highly durable markings as an alternative to conventional traffic paint. The growing popularity, e.g., 36.5% maintenance engineers believe thermoplastic offer the best performance (19.8% for paint)("Striping" 1989), has been attributed to it's readiness for immediate use, superior durability, long term cost effectiveness, limited wet-night visibility, and traffic safety (low replacement factor). However, traffic paint is still the most widely used marking material to date, approximately 35 linear feet of solvent-borne paint stripe are used for each linear foot of thermoplastic stripe used (Dale 1988), due to it's low initial application cost.

Thermoplastic materials are, by definition, materials that can be heated to a liquid state, reshaped, and cooled to form a new object. Thermoplastic pavement marking materials consist of a resin binder, pigments (coloring agents), fillers, and reflective glass beads. They are applied at elevated temperatures by spray or extrusion equipment, and cool rapidly on the pavement surface to form a thick solid marking material. Most application specifications call for an application temperature of 425°F (218°C), which, can be seen from Figure 2-10, provides near optimum bond strength for these materials (Dale 1988).

Developed in Great Britain before World War II, the first resins used were mixtures of wool grease and various waxes. After World War II alkyd resins or hydrocarbon resins were used as the binder, depending on the economic comparison. Hydrocarbon-based thermoplastics use petroleum-based organic compounds as a binder, which makes them very susceptible to oil drippings, thus they are generally only used for longitudinal marking applications. Alkyd-based thermoplastic markings use synthetic alkyd resins for a binder, and are not susceptible to oil drippings. They perform exceedingly well as transverse markings.

2.3.2.1 Performance

Thermoplastic marking materials have several clear-cut advantages when compared to conventional traffic paint. The most apparent is its superior durability, e.g., southern states report an average service life of 10 years with some thermoplastic markings lasting the life of the pavement (Bowman and Kowshik 1994). The average thermoplastic life in years as a function of traffic volume is shown in Figure 2-11 ("Roadway" 1994). In the southern states, the service life of thermoplastic markings is almost a direct function of the thickness of the markings and the volume of traffic passing over the markings. It is the same thickness (125 mils or 1/8 inch), which increases the durability of the marking, that reduces the average service life of thermoplastic markings due to the snow removal in northern climates.

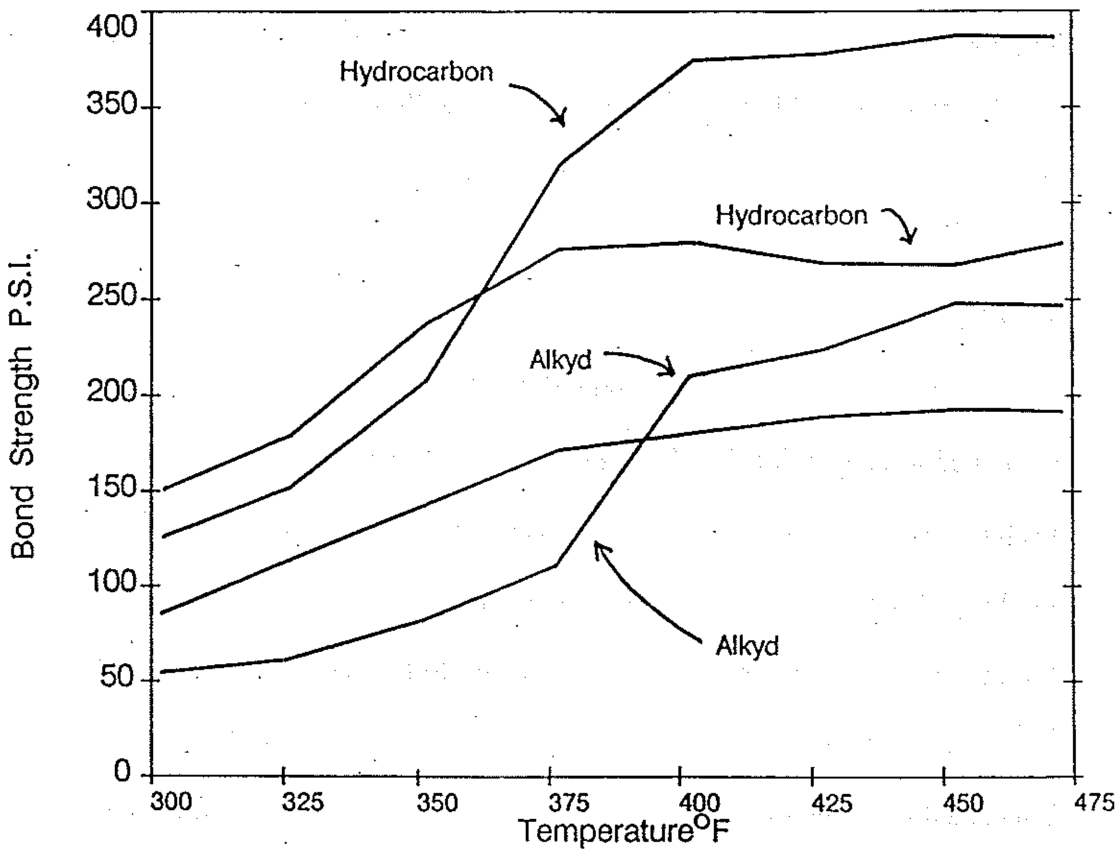


Figure 2-10. Application Temperature vs. Bond Strength

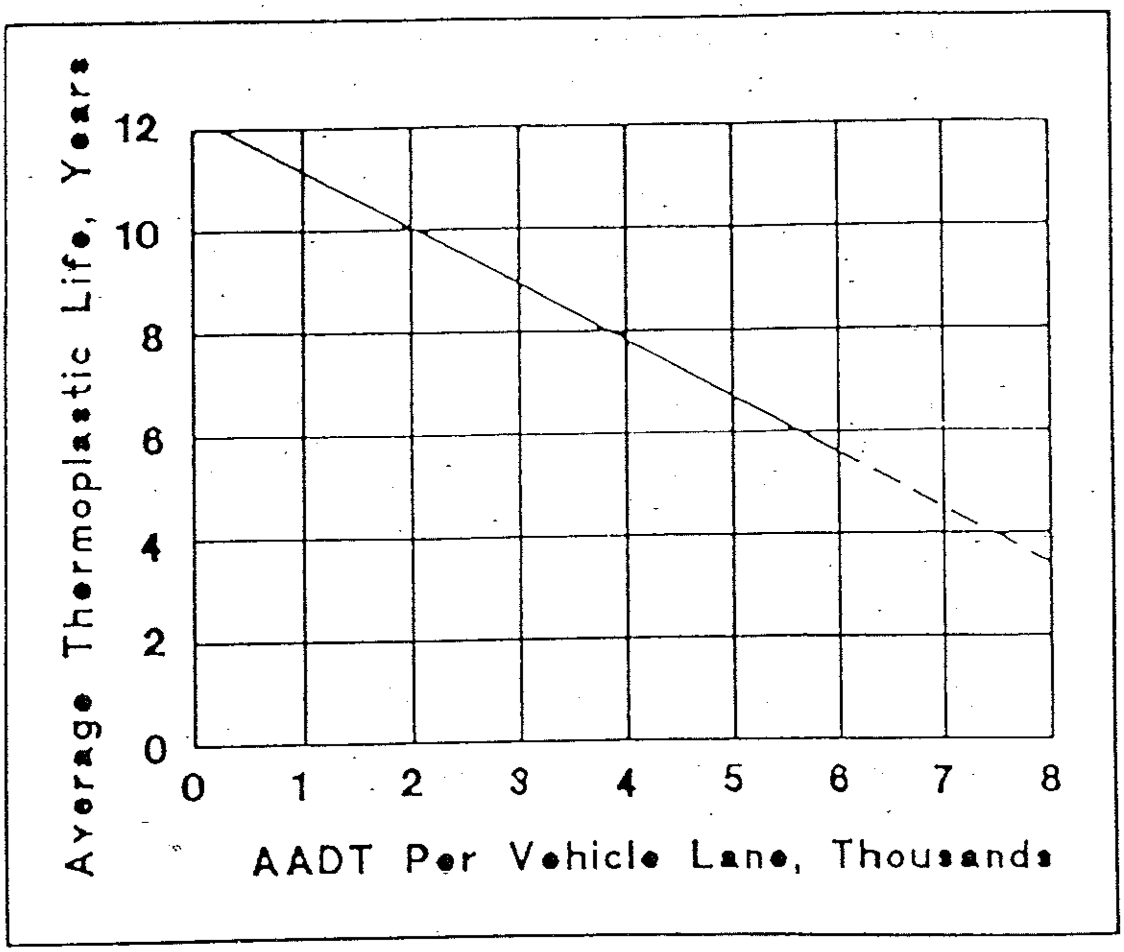


Figure 2-11. Average Thermoplastic Life vs. Traffic Volume

In northern climates, the life expectancy of thermoplastic is most often related to winter weather induced failures, such as abrasion, shaving and bond failure. Abrasion and shaving are principally caused by snow removal equipment. Early research related the snowplow activity, as measured by mean annual snowfall, to thermoplastic durability as shown in Figure 2-12 ("Roadway" 1994). It also may be noted that thermoplastic striping is much more durable on bituminous pavements than on Portland cement concrete (PCC) pavements.

The presence of curing compounds and latency in new PCC pavements prevent marking materials access to the structure of the pavement and bond failure can be immediate. It is the poor bonding of thermoplastic material on PCC which leads to severely damaged markings by snow removal equipment in high snowfall areas. Therefore, a one year curing period is recommended prior to the installation of the thermoplastic marking ("Roadway" 1994). The use of a primer-sealer on a PCC pavement before the application of the thermoplastic is essential to improve the bonding between the materials.

The overall service life of thermoplastic in northern areas is mainly a function of two variables, Annual Average Daily Traffic (AADT) and snowplow activity, which is related to the amount of Mean Annual Snowfall within the particular geographical location (Figure 2-13). It can be observed that the service life of thermoplastic is drastically reduced on roadways with high traffic volumes in regions with severe winter conditions.

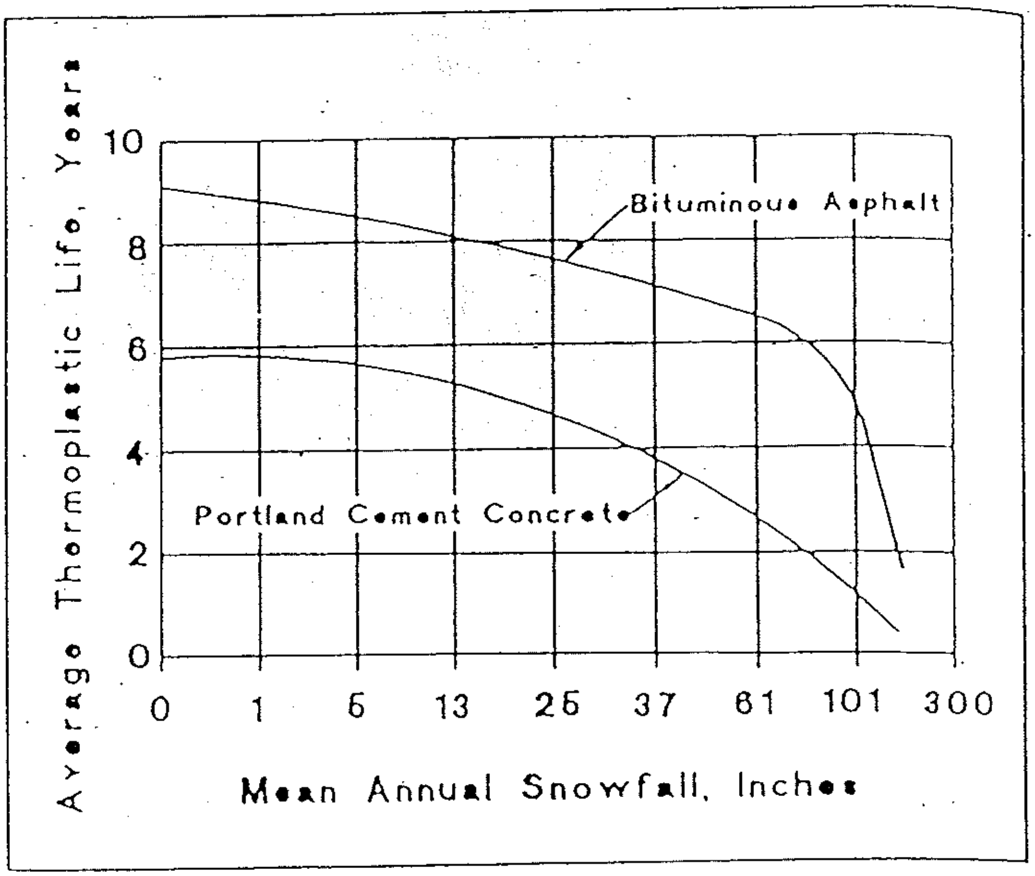


Figure 2-12. Average Thermoplastic Life vs. Annual Snowfall

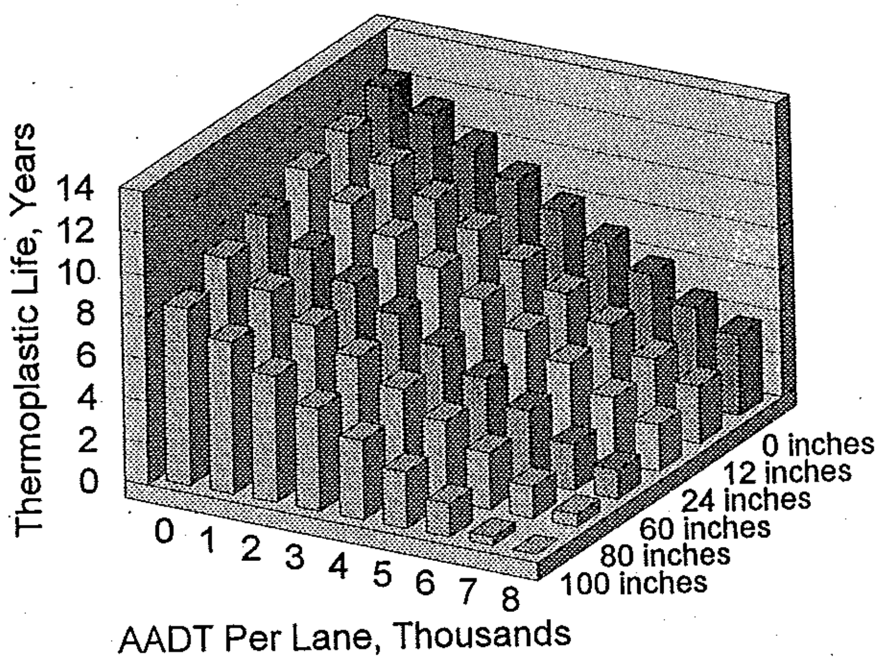


Figure 2-13. Average Thermoplastic Life vs. AADT and Mean Annual Snowfall

Thermoplastic markings have a high initial retroreflectivity due to the drop-on application of the glass beads immediately after the application of the hot applied thermoplastic. Glass beads are also premixed within the material in order to sustain adequate retroreflectivity throughout the service life of the material. As the thick thermoplastic marking is worn away by traffic flow, the beads premixed into the material are continuously exposed, thereby enabling the markings to retain brightness until most of the material has been worn from the pavement (Figure 2-14). In comparison thin markings such as conventional traffic paint and other quick drying materials should be renewed when the material in the wheel paths has been worn to half of its original area, due to the loss of the glass beads ("Roadway" 1994).

Thermoplastic's dry retroreflectivity is generally equivalent to beaded paint, but its retroreflectivity is comparatively better under heavy rain (Bowman and Kowshik 1994). The thick markings extend above the surface water film, negating some of the focusing water effects of the films ("Roadway" 1994). Unfortunately, it is this thickness which gives thermoplastic wet night visibility which makes the markings unsuitable for use in regions with severe winter conditions, where the material is susceptible to snow removal equipment.

2.3.2.2 Summary

Thermoplastic markings when properly applied are considered to be a cost effective alternative to conventional traffic paint when durability and limited wet night visibility are serious site concerns. Thermoplastic has an advantage over paint when year-round painting is not possible and when wet night visibility is important (Bowman and Kowshik 1994). Thermoplastic markings sustain retroreflectivity throughout the

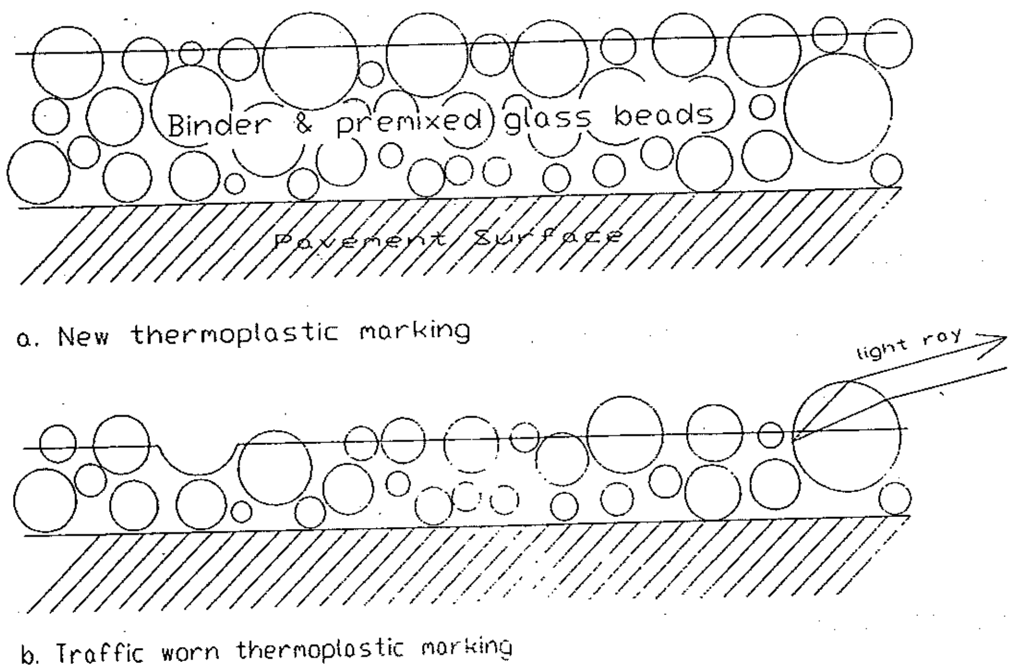


Figure 2-14. Sustained Retroreflectivity Throughout a Thermoplastic's Service Life

service life of the material. With a non-durable material, such as traffic paint, a significant portion of the marking cycle takes place when the marking system has lost its retroreflectiviy from bead loss and the roadway is simply waiting to be marked. This is a serious public safety concern, according to the MUTCD, markings that must be visible at night should be retroreflective unless ambient illumination assures adequate visibility ("Manual" 1988). In order for thermoplastic markings to be cost competitive with conventional traffic paint, the markings must remain in place, with satisfactory retroreflectivity, for a minimum of three to six years ("Roadway" 1994).

In the southern states, where thermoplastic markings are extremely durable, the higher initial cost is balanced by the longer service life, making the use of thermoplastic markings highly cost effective. Additionally, a longer service life means that maintenance workers are replacing the lane markings less frequently, decreasing the risk of injury or death from this dangerous task.

Thermoplastics superior durability and wet night visibility can be attributed to the thickness (125 mil, 1/8 inch) of the material. It is the same thickness which decreases the service life of the thermoplastic in northern climates, where the thick markings are damaged by snow removal equipment. In regions with severe winter conditions, thermoplastic markings lose their cost-effectiveness, and should not be considered as a pavement marking alternative. Thinner applications of 90 mil or less, are usually more cost effective in snow removal regions. Material cost are lower, application is faster, and damage from snowplow activity is reduced. However, thinner applications lose their wet night visibility.

Many state agencies are still using the paint drop-on bead gradations for thermoplastics, when new advances in binder and glass bead technologies has made use of larger sized glass beads to project up through submerging films of water and achieve improved wet reflective performance (Kalchbrenner 1989). With these advances, a thinner spray application (40 to 60 mil) with a combination of intermixed beads and a drop-on surface application of a mix of standard and large bead sizes, may be the most cost effective technique for northern climates.

2.3.3 Preformed Tapes

Cold-applied plastic pavement marking tapes (preformed tapes) are composed of resin binders, pigments, glass beads, and fillers. These materials are usually backed with an adhesive for bonding and are applied to the pavement surface with pressure or heat. A surface coat of firmly bonded glass beads is added for high initial retroreflectivity. Preformed tapes are manufactured in continuous rolls of various widths, precut symbols and shapes, and in sheets from which customized markings are created. They are often used for pedestrian crossings, stop bars, arrows, words, symbols, and in some cases as lane lines in areas with low traffic volumes.

Preformed tapes are classified in terms of the expected service life: temporary and permanent. Permanent preformed tapes are any inlaid installation, or thick overlaid installation, which have achieved a good bond with the pavement surface for more than one year. During inlay application method, the pressure-sensitive, self bonding tape is positioned by an applicator device, and is rolled firmly into the asphalt by the finish roller while the asphalt is still warm (at least 54°C or 130°F) and the result is a partially embedded marking in the surface of the pavement. The overlay application is used on existing pavement surfaces, where the preformed tape is bonded to relatively new AC pavement surface with pressure-sensitive films. Contact cement is often applied prior to the installation of the pressure sensitive markings on old AC or PCC for better bonding performance. A partial bond is achieved by the use of a hand-roller, until a secure bond is achieved though daily traffic compaction.

Temporary preformed plastic tapes are thinner than permanent tapes, have a foil backing, with a precoating of adhesive for self bonding and are normally used in overlay installations ("Roadway" 1994).They are often used as temporary markings in construction projects, were the ease of removability on new AC or PCC pavements without permanently marring the final surface is desired. Unlike other markings which are removed by heat, solvents, grinding, or sandblasting, temporary preformed plastic tape can be removed nearly intact with a roll-up device, without leaving any significant mark on the pavement which may confuse drivers.

2.3.3.1 Performance

Permanent inlaid applications of preformed marking tape on new asphalt, when properly installed are highly durable. The Colorado Department of Transportation has experienced good performance with these materials; they remain over 90% intact and in place after several years of service on freeways with over 100,000 vehicles per day (Griffin 1990). Inlaid markings outperform overlaid markings if a good bond is achieved with the pavement ("Roadway" 1994). This is very apparent in northern climates, where partially embedded inlaid marking tapes offer less of a target for snow plow blades than overlaid applications. One study in Kentucky reported a 4-year average service life for preformed materials, although manufactures guaranteed only 2 years for inlaid and 1 year for overlaid markings in snowbelt regions (McGrath 1981).

Although the performance of permanent preformed marking materials on asphalt is better than on concrete, they preformed significantly better on old smooth concrete than hot-applied thermoplastics and conventional traffic paints (Griffin 1990). Pretreatment of new concrete, including the grinding and removal of curing compounds and latents is recommended in order to obtain the same performance of preformed marking materials on new concrete installations (Griffin 1990).

The appearance and initial retroreflectivity of preformed materials is rated five to six times better than paint (Bowman and Kowshik 1994). However, this level of retroreflectivity is not sustained throughout the markings service life. In fact, preformed plastic materials tend to lose their initial high retroreflectivity after a few months of service, to levels below that of extruded thermoplastic markings (Griffin 1990). In most cases, the tape's initial good retroreflectivity is retained for some time, but eventually it deteriorates to an unacceptable level due to insufficient matrix beads (Roadway 1994). Most tapes utilize an exposed glass bead matrix in a 60 mil thickness, and plowing operations generally remove most of the reflectivity during the first year (Colburn 1995).

2.3.3.2 Summary

When installed properly on concrete and asphalt, permanent preformed marking materials are considered highly durable, with inlaid applications on new asphalt outperforming overlaid applications, in northern areas with heavy snow plow activity.

However, in order to justify their high installation cost ($1.25/ft) the tapes must sustain adequate night retroreflectivity throughout the markings service life. Although the tape's initial retroreflectivity levels are much higher than other film type pavement markings, this initial level quickly deteriorates to unacceptable levels often after the first year of the markings service life. Due to this lack of sustained retroreflectivity, many States only use these markings in well-illuminate areas, such as urban roadways and intersections with continuous lighting.

Permanent preformed marking materials are cost effective in illuminated sites which require small amounts of marking materials, particularly intersections, where heavy traffic volumes warranting frequent marking replacement. Preformed tape is relatively easy to install and repair, unlike other marking materials which require operation or rental cost of large-scale application equipment for installation. These machines are often difficult to handle in small areas. For these reasons inlaid preformed symbols and transverse markings used in small installations such as well-illuminated intersections. are very cost competitive with other types of pavement markings.

2.3.4 Epoxy

Much of the original developmental work on thermosetting epoxy pavement markings was done by the Minnesota Department of Transportation (DOT) and the H.B. Fuller Company during the 1970s (Dale 1988). The objective of adopting the two component epoxy systems for use as a pavement marking material was to obtain a thin-film, snowplow-resistant pavement marking capitalizing on the unusual adhesive and durability properties of the epoxy materials (Dale 1988).

Epoxy paint is a two component material, two parts of epoxy resin to one part epoxy hardener, which chemically react to create a durable, sprayable material that adheres to both bituminous asphalt and Portland cement concrete. The components are heated and mixed just prior to the application to the pavement surface, followed by pressurized air distribution of glass beads. Epoxy paint usually applied at a thickness of 15 mils and will typically cure within 20 to 40 minutes. Since the material is a 100% solid formulation there is practically no VOC (volatile organic compound) emissions, and the wet thickness is equivalent to the dry thickness (Griffin 1990).

2.3.4.1 Performance

Epoxy's durability has been proven to be good to excellent in several tests in Minnesota. In one test epoxy lasted for over a year on roads with high AADT, in comparison with 3 months or less for traffic paint (Bowman and Kowshik 1994). Under low to medium AADT conditions epoxy retroreflectivity is excellent when new and is still acceptable after 3 years (Bowman and Kowshik 1994). Poor pavement conditions, large volumes of weaving traffic, and poor application quality control requirements are some of the causes of the failures associated with epoxy.

In a Colorado pavement marking research program, where a pavement marking review team evaluated the field performance of new pavement marking materials, epoxy paint appeared to be a good pavement marking system which could outlast several applications of standard traffic paint, with adequate nighttime visibility when clean (Griffin 1990). When compared to thermoplastic skip stripes which were visible for 160 to 200 feet ahead of the vehicle at night with low beams, epoxy skip stripes were visible for 120 to 160 feet (Griffin 1990). The use of larger sized glass beads (Potters Industries PE-115 beads) in epoxy markings was also investigated. Although the larger beads did not improve the dry retroreflectivity over that obtained from the standard beads, they did improve the nighttime visibility in the center of the stripes, eliminating the problem of the sunken beads (Griffin 1990). The large beads were also severely damaged on heavily plowed and sanded mountain highways, with only the broken-up bottom half of each bead remaining. It was concluded that the large beads which maintain proper embedment and aid in wet nighttime visibility, may serve well on Colorado plains, but may be too susceptible to damage on our mountain roadways (Griffin 1990).

The two-component internally mixed thermosetting epoxy systems are the only pavement marking materials that are reported to preform as well on PCC as they do on AC pavement (Dale 1988). Unfortunately, a slight discoloration of the white formulations of epoxy material can occur and create a problem with daytime appearance of the marking material on concrete surfaces.

2.3.4.2 Summary

Epoxy is a cost competitive alternative to traffic paint on high volume roads within the snowbelt regions where all-year delineation is desired. Epoxy is safe to handle (no VOCs), has good abrasion resistance, good durability, good nighttime retroreflectivity, good bead retention and adheres well to both asphalt and concrete surfaces. Application cost are typically about $0.25/linear foot, when applied to a new surface.

However, when remarking surfaces, it is necessary for the eradication of the existing striping material except for a single application over thermoplastic or applications over past epoxy applications with at least one year of wear. It is this added cost of pavement marking removal which reduces the cost effectiveness of the markings when applied over other marking materials. The initial investment into specialized application equipment, problems with color retention, and long curing times have limited the use of epoxy.

2.3.5 Polyester

Much of the original developmental work and testing of polyester pavement marking materials was done by Ohio DOT and the Glidden Company during the 1970s (Dale 1988). The objective was to develop a thin-film marking material that would not be affected by snowplowing and would be more durable than conventional alkyd-base traffic marking paint (Dale 1988).

Polyester is a two component material consisting of a resin which resembles standard traffic paint and a catalyst which comprises 1 to 5 percent of the total system, which is most often methyl ethyl ketone peroxide (MEKP). MEKP is a noxious chemical and must be handled with gloves and safety goggles because it can cause burns and dangerous fumes. The catalyst is mixed with the resin, causing a chemical reaction which converts the resin into a hard, durable pavement marking material.

In the case of polyester traffic marking materials, a separate spray gun is used for each of the two components, with the second component, the catalysts, being sprayed into the first component after the first component has exited the spray gun, but before the first component has contacted the road (Dale 1988). Polyester is applied to the pavement surface at a 15 mil wet film thickness with 16 to 20 lbs of standard drop-on glass beads per gallon of polyester material and has a drying time ranging from 10 to 45 minutes, depending on the ambient temperature.

2.3.5.1 Performance

Field observations by the Ohio DOT in the 1970s of this product indicated that the material performed well and continued to be serviceable for several years ("Roadway" 1994). Although in some areas with heavy traffic volumes, the polyester markings were worn out after one year of service, while paint in the same areas lasted only three months ("Roadway" 1994). Nighttime visibility of polyester markings is superior to that of paint because of the increased number of beads used ("Roadway" 1994).

One of the biggest disadvantage with polyester markings is bond failure due to abrasion. In a Colorado study polyester paint was applied as the skip stripe on a mountain highway with aggressive snow and ice control operations to service the 11,000 to 31,000 vehicles per day traffic flow (Griffin 1990). After one winter the polyester material was judged to be in poor condition with most areas essentially gone, even less intact than the adjacent standard traffic paint. The Colorado Department of Highways (CDOH) concluded that polyester paint appeared to be unsuitable for the severe environment of their high traffic mountain interstate, failing to perform as well as standard alkyd traffic paint.

In addition to the bond failure caused by abrasion, bond failure can occur when polyester markings are applied to new asphalt surfaces, were the polyester flakes off with the surface aggregate particles due to the presence of free oils and creates a marking which appears to be full of holes when closely examined ("Roadway 1994"). The "Swiss cheese" effect can be avoided either by waiting 2 weeks after the paving is completed or by first striping with fast-dry paints (Bowman and Kowshik 1994). Polyester does not adequately bond to PCC pavements and should only be used for AC pavements.

2.3.5.2 Summary

It is apparent from the initial field testing that polyester markings out-perform conventional traffic paint on AC pavements. Polyester has superior night time visibility when compared to conventional traffic paints. Due to the material's low initial cost, the material could be one of the most cost-effective materials available.

However, there is some question to whether the service lives obtained in the initial field studies can be reproduced on a regular basis. More basic research is needed on the factors and delineation variables that most profoundly affect this marking material before the widespread use of this material can become feasible ("Roadway" 1994). Some of these factors and delineation variables include; bond failure because of abrasion, bond failure due to the "Swiss cheese" effect, and a long drying time.

Even though the Michigan DOT has recently developed a fast drying polyester marking material, some states are still reluctant to utilize polyester. Application equipment can be costly and troublesome to use, the material can not be applied to newly resurface roads, and the safety of the worker is a prime concern due to the toxic characteristics of the catalyst.

2.3.6 Raised Pavement Markers (RPMs)

Film type markings tend to lose their nighttime retroreflectivity on rainy nights when the glass beads are submerged by the water film which changes the optical characteristics of the beads and reduces or nullifies the amount of light returning to the driver. The is a serious need on multilane high speed freeways for a pavement marking which has adequate wet night visibility. RPMs were developed in order to address this serious safety problem.

The first RPMs were 19-mm (3/4-in) high, 100-mm (4-in) circular buttons with glass beads on top for nighttime visibility. Epoxy was used to bond the "Botts Dots", named after their developer, to the PCC pavement surface ("Pavement" 1973). In 1954, California was one of the first states to experiment with "Botts Dots" and were subsequently used as auxiliary devices to provide delineation during periods of darkness and wet weather ("Roadway" 1994). Since then ceramic nonretroreflective and retroreflective variations of the convex button have been developed.

In 1955, a rectangular RPM with glass beads as the retroreflective element was developed to improve durability on AC pavements. This wedge shape shed water and extended above the water film found in wet weather ("Roadway" 1994). Though new technological developments the use of glass beads with the wedge shaped RPMs has gave way to the use of a cube-corner (trihedral angled mirrors) retroreflector.

In the cube corner system, light rays are received on one of the three mirrored surfaces which are arranged at 90-degree angles and reflected to the second mirrored surface, and then to a third, where the light is returned in exactly the opposite direction from which it entered. These tiny tri-mirrored surfaces are arranged as shown in Figure

2-15 to provide the retroreflective unit for the RPM ("Roadway" 1994). Specifications for the round and wedge shaped RPMs are given in Figure 2-16 ("Roadway" 1994).

In the past the majority of raised markers were placed in the field with a two component epoxy adhesive that was mixed at the site either manually or mechanically (Dale 1988). The epoxy adhesive is applied to either to the pavement or the marking in a quantity such that when the marker is pressed into place, a bead of adhesive (approximately 3mm (1/8 inch)) in diameter is extruded around the base of the marker. Currently, there is a trend to replace the epoxy adhesive with bituminous adhesive for use on softer bituminous pavements (Dale 1988). One study comparing the two adhesives concluded that in some cases the retention percentage of the RPMs attached with bitumen was twice as high as the retention percentage of the epoxy bonded RPMs (Tielking and Noel 1988).

RPMs are supplied in three colors, white, yellow, and red. White and yellow retroreflective RPMs convey the same message as their thin film pavement marking counterparts, while red retroreflective RPMs convey a "wrong way" message. When used to supplement film type striping , RPMs are typically placed at the center of every other gap [24m (80 feet)].

2.3.6.1 Performance

Retroreflective RPMs perform well except in areas with snowplow activity. In snow-free areas of the country an expected service life of up to 8 years can be obtainable on most freeway locations (Roadway 1994). In areas which receive snowfall the cost of

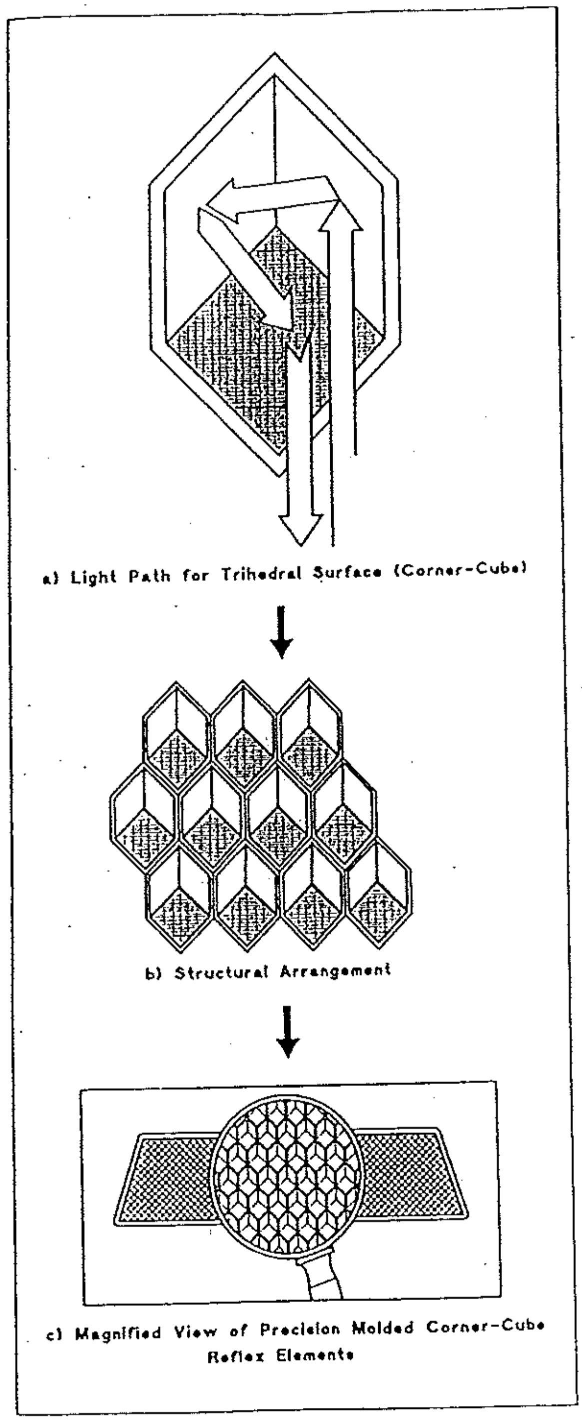


Figure 2-15. Principle and Structure of Cube-Corner Retroreflectors

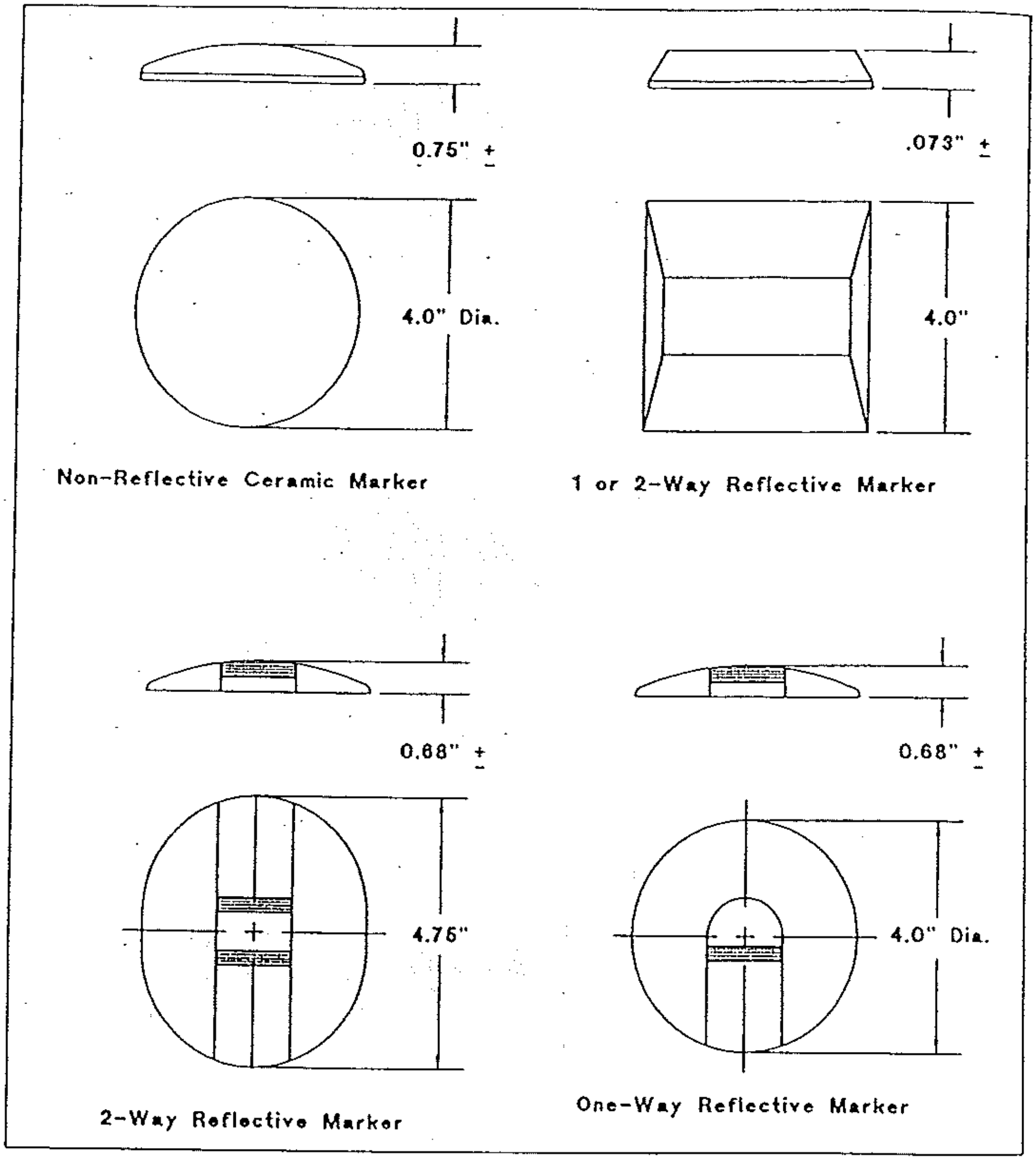


Figure 2-16. Typical Raised Pavement Marker Configurations

maintaining RPMs which are severely damaged and removed by snowplow blades has been a major deterrent to their installation. RPMs also cause considerable damage to plow blades and maintenance personal find that they cause significant vibration in the trucks while leaving snow on the pavement (Colburn 1995). This leads to increased maintenance cost and time.

Within a few months, the retroreflectivity of the cube corner RPM drops to as little as 1/20 to 1/50 of its original value due to factors such as buildup of road film and surface abrasion ("Roadway" 1994). Although this initial loss is large, the resulting value remains relatively constant and is considered to be adequate. During wet weather conditions, the retroreflective lens is covered with water film, which tends to wash away the road film and fill in the cracks on the face of the retroreflecltive surface, leading to excellent visibility, nearly one-fourth to one third of it's original value ("Roadway" 1994). Generally, the cube-corner lens will provide some retroreflectivity unless the lens face has been completely destroyed ("Roadway" 1994).

2.3.6.2 Summary

Due to the high initial cost, a RPM system can only be justified in the Sunbelt section of the United States where the long service life and increased wet weather visibility of the RPMs can be expected due to the absence of snowplow damage. Therefore, their application tends to be limited to important roadways within the Sunbelt region were additional delineation is needed. A large portion of the painted lane lines on the Interstate system in the Sunbelt region has a raised reflectorized marker in the center of every second gap (Dale 1988).

The use of RPMs in conjunction with a film type marking system has many safety benefits, especially during wet night conditions when the film markings lose their visibility. In a report on the transportation needs of older drivers, the most frequent complaint about pavement markings was that they were not visible in bad weather, and RPMs were the most often suggested way to make night driving easier and safer ("Evaluation" 1996). RPMs significantly reduce instances of erratic maneuvers in two-axle vehicles with and without the presence of overhead lighting ("Roadway" 1994). Besides providing excellent night and wet night visibility, RPMs provide an audible effect to alert sleepy drivers, thereby reducing the numbers of those types of accidents.

2.3.7 Snowplowable RPMs

A practical, durable marker compatible with snowplow activity has been under development since 1967 ("Roadway" 1994). The snowplowable marker was designed to overcome the costly damage to RPMs by snow removal equipment. A hard metal casing embedded in the pavement protects a two way replaceable cube corner reflective unit. The casing is tapered, in the hope that a snowplow blade will ride up over the markers with out damaging either the blades or the retroreflective element mounted within the metal housing ("Pavement" 1972). Because of the low profile of the casting (6-degree slope), the rise and fall of the snowplow blade are hardly discernible to the snowplow operator if the snowplow is moving slowly ("Roadway" 1994).

2.3.7.1 Performance

Snowplowable RPMs provide excellent wet night delineation and have a good maintenance record when steel snowplow blades were used in areas with light snowfall (less than 20 inches of annual snowfall).However under severe winter conditions, with the use of tungsten steel snowplow blades, the results are mixed ("Roadway" 1994). New York discontinued their trial installations of snowplowable markers due to the severe damage by snowplows equipped with tungsten carbide blades ("Pavement" 1973). While large installations of these markers in Kentucky, Ohio, New Jersey, and other states have shown that they can be used with snowplows equipped with tungsten carbide blades (Dale 1988).

Plowable reflectors appear to fail most often due to the separation of the reflector from the casting; casting pullout of properly installed markers is rare (Bodenheimer 1985). The expected life of the steel-hardened casing could be conservatively estimated at 10 years and the life of the replaceable lens insert at 3 to 4 years (Roadway 1994). This additional maintenance cost, lowers the cost effectiveness of the marking, thus making this type of marking alternative less attractive to State or local highway agencies.

2.3.7.2 Summary

There have been mixed performance results in the initial field testings of snowplowable markers. There is a question of whether the snowplowable markers are durable enough to withstand damages caused by tungsten snowplow blades in areas with moderate annual snowfall (greater than 20 inches). Experience reported in the early years of installations is not necessarily valid today, since many improvements have been made both to reflectors and installation methods (Bodenheimer 1985). In an effort to improve the performance of the snowplowable markers a number of prototype models have been fabricated and tested extensively in the last 10 years ("Roadway" 1994).

2.3.8 Recessed RPMs

In an effort to provide RPMs in snow belt areas, reflective markers are placed in recessed grooves so that the top of the reflector is flush or below the pavement surface, thus removing the RPMs from potential contact from snowplow blades. Cutting of the pavement is generally performed using diamond saw blades, although carbide blades have been used in isolated cases (Bodenheimer 1985). A typical flatbottom groove cut is made with a series of equal size cutting wheels; the cut is started by a short plunge cut, the correct length of the groove is cut (usually from 20 to 44 inches), and then the saw is withdrawn from the pavement (Bodenheimer 1985).

A modification to the groove, which saves time, fuel and wear of the cutting wheels, varies the depth of the cut by means of a guide wheel mounted eccentrically to the cutting equipment, which may be a modified concrete saw or a specially designed, scooter type vehicle (Bodenheimer 1985). After the groove has been cut the area is dried and cleaned by the use of compressed air and then the RPM is installed with an epoxy adhesive.

2.3.8.1 Performance

The reflectors which have been placed in recessed grooves have shown low susceptibility to damage from snowplows (Bodenheimer 1985). Since recessed reflectors have shown good resistance to removal by road traffic as well as removal by plowing, some states, e.g., Georgia and South Carolina, have opted to install all reflectors below grade, even if snow is not a consideration (Bodenheimer 1985). However, some states have moved away from recessed RPMs because or poor installations, the development of potholes where the pavement groove is made in asphalt overlays, and other maintenance problems (Evaluation 1996).

Above grade reflectors are best from a visibility viewpoint since they are not subject to dirt or water build-up (except under rare, flooded conditions), and are periodically cleaned by tire action (Bodenheimer 1985). Reflectors below grade, can be as visible as the above grade markers if they are free of water, snow and dirt, and provided the roadway groove provides a proper line of sight (Bodenheimer 1985).

2.3.8.2 Summary

The high installation cost of recessed RPMs can be attributed to the cost of diamond cutting blades required to provide the groove. This high installation cost combined with poor installations, the development of potholes and other maintenance problems have caused many states to move away from this marking alternative. Additional research into more cost effective installation methods, preformed during paving operation is needed.

2.4 Relevant Past Studies

An effective pavement marking system requires durability and acceptable retroreflectivity throughout the service life of the pavement marking material.

Additionally, the pavement marking system should have adequate wet night retroreflectivity in order to safely guide the driver during adverse weather conditions.

In southern climates, thermoplastic marking systems satisfy all the requirements of an effective traffic marking system. Southern states report an average service life of 10 years with some thermoplastic markings lasting the life of the pavement (Bowman and Kowshik 1994). Because the material is applied relatively thick (90 to 125 mils) as compared to paint (15 mils), it has a long life even though it wears down (Griffin 1990). This wear continuously exposes new intermixed beads and keeps the retroreflectivity high for this material throughout it's service life (Griffin 1990). The thickness of the thermoplastic which provides the markings superior durability also gives thermoplastic a limited amount of wet night visibility.

In northern climates, the life expectancy of thermoplastic is drastically reduced due to abrasion and shaving principally caused by snow plow blades. Due to the markings thickness, thermoplastic markings are unsuitable for use in regions with severe winter conditions because of their susceptibility to snowplow damage (Bowman and Kowshik 1994). Dale recommends further research on the development of new snowplowable marking materials which provide adequate wet-weather night visibility (Dale 1988).

A study to evaluate different methods of cutting recessed skip-striped grooves, and to evaluate various pavement marking materials placed into the recesses was conducted by Washington State DOT (Anderson 1981). The three year study was an attempt to find a permanent lane marking system for mountain pass highways that would tolerate snowplowing and sanding operations, studded tires, and chain wear. It was concluded that the diamond saw was the fastest and most economical method of cutting recesses in PCC pavement. All three recessed marking materials were capable of withstanding the effects of sanding operations, studded tire wear, chain wear, and snowplowing for three years without damage or loss of materials. All of the recessed markings provided adequate dry-daylight and dry-night delineation, however none of the materials provided adequate wet-night delineation. The failure of the marking systems was attributed to a lack of retroreflectance form the marking materials when they were submerged under a film of water.

When thin film markings are covered with a film of water the light is reflected in all directions and only a small portion of the light is reflected back to the light source, greatly reducing the visibility (or retroreflectivity) of the markings (Evaluation 1996). This thin water film not only prevents the collection and retroreflection of light, but also increases the optical embedment of the glass beads, therefore decreasing the proportion of the reflected cone that is returned to the driver (Kalchbrenner 1989). Dale recognized this need for wet-night retroreflection for thin film marking materials; "Until such time as a retro-reflective system is developed for film- type markings that has wet-weather nighttime visibility, raised or recessed reflectorized markers are seen as an essential complement to film-type marking installations" (Dale 1988).

In section 6005(a) of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the Federal Highway Administration (FHWA) was mandated to study all-weather pavement markings (AWPM) and to evaluate the visibility, durability, and safety performance of AWPM (Evaluation 1996). AWPM are defined as markings visible at night under dry conditions and under rainy conditions up to 0.64 cm (0.25 in) per hour of rainfall (Evaluation 1996). Virginia is one of 17 states participating in this large-scale effort, which should provide useful findings on markings for wet night visibility (Evaluation 1996). Large glass beads and textured markings are new pavement marking products which were designed to enhance wet night retroreflectivity (Evaluation 1996).

Laboratory studies conducted by Potters Industries have determined that embedded glass beads within the size range of 10 to 20 mesh, depending on the binder, could overcome the water film effect and reflect light even in rainfall rates of 1.28 cm (0.5 in) per hour (Kalchbrenner 1989). Calculations show the greater the diameter of the bead, the less effect the film of water has on the optical embedment (Kalchbrenner 1989). In a water film that would cover standard beads under wet night conditions, part of the large beads may still be above the water and provide retroreflectivity (Evaluation 1996).

The University of North Carolina at Charlotte evaluated eight pavement marking materials for wet (and dry) night conditions (King and Graham 1989). It was concluded that under actual rainfall conditions in the field, VISIBEAD (large glass bead) markings gave visibility distances double or greater than visibility distances for similar lines with standard beads.

Test sections containing polyester paint substituting Visibeads for the standard bead gradation were installed and monitored on the Ohio Turnpike (DePaulo 1990). After one winter season, approximately 25% to 30% of the pavement markings were damaged by snowplows and therefor the level of retroreflection was reduced. In some instances, the lager Visibeads were sheared off the surface of the binder or completely knocked out of the binder by the plow blades. However, in all cases the nighttime wet reflectivity level was far superior to any paint line previously used on the Ohio Turnpike.

Test sections containing epoxy markings with large glass beads were tested in Colorado (Griffin 1990). From this study Griffin concluded that the large beads improved nighttime visibility in the center of the stripes, eliminating the problem of sunken beads. However, magnified inspection of the stripes indicated that the large beads were badly damage by snowplows with only the broken-up bottom half of each bead remaining. This damage reduced the measured nighttime retroreflectivity of the markings.

Bowman explains that field testing of large glass beads on roads with a relatively large night of wet-night accidents could enable determination of the effective service lives of the bead-binder-pavement type combinations as well as expected accident reduction benefits (Bowman and Kowshik 1994)

2.5 Summary

Pavement marking systems provide visual guidance to the driver. Surrounding terrain and roadway features offer indirect visual information to the driver during the daylight hours. This information is lost at night and the driver must rely on the retroreflectivity of the pavement markings for safe guidance. Glass beads are used in pavement marking systems to provide this retroreflection. The optical characteristics of glass beads allow for the collection of light from the headlights of an automobile and then reflect this light back in a cone towards the drivers eyes. Unfortunately, during rainy weather conditions a thin film of water can cover the glass beads embedded in the pavement markings and interfere with the collection and retroreflection of light. This is extremely hazardous during the night, when the driver is more apt to look to the pavement markings for a safe route of travel.

The FHWA has recognized the wet-night retroreflection of pavement marking materials as a serious safety issue, and mandated the AWPM study within the 1991 ISTEA. The use of large glass beads in pavement markings to overcome the water film effects on the collection and retroreflection of light has shown promising results in the southern areas of the country. However, in order for a pavement marking system to be effective it must also have durability as well as retroreflectivity. The large glass beads are often used on film type markings such as latex traffic paint, epoxy, and thermoplastic markings. In northern climates, film type markings are often damaged by snow plow blades reducing the level of retroreflection and the service life of the marking system. If the pavement marking material is not shared off the pavement surface, the tops of the larger glass beads are broken off or are completely knocked out of the binder.

In southern areas of the country where there is little or no snow removal during the winter season, thermoplastic has proven to be the most cost effective marking material. This is due to superior durability of the marking material combined with the pavement marking system's ability to sustain high retroreflectivity levels throughout the service life of the material. Both of these characteristics are related to the thickness of the marking material. Thermoplastic's thickness (125 mil, 1/8 inch) wears down slowly (approx 10 mils/year) and continuously uncovers premixed glass beads within the marking material, providing a high level of night visibility throughout the surface life of the marking material. Thermoplastic's thickness extends above the water film and prevents the surface beads of the marking from flooding out and thus provides a limited level of wet-night visibility. This limited level wet-night retroreflection although superior to thin film markings such as traffic paint and epoxy is considered to be below the adequate retroreflectivity level needed. Thus many installations of thermoplastic in the Sunbelt are supplemented with RPMs placed at the center of every other gap in striping (24m or 80ft spacing) for adequate wet night visibility. If the operational problems with the application of large glass beads can be resolved, then it will not be necessary to supplement thermoplastic markings with RPMs in order to provide the necessary wet night visibility.

The RPM supplemented thermoplastic system which is very cost effective in non-snow removal areas of the country, loses this cost effectiveness in northern climates where snow plow damage reduces the service life of the thick thermoplastic markings and completely removes most of the RPMs within the first winter season. As previously mentioned the use of larger sized glass beads with the thermoplastic system in order replace the snow plow susceptible RPMs, would most likely reduce cost effectiveness and performance of the system due to missing and broken glass beads. Snow plowable RPMs have shown some promise in areas with low to moderate annual snowfall accumulations, but have mixed results in northern areas where there is high snow removal activity. Presently, most of the pavement marking systems in the northeast do not have or maintain adequate wet night visibility throughout the service life of the system.

In northern climates, the thickness of the thermoplastic marking which provides the systems long life and limited wet-night retroreflectlivity in warmer climates, drastically reduces the service life and retroreflectivity of the marking system due to the susceptibility of the material and glass beads to snow plow damage. In some cases, where Open Graded Friction Course (OGFC) is used as a surface course on highways for its drainage and frictional properties, the snow plow blade damage may not only be confined to the pavement marking. When thermoplastic is applied to the porous OGFC, the hot thermoplastic liquid easily penetrates the material to form a deep, strong bond. Due to this bond, the snow plow blade not only shears off the thermoplastic marking but also the penetrated layers of OGFC, leaving a damaged pavement surface (pot holes along the lane lines). This is why many of the state agencies in the northeast will not even consider thermoplastic as a traffic marking alternative.

If thermoplastic could be applied to a recess grooved into the OGFC surface, then the snowplow blade would pass by without damaging the marking material or the pavement surface. The long service life of the material in non-snow removal areas could be surpassed, not only would there be a lack of contact between the marking and the snowplow blade but the material would wear down at a slower rate due to the embedment of the marking into the pavement surface. Unfortunately, the level of wet night visibility of the thermoplastic marking may be reduced when the marking is recessed flush with the pavement surface. The use of large glass beads may be the solution to this problem. In this case the large glass beads may avoid much of the snowplow blade damage which has made them ineffective in the northern areas of the country.

CHAPTER 3. TEST SECTIONS AND EVALUATION

3.1 Location of Test Sections

The RIDOT was originally reluctant in allowing the URI research team to install three test sections on the Interstate Highway System, from which the problem statement originated. Instead, the RIDOT Design Section suggested the use of one of the Transportation Improvement Programs (TIP) resurfacing projects for FY-96. The URI research team quickly informed the RIDOT that these TIP projects did not satisfy the test section requirements of the original scope of work. In particular, the fact that none of the TIP projects used Modified Open Graded Friction Course (MOGFC) as the final course.

On May 30, 1996 a letter was sent to Mr. James Capaldi, Chief Engineer of RIDOT, informing him of the concerns with using a TIP resurfacing project for the location of the three test sections and requesting his reconsideration on the utilization of a 2,000 ft portion of the I-95 resurfacing project as test sections for this research project. With the help of Mr. Colin Franco, Managing Engineer of Research, a meeting between the URI research team and representatives from the RIDOT was held on June 13, 1996. The URI research team requested permission to utilize a section of I-95 northbound for the location of the three proposed test sections. At this meeting, Mr. Stephen Cardi, Jr, Vice President of Cardi Corporation and Co-principal investigator of the research project, reaffirmed his commitment to the project. The RIDOT representatives (from design, construction, traffic, and research sections) agreed to recommend the utilization of the proposed location on I-95 northbound (exit 14-15) as the site for the three test sections to the Chief Engineer. Appendix B contains the letter sent to Mr. Capaldi, and the minutes of the 6/13/96 meeting, and the formal approval letter received from RIDOT.

3.2 Traffic Marking Placement Plans

After receiving RIDOT's permission to install the three test sections on the I-95 northbound resurfacing site, the URI research team developed the recessed traffic marking placement plans as shown in Appendix C. These plans show the location of the three types of recessed skip stripes within each test section along with the control portion (non-recessed skip stripes) of each test section. This control section was necessary, because the I-95 resurfacing project used permanent inlaid marking tape for the skip stripes.

3.3 Permanent Inlaid Marking Tape

A new pavement marking product (3M Stamark High Performance Tape - Series 380) was used by RIDOT for the skip stripes located outside the limits of the three test sections. This marking material is a patterned (raised diamonds) preformed tape coated with a pressure sensitive adhesive (PSA) backing and supplied in continuous rolls for application purposes. This product was chosen for the ease in which the marking is applied to the asphalt during the paving operation.

The marking tape is applied to the fresh asphalt with a manual highway tape applicator, while the asphalt is still hot (120°F-150°F). The tape is then "inlaid" or pressed into the road surface by rolling over the applied tape with the finishing roller.

According to the manufacturer, Stamark tapes should only be overlaid on OGFC, but a partial inlay can be achieved under certain conditions.

On Tuesday night, September 10, 1996, the URI research team observed the application of the MOGFC layer and the installation of the permanent inlaid preformed marking tape skip stripes. The striping crew was directed to substitute 6 inch tabs of inlaid tape at the beginning of the stripes along the 1,000 ft test section and the 500 ft exit ramp test section which corresponded to the future placement of the thermoplastic stripes as shown in the traffic marking placement plans. The same procedure was repeated on Thursday night, September 26, when the 500 ft curved test section was paved with MOGFC. Pictures of the inlaid tape application procedure are shown in Appendix D.

As mentioned previously, this was the first time permanent inlaid marking tape has been used as traffic marking skip stripes on MOGFC in Rhode Island. The URI research team decided that this was an excellent opportunity to evaluate the durability and retroreflectivity of the new marking material as well. Therefore, sections of the inlaid marking tape near each test section shown in Appendix C were included in the evaluation phase of this project.

3.4 Construction of the Test Sections

The three test sections on I-95 Northbound were installed by the Traffic Markings crew under the direction of the URI research team on Thursday, December 5, 1996. It was a sunny day with a temperature of 48°F. The 6 inch inlaid preformed tape tabs were easily removed with a screwdriver. Drops of moisture were observed on the backing of the removed tabs even though it had been 4 days since the last precipitation had occurred. It may be noted that the region received the first significant snowfall of the season the day after the installation.

3.4.1 Creation of the Traffic Marking Recesses

A gasoline powered pavement cutter equipped with a 6 inch carbide tipped blade was used to create the 6 inch wide traffic marking recesses on the MOGFC as shown in Appendix E.

3.4.2 Cleaning the Traffic Marking Recesses

A substantial amount of loose debris was generated and deposited by the pavement cutter during the creation of the traffic marking recesses. The debris was quickly removed from the finished traffic marking recesses with a gasoline powered blower.

3.4.3 Application of the Thermoplastic to the Traffic Marking Recesses

The white Alkyd thermoplastic skip stripes were applied to the traffic marking recesses with a small portable thermoplastic applicator. The premelted molten thermoplastic was loaded from the Vulcan melting kettles into the portable thermoplastic applicator's storage reservoir. This reservoir was kept heated in order to hold the molten material at the specified application temperature of 400°F to 440°F. The molten thermoplastic was then applied to the traffic marking recesses though an extrusion die, or shoe. The glass beads were uniformly applied onto the extruded markings by gravity drop-on glass bead dispenser, located just behind the extrusion die.

The extrusion die had to be manually adjusted to an applied thickness setting of 0 inch during application of the thermoplastic to the 1/8 inch recess in order to obtain fully recessed traffic markings. Pictures of the installation of the creation of the traffic marking recesses and the application of the thermoplastic markings are shown in Appendix F.

3.5 Retroreflectometer Geometry (12 meter vs. 30 meter)

Retroreflectivity is the most commonly used method of evaluating the performance of delineation techniques ("Roadway" 1994). As previously mentioned in Chapter 2, retroreflectivity is the amount light from the vehicle head lights which is returned (reflected) into the driver's view by a pavement marking. Portable retroreflectometers are used in the field to measure the retroreflectivity of pavement markings. Optical devices mounted to the bottom of these retroreflectometers measure the percentage of light returned from pavement markings by shining an internal tungsten-halogen light source off of a fixed sample area at a predetermined fixed geometry.

Retroreflectometers measure the coefficient of retrorefleced luminance (R_L), which is expressed as millicandles per square meter per lux ($mcd \bullet m^{-2} \bullet lx^{-1}$). This measurement is made at a particular fixed geometry (governed by model type) which is intended to represent the actual field geometry of light rays traveling from the vehicle head lights to the pavement marking and reflected back towards driver's field of vision. The two most commonly fixed geometry's utilized by portable retrorefectometers are 12 meters and 30 meters.

A 12 meter fixed geometry simulates a visual distance of 12 meters (≈40 ft) for the driver of a passenger car with an eye height of 1.07 meters (3.5 ft) and a headlight mounting height of 0.69 meters (2.25 ft). While a 30 meter fixed geometry corresponds to a 30 meter (≈99 ft) viewing distance, an eye height of 1.2 meters (3.9 ft) and a headlight mounting height of 0.65 meters (2.13 ft).

The Retrolux 1500 pavement making retroreflectometer with a 30 meter fixed geometry was chosen to evaluate the retroreflectivity of the traffic markings. The 30 meter geometry was better suited to represent a driver's viewing of skip lane lines on an interstate highway system. Drivers traveling at high speeds, tend to focus their vision further than 12 meters (40 ft) ahead of their vehicles. Furthermore, 10ft skip lane lines are used to inform the driver of upcoming changes in the horizontal geometry of roadway and are spaced 30 ft apart. A 12 meter geometry assumes that the driver is only focused on the first skip stripe ahead of the vehicle, rather than focusing on the second or third skip stripes ahead of the vehicle which corresponds to a 30 meter geometry. Therefore, a 30 meter geometry accurately represents a driver's focused line of sight while safely navigating the upcoming roadway on an interstate highway system at night.

3.6 Evaluation of Recessed Markings for Durability and Retroreflectivity

The durability of each traffic marking was objectively determined by the percentage retained method. The percentage retained is defined as the nominal area of the marking minus the area of loss, divided by the nominal area, and multiplied by 100 ("Roadway" 1994).

The retroreflectivity of each skip stripe was measured by the Retrolux 1500 pavement marking retroreflectometer. A total of four retroreflectivity measurements were taken on each skip strip, two measurements 3 ft from the leading edge and two measurements 6 ft from the leading edge. These measurements were then averaged to obtain a single representative retroreflectivity value for each stripe.

CHAPTER 4. RESULTS AND ANALYSIS OF EVALUATIONS

4.1 Durability

The durability of each skip stripe was determined by utilizing the percentage retained method. The durability evaluations for the stripes within the 1,000 ft tangent test section were conducted on December 5, 1996, December 30, 1996, April 7, 1997, July 30, 1997, November 19, 1997, July 2, 1998, December 7, 1998, and June 30, 1999. The average durability for each type of recessed traffic marking was determined by averaging the percent retained of the six skip stripes within each grouping category as shown in Appendix G. The average durability of the various types of recessed traffic markings located on the high speed lane of the 1,000 ft tangent test section is presented in Figure 4-1.

The fully recessed, semi recessed, and tapered recessed white skip stripes in the high speed lane on the 1,000 ft tangent test section received very little snowplow blade damage (average percent retained ≥ 97%) at the leading edge of the stripe over the three winter maintenance seasons. The non recessed white skip stripes had a slightly lower average percent retained (95%), while the permanent inlaid marking tape received severe snowplow blade damage, with an average percentage retained of 50.8% at the end of the first winter maintenance season (April 7, 1997). However, it must be noted that the damaged inlaid tape stripes were replaced by the manufacturer, thus explaining the 96.7% average percent retained observed on the July 30, 1997 test section evaluation. However, the average percentage retained fell again to 68.3% after the third winter maintenance season (June 30, 1999).

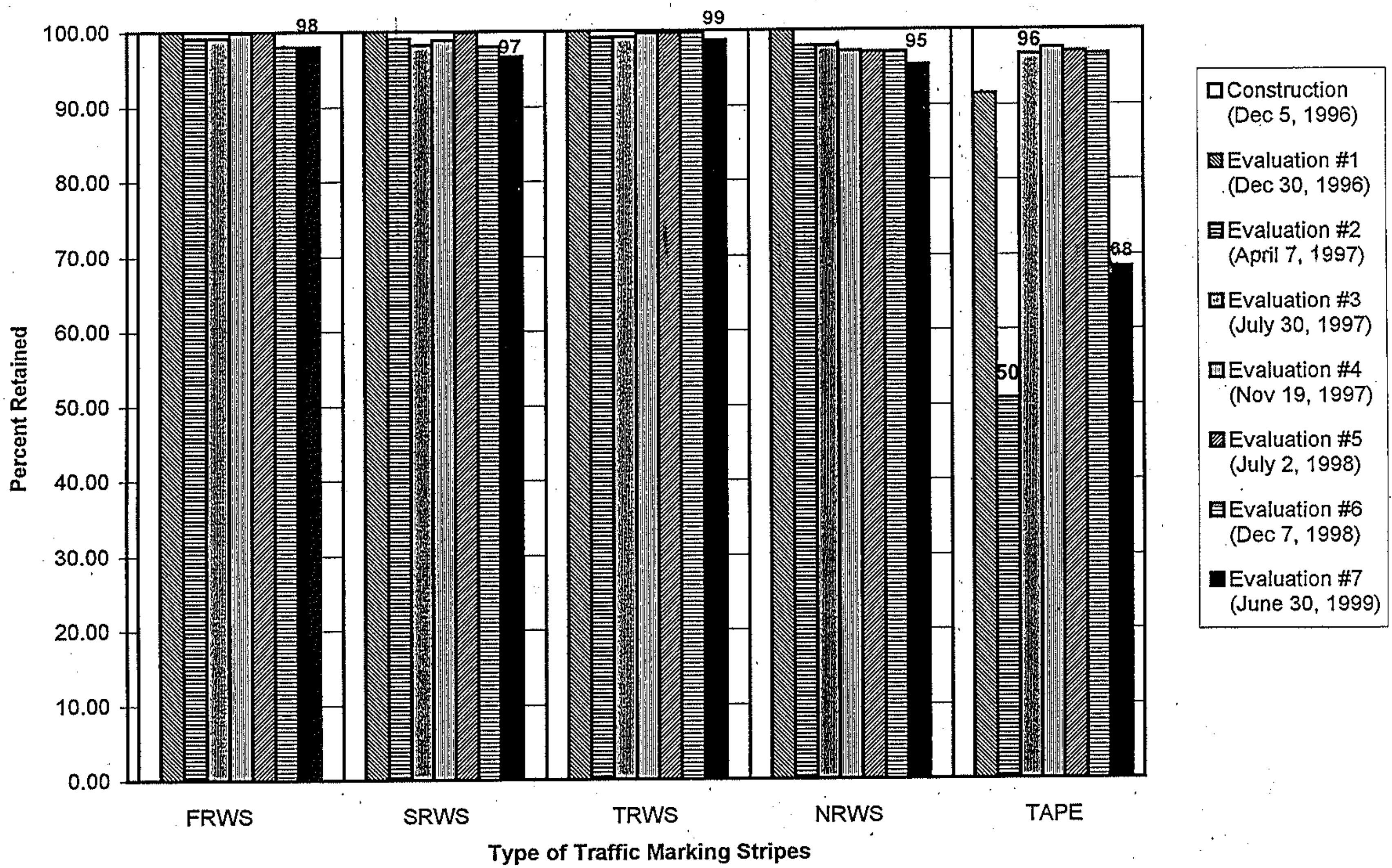


Figure 4-1. Average Durability of the 1000' Tangent Highway Section (Fourth Lane - High Speed Lane)

The fully recessed, semi recessed, and tapered recessed white skip stripes in the middle lane on the 1,000 ft tangent test section also received very little snowplow blade damage (average percent retained ≥ 98%) at the leading edge of the stripe over the three winter maintenance seasons as shown in Figure 4-2. The non recessed white skip stripes had a slightly lower average percent retained of 96.6%. The permanent inlaid marking tape received a high amount of snowplow blade damage with an average percent retained of 78.5% at the end of the first winter maintenance season (April 7, 1997). The increase to an average percentage retained of 98.5% on July 30, 1997 was caused by the replacement of the damaged inlaid tape skip stripes within the test section. The inlaid marking tape received a final average percentage retained value of 95.1% at the end of the third winter maintenance season (June 30, 1999).

The durability evaluations for the stripes within the 500 ft exit ramp test section were performed on December 5, 1996, December 30, 1996, April 7, 1997, July 30, 1997, November 19, 1997, July 2, 1998, December 7, 1998, and June 30, 1999. The average durability for each type of recessed traffic marking was determined by averaging the percent retained of the four skip stripes within each grouping category (three skip stripes for the non recessed) as shown in Appendix H. The average durability of the various types of recessed traffic markings (excluding the inlaid tape) located on the 500 ft exit ramp test section is shown in Figure 4-3.

The fully recessed, semi recessed, and tapered recessed white skip stripes on the 500 ft exit ramp test section received very little snowplow blade damage (average percent retained ≥ 97.0%) over the three winter maintenance seasons. The non recessed skip stripes received significantly more damage (88.0% retained) to the leading edge of the

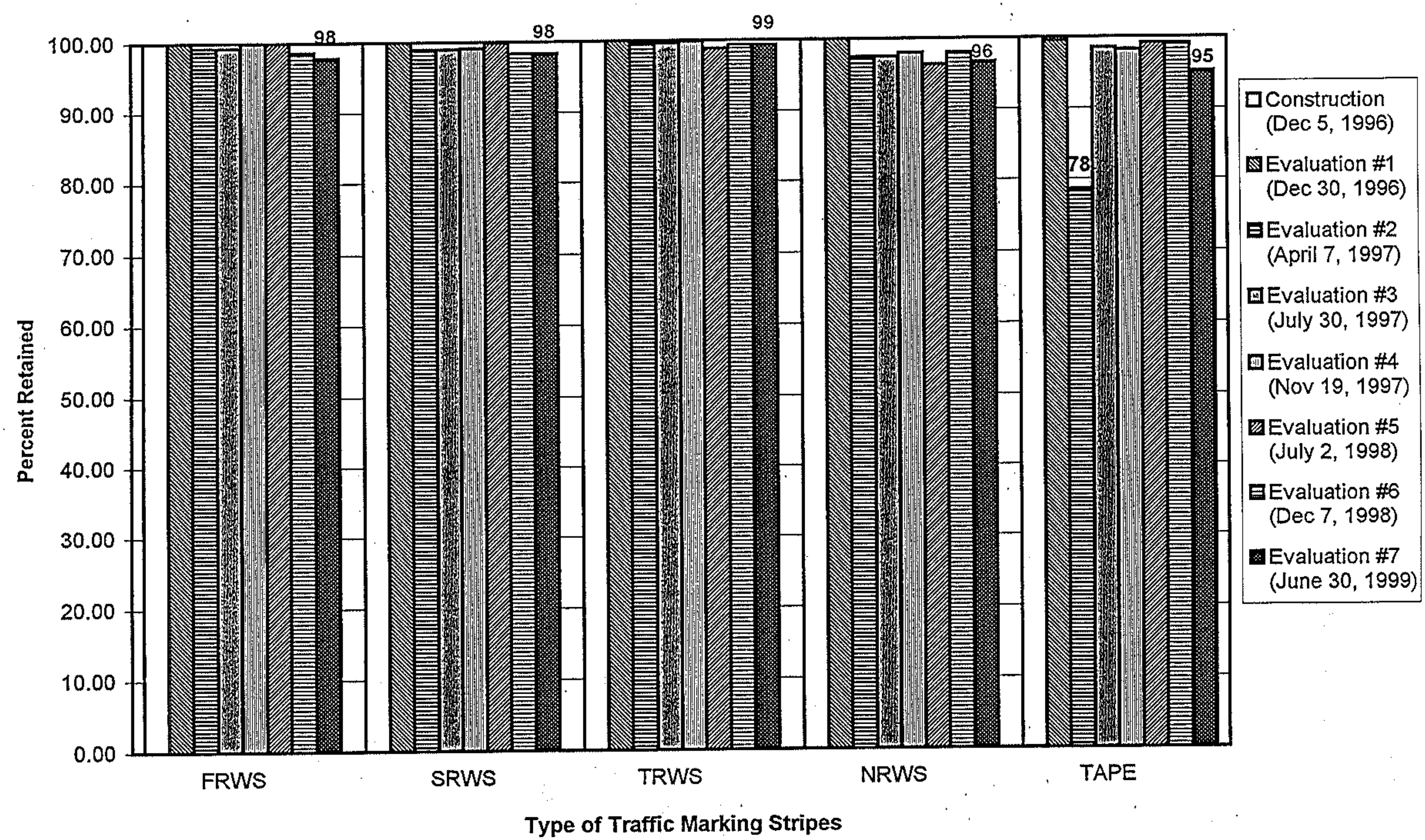
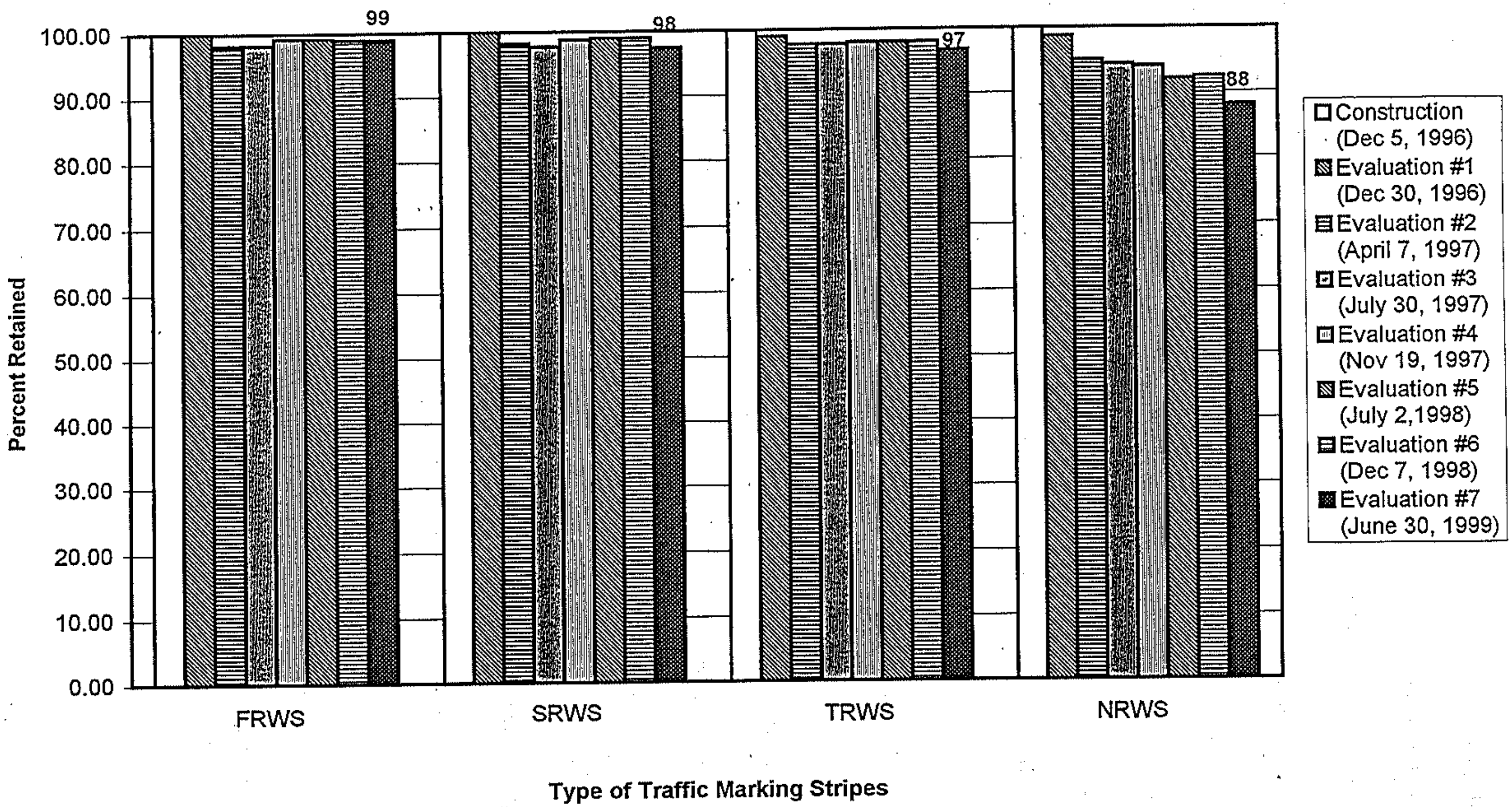


Figure 4-2. Average Durability of the 1000' Tangent Highway Section (Third Lane - Middle Lane)



4-3. Average Durability of the 500' Exit Ramp Section

thermoplastic stripes.

The durability evaluations for the stripes within the 500 ft curved test section were conducted on December 5, 1996, January 6, 1997, April 9, 1997, July 30, 1997, November 19, 1997, July 2, 1998, December 7, 1998, and June 30, 1999. The average durability for each type of recessed traffic marking was determined by averaging the percent retained of the nine skip stripes within each grouping category as shown in Appendix I. The average durability of the various types of recessed traffic markings located on the 500 ft curved test section is shown in Figure 4-4.

The fully recessed, semi recessed, tapered recessed, and non recessed white skip stripes on the 500 ft curved test section received very little snowplow blade damage (average percent retained ≥ 97%) over the first winter maintenance season. However, the permanent inlaid marking tape received the greatest amount of snowplow blade damage, with an average percent retained of 31.2 % at the end of the first winter maintenance season. Furthermore, most of this damage occurred after only one snowplowing event, i.e., the 42.5% average percent retained on January 6, 1997, as shown in Figure 4-4. Once again, the 97.6% average percent retained recorded on July 30, 1997 is a direct result of the replacement of the damaged inlaid tape stripes within the limits of the test section.

However, the average percentage retained value fell again to 81% after the third winter maintenance Season (June 30, 1999).

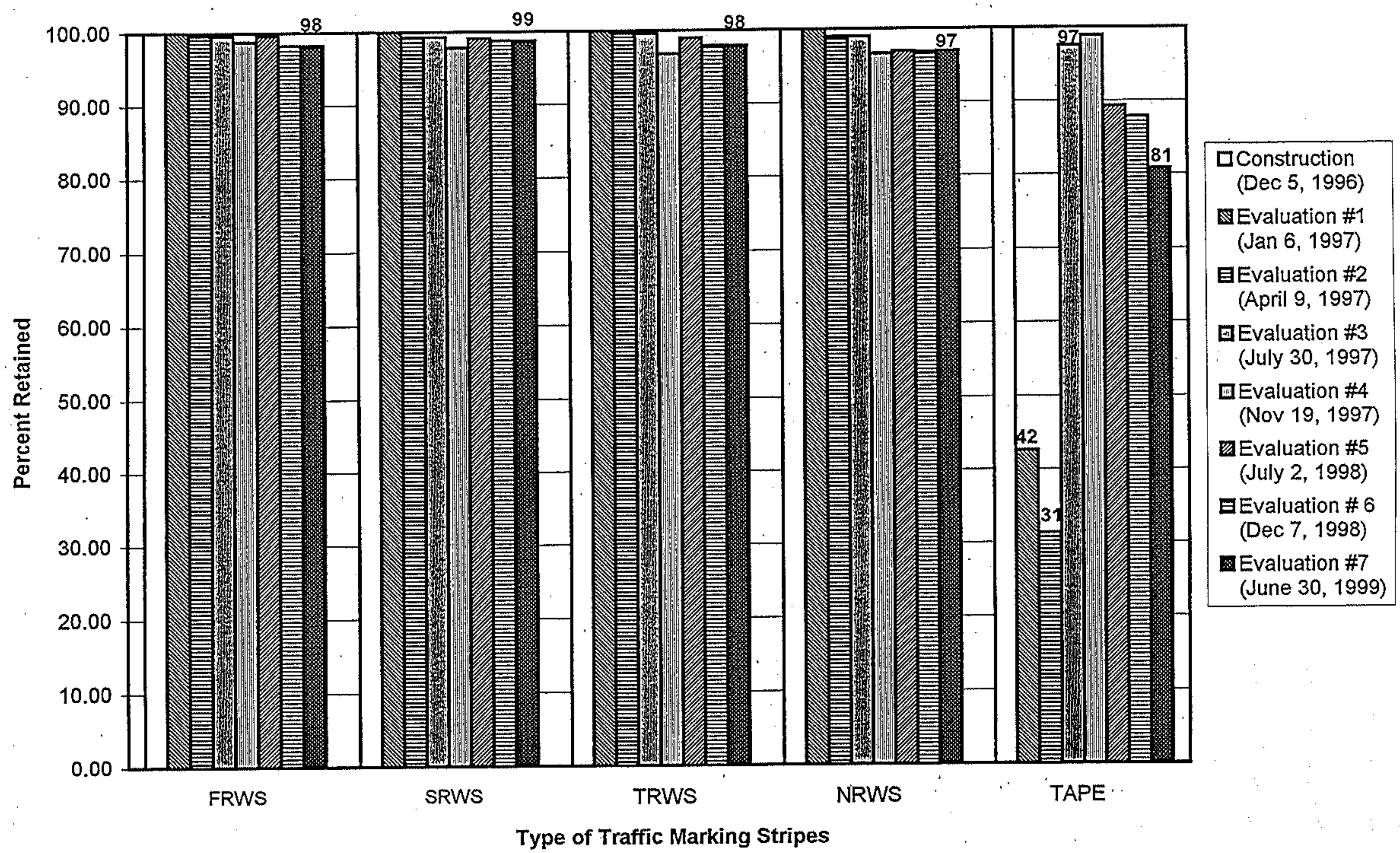


Figure 4-4. Average Durability of the 500' Curved Highway Section

4.2 Retroreflection

The retroreflectivity of each skip stripe was measured by the Retrolux 1500 pavement marking retroreflectometer. The retroreflectivity evaluations for the stripes within the 1,000 ft tangent test section were conducted on December 30, 1996, April 7, 1997, July 30, 1997, November 19, 1997, July 2, 1998, December 7, 1998, and June 30, 1999. Three evaluations were conducted during dry daylight conditions on December 30, 1996, April 7, 1997, and November 19, 1997. The July 2, 1998 and the June 30, 1999 evaluations were conducted during dry night conditions.

On July 30, 1997 a wet evaluation was conducted during the night with simulated wetness conditions. The retroreflectivity of the traffic markings during wet conditions was simulated by pouring water over the traffic marking stripes. The retroreflectivity readings were then taken with the retroreflectometer approximately 60 seconds after the initial wetting of the stripe. The second wet evaluation was conducted on a night (December 7, 1998) with light scattered showers.

4.2.1 Dry Day and Night Evaluations

The average retroreflectivity for each type of recessed traffic marking was determined by averaging the retroreflectvity measurements of the six skip stripes within each grouping category as shown in Appendix G. The average retroreflectivity of the various types of recessed traffic markings located on the high speed lane of the 1,000 ft tangent test section is shown in Figure 4-5.

There is a substantial reduction in the average retroreflectivity for all types of

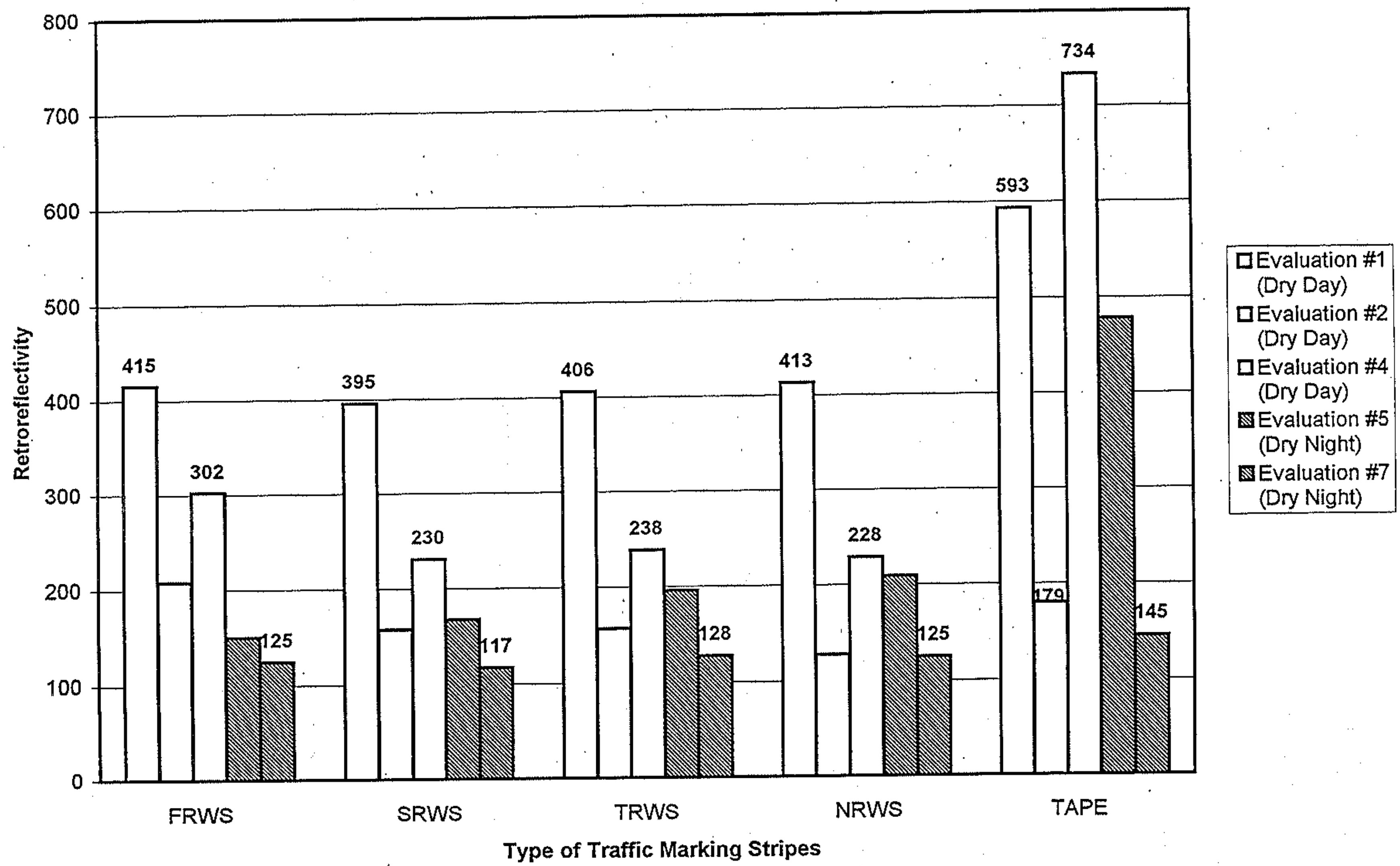


Figure 4-5. Dry Day and Night Retroreflectivity for 1000' Tangent Highway Section (Fourth Lane - High Speed Lane)

recessed traffic markings over the first winter maintenance season. This reduction in retroreflectivity is caused by a combination of traffic wear and snowplow blade damage. The glass beads which provide retroreflectivity are often broken, worn, or completely scraped off of the marking by snowplow blades during the winter maintenance season. The fully recessed, semi recessed, tapered recessed, and non recessed traffic markings had approximately the same initial level of retroreflectivity of 415, 395, 406, and 413 mcd/m²•lux, respectively. The permanent inlaid tape had the highest initial average retroreflectivity level of 593 mcd/m²•lux.

After the first winter maintenance season (November 19, 1997) the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings average retroreflectivity values fell to 302, 230, 238, and 228 mcd/m²•lux, respectively. This drop in average retroreflectivity values corresponds to a percent reduction of 27%, 42%, 41%, and 45% for the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings, respectively. The permanent inlaid tape had a 70% reduction in average retroreflectivity after the first winter maintenance season, which was attributed to the lack of durability (in some cases entire markings were missing) against snow plow blade damage.

After the third winter maintenance season (June 30, 1999) the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings average retroreflectivity values fell to 125, 117, 128, and 125 mcd/m²•lux, respectively. This drop in average retroreflectivity values (from initial values) corresponds to a percent reduction of 70%, 70%, 69%, and 70% for the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings, respectively. The permanent inlaid tape had a 80% (from 734 mcd/m²•lux. with the replacement stripes to 145 mcd/m²•lux) reduction in average retroreflectivity after the third winter maintenance season, which was attributed to the lack of durability against snow plow blade damage.

The average retroreflectivity of the various types of recessed traffic markings located on the middle lane of the 1,000 ft tangent test section is shown in Figure 4-6. The initial average retroreflectivity levels for the fully recessed, semi recessed, tapered recessed, non recessed, and the permanent inlaid tape were 402, 388, 427, 391, and 649 mcd/m²•lux, respectively.

After the first winter maintenance season the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings average retroreflectivity values fell to 278, 187, 220, 226, and 264 mcd/m²•lux, respectively. This drop in average retroreflectivity values corresponds to a percent reduction of 31%, 52%, 49%, 42%, and 59% for the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings, respectively.

After the third winter maintenance season the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings average retroreflectivity values fell (from initial value) to 119, 106, 115, 124, and 134 mcd/m²•lux, respectively. This drop in average retroreflectivity values corresponds to a percent reduction of 70%, 73%, 73%, 68%, and 79% for the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings, respectively.

The retroreflectiviy evaluations for the stripes within the 500 ft exit ramp test section were performed on December 30, 1996, April 9, 1997, and November 19, 1997 during dry daylight conditions. Dry night evaluations of the 500 ft exit ramp test section

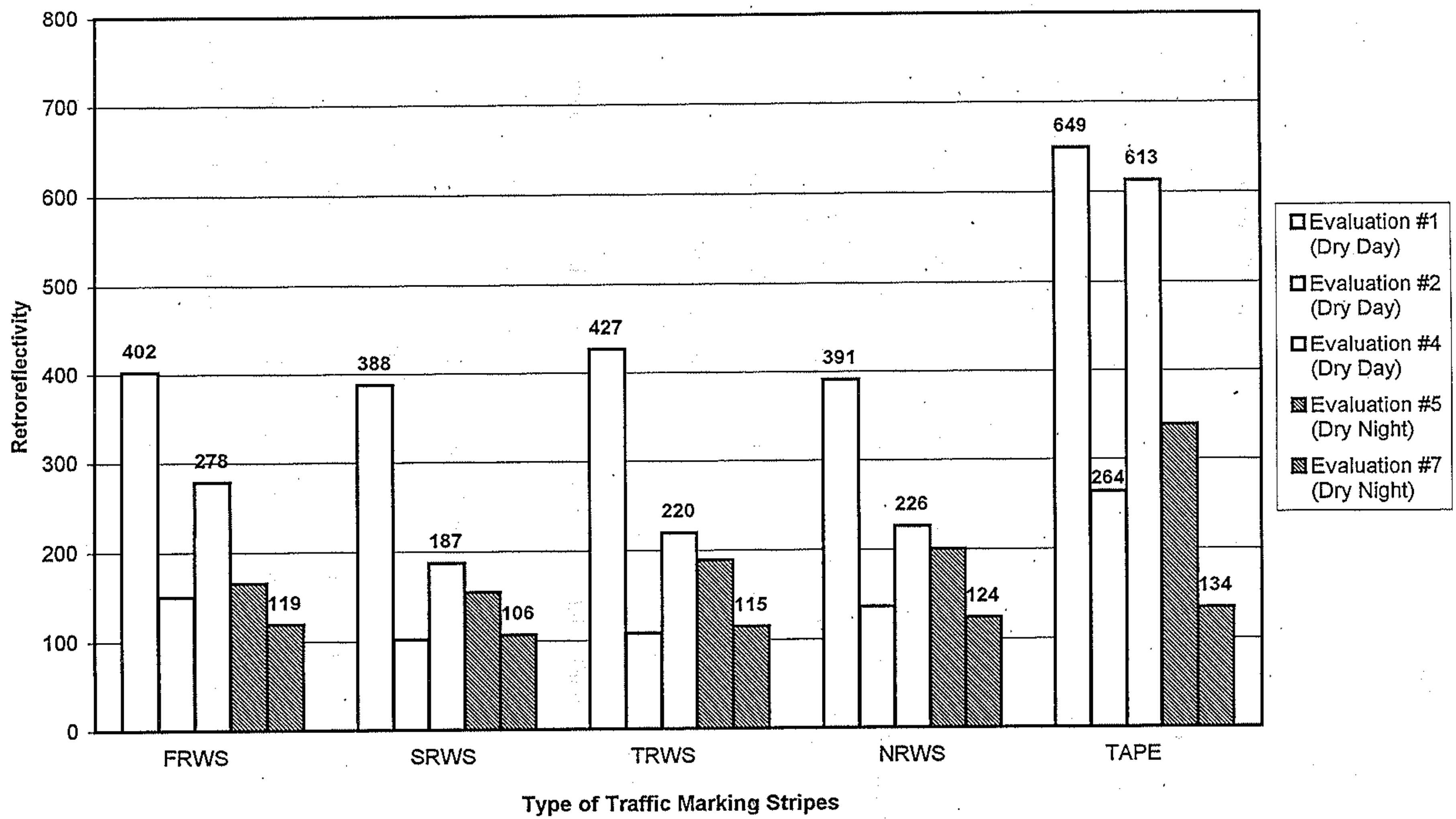


Figure 4-6. Dry Day and Night Retroreflectivity for 1000' Tangent Highway Section (Third Lane - Middle Lane)

were performed on July 2, 1998 and June 30, 1999. The average durability for each type of recessed traffic marking was determined by averaging the retroreflectivity readings of the four skip stripes within each grouping category (three skip stripes for the non recessed) as shown in Appendix H. The average retroreflectivity of the various types of recessed traffic markings (excluding the inlaid tape) located on the 500 ft exit ramp test section is shown in Figure 4-7.

The initial average retroreflectivity levels for the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings were 358, 303, 285, and 199 mcd/m²•lux, respectively. The differences in the initial average retroreflectivity between the type of recessed markings can be attributed to a substantial amount of wear received by the markings on the exit ramp, before December 30, 1996, even though there was only one snowplowing event. The initial average retroreflectivity readings increase as the depth of the traffic marking recess increases.

After the first winter maintenance season (November 19, 1997) the average retroreflectivity values of fully recessed, semi recessed, tapered recessed, and non recessed traffic markings fell to 128, 161, 161, and 223 (increased) mcd/m²•lux, respectively.

After the third winter maintenance season (June 30, 1999) the fully recessed, semi recessed, tapered recessed, and non recessed traffic markings average retroreflectivity values fell to 90, 96, 107, and 148 mcd/m²•lux, respectively. The fully and semi recessed traffic markings were the only marking types on the 500 ft exit ramp test section which did not retain an average retroreflectivity value above the recommended minimum value of 100 mcd/m²•lux for adequate driver visibility.

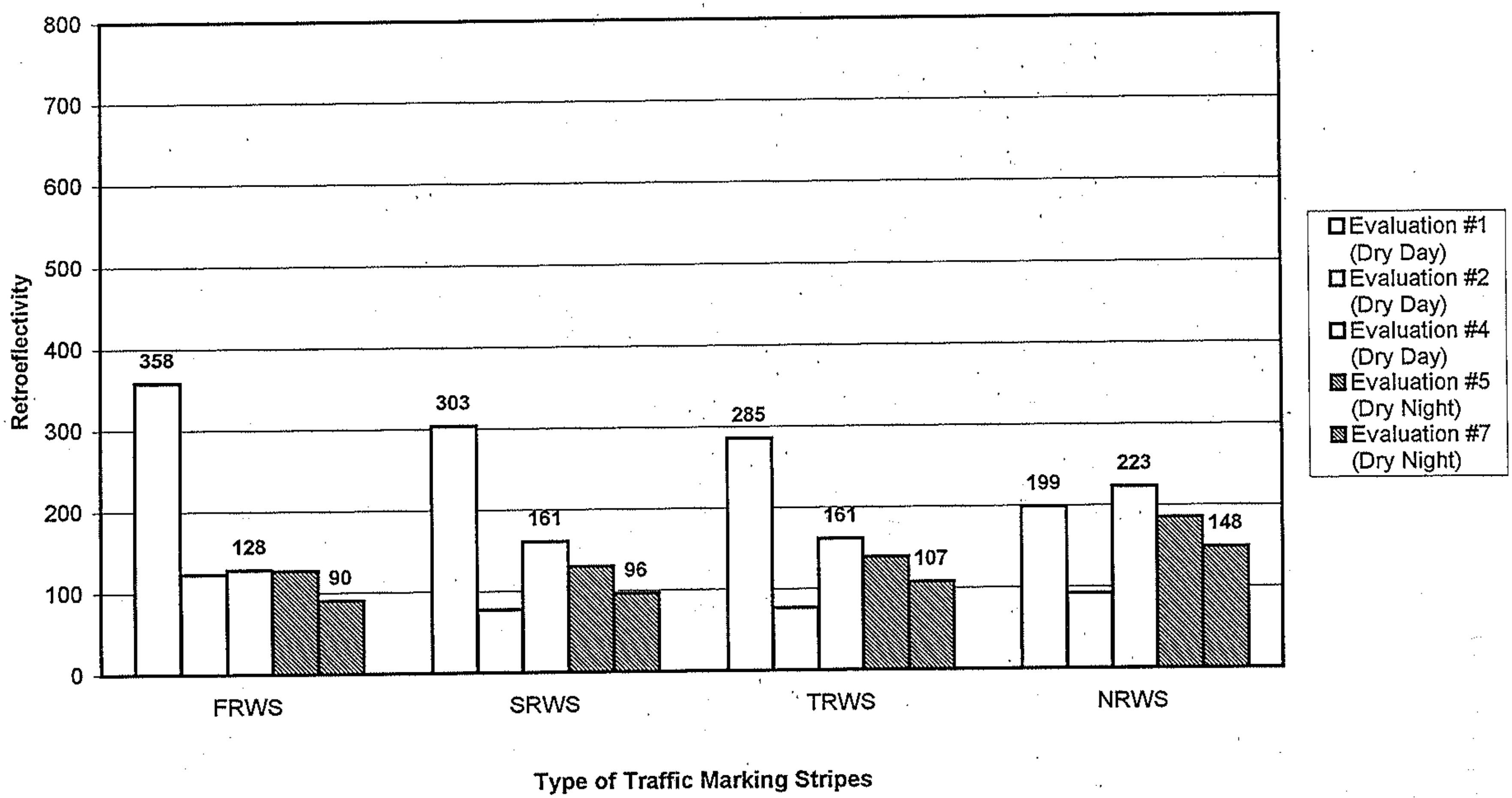


Figure 4-7. Dry Day and Night Retroreflectivity for 500' Exit Ramp Section

The retroreflectivity evaluations for the stripes within the 500 ft curved test section were conducted on Jan 6, 1997, April 9, 1997, and November 19, 1997 during dry daylight conditions. Dry night evaluations of the 500 ft curved test section were performed on July 2, 1998 and June 30, 1999.

The average retroreflectivity for each type of recessed traffic marking was determined by averaging the retroreflectivity readings of the nine skip stripes within each grouping category as shown in Appendix I. The average retroreflectivity of the various types of recessed traffic markings located on the 500 ft curved test section is presented in Figure 4-8.

The fully recessed, semi recessed, tapered recessed, and non recessed traffic markings had approximately the same initial level of retroreflectivity of 329, 316, 324, and 333 mcd/m²•lux, respectively. The permanent inlaid tape had the lowest average retroreflectivity level (205 mcd/m²•lux) during the first evaluation. This initial low average retroreflectivity is directly related to the lack of durability against snowplow damage (an average of 42.6% percent retained by January 6, 1997).

After the first winter maintenance season (November 19, 1997) the average retroreflectivity values of fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings fell to 220, 199, 200, 193, and 99 mcd/m²•lux, respectively. This drop in average retroreflectivity values corresponds to a percent reduction of 33%, 37%, 38%, 42%, and 52% for the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings, respectively.

After the third winter maintenance season (June 30, 1999) the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings

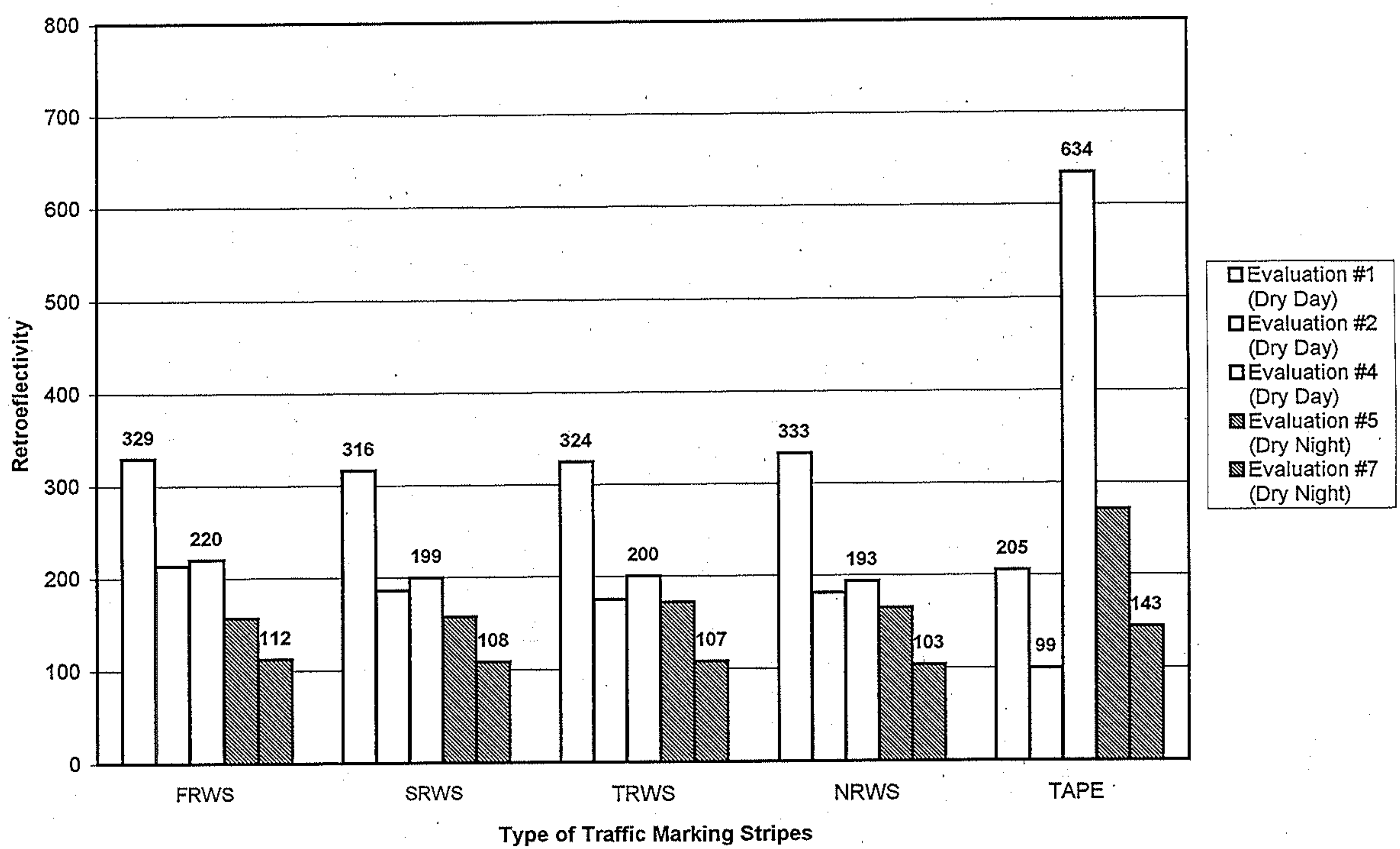


Figure 4-8. Dry Day and Night Retroreflectivity for 500' Curved Highway Section

average retroreflectivity values fell to 112, 108, 107, 103, and 143 mcd/m²•lux, respectively. This drop in average retroreflectivity values corresponds to a percent reduction of 66%, 66%, 67%, 69%, and 30% for the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape traffic markings, respectively.

4.2.2 Statistical Analysis of Retroreflectivity Results

A two sample t-test was performed on the differences in readings between the fully recessed and non recessed traffic markings on the high speed lane within the 1,000 ft tangent test section. The null hypothesis (Ho) chosen for this statistical test of significance (Ho: Ud® = Ud©) indicates that the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the wear for the non recessed (control) traffic markings. The null hypothesis is typically a statement of "no effect" or "no difference" (Rossman1996). The significance test is designed to assess the evidence against the null hypothesis.

The alternative hypothesis (Ha) states what the researcher suspects or hopes to be true about the parameter of interest (Rossman1996). The alternative hypothesis for this statistical test of significance (Ha: Ud® < Ud©) indicates that the wear received by the recessed traffic markings is less than the wear received by the non recessed (control) traffic markings.

The test statistic is a value computed by standardizing the observed sample statistic on the basis of the hypothesized parameter value and is used to assess the evidence against the null hypothesis (Rossman1996). The equation used for this statistical test of significance was;

$$t = X_1 - X_2 / (SD_1^2 / N_1 + SD_2^2 / N_2)^{1/2}$$

where,

t = Test statistic

X_1 = Mean of the difference in retrorefectivity readings for the fully recessed traffic markings.

X_2 = Mean of the difference in retrorefectivity readings for the non recessed traffic markings.

SD_1 = Standard deviation of the differences in retroreflectivity reading for the fully recessed traffic markings.

SD_2 = Standard deviation of the differences in retroreflectivity reading for the non recessed traffic markings.

N_1 = Sample size of fully recessed traffic markings.

N_2 = Sample size of non recessed traffic markings

Statistical values for fully recessed and non recessed markings were computed as shown in Tables 4-1 and 4-2, respectively. The t value was computed as follows:

$$t = 289.92 - 287.96 / (9.88^2 / 6 + 20.47^2 / 6)^{1/2}$$

$$= \mathbf{0.21}$$

The p-value is the probability, assuming the null hypothesis to be true, of obtaining a test statistic as extreme or more extreme than the one actually observed (Rossman1996). "Extreme" means "in the direction of the alternative hypothesis". Therefore the p-value which corresponds to the chosen alternative hypothesis is;

$$\Pr(T < -t) \quad \rightarrow \quad \Pr(T < -0.21)$$

Table 4-1. Average Difference in Retroreflectivity Readings of the Fully Recessed Markings on High Speed Lane of 1,000 ft Tangent Test Section.

Fully Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	391.75	107.75	283.25
2	414.00	125.75	288.25
3	416.00	130.50	285.50
4	420.50	135.25	285.25
5	418.75	131.25	287.50
6	427.25	117.50	309.75
		Mean	**289.92**
		SD	**9.88**

Table 4-2. Average Difference in Retroreflectivity Readings of the Non Recessed Markings on High Speed Lane of 1,000 ft Tangent Test Section.

Fully Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	387.25	127.50	259.75
2	402.00	128.50	273.50
3	397.25	119.50	277.75
4	426.50	124.75	301.75
5	419.75	116.25	303.50
6	443.00	131.50	311.50
		Mean	**287.96**
		SD	**20.47**

The p value was obtained by entering the t - distribution table shown in Appendix J with a t value of -0.21 and a degree of freedom of 5 (N-1). The p-value obtained was greater than 0.2, (p-value > 0.2).

One judges the strength of the evidence that the data provides against the null hypothesis (Ho) by examining the p-value (Rossman1996). The smaller the p-value, the stronger the evidence against Ho (and thus in favor of Ha). For instance, typical evaluations are:

$p\text{-value} > 0.1$	little or no evidence against Ho
$0.05 < p\text{-value} \leq 0.1$	some evidence against Ho
$0.01 < p\text{-value} \leq 0.05$	moderate evidence against Ho
$0.001 < p\text{-value} \leq 0.01$	strong evidence against Ho
$p\text{-value} \leq 0.001$	very strong evidence against Ho

Therefore, there is no evidence against the null hypothesis, i.e., the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the wear for the non recessed (control) traffic markings. Therefore, there is no evidence against the null hypothesis and thus the evidence is supporting the null hypothesis, i.e., the wear received by the fully recessed traffic markings on the high speed lane of the 1,000 ft tangent test section equals the wear received by the non recessed traffic markings.

A two sample t-test was also performed on the differences in readings between the fully recessed and non recessed traffic markings on the middle lane within the 1,000 ft tangent test section. The null hypothesis (Ho) chosen for this statistical test of significance (Ho: Ud® = Ud©) indicates that the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the wear for the non recessed (control) traffic markings. The alternative hypothesis for this statistical test of significance (Ha: Ud® < Ud©) indicates that the wear received by the recessed traffic markings is less than the wear received by the non recessed (control) traffic markings.

Statistical values for fully recessed and non recessed markings were computed as shown in Tables 4-3 and 4-4, respectively. The t value was computed as follows:

$$t = 283.08 - 267.42 \ / \ (26.02^2 / 6 + 28.70^2 / 6)^{1/2}$$

$$= \mathbf{0.99}$$

Therefore the p-value which corresponds to the chosen alternative hypothesis is;

$$\Pr (T < {}^{-} t) \quad \rightarrow \quad \Pr (T < {}^{-}0.99)$$

The p value was obtained by entering the t - distribution table shown in Appendix J with a t value of 0.17 and a degree of freedom of 5 (N-1). The p-value obtained was greater than 0.2. Therefore, there is no evidence against the null hypothesis, i.e., the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the wear for the non recessed (control) traffic markings. This may be due to the fact that the crown of the pavement is located on the middle lane line. Typically, the most severe snowplow blade damage occurs at the highest point of the pavement cross section.

Table 4-3. Average Difference in Retroreflectivity Readings of the Fully Recessed Markings on Middle Lane of 1,000 ft Tangent Test Section.

Fully Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	415.00	104.50	310.50
2	416.75	114.75	302.00
3	413.25	125.50	287.75
4	368.00	127.00	241.00
5	391.25	127.50	263.75
6	409.50	116.00	293.50
		Mean	**283.08**
		SD	**26.02**

Table 4-4. Average Difference in Retroreflectivity Readings of the Non Recessed Markings on Middle Lane of 1,000 ft Tangent Test Section.

Fully Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	400.50	124.75	275.75
2	437.25	116.75	320.50
3	384.25	131.50	252.75
4	386.75	124.50	262.25
5	366.75	128.00	238.75
6	371.00	116.50	254.50
		Mean	**267.42**
		SD	**28.70**

Again, a two sample t-test was performed on the differences in readings between the fully recessed and non recessed traffic markings on the 500 ft curved test section. Statistical values for fully recessed and non recessed markings were computed as shown in Tables 4-5 and 4-6, respectively. The t value was computed as follows:

$$t = 217.33 - 229.89 / (44.34^2 / 9 + 29.42^2 / 9)^{1/2}$$

$$= -.7081$$

Table 4-5. Average Difference in Retroreflectivity Readings of Fully Recessed Markings on the 500 ft Curved Test Section.

Fully Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	374.50	122.75	251.75
2	335.50	127.75	207.75
3	343.50	133.00	210.50
4	337.25	113.25	224.00
5	315.00	62.00	253.00
6	348.50	53.50	295.00
7	320.50	127.50	193.00
8	292.50	133.75	158.75
9	296.50	134.25	162.25
		Mean	**217.33**
		SD	**44.34**

Table 4-6. Average Difference in Retroreflectivity Readings of the Non Recessed Markings on the 500 ft Curved Test Section.

Non Recessed Stripe Number	Initial Reading (12/30/1996)	Final Reading (06/30/1999)	Difference in Readings
1	373.00	121.00	252.00
2	358.25	126.00	232.25
3	340.25	115.00	225.25
4	329.75	93.25	236.50
5	343.50	77.00	266.50
6	342.00	82.75	259.25
7	286.25	115.25	171.00
8	310.50	105.50	205.00
9	311.75	90.50	221.25
		Mean	**229.89**
		SD	**29.42**

Therefore the p-value which corresponds to the chosen alternative hypothesis is;

$$\Pr(T < {}^{-}t) \quad \rightarrow \quad \Pr(T < 0.71)$$

The p value was obtained by entering the t - distribution table shown in Appendix J with a t value of 0.71 and a degree of freedom of 8 (N-1). The p-value obtained was greater than 0.2. Therefore, there is no evidence against the null hypothesis, i.e., the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the wear for the non recessed (control) traffic markings.

Therefore, there is no evidence against the null hypothesis and thus strong evidence in favor of the null hypothesis , i.e., the wear received by the fully recessed traffic markings on the 500 ft curved test section is equal to the wear received by the non recessed traffic markings

A two sample T-test was not performed for the 500 ft exit ramp test section, due to the large difference between the initial readings between the fully recessed and non recessed traffic markings.

4.2.3 Wet Night Retroreflectivity Analysis

The July 30, 1997 and December 7, 1998 evaluations were conducted during the night with simulated wetness conditions and at night with light scattered showers, respectively. The July 30, 1997 evaluation was conducted at night with simulated wet conditions. The retroreflectivity of the traffic markings during wet conditions was simulated by uniformly pouring water over the traffic marking stripes. The Retroreflectivity readings were then taken with the retroreflectometer approximately 60 seconds after the initial wetting of the stripe. The December 7, 1998 evaluation was conducted during a night with light scattered showers that tapered off as the wet night evaluation progressed.

The average wet night retroreflectivity for both wet night evaluations (#3 - simulated and #6 - actual) of the various types of recessed traffic markings located on the high speed lane of the 1,000 ft tangent test section is shown in Figure 4-9. During the simulated wet night condition evaluation (July 30, 1997) the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were substantially reduced (from their dry levels) to 44, 53, 58, 64, and 115 mcd/m²•lux, respectively. During the actual wet night condition evaluation (July 30, 1997), the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were also substantially reduced to 54, 58, 85, 92, and 88 mcd/m²•lux, respectively. The simulated wet night average retroreflectivity values for all recessed and non-recessed types of the thermoplastic markings are slightly higher than their corresponding actual wet night values. Additionally, for both wet night evaluations (Simulated and Actual) the average retroreflective values increase as the type of recess progresses from full recessed to non recessed

Several sets of separate researchers have now arrived at a value of about 100 mcd/m²•lux as a minimum retroreflectivity level for adequate visibility ("Roadway"1994). All of the average retroreflectivity values for the recessed and non-recessed thermoplastic traffic markings located on the high speed lane of the 1,000 ft tangent test section fall below this minimum value, during both wet night evaluations. The permanent inlaid tape retains the highest level of retroreflectivity, however this is misleading due to the number of recently replaced damaged skip stripes within the test section limits.

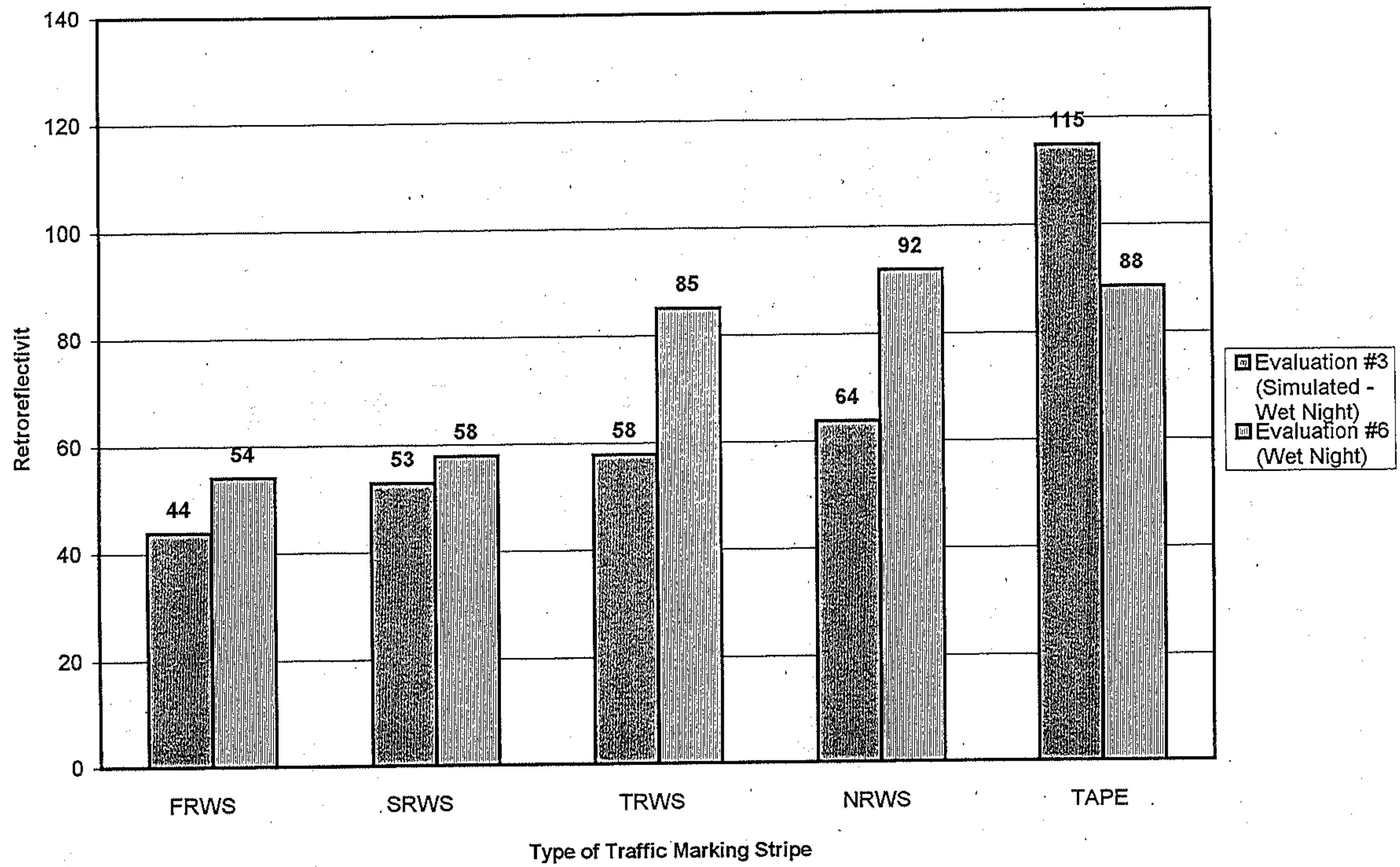


Figure 4-9. Wet Night Retroreflectivity 1000' Tangent Highway Section (Fourth Lane- High Speed Lane)

The average wet night retroreflectivity for both wet night evaluations (#3 - simulated and #6 - actual) of the various types of recessed traffic markings located on the middle lane of the 1,000 ft tangent test section is shown in Figure 4-10. During the simulated wet night condition evaluation on July 30, 1997, the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were further reduced to 45, 55, 54, 45, and 106 mcd/m²•lux, respectively.

During the actual wet night condition evaluation (July 30, 1997), the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were also substantially reduced to 79, 88, 152, 205, and 116 mcd/m²•lux, respectively. The simulated wet night average retroreflectivity values for fully recessed and semi recessed types of the thermoplastic markings are slightly higher than their corresponding actual wet night values. However, the simulated wet night average retroreflectivity values for the tapered recessed and non recessed are substantially higher than their corresponding actual wet night value. This spike in the average wet night (actual) retroreflectivity, corresponds to the tapering off of the scattered showers. Additionally, the average actual wet night retroreflectivity for fully recessed and semi recessed thermoplastic markings fall below the minimum recommended value of 100 mcd/m²•lux for adequate driver visibility.

The average wet night retroreflectivity for both wet night evaluations (#3 - simulated and #6 - actual) of the various types of recessed traffic markings located on the high speed lane of the 500 ft exit ramp test section is shown in Figure 4-11. During the simulated wet night condition evaluation (July 30, 1997) the fully recessed, semi recessed,

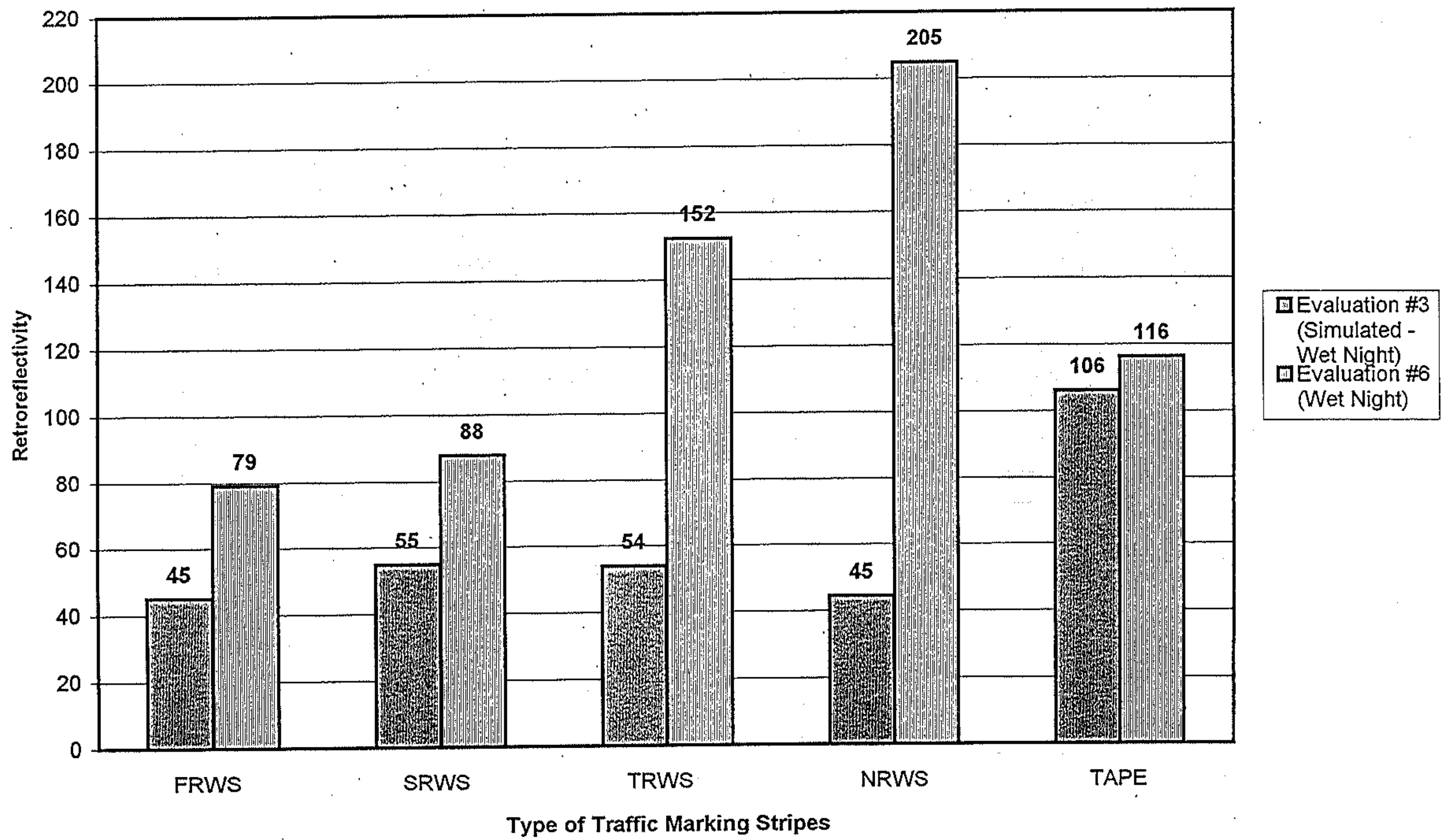


Figure 4-10. Wet Night Retroreflectivity for 1000' Tangent Highway Section (Third Lane - Middle Lane)

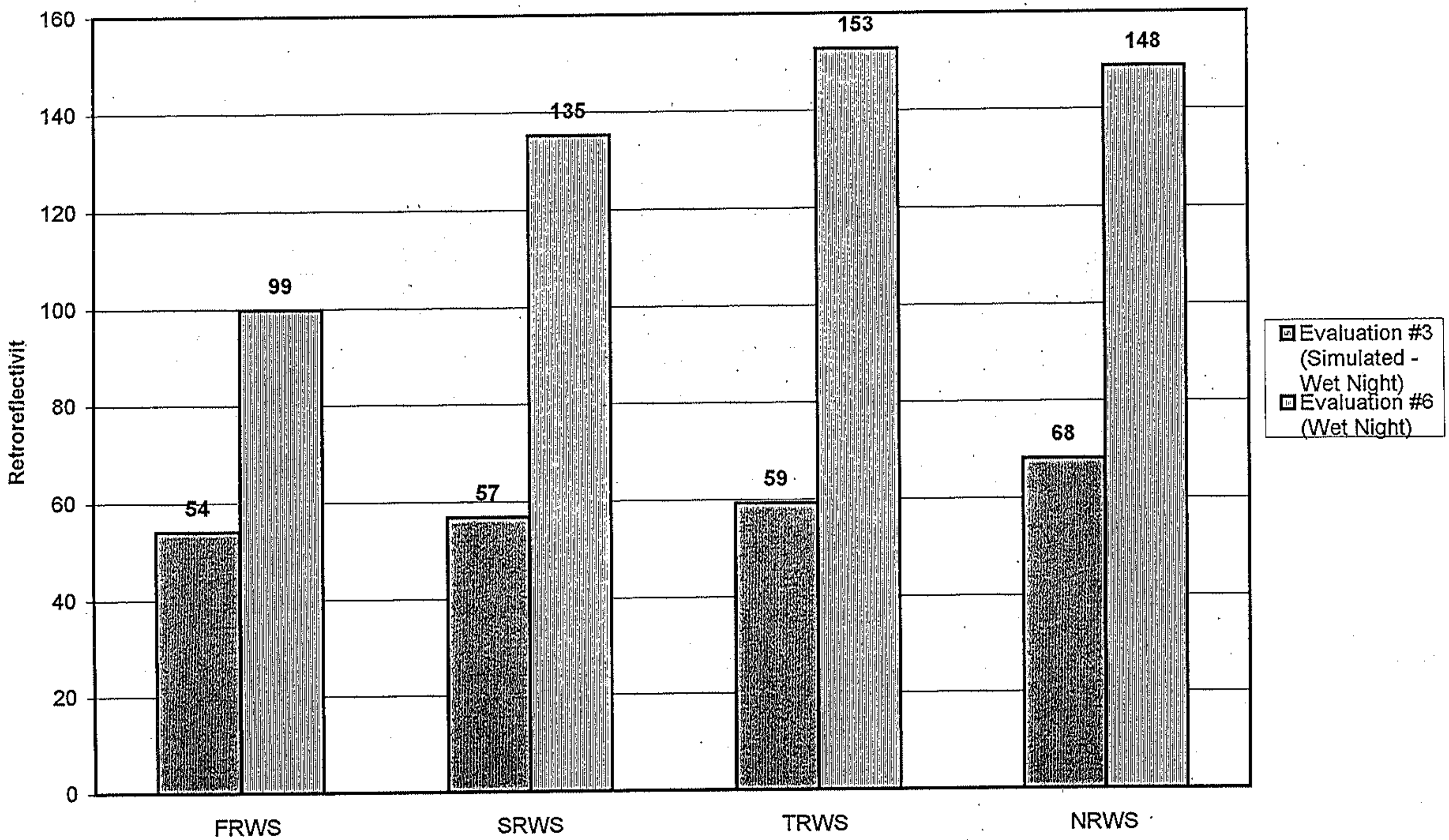


Figure 4-11. Wet Night Retroreflectivity for 500' Exit Ramp Section

tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were substantially reduced (from their dry levels) to 58, 57, 59, and 68 mcd/m²•lux, respectively. During the actual wet night condition evaluation (July 30, 1997), the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were also substantially reduced to 99, 135, 153, and 148 mcd/m²•lux, respectively. The simulated wet night average retroreflectivity values for all recessed and non-recessed types of the thermoplastic markings are significantly higher than their corresponding actual wet night values. Additionally, for both wet night evaluations (Simulated and Actual) the average retroreflective values increase as the type of recess progresses from full recessed to non recessed. Only the fully recessed markings fail to retain an average retroreflectivity value above the minimum recommended value of 100 mcd/m²•lux for adequate driver visibility, during the actual wet night evaluation.

The average wet night retroreflectivity for both wet night evaluations (#3 - simulated and #6 - actual) of the various types of recessed traffic markings located on the high speed lane of the 500 ft curved highway test section is shown in Figure 4-12. During the simulated wet night condition evaluation (July 30, 1997) the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were substantially reduced (from their dry levels) to 57, 58, 61, 58, and 143 mcd/m²•lux, respectively. During the actual wet night condition evaluation (July 30, 1997), the fully recessed, semi recessed, tapered recessed, non recessed, and permanent inlaid tape average retroreflectivity values were 189, 204, 211, 205 and 220 mcd/m²•lux, respectively. The simulated wet night average retroreflectivity values for all

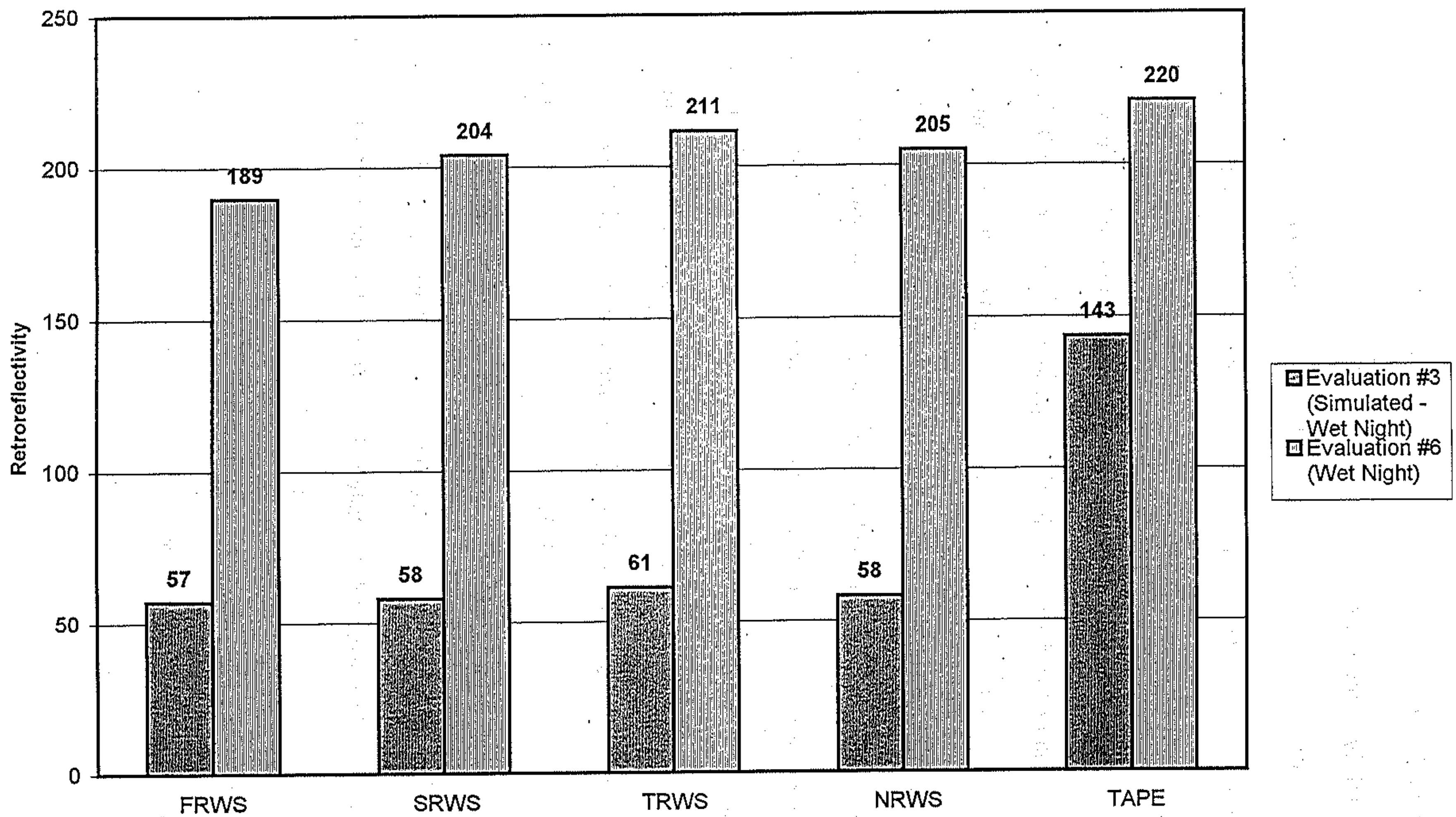


Figure 4- 12. Wet Night Retroreflictivity 500' Curved Highway Section

recessed and non-recessed types of the thermoplastic markings are significantly lower than their coorisponding actual wet night values. Additionally, for both wet night evaluations (Simulated and Actual) the avaerage retroreflective values increase as the type of recess progresses from full recessed to non recessed and tapered recess.

4.3 Summary

There was very little difference in durability between fully recessed and non recessed thermoplastic traffic markings on the 1,000 ft tangent test section and the 500 ft curved test section. Both sections retained over 95 % of their thermoplastic markings, with the non recessed receiving slightly more leading edge damage than the fully recessed. However, in all cases the non recessed thermoplastic received slightly more leading edge loss than their recessed counterparts. This is expected due to the relatively low number of snowplowing events which occurred over the three winter maintenance seasons and the durability of the material (average life of 7 years).

However, the permanent inlaid marking tape received a substantial amount of snowplow blade damage on the high speed lane and the middle lane of the 1000 ft tangent test section with an average of 50.8 % and 78.5% of the markings retained, respectively, at the end of the first winter maintenance season. Furthermore, the permanent inlaid tape was critically damaged on the 500 ft curved test section, with only 31.4% of the markings retained at the end of the winter maintenance season. In some cases, whole markings were sheared off of the pavement surface (0% retained) by the snowplow blades.

After the first winter maintenance season, the missing and damaged permanent inlaid marking tape markings were replaced throughout the high speed lane and the middle lane of the 1000 ft tangent test section and their average percent retained increased to 96% and 98%, respectively. However, by the end of the third winter maintenance season the percent retained values for the high speed lane and the middle lane fell again to 68% and 95%, respectively. Furthermore, the permanent inlaid on the 500 ft curved test section, which was critically damaged after the first winter maintenance season (31.4% retained) was replaced and only retained 81% of the markings retained by the end of the third winter maintenance season.

The largest difference in durability levels between recessed and non recessed thermoplastic traffic markings occurred on the 500 ft exit ramp test section, with 97% and 88% retained, respectively, at the end of the third winter maintenance season. The non- recessed thermoplastic stripes on the 500 ft exit ramp also received the greatest amount of leading edge snowplow damage, than any other grouping of thermoplastic traffic markings within the study.

There was a substantial reduction in average retroreflectivity for all types of recessed thermoplastic traffic markings. This reduction in average retroreflectivity is caused by a combination of traffic wear and snowplow blade damage. The glass beads which provide retroreflectivity are often broken, worn, or completely scraped off of the marking by snowplow blades during the winter maintenance season.

All of the recessed and non recessed types of thermoplastic traffic markings on the 1,000 ft tangent highway and 500 ft curved had similar final values (within ten units of each other), at the end of the third winter maintenance season. The traffic markings on the 500 ft exit ramp test section retained the lowest levels of average retroreflectivity at the end of the third winter maintenance season. In fact, the tapered and non recessed traffic markings were the only marking type which retained an average retroreflectivity above the recommended minimum retroreflectivity value of 100 mcd/m²•lux for adequate driver visibility.

The initial average retroreflectivity levels of the permanent inlaid tape were significantly higher than the thermoplastic markings on the 1,000 ft tangent test section. However, the average retroreflectvity level of the permanent inlaid tape fell below the average retroreflectivity level of the fully recessed thermoplastic markings on the high speed lane at the end of the first winter maintenance season. This substantial drop in retroreflectivity is directly related to the lack of durability against snowplow blade damage (missing markings have no retroreflectivity) over the first winter maintenance season. However, this drop of retroreflectivity is followed by a significant increase in retroreflectivity due to the replacement of severely damaged and missing permanent inlaid tape with pressure sensitive adhesive overlay tape. However, these high values diminish to levels just slightly over all recessed (and non recessed) types by the end of the third winter maintenance season, due to the continued loss of replaced (overlaid) and non replaced tape (original inlaid) traffic markings.

The initial average retroreflectivity level of the permanent inlaid marking tape on the 500 ft curved section was lower than any other marking, due to snowplow blade damage after only one winter maintenance event (42.6% retained). At the end of the first winter maintenance season the average retroreflectivity level of the tape fell slightly below the recommended minimum retroreflectivity value of 100 mcd/m²•lux for adequate driver visibility. Once again, this drop in average retroreflectivity was also due to the marking materials lack of resistance to snowplow blade damage (31% retained at the end of the season). The missing inlaid tape markings on the 500 ft curved highway test section were also replaced with a pressure sensitive adhesive overlay tape after the first winter maintenance season. However, the initial jump in the average retroreflecivty value caused by the replacement markings also diminished to average retroreflectivity values slightly above the various thermoplastic markings by the end of the third winter maintenance season.

A two sample t-test was performed on the differences in retroreflectivity readings between the fully recessed and non recessed traffic markings on the high speed and the middle lane within the 1,000 ft tangent test section, and the markings within the 500 ft curved section.

There was no evidence that the wear received by the fully recessed traffic markings (indicated by a reduced retroreflectivity) on the high speed lane of the 1,000 ft tangent test section was significantly less then the amount received by the non recessed traffic markings. There was evidence that the wear (indicated by a reduced retroreflectivity) received by the recessed traffic markings equals the amount received by the non recessed (control) traffic markings on the middle lane of the 1,000 ft tangent test section. This may be attributed to the fact that the middle lane lines are located on the highest point (crown) of the pavement cross section.

Finally, there was also no evidence that the wear received by the fully recessed traffic markings on the 500 ft tangent test section was significantly less then the amount received by the non recessed traffic markings.

During the actual wet night elevation the average retroreflectivity of the all recessed and non recessed types of thermoplastic traffic markings on the three test sections were substantially reduced (from their dry average retroreflectivity values) due to water film effect **(See Section 2.2.2).** Additionally, for the actual wet night evaluation the average retroreflective values increase as the type of recess progresses from full recessed to non recessed and tapered recess. The water film effect has less of an influence on the tapered and non recessed thermoplastic markings, the water film tends to run off 1/8 inch thick (above the road grade) thermoplastic stripe in the direction of the cross slope. Furthermore, the average wet night (actual) retroreflectivity values for the fully recessed and semi recessed markings on the 1000 ft tangent highway test section fail (both lanes) to retain an average retroreflectivity value above the minimum recommended value of 100 $mcd/m^2 \cdot lux$ for adequate driver visibility, during the actual wet night evaluation.

CHAPTER 5

SPECIFICATIONS AND COST EFFECTIVENESS OF TRAFFIC MARKING RECESSES

5.1 Recommended Construction Specifications for Traffic Marking Recesses

Model construction specifications for recessed thermoplastic traffic markings have been developed through this study, and are presented below.

Description:

1.1 This specification covers the creation by mechanical means of three types of traffic marking recesses on MOGFC for the application of thermoplastic skip stripes.

Equipment:

2.1 The equipment to create the traffic marking recesses shall be approved by the Engineer prior to the start of work.

2.2 The mobile pavement cutter shall be a gasoline powered pavement scarifier which is capable of creating traffic marking recesses 6 inch wide, 10 foot long, and up to 1/8 inch deep in one pass.

2.3 The mobile pavement cutter shall have a variable depth setting control and an engage/disengage lever to raise or lower the cutting drum without losing the depth setting.

2.4 The mobile pavement cutter shall have a six shaft cutting drum assembly capable of creating a uniform finished surface texture. The cutting drum assembly should be designed for quick changes with spare cutting drum assemblies.

2.5 The cutting drum shall consist of tungsten carbide cutters or another type of capable cutting material as approved by the Engineer.

2.6 The pavement cutter should have a performance capability of 350 - 500 square feet per hour at 1/8 inch cutting depth.

2.7 A gasoline powered blower shall be used to clean the loose debris from the finished traffic marking recess before applying the thermoplastic.

<u>Construction Methods:</u>

3.1 The 1/8 inch full depth recesses shall be created in the MOGFC with the approved equipment by setting the variable depth control and checking the depth of the initial recess with a machinist ruler or other approved measuring device. Once a depth of approximately 1/8 inch has been obtained by the operator, the engage/disengage lever should be used to raise or lower the cutting drum without losing the depth setting.

3.1.1 After the initial depth setting has been set, the operator shall lower the cutting drum with the engage/disengage lever to begin the 10 foot skip stripe and then raise the cutting drum at the end of the recess.

3.1.2 The extrusion die on the thermoplastic application equipment should be manually adjusted to 0 inches in order to obtain fully recessed thermoplastic traffic markings on MOGFC.

3.2 The 1/16 inch semi depth recesses shall be created in the MOGFC the approved equipment by setting the variable depth control and checking the depth of the initial recess with a machinist ruler or other approved measuring device. Once a depth of approximately 1/16 inch has been obtained by the operator, the engage/disengage lever should be used to raise or lower the cutting drum without losing the depth setting.

3.2.1 After the initial depth setting has been set, the operator shall lower the cutting drum with the engage/disengage lever to begin the 10 foot skip stripe and then raise the cutting drum at the end of the recess.

3.2.2 The extrusion die on the thermoplastic application equipment should be manually adjusted to 60 mil (approximately 1/16 inch) in order to obtain semi recessed thermoplastic traffic markings on MOGFC.

3.3 The tapered end recesses shall be created in the MOGFC with the approved equipment by setting the variable depth control at 1/8 inch at the beginning of the recess. The engage/disengage lever should be lowered at the beginning of the recess and slowly raised by the operator within 2 ft of the beginning of the recess to obtain the tapered end..

3.1 Thermoplastic markings shall then be applied to the beginning of the tapered end recess and continue until a full length of 10 ft has been obtained.

Method of Measurement:

4.1 Traffic marking recesses will be measured by the linear foot of recess in the width shown on the plans complete in place and accepted.

5.2 Cost Considerations

5.2.1 Equipment

The gasoline powered concrete scarifier used to create the traffic marking recesses was manufactured by EDCO (Model CPM-8) and currently cost $3,148.00 to own and $90.00/day to rent. The teeth on the cutting drum last for 7,500 ft^2 - 10,000 ft^2 depending on the type of material being scarified, while the drum will last from 6 to 12 months depending upon the level of usage. The cost of a complete set of tungsten carbide cutters is $811.20 ($19.40 each tooth) and the cost of a new drum is $512.00.

The gas powered blower used to clean the recesses cost $120.00 to own and 35.00/day to rent. Gas consumption for the operation of the pavement cutter and the blower has been estimated to be $30.00/day, based on a 5 hours operational time.

5.2.2 Labor

The creation of traffic marking recesses requires three man crews; one man to operate the pavement cutter ($22.50/hr), one man to clean the recesses with the blower ($22.50/hr), and one foreman to oversee the work and check the depth of the recesses ($42.50/hr). The total labor cost for the traffic marking recess crew is $700/day, based on the 8 hour workday.

5.2.3 Estimated Total Cost Per Linear Foot of Traffic Marking Recesses

A total estimated equipment and labor cost of $855.00/day to create traffic marking recesses was based on the use of rental equipment. The Model CPM-8 concrete scarifier can create traffic marking recesses (1/8 inch deep) at the rate of 350 to 500 square feet per hour. This corresponds to an average rate of 850 linear ft/hr for the creation of 6 inch wide traffic marking recesses. The expected equipment operational time of 5 hour/day due to the restricted amount of construction time (10:00am - 3:00pm) on major highways due to rush hour traffic consideration. Therefore, an estimated total of 4,250 linear ft/day of traffic marking recesses can be created. Lane markings are typically 10 ft long skip stripes with a 30 ft spacing between stripes, therefore an estimated 3.2 miles of traffic marking recesses (skip stripes) can be created in one day. This corresponds to approximately one mile of a 4 lane highway per day. A total installation cost of $0.20 per linear foot of traffic marking recesses was estimated from the total cost/day devided by the estimated daily recessing rate ($855.00/4,250 linear ft). This installation cost does not include the traffic control cost. It is assumed that the traffic marking recessing crew will use the same traffic control which is provided for the application of the thermoplastic striping.

5.2.4 Estimated Total Installation Cost of Recessed Thermoplastic Traffic Markings

Thermoplastic markings have an estimated installation cost (including traffic control) of $0.40 to $0.60 per linear foot of installed marking (Roadway.1994). An installation cost of $0.53 per linear foot was chosen to represent the current cost of thermoplastic application ($0.50 per linear ft + (2% yearly inflation) x 3 years). Therefore, an estimated total installation cost of $0.73/linear ft for fully recessed traffic markings was estimated by adding the extra cost of creating the traffic marking recesses ($0.20/linear ft) to the installation cost for the thermoplastic markings ($0.53 per linear ft).

5.2.5 Time

The creation of traffic marking recesses can be easily integrated with the application of thermoplastic markings.

5.3 Life Cycle Cost Analysis

A service life of 6 years for fully recessed thermoplastic traffic markings and 3 years for the non recessed thermoplastic markings were assumed based on an estimation of how long a majority markings could sustain a minimum amount of retroreflectivity for adequate driver visibility. Currently, there is no maintenance program in Rhode Island for periodic retroreflectivity evaluations of traffic markings on Interstate Highways. Therefore, the decision to replace traffic markings tends to be dependent on durability, rather than minimum allowable retroreflectivity. Often, ineffective thermoplastic traffic markings without adequate retroreflectivity are not replaced for several years until signs of physical damage are apparent.

The life cycle cost analysis shown in Table 5-1 was based on assumed effective traffic marking service life for recessed (6 years) and non recessed (3 years) thermoplastic markings. A 20 year life cycle was chosen to establish the cost effectiveness of installing fully recessed traffic marking recesses on MOGFC. The analysis was based on 4,250 linear ft of thermoplastic skip markings, which is enough skip striping to cover 1 mile of a 4 lane highway. A constant inflation rate of 2% was used to determine the future replacement cost for the traffic markings.

Table 5-1. 20 Year Life Cycle Cost Analysis

Year	Non Recessed Thermoplastic Traffic Markings ($0.53/lin ft)		Recessed Thermoplastic Traffic Markings ($0.73/lin ft)	
	Yearly Cost	Cumulative	Yearly Cost	Cumulative
0	$ 2,253	$ 2,253	$ 3,103	$ 3,103
1	0	$ 2,253	0	$ 3,103
2	0	$ 2,253	0	$ 3,103
3	$ 2,391	$ 4,644	0	$ 3,103
4	0	$ 4,644	0	$ 3,103
5	0	$ 4,644	0	$ 3,103
6	$ 2,538	$ 7,182	$ 3,494	$ 6,597
7	0	$ 7,182	0	$ 6,597
8	0	$ 7,182	0	$ 6,597
9	$ 2,694	$ 9,876	0	$ 6,597
10	0	$ 9,876	0	$ 6,597
11	0	$ 9,876	0	$ 6,597
12	$ 2,857	$ 12,733	$ 3,935	$ 10,532
13	0	$ 12,733	0	$ 10,532
14	0	$ 12,733	0	$ 10,532
15	$ 3,031	$ 15,764	0	$ 10,532
16	0	$ 15,764	0	$ 10,532
17	0	$ 15,764	0	$ 10,532
18	$ 3,217	$ 18,982	$ 4,432	$ 14,964
19	0	$ 18,982	0	$ 14,964
20	0	$ 18,982	0	$ 14,964
Total Life Cycle Cost		**$ 18,982**		**$ 14,964**

The total 20 year life cycle cost for 1 mile of non recessed and fully recessed thermoplastic traffic markings on a four lane highway are $18,982 and $14,964, respectively. Therefore, the installation of fully recessed thermoplastic markings are cost effective over a traffic marking life cycle of 20 years, when compared to the non recessed traffic markings. In fact, the cumulative cost of the non recessed thermoplastic traffic markings exceeds the cumulative cost of the fully recessed thermoplastic traffic markings after the first replacement of non recessed thermoplastic traffic markings (end of year 3). Furthermore, the fully recessed thermoplastic markings need to be replaced three times over the 20 year cycle, while the non recessed thermoplastic markings need to be replaced six times over the same cycle. The three extra replacements of non recessed thermoplastic skip stripes not only incurs an added vehicle user cost due to traffic delays, but also further increases the risk of safety hazards for the more frequently exposed traffic marking replacement crew.

5.4 Summary

The extra cost of creating traffic marking recesses for the application of thermoplastic traffic markings was an estimated $ 0.20 per linear foot. The total cost for the installation of fully recessed traffic markings was an estimated $ 0.73 per linear foot. These estimates were based on a daily production rate of 4,250 linear ft per day of fully recessed thermoplastic skip lane lines with the use of rental equipment. This production rate corresponds to 1 mile of installed skip stripes on a four lane Interstate Highway.

The results of a 20 year life cycle analysis showed that the fully recessed traffic markings were more cost effective than the non recessed traffic markings. It should be noted that the break even point occurs during the first replacement of the non recessed thermoplastic. This analysis was based on a replacement factors of 3 years for non recessed traffic markings and 6 years for fully recessed traffic markings. Replacing traffic markings less frequently reduces the risk to traffic marking replacement crews as well as reducing vehicle user cost incurred by traffic delays.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This study explored a cost-effective method of thermoplastic traffic marking application on MOGFC which substantially reduces the amount of snowplow blade damage to the thermoplastic traffic markings during the winter maintenance season and thereby increases the expected service life of the traffic markings. The conclusions and recommendations based on the findings of this investigation are summarized below.

6.1 Conclusions

1. Visible snowplow blade damage to thermoplastic traffic markings can be reduced by fully recessing thermoplastic traffic markings on MOGFC. On all three test sections, the fully recessed traffic markings on each test section received less visible snowplow blade damage than any other type of recessed or non recessed thermoplastic traffic markings. However, this difference in durability was very minimal, i.e., the non recessed thermoplastic traffic markings received slightly more leading edge damage than the fully recessed thermoplastic traffic markings. This result was expected due to the low number of snowplowing events which occurred over three winter maintenance seasons.
2. The permanent inlaid marking tape lacked the durability needed to withstand snowplow blade damage. This was particularly evident on the 500 ft curved test section, where a majority of the stripes were completely sheared off of the pavement surface by the end of the winter maintenance season. This substantial damage may be caused by a lack of sufficient embedment obtained by rolling the marking tape into the hot MOGFC

immediately after compaction. This lack of embedment on MOGFC can be attributed to poor application quality control (It is very important to inlay the marking tape at the proper pavement temperature) and/or the less malleable characteristics of MOGFC mixes due to the larger aggregate sizes in the gradation.

3. The retroreflectivity levels retained by individual intact permanent inlaid tape markings were higher than the retoreflectivity levels retained by individual thermoplastic traffic markings. However, as a group the permanent inlaid tape retained a lower average retroreflectivity value than fully recessed thermoplastic markings on the high speed lane of the 1,000 ft tangent test section and the 500 ft curved test section. This is due to the zero retroreflectivity values considered for completely missing permanent inlaid tape stripes on both test sections.

4. A statistical analysis of the differences in retroreflectivity readings between the fully recessed and non recessed traffic markings on the high speed lane of the 1,000 ft tangent section and the 500 ft curved test section revealed no evidence that fully recessing thermoplastic traffic markings reduce the amount of snowplow blade damage to the glass beads.

5. Wet night conditions reduce the visibility of all the types of traffic markings in this study. However, the fully recessed and the semi recessed thermoplastic traffic markings on the 1,000 ft tangent highway test section (highspeed and middle lane), failed to retain the recommended minimum retroreflectivity level of 100 $mcd/m^2 \cdot lux$

for adequate driver visibility, during the actual wet night evaluation. This significant loss in retroreflectivity is most likely due to the water film effect. This effect seemed to be nullified on the super elevated 500 ft curved test section, due to the quick draining conditions present on that type of steep cross slope.

6. Fully recessed thermoplastic traffic markings were found to be cost effective when compared to non recessed thermoplastic traffic markings over a 20 year life cycle. This life cycle analysis was based on estimated installation and replacement costs for fully recessed and non recessed thermoplastic traffic lane markings for a 1 mile section on a 4 lane Interstate Highway. A service life of 6 years was assumed for fully recessed traffic markings and a service life of 3 years was assumed for the non recessed traffic markings. Both of these assumptions were based on the expected sustained adequate visibility of the markings, rather than the durability of the marking.

6.2 Recommendations

1. It could be considered that the use of the permanent inlaid traffic marking tape on MOGFC would be discontinued, until the specific cause of marking failure can be identified and rectified.

2. Continued annual evaluations of the test sections by Rhode Island Department of Transportation to further verify the durability benefits of fully recessing thermoplastic traffic markings on MOGFC is highly recommended. Further evaluation of the test sections will also aid in a better estimation of actual service lives for fully recessed and

non recessed thermoplastic markings. Thus it will increase the accuracy of the estimated cost effectiveness of installing fully recessed thermoplastic markings on MOGFC.

3. The use of larger glass bead gradations may negate the water film effect on all types of thermoplastic markings (recessed and non recessed). Large bead pavement marking systems have proven to be four to five times brighter than standard bead marking systems during heavy rainfall events. The RIDOT specifies a standard bead gradation for thermoplastic pavement markings.

4. Currently, the decision to replace traffic markings in Rhode Island (and probably other states in New England) is based on the physical appearance (durability) of the marking, rather than the visibility (retroreflectivity) of the marking. As a result, intact traffic markings which do not have an adequate levels of retroreflectivity for driver visibility are often left in service for several years after the markings have lost their effectiveness. Therefore, it is recommended that a program to periodically check small samples of traffic markings on Interstate Highways should be implemented in order to increase driving safety for the general public.

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APPENDIX A

DOCUMENTATION OF THE PROBLEM STATEMENT

RHODE ISLAND

Material shows its true stripes as asphalt foe

■ Road officials in Maryland and Connecticut also report problems with the substance — thermoplastic — pulling up certain types of pavement.

By STEVE WINTER
Journal-Bulletin Staff Writer

Lincoln Almond, who is seeking the Republican nomination for governor, yesterday continued to prod the state Department of Transportation for information about the state's use of a road-striping material that is causing holes on some major highways.

Almond, in a news release, said he has written to DOT and Governor Sundlun, seeking a copy of the contract awarded for the road striping, the job specifications, and "amounts paid and nature of services" provided.

The Journal-Bulletin yesterday submitted a series of questions to DOT officials seeking similar information. Neither DOT Director Dante Boffi nor spokesman Chuck Alves responded.

Almond brought attention to the issue of lane stripes this week by questioning why chunks of pavement were missing on Routes 6, 95 and 295, mainly in Johnston and Cranston. The chunks, he said, were in the exact location of the road stripes.

On Wednesday, DOT officials confirmed problems in areas where the state applied thermoplastic striping instead of the more traditional painted stripes. The DOT statement mentioned that both Connecticut and Maryland had experienced similar problems.

Yesterday, Almond challenged DOT's comments.

"According to our initial research, suppliers of both paint and thermoplastic road striping materials insist that this problem is unique to Rhode Island. The reason for the problem is not yet clear, and several questions remain," Almond said yesterday.

However, highway officials in both Maryland and Connecticut told the Journal-Bulletin yesterday that they have had difficulties with asphalt being torn apart beneath thermoplastic road stripes.

The suspected culprit: a snowplow.

"We found that when snowplows hit the lines, they would pull up the lines, as well as the asphalt material," Jack Mitchell, chief of the structural and pavement inspection section of the Maryland State Highway Administration, said.

He said the biggest problems were on highways that had a thin top layer of asphalt known as "open-grated friction course" — the same type of pavement Rhode Island has used on Routes 6, 95 and 295.

> Using thermoplastic striping 'means you have your employees putting down lane stripes a lot less frequently. It's a safety issue. Painting lines is one of the most dangerous jobs we do.'
>
> JACK MITCHELL
> Maryland highway official

That type of asphalt is usually less than an inch thick and is designed to allow water to seep through to a lower layer and then drain off the roadway. "The idea is to help cars avoid hydroplaning," Mitchell said.

But when the top layer of asphalt is thin, it can become dislodged fairly easily when a stripe is pulled off, he said.

"The blade of the snowplow would catch the edge of the stripe," Mitchell said.

He said the problem in Maryland has been corrected by using a thinner amount of striping material and applying it so that the ends are rounded, not squared, and less likely to catch.

In Connecticut, ashalt was being pulled up but not in stripe-size chunks, said Walter Coughlin, manager of traffic engineering for the Department of Transportation.

"Maybe a foot-long section would pull up and take the pavement with it," he said.

Connecticut officials discovered that the thermoplastic striping works best when it's put down immediately after repaving. The heat of the freshly poured asphalt forms a more permanent bond, he said.

The use of thermoplastic striping started in the early 1980s and is likely to become more widespread because the Environmental Protection Agency is considering a regulation that would limit the amount of pollutants in striping.

Traditionally, states have used oil-based paints to apply lane markings. Those paints have significant amounts of pollutants that the EPA wants to reduce, according to Steve Majkut, chief of the Rhode Island's Department of Environmental Management's Division of Air Resources.

Thermoplastic striping is used in all 50 states to some degree, Gary Sears, technical director for Atlanta-based Pave-Mark Corp., a manufacturer of the material, said yesterday.

Officials from other states say they began using thermoplastic striping primarily because it lasts longer than paint — and provides a brighter lane marking.

The material consists of solid materials, primarily calcium carbonate filler (similar to marble dust), Sears said. It also contains plastics and resins, but none of the pollutants likely to be outlawed by the EPA.

The thermoplastic striping is about six times more expensive than oil-based paints, but it may last five years, according to Mitchell, the Maryland highway official. Because paints normally last only six months to a year, thermoplastic is more economical in the long run, he said.

"It also means you have your employees putting down lane stripes a lot less frequently," said Mitchell. "It's a safety issue. Painting lines is one of the most dangerous jobs we do."

The thermoplastic striping is also easier to see at night because it contains glass particles that reflect light.

It is usually applied to highways by heating it to a liquid, then spraying it on the road. It reforms as a solid material that sits atop the road, usually in a thickness of only a few thousandths of an inch.

It can also be put down in solid strips. This requires a special machine that applies a glue and stamps the precut material into the road.

APPENDIX B

REQUEST TO USE I-95 NORTHBOUND AS THE TEST SECTION SITE

UNIVERSITY OF
RHODE ISLAND

May 30, 1996

Mr. James Capaldi, P.E.
Chief Engineer
RI Department of Transportation
Two Capitol Hill
Providence, RI 02903

Re: NETC Project 95-3 "Implementation and Evaluation of Traffic Marking Recesses for Application of Thermoplastic Pavement Markings on Modified Open Graded Mixes"

Dear Mr. Calpaldi:

It was nice to see you at the Rhode Island Department of Transportation TRAC Educational Program Kick-off yesterday. As I mentioned and wrote before, the URI research team is currently searching for a resurfacing project which will use Modified Open Graded Friction Coarse (MOGFC) for the implementation of the referred research project. We were informed indirectly through RIDOT that utilizing interstate highway resurfacing projects for the 2,000 feet of test sections was undesirable due to federal requirements and other constraints.

Although Mr. Mike Bennett and Mr. Bob Smith encouraged the URI research team to consider the Transportation Improvement Program (TIP) resurfacing projects scheduled for FY-96 as candidates for the test sections, we are concerned that these projects do not satisfy the test section requirements of the original project proposal. Most importantly, the surface layer of the resurfacing project must be MOGFC. The details of the test section requirements and the criteria used by the URI research team to identify possible resurfacing project candidates for the test sections can be found in the enclosed letter to Ms. Despina Metakos, chairperson of NETC Technical Committee.

To the best of our knowledge, the only resurfacing project that will use MOGFC as a surface layer and thermoplastic as the pavement marking material this year is the continuation of the resurfacing along I-95 from Route 4 to Providence. This resurfacing project meets all of the project selection criteria, and the contract was recently awarded to the Cardi Corporation. As you may note, Mr. Stephen A. Cardi, II, is a Co-principle investigator in this joint research project. Without Mr. Cardi's expertise and prompt and precise response, this research project would not have been awarded to the URI research team. We also believe that the Cardi Corporation may be the most qualified contractor for this particular task, i.e., traffic marking recesses on MOGFC.

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
1 Lippitt Road, Bliss Hall, Kingston, Rhode Island 02881-0805
Phone: 401-874-2692 Fax: 401-874-2786

In a recent meeting with Mr. Cardi, the URI research team questioned the feasibility of utilizing the I-95 resurfacing project as the location for the test sections. He thought that the I-95 resurfacing project would be an excellent choice and assured us that his firm has the capability of implementing the test sections, with little or no interference to the overall project. We were also informed that he would contact you in the near future to discus any concerns you might have regarding the implementation of the test sections on the I-95 resurfacing project.

In summary, we would appreciate your reconsideration on the utilization of a 2,000 ft portion of the I-95 resurfacing project as test sections for the referred research project. If you need any further clarification, please contact me or Mr. Sean Corrigan at (401)874-5498. Thank you for your cooperation.

Sincerely,

K. Wayne Lee, Ph.D.,P.E.
Principal Investigator

KWL/SC/sc

cc: Mr. Ed Parker, Chief Transportation Engineer
Mr. Mike Bennett, RIDOT Design/Program Development
Mr. Bob Smith, RIDOT Design/Program Development
Mr. Paul Annarummo, RIDOT Transportation/Program Development
Ms. Despina Metakos, RIDOT Traffic Management
Messrs. Collin Franco and Francis Manning, RIDOT Research
Mr. James Growney, Interim Chairperson, FHWA-Region I
Mr. Stephen Cardi, II Co-Principle Investigator
Mr. Sean Corrigan, URI Research Assistant
W/O Enclosure

Title of Project: IMPLEMENTATION AND EVALUATION OF TRAFFIC MARKING RECESSES FOR THE APPLICATION OF THERMOPLASTIC PAVEMENT MARKINGS ON MODIFIED OPEN GRADE MIXES.

Meeting No. RIDOT #1
Date: 06/13/96
Project Period: 9/1/95 - 6/30/98

RIDOT Members: Collin Franco, Research
Francis manning, Research
John Pilkington, Construction
Robert Smith, Design
Bob Rocchio, Traffic

Project Members: Prof. Wayne Lee, Ph.D., P.E.
Stephen A. Cardi, II
Sean Corrigan, Graduate Research Assistant

The following topics were discussed;

1. Mr. Sean Corrigan presented the significance of the problem from which the NETC research project originated. In order to simulate this problem, the following test section requirements were presented:

a. The surface layer must be MOGFC

b. The resurfacing site must have the required design speeds, and

c. The resurfacing project should contain the proper geometry.

2. The URI research team requested the permission from RIDOT to locate the test sections on I-95 northbound beginning at exit 14-15 Warwick/Cranston. This area satisfies all of the test section requirements and would facilitate the construction and evaluation efforts due to the close proximity of the three geometric test sections.

3. Mr. Cardi reaffirmed his firm commitment to this project and answered various questions and concerns regarding the construction of the traffic marking recesses.

4. Prof. Lee mentioned that this was a NETC sponsored project and that any cost needed for traffic control is within the project budget.

5. The members of the RIDOT verbally gave their blessing for the utilization of proposed location on I-95 northbound (exit 14-15) as the site for the three test sections.

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS

Rhode Island Department of Transportation
Program Operations
Research and Technology
Two Capitol Hill, RM 013
Providence, RI 02903 - 1124
PHONE 401 - 277 - 4955; FAX 401 - 277 - 6038; TDD 401 - 277

June 18, 1996

Dr. K. Wayne Lee
University of Rhode Island
Department of Civil and Environmental Engineering
Bliss Hall
Kingston, RI 02881

Subject: NETC Traffic Marking Recesses Project

Dear Dr. Lee:

Thank you and Sean for meeting with us on June 13, 1996 to discuss the field test sections for this research project. It was agreed at the meeting that it would be best to use the current I-95 construction project. We have made this recommendation to the Chief Engineer and he has concurred. The RIDOT now will proceed with the installation of the test sections on this project.

We also discussed with the Chief Engineer the possibility of publicizing this research activity. He has decided that we should wait at least until there is success to report.

Colin Franco, P.E.
Managing Engineer
Research & Technology Development

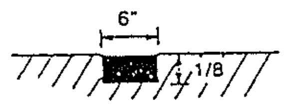
CAF/FJM/kjb

c: Mr. Capaldi
Mr. Pilkington
Mr. Smith
Mr. Rocchio
Mr. Manning
Project file
file

APPENDIX C

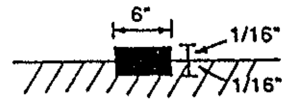
TRAFFIC MARKING PLACEMENT PLANS

6FRWS DETAIL



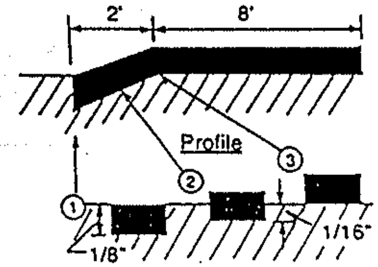
TYPICAL X-SECTION
6" Fully Recessed White Stripe
(1/8" Recess)

6SRWS DETAIL



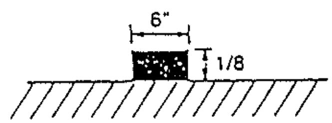
TYPICAL X-SECTION
6" Semi-Recessed White Stripe
(1/16" Recess)

6TRWS DETAIL



TYPICAL X-SECTION
2' Tapered Recessed White Stripe

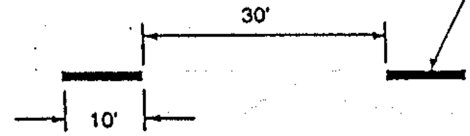
6NRWS DETAIL



TYPICAL X-SECTION
6" Non-Recessed White Stripe

6WS DETAIL

TYPICAL
6" White Pavement Markings



TYPICAL STRIPING DETAIL

LEGEND

- 6FRWS 6" Fully-Recessed White Stripe
- 6SRWS 6" Semi-Recessed White Stripe
- 6TRWS 6" Tapered-Recessed White Stripe
- 6NRWS 6" Non-Recessed White Stripe
- 6WS 6" White Stripe (Preformed tape)

UNIVERSITY OF RHODE ISLAND DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING		
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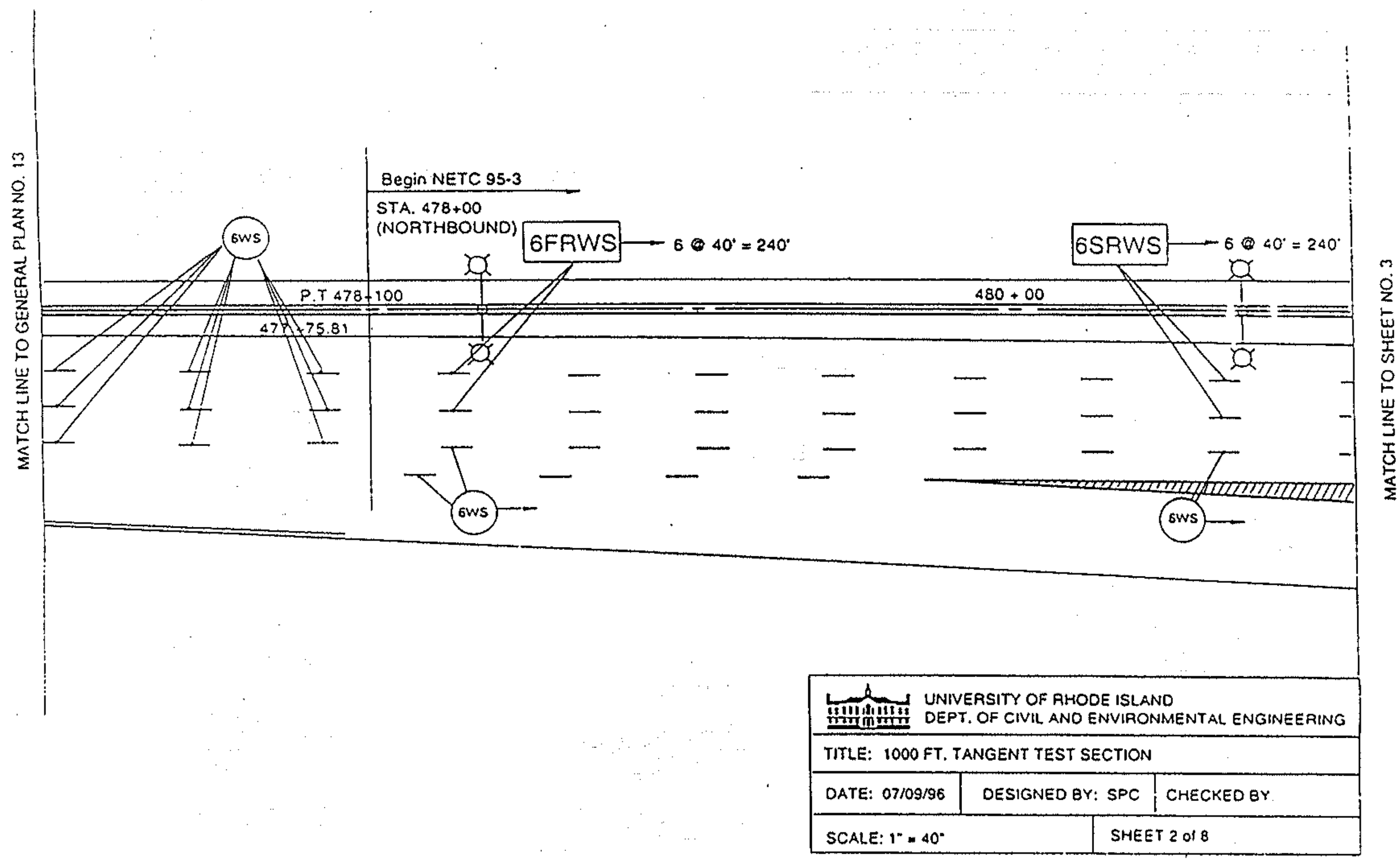
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6WS
Begin NETC 95-3
STA. 478+00
(NORTHBOUND)
6FRWS
6 @ 40' = 240'
P.T 478+100
477+75.81
6WS
6SRWS
6 @ 40' = 240'
480 + 00
6WS
MATCH LINE TO SHEET NO. 3
UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
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DATE: 07/09/96
DESIGNED BY: SPC
CHECKED BY
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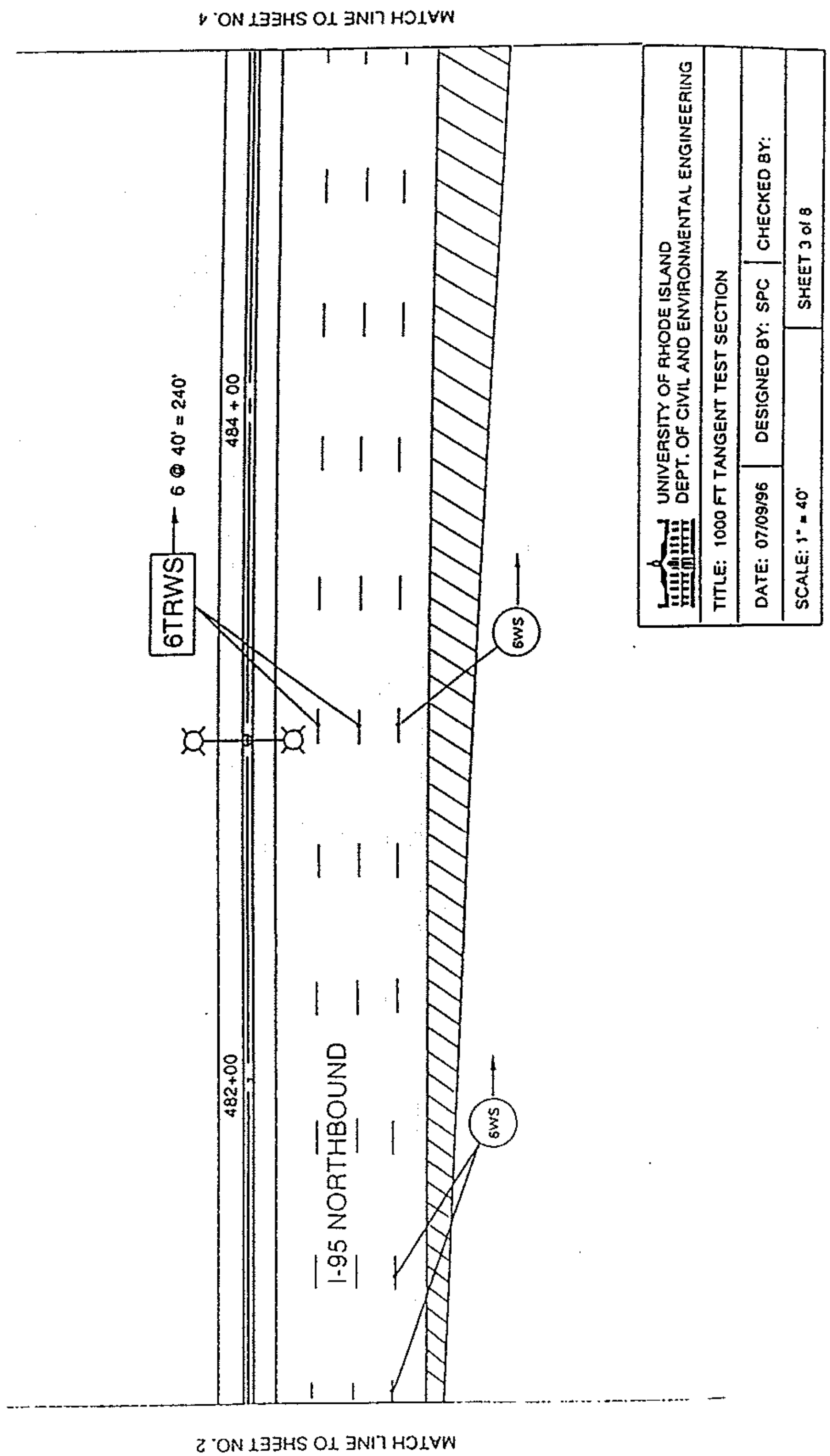
SHEET 2 of 8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6TRWS
6 @ 40' = 240'
484 + 00
482+00
I-95 NORTHBOUND
6WS
6WS
UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
TITLE: 1000 FT TANGENT TEST SECTION
DATE: 07/09/96
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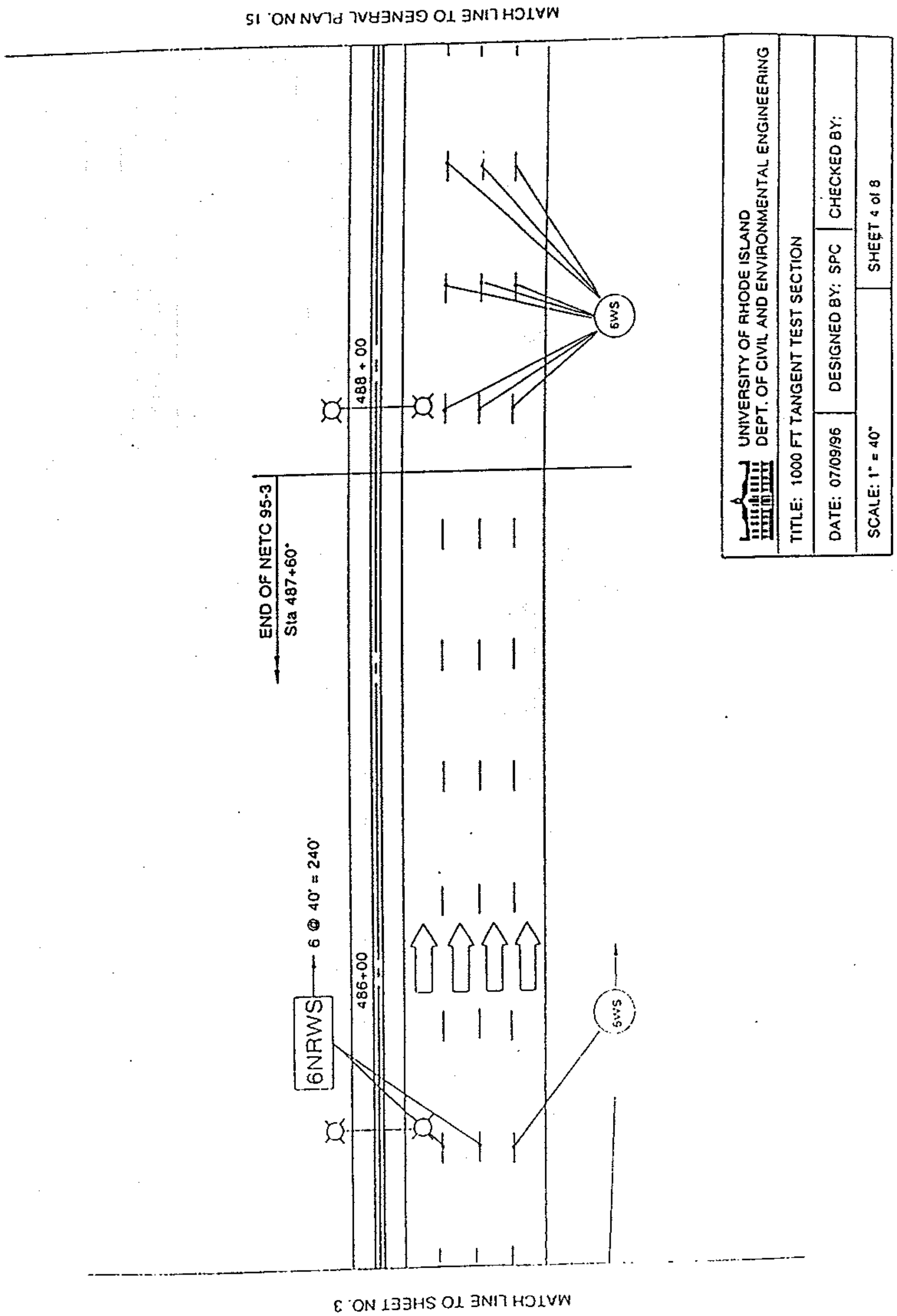
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END OF NETC 95-3
Sta 487+60'
488 + 00
6WS
6NRWS
6 @ 40' = 240'
486+00
6WS
MATCH LINE TO SHEET NO. 3
UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
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DATE: 07/09/96
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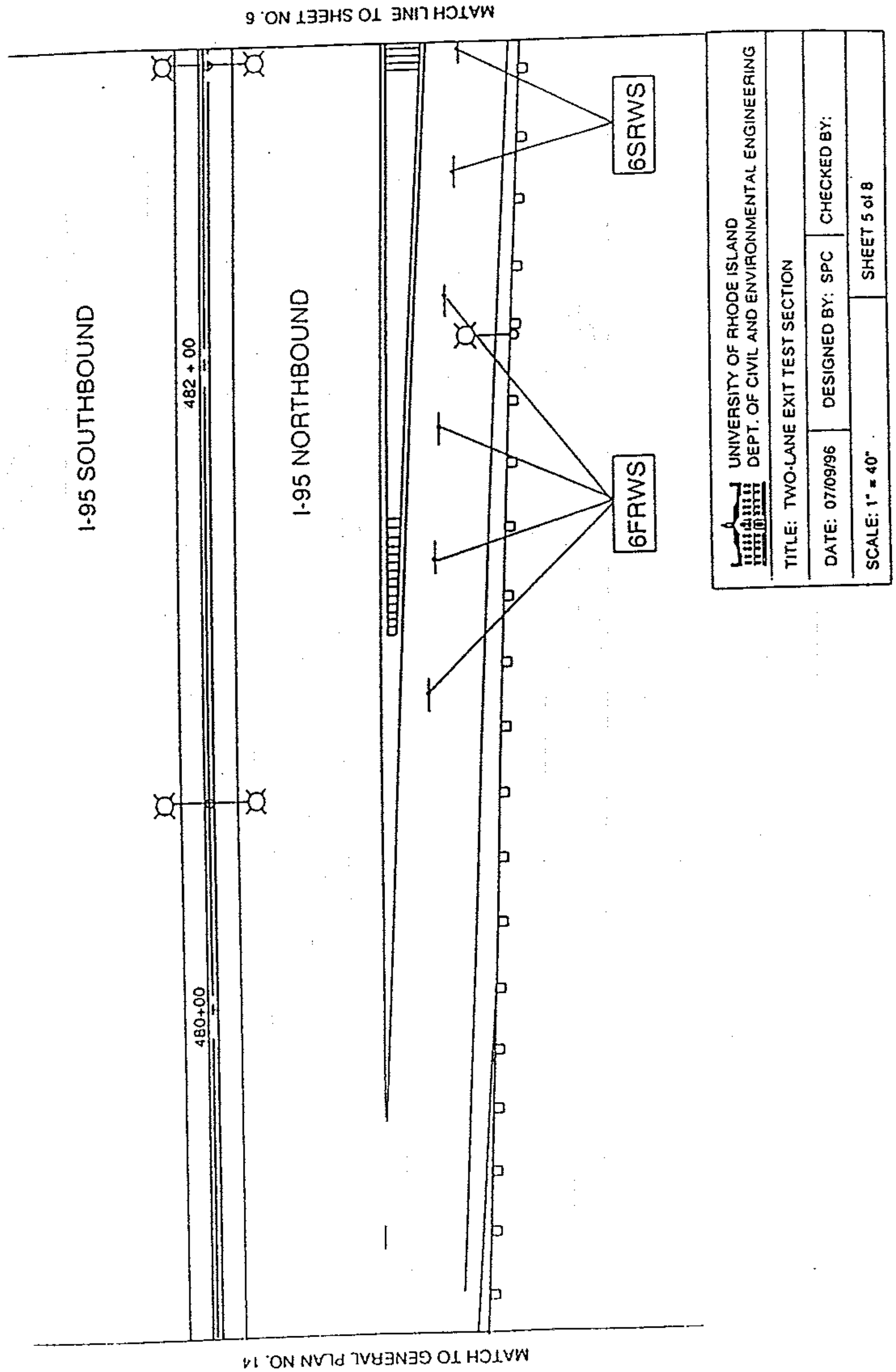
SHEET 4 of 8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I-95 SOUTHBOUND
I-95 NORTHBOUND
482 + 00
480+00
6SRWS
6FRWS
UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
TITLE: TWO-LANE EXIT TEST SECTION
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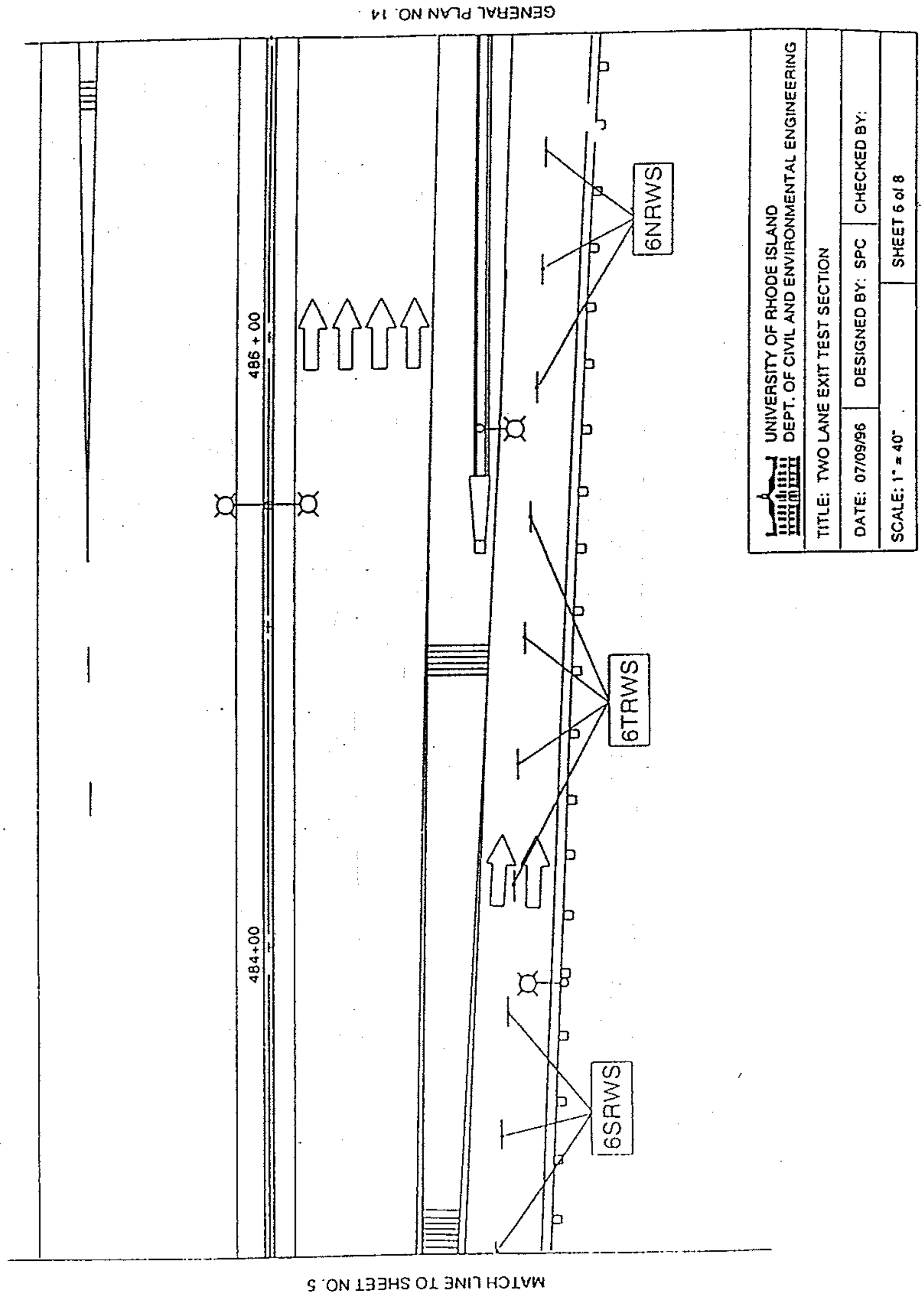
GENERAL PLAN NO. 14
486 + 00
484+00
6NRWS
6TRWS
6SRWS
UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
TITLE: TWO LANE EXIT TEST SECTION
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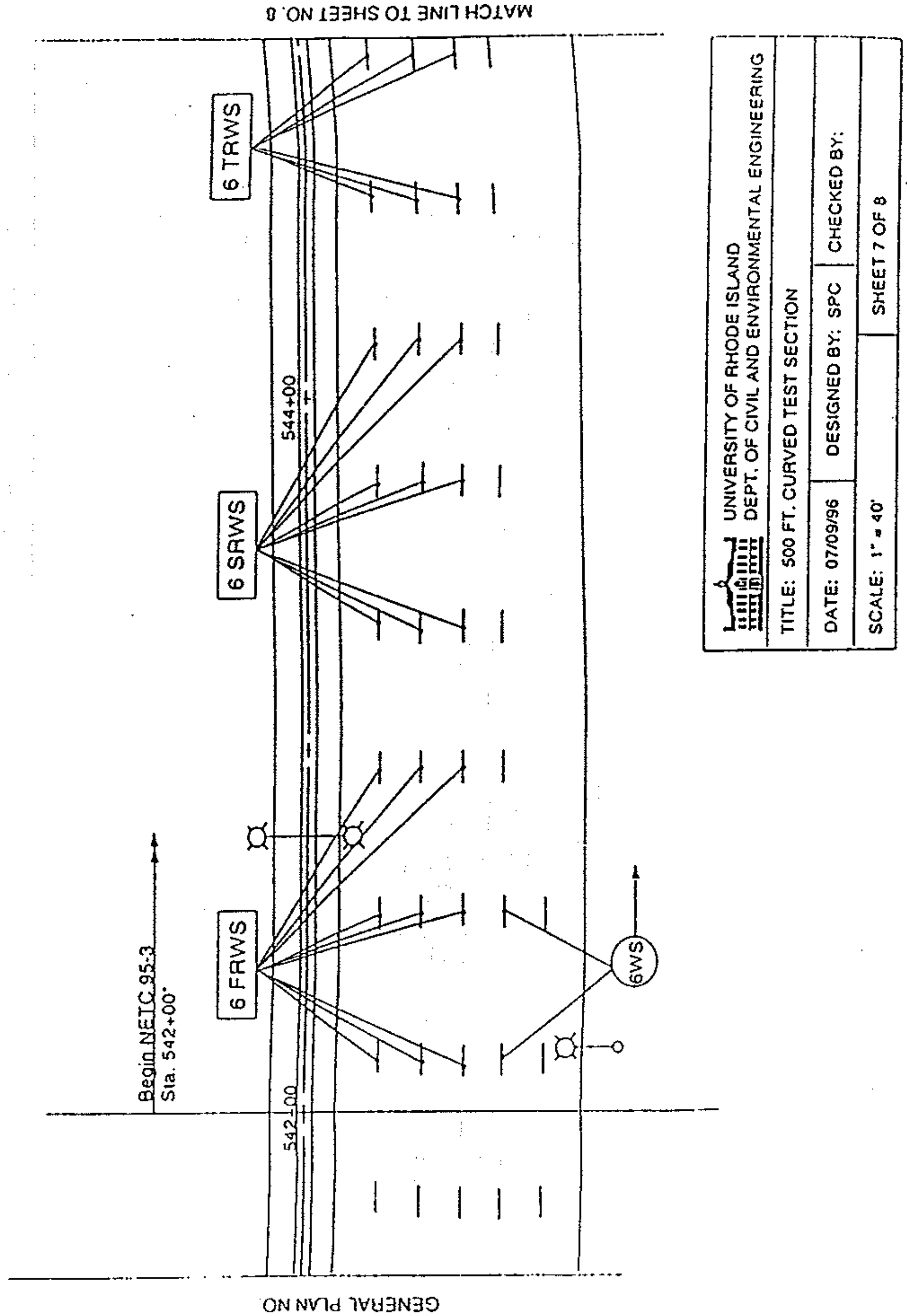
MATCH LINE TO SHEET NO. 8
6 TRWS
544+00
6 SRWS
6 FRWS
6WS
Begin NETC 95-3
Sta. 542+00'
542+00
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UNIVERSITY OF RHODE ISLAND
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
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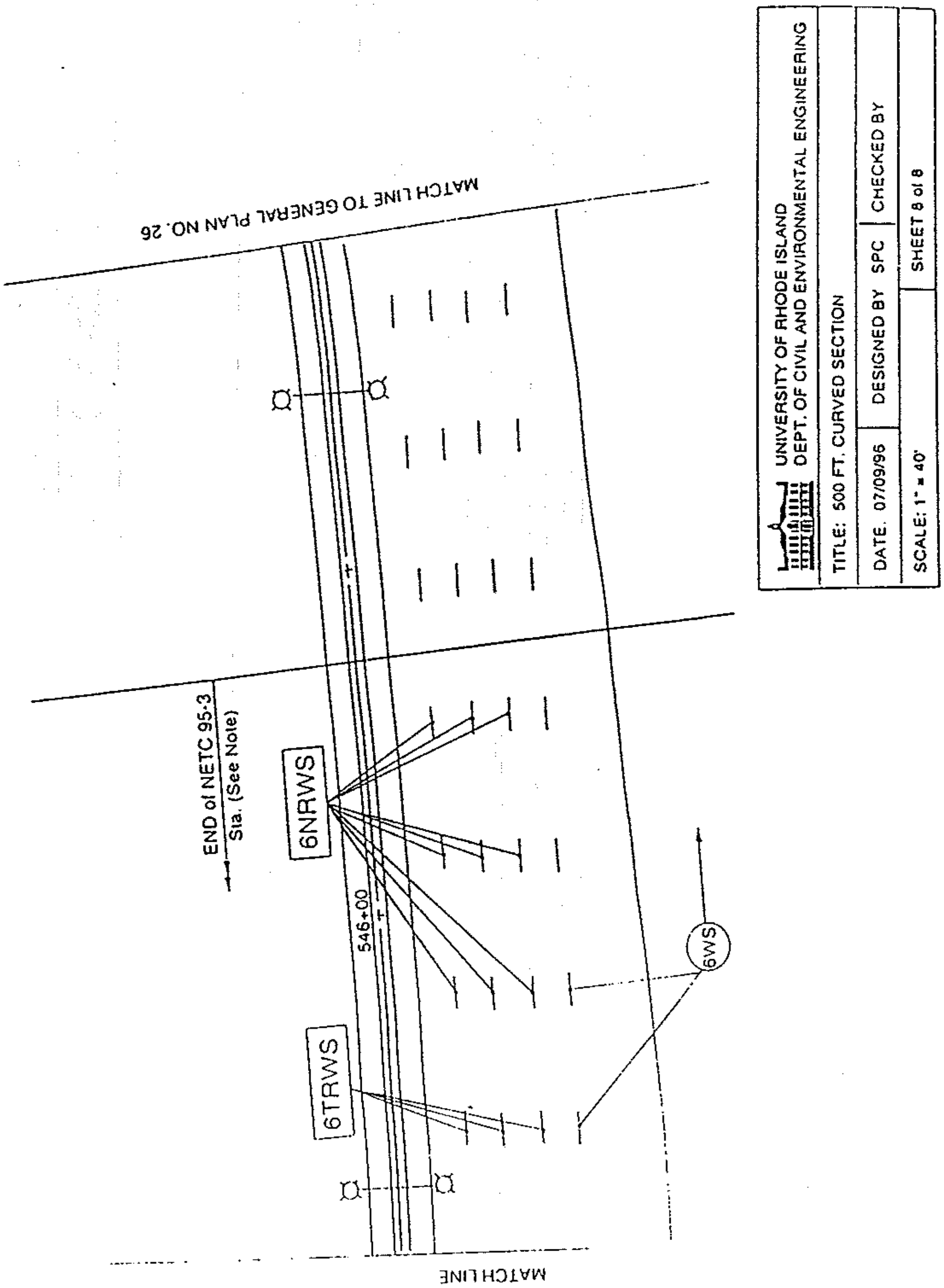
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Sta. (See Note)
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546+00
6TRWS
6WS
MATCH LINE
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DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING
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DATE: 07/09/96
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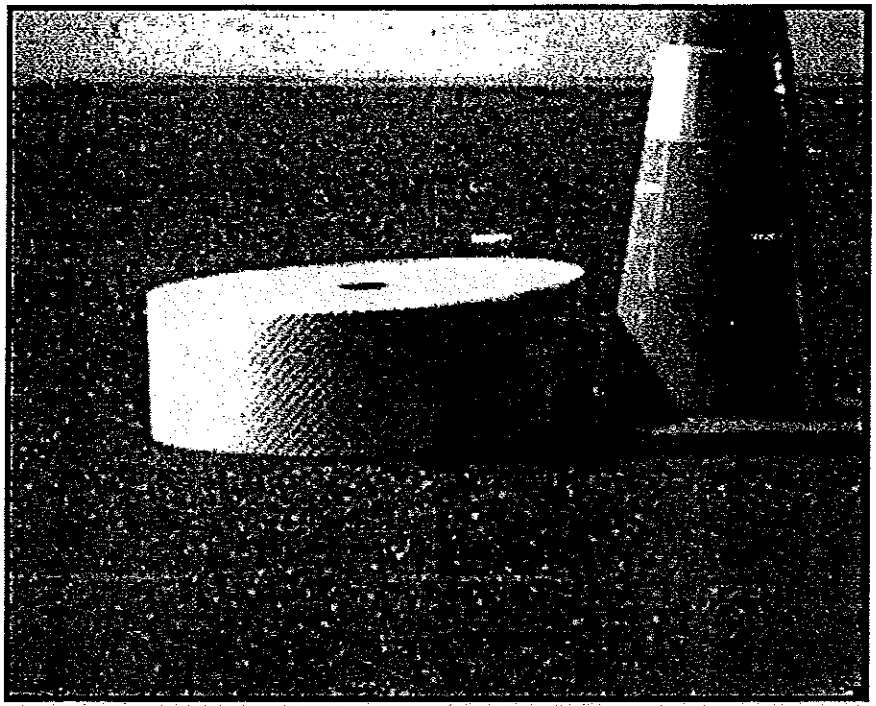
APPENDIX D

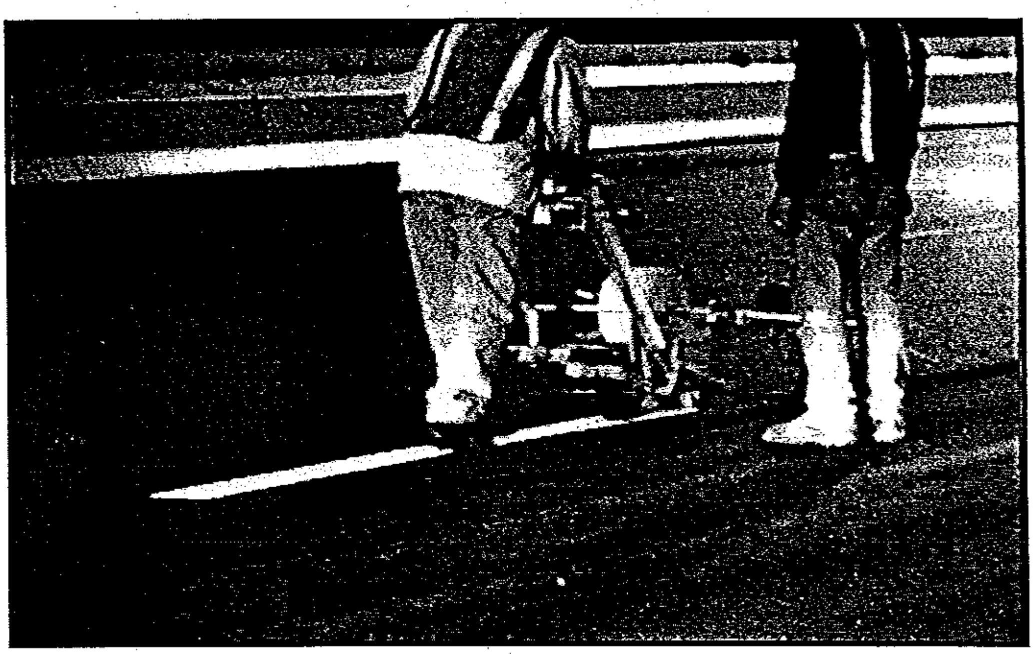
PICTURES OF THE INLAID TAPE APPLICATION PROCEDURE



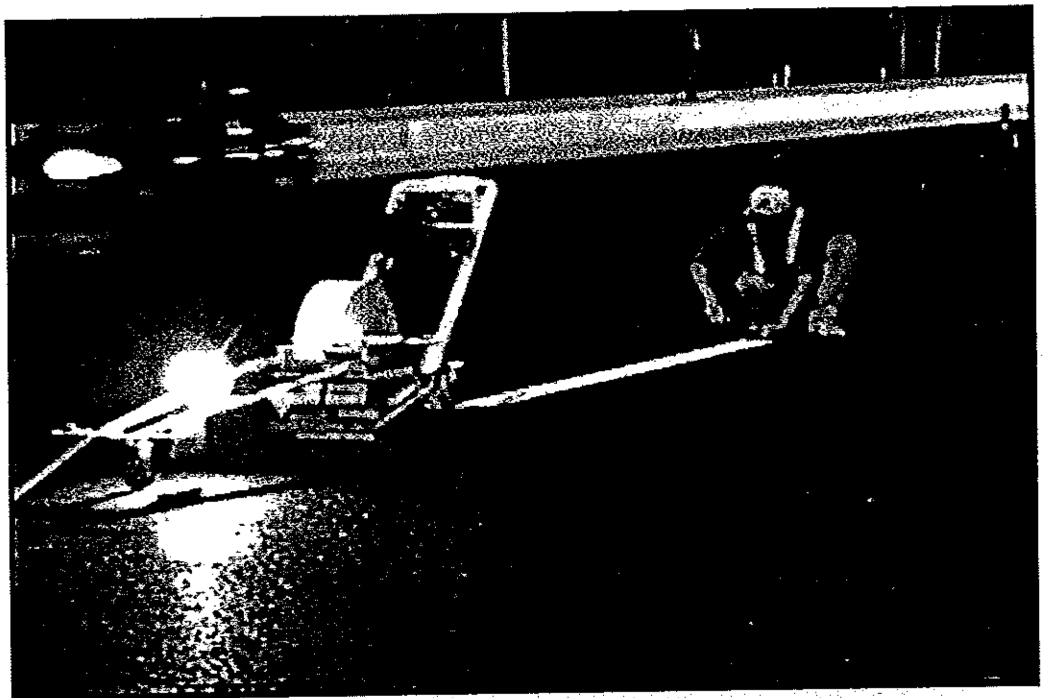
Preformed Marking Tape

Lane Line Measurement

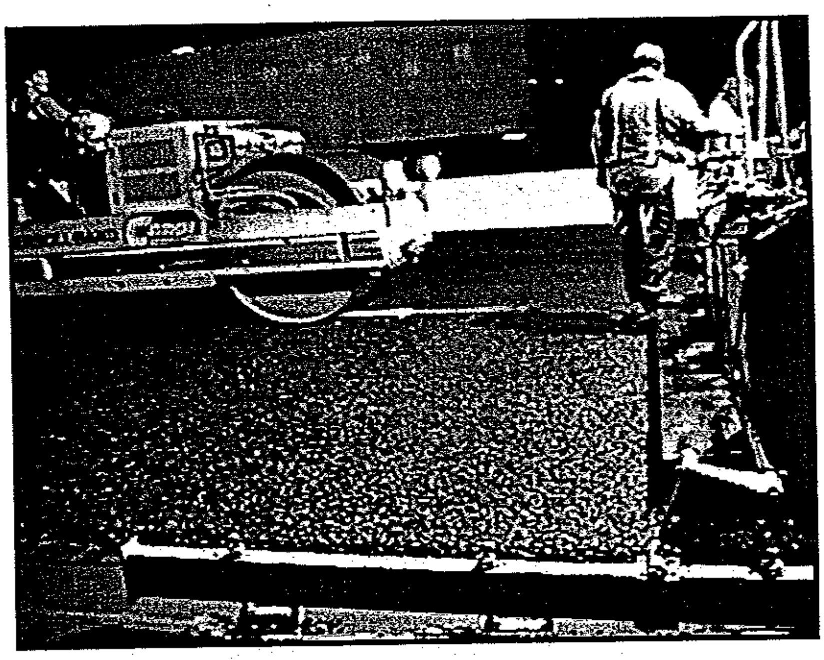
Lane Line Location



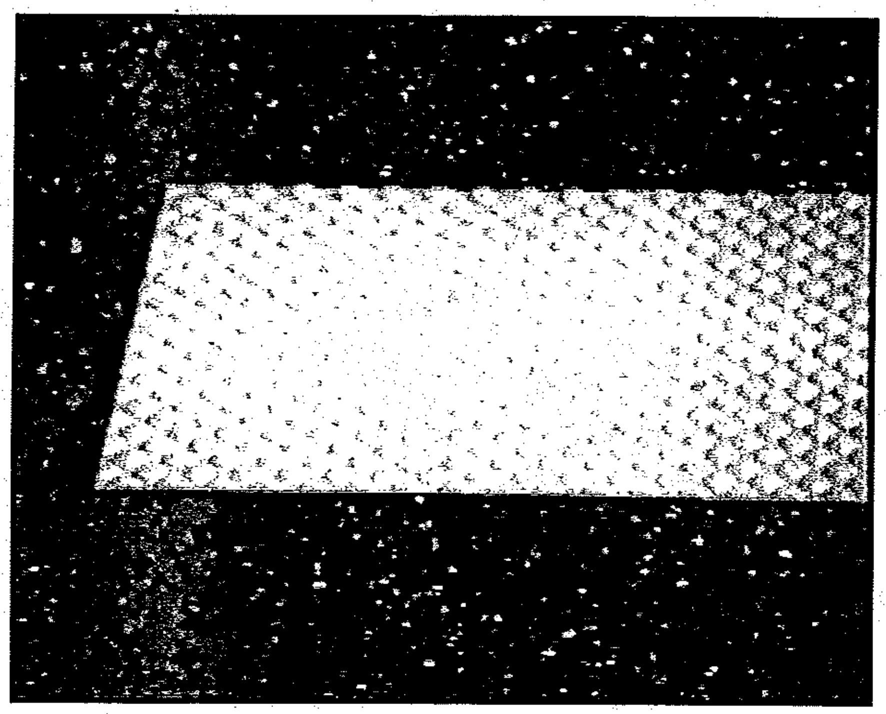
Marking Tape Application



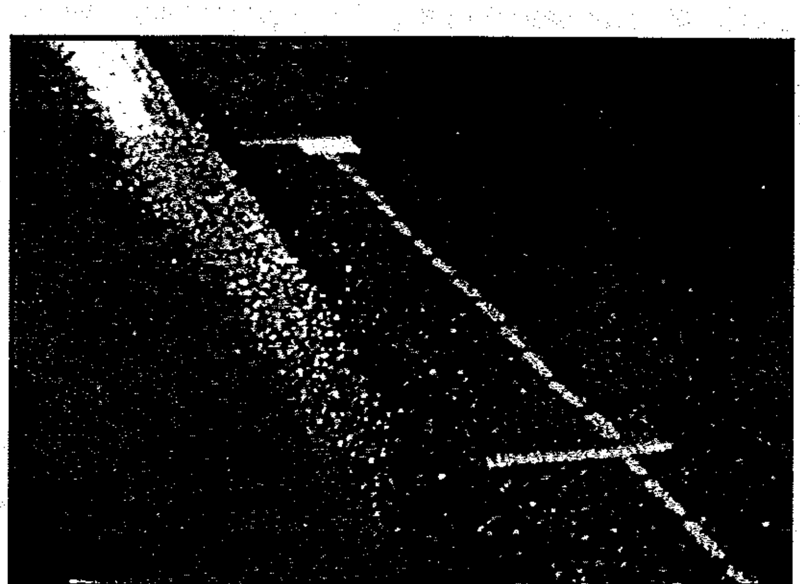
Final Marking Placement



Rolled Into (Inlaid) MOGFC



Permanent Inlaid Marking Tape



6 Inch Temporary Tabs

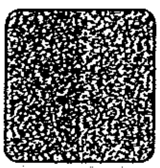
APPENDIX E

PAVEMENT CUTTER SPECIFICATIONS

EDCO
Concrete Scarifiers

Look at the surface-preparation jobs an EDCO Scarifier can do!

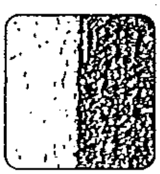
Clean
- Warehouse floors
- Manufacturing facilities
- Service bays



Texture
- Prepare surfaces for better adhesion of coatings

Level
- Sidewalk irregularities
- Uneven joints
- Bumps
- Uneven surfaces needing repair

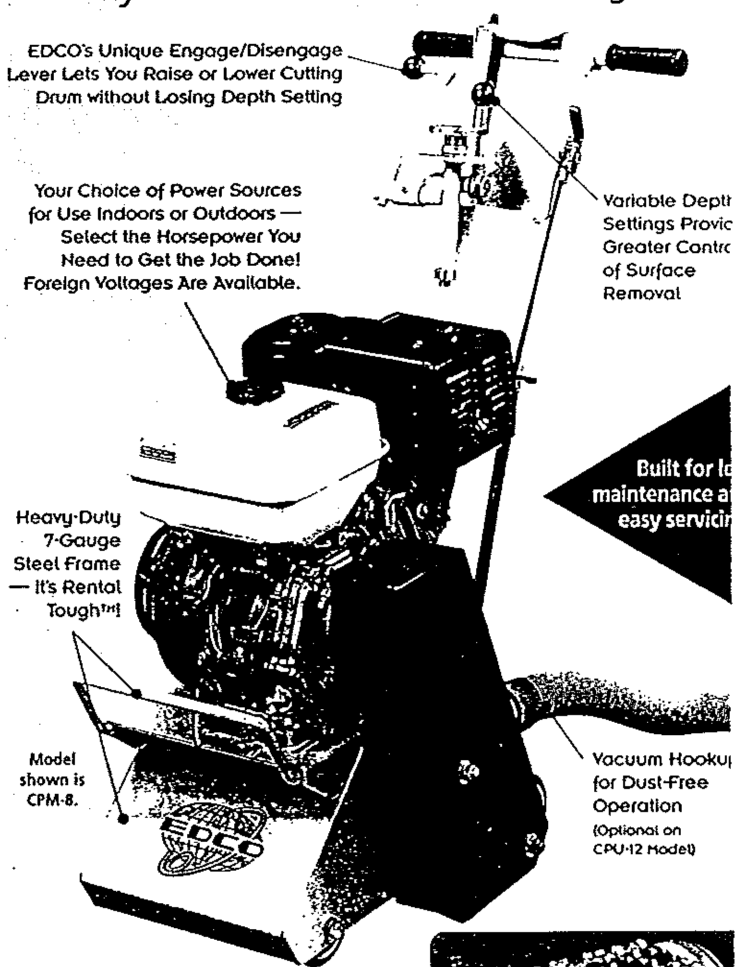
Groove
- Walkways
- Bridge decks
- Dairy barns
- Parking decks

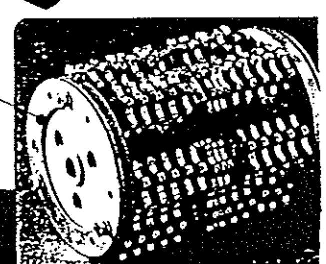


Remove
- Traffic lines
- Paint
- Coatings
- Ice
- Mortar
- Delaminated surfaces
- Contaminants like dirt, black oil and other residual oils

Any questions?
Call EDCO!
1-800-638-3326
or 301-663-1600

Why EDCO Scarifiers Are Rental Tough™!





Change Drums in Minutes — No Downtime!

With EDCO's quick-change drum design and spare drum assemblies, you'll be back on the job in minutes. Our six-shaft drum assembly holds more cutters per loading for added grinding action, a more uniform surface texture and fewer drum change

With EDCO Scarifiers, you can choose from a variety of accessories and cutters t achieve the profile, depth and speed you need for each job.

- Tungsten carbide cutters
- Hardened-steel cutters
- Diamond grooving heads
- 3M Roto Peen flaps

1

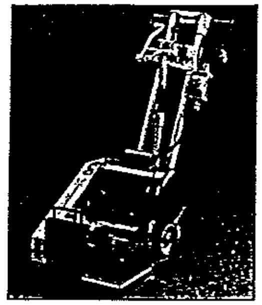
Push Models

"In the rental industry, you look for a product that will take the abuse and still hold up. EDCO products say 'Rental Tough' and they really are. EDCO Scarifiers are far superior to competitors' products — I've heard my customers wonder why they ever tried any other brand.

"I have four EDCO Scarifiers that stay busy daily, and rarely need service. EDCO equipment is extremely reliable and has been a very profitable product for our business and the contractors we work with."

Denny Webster
Knipper's Rental Center
Santa Ana, California

CPM-4



- Up to 4" working width (13 cm)
- Up to $^1/_{16}$" working depth per pass (2 mm)
- Grinds within $^3/_4$" of vertical surfaces (19 mm)
- Lightweight for easy transport and maneuverability
- Economical

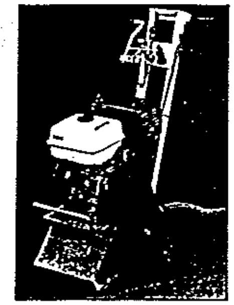
Ideal for

- Removing traffic lines from warehouse floors
- Working around stationary equipment
- Small, narrow areas or edges

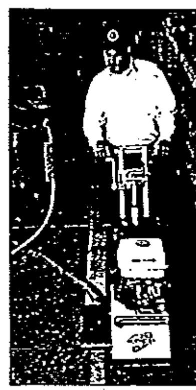
Performance

- 350-500 square feet per hour (33-46 sq m/hr) at a depth of $^1/_{16}$" (2 mm)
- Removes traffic lines at 800-1,000 lineal feet per hour (243-305 lineal m/hr)

CPM-8



- Up to 8" working width (20 cm)
- Up to $^1/_8$" working depth per pass (3 mm)
- Power source directly over drum to eliminate vibration and maximize surface contact
- Compact design
- Front-mounted lifting handle makes loading and unloading easy



Ideal for

- Sidewalk repair
- Coating removal
- Floor preparation or cleaning
- Creating nonslip surfaces
- Traffic line removal

Performance

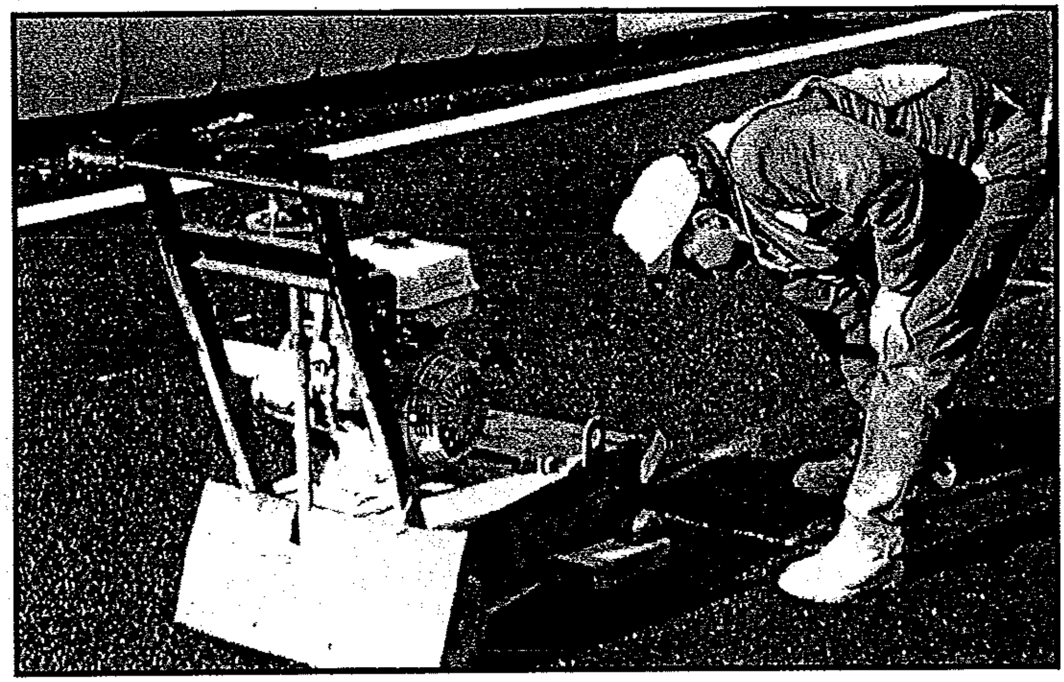
- 350-500 square feet per hour (33-46 sq m/hr) at $^1/_8$" depth (3 mm)

Optional edger attachment allows the CPM-8 to work within $^3/_4$" (19mm) of vertical surfaces or close to the edge of platforms.

EDCO Scarifiers are built for low maintenance and easy servicing.

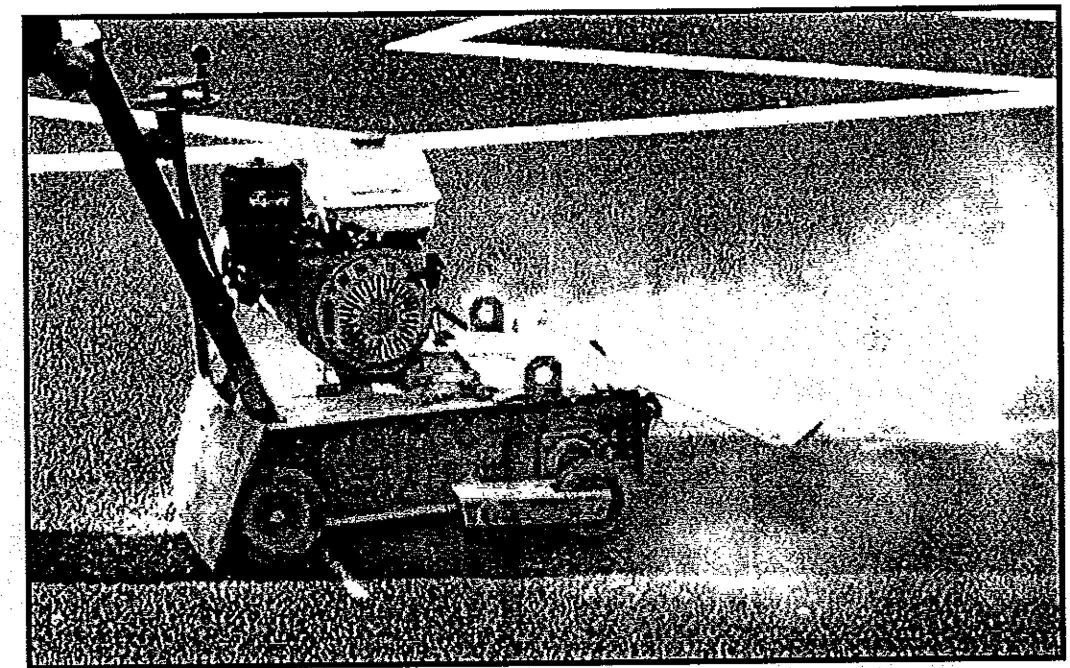
APPENDIX F

PICTURES OF THE RECESSED TRAFFIC MARKING PROCEDURE



Pavement Cutter

Creating Traffic Marking Recesses



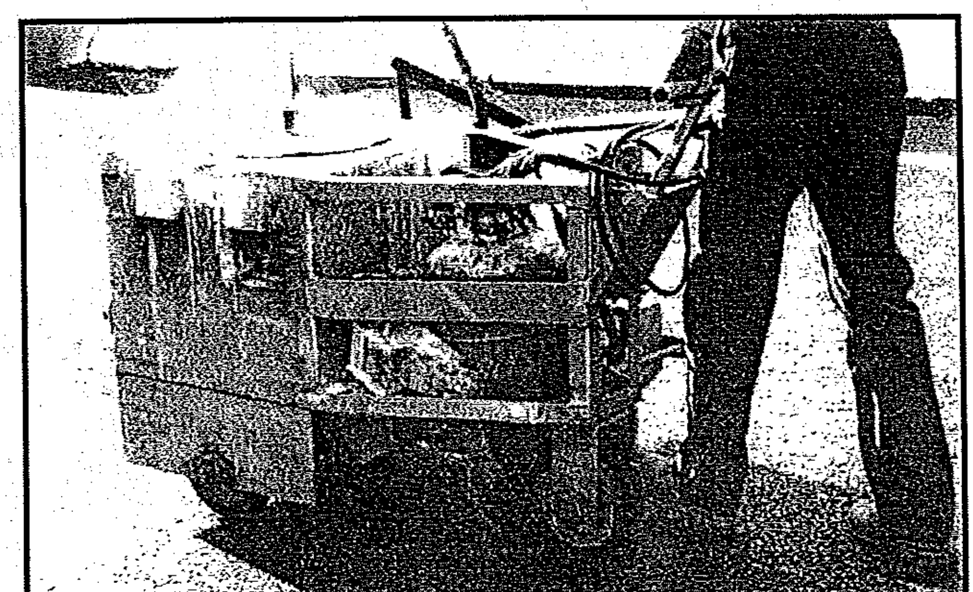
Creating Traffic Marking Recesses

Quality Control

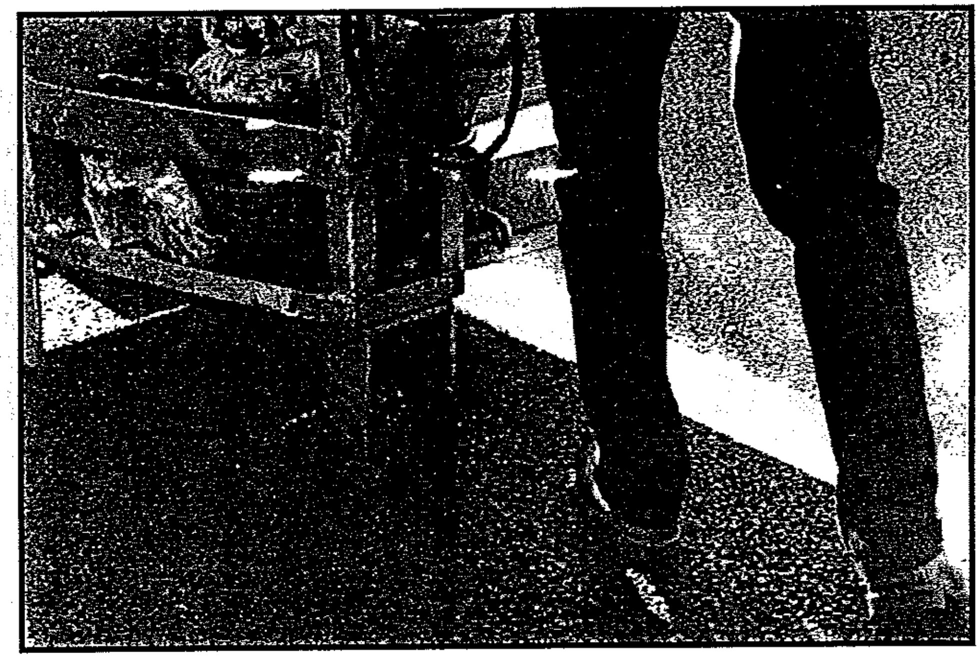
Cleaning Traffic Marking Recesses

Finished Recess

Thermoplastic Application Crew

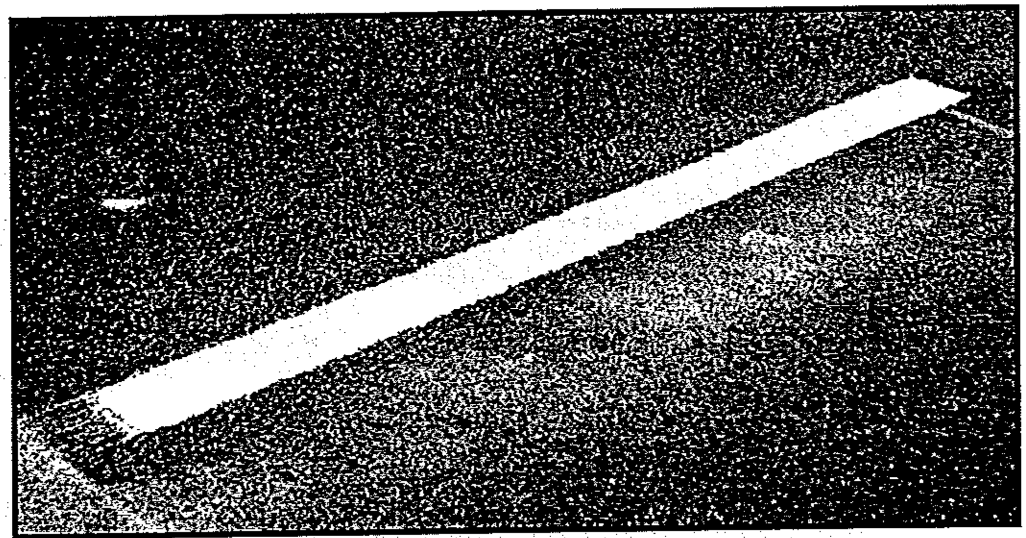


Portable Thermoplastic Applicator

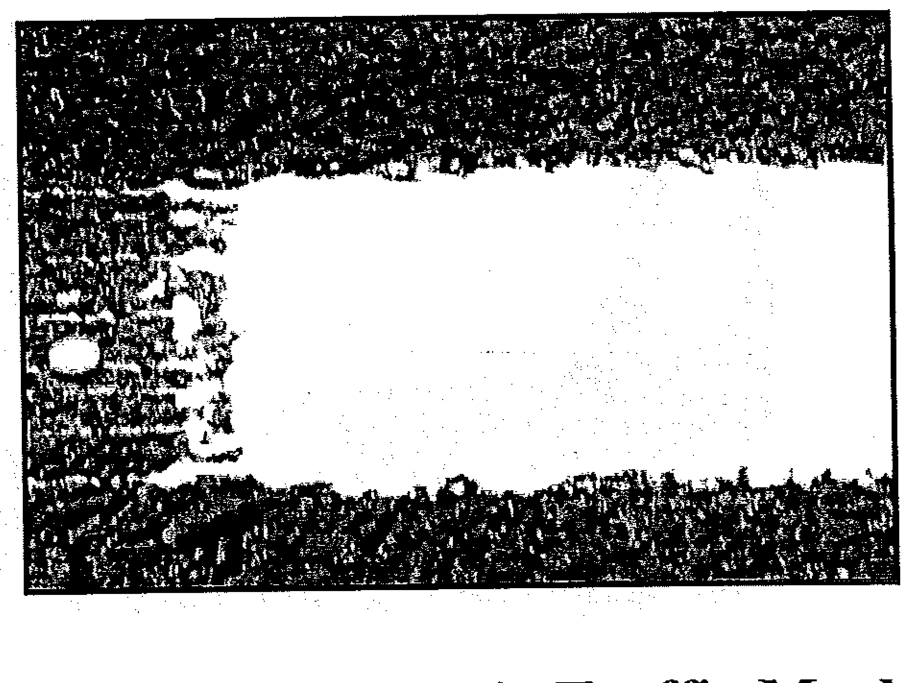


Applying Thermoplastic Markings

Applying Thermoplastic Markings



Recessed Thermoplastic Traffic Marking



Recessed Thermoplastic Traffic Marking

APPENDIX G

EVALUATION DATA FOR 1,000 FT TANGENT TEST SECTION

DECEMBER 30, 1996 - 1,000 FT. TANGENT HIGHWAY SECTION

STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	404	393	398.5	384	386	385.0	391.75	100.00
2	420	409	414.5	413	414	413.5	414.00	100.00
3	412	411	411.5	420	421	420.5	416.00	100.00
4	415	419	417.0	424	424	424.0	420.50	100.00
5	429	425	427.0	408	413	410.5	418.75	100.00
6	442	447	444.5	408	412	410.0	427.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.							**414.71**	**100.00**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LANE							12.14	0.00
7	435	427	431.0	397	401	399.0	415.00	100.00
8	410	414	412.0	428	415	421.5	416.75	100.00
9	416	418	417.0	409	410	409.5	413.25	100.00
10	415	416	415.5	318	323	320.5	368.00	100.00
11	363	370	366.5	412	420	416.0	391.25	100.00
12	414	420	417.0	399	405	402.0	409.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE							**402.29**	**100.00**
STANDARD DEVIATION FOR FRWS ON SECOND LANE							19.19	0.00
1	371	373	372.0	404	407	405.5	388.75	100.00
2	371	370	370.5	402	401	401.5	386.00	100.00
3	350	379	364.5	376	379	377.5	371.00	100.00
4	411	394	402.5	394	387	390.5	396.50	100.00
5	410	414	412.0	420	422	421.0	416.50	100.00
6	423	420	421.5	406	407	406.5	414.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.							**395.46**	**100.00**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE							17.44	0.00
7	401	408	404.5	378	375	376.5	390.50	100.00
8	430	432	431.0	362	371	366.5	398.75	100.00
9	347	348	347.5	351	351	351.0	349.25	100.00
10	370	377	373.5	354	357	355.5	364.50	100.00
11	432	441	436.5	392	390	391.0	413.75	100.00
12	403	412	407.5	413	408	410.5	409.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE							**387.63**	**100.00**
STANDARD DEVIATION FOR SRWS ON SECOND LANE							25.61	0.00
1	402	408	405.0	402	396	399.0	402.00	100.00
2	415	417	416.0	395	394	394.5	405.25	100.00
3	397	399	398.0	420	421	420.5	409.25	100.00
4	429	434	431.5	425	424	424.5	428.00	100.00
5	392	397	394.5	405	409	407.0	400.75	100.00
6	388	385	386.5	388	399	393.5	390.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.							**405.88**	**100.00**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							12.61	0.00

DECEMBER 30, 1996 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
7	398	375	386.5	432	430	431.0	408.75	100.00
8	420	416	418.0	427	428	427.5	422.75	100.00
9	423	429	426.0	422	427	424.5	425.25	100.00
10	437	440	438.5	423	426	424.5	431.50	100.00
11	432	435	433.5	444	449	446.5	440.00	100.00
12	449	445	447.0	417	417	417.0	432.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**426.71**	**100.00**
STANDARD DEVIATION FOR TRWS ON SECOND LANE							10.66	0.00
1	367	366	366.5	405	411	408.0	387.25	100.00
2	406	413	409.5	395	394	394.5	402.00	100.00
3	435	435	435.0	357	362	359.5	397.25	100.00
4	418	419	418.5	434	435	434.5	426.50	100.00
5	419	424	421.5	415	421	418.0	419.75	100.00
6	441	438	439.5	443	450	446.5	443.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**412.63**	**100.00**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							20.78	0.00
7	431	428	429.5	369	374	371.5	400.50	100.00
8	426	431	428.5	444	448	446.0	437.25	100.00
9	382	383	382.5	388	384	386.0	384.25	100.00
10	365	361	363.0	411	410	410.5	386.75	100.00
11	319	325	322.0	406	417	411.5	366.75	100.00
12	370	378	374.0	370	366	368.0	371.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**391.08**	**100.00**
STANDARD DEVIATION FOR NRWS ON SECOND LANE							25.62	0.00
1	305	311	308.0	360	359	359.5	333.75	50.00
2	545	548	546.5	686	684	685.0	615.75	100.00
3	536	540	538.0	552	557	554.5	546.25	100.00
4	678	681	679.5	615	633	624.0	651.75	100.00
5	653	651	652.0	688	706	697.0	674.50	99.00
6	708	710	709.0	763	761	762.0	735.50	99.50
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**592.92**	**91.42**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							141.64	20.29
7	745	748	746.5	759	768	763.5	755.00	100.00
8	722	726	724.0	674	683	678.5	701.25	100.00
9	698	698	698.0	672	678	675.0	686.50	100.00
10	571	584	577.5	599	598	598.5	588.00	97.00
11	644	646	645.0	619	622	620.5	632.75	100.00
12	530	528	529.0	531	524	527.5	528.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**648.63**	**99.50**
STANDARD DEVIATION FOR TAPE ON SECOND LANE							82.39	1.22

APRIL 7, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	222	208	215.0	254	250	252.0	233.50	100.00
2	211	222	216.5	204	210	207.0	211.75	100.00
3	207	209	208.0	202	204	203.0	205.50	99.00
4	195	206	200.5	218	217	217.5	209.00	99.00
5	209	213	211.0	210	218	214.0	212.50	100.00
6	177	176	176.5	174	179	176.5	176.50	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR FRWS ON H.S.L.							**208.13**	**99.17**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LANE							18.35	1.17
7	178	177	177.5	184	194	189.0	183.25	100.00
8	175	178	176.5	166	168	167.0	171.75	99.00
9	151	163	157.0	160	156	158.0	157.50	98.00
10	148	151	149.5	103	110	106.5	128.00	99.00
11	115	117	116.0	143	151	147.0	131.50	100.00
12	113	112	112.5	151	150	150.5	131.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR FRWS ON 2ND LANE							**150.58**	**99.33**
STANDARD DEVIATION FOR FRWS ON SECOND LANE							23.67	0.82
1	131	132	131.5	151	152	151.5	141.50	99.00
2	144	154	149.0	163	161	162.0	155.50	99.00
3	155	156	155.5	160	161	160.5	158.00	99.00
4	161	169	165.0	147	146	146.5	155.75	99.00
5	145	143	144.0	164	162	163.0	153.50	99.00
6	165	172	168.5	198	194	196.0	182.25	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR SRWS ON H.S.L.							**157.75**	**99.00**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE							13.35	0.00
7	78	87	82.5	79	80	79.5	81.00	99.00
8	113	118	115.5	98	95	96.5	106.00	99.00
9	108	102	105.0	112	116	114.0	109.50	98.00
10	110	114	112.0	112	116	114.0	113.00	99.00
11	113	115	114.0	96	96	96.0	105.00	99.00
12	93	93	93.0	102	96	99.0	96.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR SRWS ON 2ND LANE							**101.75**	**99.00**
STANDARD DEVIATION FOR SRWS ON SECOND LANE							11.65	0.63
1	164	152	158.0	159	168	163.5	160.75	100.00
2	162	161	161.5	119	121	120.0	140.75	99.00
3	168	171	169.5	199	200	199.5	184.50	99.00
4	190	193	191.5	133	138	135.5	163.50	99.00
5	144	140	142.0	174	179	176.5	159.25	99.00
6	107	100	103.5	163	158	160.5	132.00	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR TRWS ON H.S.L.							**156.79**	**99.17**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							18.47	0.41

APRIL 7, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
7	85	95	90.0	129	131	130.0	110.00	100.00
8	127	130	128.5	103	94	98.5	113.50	100.00
9	117	120	118.5	104	108	106.0	112.25	99.00
10	129	130	129.5	94	101	97.5	113.50	99.00
11	97	108	102.5	85	97	91.0	96.75	100.00
12	93	94	93.5	102	107	104.5	99.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**107.50**	**99.67**
STANDARD DEVIATION FOR TRWS ON SECOND LANE							7.60	0.52
1	107	102	104.5	138	136	137.0	120.75	98.00
2	117	123	120.0	110	116	113.0	116.50	98.00
3	125	111	118.0	119	117	118.0	118.00	99.00
4	114	110	112.0	132	132	132.0	122.00	98.00
5	134	136	135.0	131	131	131.0	133.00	97.00
6	152	146	149.0	159	160	159.5	154.25	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**127.42**	**97.83**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							14.37	0.75
7	131	132	131.5	104	97	100.5	116.00	96.00
8	120	122	121.0	95	99	97.0	109.00	99.00
9	129	132	130.5	156	162	159.0	144.75	97.00
10	169	174	171.5	157	165	161.0	166.25	97.00
11	127	125	126.0	125	125	125.0	125.50	98.00
12	158	159	158.5	151	153	152.0	155.25	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**136.13**	**97.50**
STANDARD DEVIATION FOR NRWS ON SECOND LANE							22.81	1.05
1	155	150	152.5	179	183	181.0	166.75	45.00
2	318	318	318.0	410	411	410.5	364.25	100.00
3	266	266	266.0	299	294	296.5	281.25	80.00
4	354	347	350.5	0	0	0.0	175.25	50.00
5	0	0	0.0	179	187	183.0	91.50	20.00
6	0	0	0.0	0	0	0.0	0.00	10.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**179.83**	**50.83**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							130.10	34.41
7	279	290	284.5	271	260	265.5	275.00	65.00
8	130	138	134.0	166	174	170.0	152.00	60.00
9	194	195	194.5	105	101	103.0	148.75	55.00
10	361	355	358.0	371	375	373.0	365.50	95.00
11	335	344	339.5	339	346	342.5	341.00	97.00
12	287	303	295.0	301	317	309.0	302.00	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**264.04**	**78.50**
STANDARD DEVIATION FOR TAPE ON SECOND LANE							93.41	20.55

JULY 30, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION

STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	81	96	88.5	55	59	57.0	72.75	100.00
2	41	41	41.0	35	35	35.0	38.00	100.00
3	45	52	48.5	38	44	41.0	44.75	99.00
4	45	50	47.5	61	68	64.5	56.00	99.00
5	13	9	11.0	35	40	37.5	24.25	100.00
6	17	21	19.0	35	37	36.0	27.50	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.							**43.88**	**99.17**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LANE							18.27	1.17
7	35	30	32.5	37	40	38.5	35.50	100.00
8	24	25	24.5	43	43	43.0	33.75	99.00
9	27	33	30.0	42	39	40.5	35.25	98.00
10	53	57	55.0	59	73	66.0	60.50	99.00
11	56	50	53.0	48	47	47.5	50.25	100.00
12	42	47	44.5	69	64	66.5	55.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE							**45.13**	**99.33**
STANDARD DEVIATION FOR FRWS ON SECOND LANE							11.75	0.82
1	47	43	45.0	49	50	49.5	47.25	99.00
2	13	8	10.5	67	66	66.5	38.50	99.00
3	48	45	46.5	81	81	81.0	63.75	99.00
4	46	49	47.5	52	61	56.5	52.00	97.00
5	70	69	69.5	57	56	56.5	63.00	98.00
6	42	44	43.0	59	66	62.5	52.75	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.							**52.88**	**98.17**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE							9.59	0.98
7	37	40	38.5	63	61	62.0	50.25	99.00
8	27	29	28.0	71	76	73.5	50.75	99.00
9	68	72	70.0	73	75	74.0	72.00	98.00
10	48	47	47.5	29	34	31.5	39.50	99.00
11	64	62	63.0	73	66	69.5	66.25	99.00
12	45	41	43.0	58	57	57.5	50.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE							**54.83**	**99.00**
STANDARD DEVIATION FOR SRWS ON SECOND LANE							11.99	0.63
1	32	40	36.0	68	67	67.5	51.75	100.00
2	35	35	35.0	57	57	57.0	46.00	99.00
3	46	49	47.5	59	50	54.5	51.00	99.00
4	65	65	65.0	91	84	87.5	76.25	99.00
5	75	70	72.5	65	67	66.0	69.25	99.00
6	52	49	50.5	56	55	55.5	53.00	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.							**57.88**	**99.17**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							11.97	0.41

JULY 30, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
7	50	51	50.5	55	57	56.0	53.25	100.00
8	50	57	53.5	58	59	58.5	56.00	100.00
9	44	47	45.5	71	65	68.0	56.75	99.00
10	39	40	39.5	57	65	61.0	50.25	99.00
11	60	58	59.0	55	68	61.5	60.25	100.00
12	52	48	50.0	46	43	44.5	47.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**53.96**	**99.67**
STANDARD DEVIATION FOR TRWS ON SECOND LANE							4.71	0.52
1	57	50	53.5	70	65	67.5	60.50	98.00
2	70	77	73.5	61	53	57.0	65.25	98.00
3	54	50	52.0	57	59	58.0	55.00	99.00
4	66	56	61.0	86	81	83.5	72.25	98.00
5	74	63	68.5	69	63	66.0	67.25	97.00
6	51	62	56.5	72	63	67.5	62.00	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**63.71**	**97.83**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							5.95	0.75
7	37	37	37.0	63	61	62.0	49.50	96.00
8	42	42	42.0	39	36	37.5	39.75	99.00
9	40	40	40.0	43	51	47.0	43.50	97.00
10	30	28	29.0	70	72	71.0	50.00	97.00
11	51	51	51.0	60	59	59.5	55.25	98.00
12	24	24	24.0	37	31	34.0	29.00	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**44.50**	**97.50**
STANDARD DEVIATION FOR NRWS ON SECOND LANE							9.32	1.05
1	105	117	111.0	152	159	155.5	133.25	*100.00*
2	18	20	19.0	47	58	52.5	35.75	100.00
3	74	81	77.5	57	61	59.0	68.25	80.00
4	221	214	217.5	125	146	135.5	176.50	*100.00*
5	21	19	20.0	198	197	197.5	108.75	*100.00*
6	122	146	134.0	200	199	199.5	166.75	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**114.88**	**96.67**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							55.31	8.16
7	129	130	129.5	153	158	155.5	142.50	*100.00*
8	219	198	208.5	144	159	151.5	180.00	*100.00*
9	105	86	95.5	204	215	209.5	152.50	*100.00*
10	78	85	81.5	57	66	61.5	71.50	95.00
11	5	7	6.0	73	75	74.0	40.00	97.00
12	59	58	58.5	38	45	41.5	50.00	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**106.08**	**98.50**
STANDARD DEVIATION FOR TAPE ON SECOND LANE							59.42	2.07

November 19, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	303	309	306.0	313	315	314.0	310.00	100.00
2	303	306	304.5	315	316	315.5	310.00	99.00
3	332	332	332.0	312	319	315.5	323.75	100.00
4	283	292	287.5	290	302	296.0	291.75	100.00
5	337	336	336.5	321	316	318.5	327.50	100.00
6	236	244	240.0	263	257	260.0	250.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.							**302.17**	**99.83**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LAN							28.50	0.41
7	278	274	276.0	326	330	328.0	302.00	100.00
8	295	305	300.0	364	365	364.5	332.25	100.00
9	264	273	268.5	287	293	290.0	279.25	100.00
10	272	281	276.5	201	202	201.5	239.00	100.00
11	216	217	216.5	288	291	289.5	253.00	100.00
12	253	249	251.0	271	276	273.5	262.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE							**277.96**	**100.00**
STANDARD DEVIATION FOR FRWS ON SECOND LANE							34.39	0.00
1	226	222	224.0	263	261	262.0	243.00	99.00
2	194	191	192.5	207	212	209.5	201.00	98.00
3	179	165	172.0	297	301	299.0	235.50	100.00
4	229	230	229.5	206	208	207.0	218.25	98.00
5	209	215	212.0	253	259	256.0	234.00	99.00
6	233	235	234.0	254	269	261.5	247.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.							**229.92**	**98.83**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE							17.37	0.75
7	188	191	189.5	187	190	188.5	189.00	99.00
8	186	183	184.5	175	181	178.0	181.25	100.00
9	214	215	214.5	214	218	216.0	215.25	98.00
10	174	178	176.0	189	186	187.5	181.75	98.00
11	166	165	165.5	155	165	160.0	162.75	100.00
12	182	185	183.5	199	205	202.0	192.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE							**187.13**	**99.17**
STANDARD DEVIATION FOR SRWS ON SECOND LAN							17.23	0.98
1	211	211	211.0	220	223	221.5	216.25	100.00
2	236	239	237.5	224	226	225.0	231.25	99.00
3	241	249	245.0	265	260	262.5	253.75	100.00
4	264	271	267.5	240	245	242.5	255.00	100.00
5	229	233	231.0	241	242	241.5	236.25	100.00
6	206	221	213.5	254	257	255.5	234.50	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.							**237.83**	**99.67**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							14.63	0.52

November 19, 1997 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)

STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
7	158	163	160.5	233	231	232.0	196.25	100.00
8	236	244	240.0	191	206	198.5	219.25	100.00
9	221	224	222.5	238	243	240.5	231.50	100.00
10	239	252	245.5	210	211	210.5	228.00	100.00
11	223	227	225.0	193	203	198.0	211.50	99.00
12	203	214	208.5	248	258	253.0	230.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**219.54**	**99.83**
STANDARD DEVIATION FOR TRWS ON SECOND LAN							13.77	0.41
1	231	224	227.5	232	229	230.5	229.00	97.00
2	216	213	214.5	216	213	214.5	214.50	97.00
3	221	225	223.0	219	224	221.5	222.25	98.00
4	223	218	220.5	228	234	231.0	225.75	97.00
5	232	244	238.0	230	238	234.0	236.00	97.00
6	221	223	222.0	257	257	257.0	239.50	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**227.83**	**97.17**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							9.14	0.41
7	227	221	224.0	232	230	231.0	227.50	100.00
8	216	217	216.5	219	222	220.5	218.50	98.00
9	221	217	219.0	216	219	217.5	218.25	97.00
10	238	248	243.0	209	210	209.5	226.25	97.00
11	216	220	218.0	217	216	216.5	217.25	97.00
12	269	268	268.5	223	227	225.0	246.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**225.75**	**98.00**
STANDARD DEVIATION FOR NRWS ON SECOND LAN							11.18	1.26
1	882	881	881.5	912	926	919.0	900.25	*100.00*
2	367	360	363.5	475	475	475.0	419.25	*100.00*
3	294	300	297.0	353	367	360.0	328.50	85.00
4	988	979	983.5	851	857	854.0	918.75	*100.00*
5	924	910	917.0	922	929	925.5	921.25	*100.00*
6	908	906	907.0	914	924	919.0	913.00	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**733.50**	**97.50**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							280.13	6.12
7	914	914	914.0	911	933	922.0	918.00	*100.00*
8	881	907	894.0	927	921	924.0	909.00	*100.00*
9	924	922	923.0	895	906	900.5	911.75	*100.00*
10	324	328	326.0	327	332	329.5	327.75	95.00
11	307	315	311.0	302	312	307.0	309.00	97.00
12	293	295	294.0	304	315	309.5	301.75	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**612.88**	**98.17**
STANDARD DEVIATION FOR TAPE ON SECOND LAN							328.80	2.14

July 2, 1998 - 1,000 FT. TANGENT HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	124	121	122.5	134	130	132.0	127.25	100.00
2	152	152	152.0	159	157	158.0	155.00	100.00
3	148	156	152.0	158	160	159.0	155.50	100.00
4	148	155	151.5	169	168	168.5	160.00	100.00
5	155	161	158.0	149	157	153.0	155.50	100.00
6	154	154	154.0	147	147	147.0	150.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.							**150.63**	**100.00**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LAN							11.84	0.00
7	143	136	139.5	225	227	226.0	182.75	100.00
8	149	149	149.0	139	140	139.5	144.25	100.00
9	165	167	166.0	163	162	162.5	164.25	100.00
10	170	171	170.5	161	158	159.5	165.00	100.00
11	153	160	156.5	180	181	180.5	168.50	100.00
12	168	169	168.5	169	168	168.5	168.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE							**165.54**	**100.00**
STANDARD DEVIATION FOR FRWS ON SECOND LANE							12.40	0.00
1	171	171	171.0	179	171	175.0	173.00	100.00
2	173	167	170.0	164	160	162.0	166.00	100.00
3	158	167	162.5	238	239	238.5	200.50	100.00
4	139	139	139.0	148	149	148.5	143.75	99.00
5	138	140	139.0	150	157	153.5	146.25	100.00
6	168	169	168.5	179	181	180.0	174.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.							**167.29**	**99.83**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE							20.89	0.41
7	173	174	173.5	175	172	173.5	173.50	100.00
8	173	171	172.0	151	155	153.0	162.50	99.00
9	174	181	177.5	188	188	188.0	182.75	100.00
10	108	103	105.5	130	136	133.0	119.25	100.00
11	119	120	119.5	142	142	142.0	130.75	100.00
12	154	160	157.0	158	166	162.0	159.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE							**154.71**	**99.83**
STANDARD DEVIATION FOR SRWS ON SECOND LAN							24.72	0.41
1	171	174	172.5	193	194	193.5	183.00	100.00
2	192	193	192.5	192	192	192.0	192.25	100.00
3	199	206	202.5	202	201	201.5	202.00	100.00
4	206	206	206.0	202	204	203.0	204.50	99.00
5	195	195	195.0	189	184	186.5	190.75	99.00
6	195	197	196.0	201	210	205.5	200.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.							**195.54**	**99.67**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							8.25	0.52

July 2, 1998 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
7	147	145	146.0	164	160	162.0	154.00	100.00
8	207	211	209.0	174	175	174.5	191.75	100.00
9	211	203	207.0	204	208	206.0	206.50	100.00
10	178	183	180.5	182	189	185.5	183.00	99.00
11	203	204	203.5	202	202	202.0	202.75	97.00
12	194	195	194.5	196	198	197.0	195.75	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**188.96**	**98.83**
STANDARD DEVIATION FOR TRWS ON SECOND LAN							19.02	1.47
1	211	212	211.5	190	191	190.5	201.00	99.00
2	199	196	197.5	190	197	193.5	195.50	100.00
3	197	199	198.0	211	211	211.0	204.50	95.00
4	225	234	229.5	223	233	228.0	228.75	97.00
5	220	224	222.0	211	215	213.0	217.50	97.00
6	199	200	199.5	210	207	208.5	204.00	94.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**208.54**	**97.00**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							12.27	2.28
7	216	214	215.0	196	190	193.0	204.00	97.00
8	196	197	196.5	208	208	208.0	202.25	99.00
9	194	195	194.5	202	202	202.0	198.25	98.00
10	194	188	191.0	207	203	205.0	198.00	95.00
11	186	181	183.5	195	191	193.0	188.25	95.00
12	198	205	201.5	215	219	217.0	209.25	94.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**200.00**	**96.33**
STANDARD DEVIATION FOR NRWS ON SECOND LAN							7.10	1.97
1	366	360	363.0	476	479	477.5	420.25	*95.00*
2	290	292	291.0	335	333	334.0	312.50	100.00
3	222	218	220.0	231	236	233.5	226.75	87.00
4	440	442	441.0	730	738	734.0	587.50	*100.00*
5	772	775	773.5	543	543	543.0	658.25	*100.00*
6	648	641	644.5	682	687	684.5	664.50	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**478.29**	**97.00**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							186.07	5.29
7	424	423	423.5	418	423	420.5	422.00	*100.00*
8	310	311	310.5	341	341	341.0	325.75	*100.00*
9	443	444	443.5	455	457	456.0	449.75	*100.00*
10	339	336	337.5	255	261	258.0	297.75	97.00
11	348	340	344.0	250	262	256.0	300.00	98.00
12	239	239	239.0	228	234	231.0	235.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**338.38**	**99.17**
STANDARD DEVIATION FOR TAPE ON SECOND LAN							81.69	1.33

December 7, 1998 - 1,000 FT. TANGENT HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	35	38	36.5	64	69	66.5	51.50	98.00
2	52	51	51.5	58	57	57.5	54.50	98.00
3	53	47	50.0	66	72	69.0	59.50	98.00
4	56	54	55.0	49	52	50.5	52.75	98.00
5	61	55	58.0	63	61	62.0	60.00	98.00
6	42	46	44.0	49	48	48.5	46.25	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.							**54.08**	**98.00**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LAN							5.18	0.00
7	105	92	98.5	66	74	70.0	84.25	98.00
8	89	81	85.0	71	67	69.0	77.00	100.00
9	76	76	76.0	66	60	63.0	69.50	98.00
10	93	87	90.0	90	88	89.0	89.50	100.00
11	67	65	66.0	71	60	65.5	65.75	98.00
12	104	101	102.5	78	69	73.5	88.00	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE							**79.00**	**98.67**
STANDARD DEVIATION FOR FRWS ON SECOND LAN							9.89	1.03
1	60	62	61.0	69	65	67.0	64.00	98.00
2	65	63	64.0	63	60	61.5	62.75	98.00
3	56	49	52.5	68	60	64.0	58.25	98.00
4	61	55	58.0	67	63	65.0	61.50	98.00
5	46	44	45.0	62	63	62.5	53.75	98.00
6	52	43	47.5	46	46	46.0	46.75	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.							**57.83**	**98.00**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LAN							6.56	0.00
7	91	80	85.5	79	72	75.5	80.50	98.00
8	97	84	90.5	70	62	66.0	78.25	98.00
9	130	122	126.0	94	79	86.5	106.25	98.00
10	63	58	60.5	74	64	69.0	64.75	98.00
11	94	85	89.5	96	87	91.5	90.50	98.00
12	115	108	111.5	105	95	100.0	105.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE							**87.67**	**98.33**
STANDARD DEVIATION FOR SRWS ON SECOND LAN							16.40	0.82
1	62	59	60.5	69	62	65.5	63.00	100.00
2	100	90	95.0	93	90	91.5	93.25	100.00
3	77	73	75.0	71	75	73.0	74.00	100.00
4	95	86	90.5	99	89	94.0	92.25	99.00
5	93	80	86.5	93	93	93.0	89.75	99.00
6	96	87	91.5	110	100	105.0	98.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.							**85.08**	**99.67**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE							13.59	0.52

December 7, 1998 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
7	92	80	86.0	114	105	109.5	97.75	98.00
8	168	177	172.5	174	163	168.5	170.50	100.00
9	163	176	169.5	163	150	156.5	163.00	98.00
10	187	172	179.5	140	144	142.0	160.75	100.00
11	142	157	149.5	143	148	145.5	147.50	100.00
12	197	191	194.0	163	149	156.0	175.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**152.42**	**99.33**
STANDARD DEVIATION FOR TRWS ON SECOND LA							28.39	1.03
1	94	89	91.5	65	59	62.0	76.75	99.00
2	79	79	79.0	110	103	106.5	92.75	100.00
3	96	85	90.5	97	88	92.5	91.50	95.00
4	101	101	101.0	101	94	97.5	99.25	97.00
5	109	112	110.5	102	101	101.5	106.00	97.00
6	82	79	80.5	94	84	89.0	84.75	94.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**91.83**	**97.00**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LAN							10.34	2.28
7	220	209	214.5	209	192	200.5	207.50	98.00
8	186	174	180.0	164	178	171.0	175.50	98.00
9	188	176	182.0	206	200	203.0	192.50	98.00
10	224	217	220.5	211	210	210.5	215.50	98.00
11	234	220	227.0	232	219	225.5	226.25	98.00
12	232	220	226.0	205	192	198.5	212.25	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**204.92**	**98.00**
STANDARD DEVIATION FOR NRWS ON SECOND LA							18.15	0.00
1	71	75	73.0	86	90	88.0	80.50	*100.00*
2	61	58	59.5	64	65	64.5	62.00	*100.00*
3	69	66	67.5	56	57	56.5	62.00	80.00
4	107	102	104.5	116	113	114.5	109.50	*100.00*
5	113	101	107.0	109	101	105.0	106.00	*100.00*
6	109	100	104.5	121	113	117.0	110.75	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**88.46**	**96.67**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LAN							23.28	8.16
7	92	90	91.0	101	96	98.5	94.75	*100.00*
8	100	90	95.0	92	83	87.5	91.25	*100.00*
9	108	101	104.5	102	98	100.0	102.25	*100.00*
10	139	129	134.0	118	115	116.5	125.25	97.00
11	132	119	125.5	120	109	114.5	120.00	98.00
12	180	169	174.5	159	147	153.0	163.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**116.21**	**99.17**
STANDARD DEVIATION FOR TAPE ON SECOND LA							26.96	1.33

JUNE 30, 1999 - 1,000 FT. TANGENT HIGHWAY SECTION									
STRIPE	FIRST THIRD			SECOND THIRD				TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG		AVG.	RETAINED
1	106	107	106.5	108	110	109.0		107.75	98.00
2	127	130	128.5	125	121	123.0		125.75	98.00
3	139	132	135.5	127	124	125.5		130.50	98.00
4	129	129	129.0	143	140	141.5		135.25	98.00
5	131	138	134.5	128	128	128.0		131.25	98.00
6	108	114	111.0	125	123	124.0		117.50	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON H.S.L.								**124.67**	**98.00**
STANDARD DEVIATION FOR FRWS ON HIGH SPEED LANE								10.28	0.00
7	120	115	117.5	92	91	91.5		104.50	98.00
8	116	118	117.0	109	116	112.5		114.75	98.00
9	133	128	130.5	117	124	120.5		125.50	97.00
10	143	144	143.5	107	114	110.5		127.00	98.00
11	128	127	127.5	127	128	127.5		127.50	98.00
12	120	115	117.5	115	114	114.5		116.00	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS** ON 2ND LANE								**119.21**	**97.83**
STANDARD DEVIATION FOR FRWS ON SECOND LANE								9.12	0.41
1	127	125	126.0	127	123	125.0		125.50	96.00
2	134	137	135.5	121	124	122.5		129.00	97.00
3	111	109	110.0	116	115	115.5		112.75	97.00
4	100	106	103.0	108	109	108.5		105.75	96.00
5	102	104	103.0	112	114	113.0		108.00	97.00
6	115	113	114.0	132	133	132.5		123.25	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON H.S.L.								**117.38**	**96.67**
STANDARD DEVIATION FOR SRWS ON HIGH SPEED LANE								9.80	0.52
7	120	115	117.5	123	119	121.0		119.25	98.00
8	125	125	125.0	111	116	113.5		119.25	98.00
9	113	119	116.0	115	120	117.5		116.75	98.00
10	90	87	88.5	87	87	87.0		87.75	98.00
11	68	73	70.5	91	94	92.5		81.50	98.00
12	109	105	107.0	119	115	117.0		112.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS** ON 2ND LANE								**106.08**	**98.33**
STANDARD DEVIATION FOR SRWS ON SECOND LANE								16.95	0.82
1	120	128	124.0	128	127	127.5		125.75	98.00
2	129	128	128.5	128	127	127.5		128.00	98.00
3	125	125	125.0	137	138	137.5		131.25	98.00
4	136	131	133.5	130	134	132.0		132.75	98.00
5	117	117	117.0	131	132	131.5		124.25	98.00
6	113	116	114.5	132	132	132.0		123.25	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON H.S.L.								**127.54**	**98.17**
STANDARD DEVIATION FOR TRWS ON HIGH SPEED LANE								3.84	0.41

JUNE 30, 1999 - 1,000 FT. TANGENT HIGHWAY SECTION (CONT.)

STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
7	112	109	110.5	108	108	108.0	109.25	98.00
8	130	125	127.5	84	100	92.0	109.75	100.00
9	105	106	105.5	124	130	127.0	116.25	98.00
10	111	104	107.5	109	113	111.0	109.25	100.00
11	117	118	117.5	115	123	119.0	118.25	100.00
12	116	123	119.5	129	129	129.0	124.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS** ON 2ND LANE							**114.50**	**99.33**
STANDARD DEVIATION FOR TRWS ON SECOND LANE							6.16	1.03
1	122	118	120.0	134	136	135.0	127.50	96.00
2	131	134	132.5	123	126	124.5	128.50	96.00
3	119	120	119.5	123	116	119.5	119.50	96.00
4	123	124	123.5	130	122	126.0	124.75	96.00
5	113	121	117.0	116	115	115.5	116.25	94.00
6	127	128	127.5	135	136	135.5	131.50	94.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON H.S.L.							**124.67**	**95.33**
STANDARD DEVIATION FOR NRWS ON HIGH SPEED LANE							5.78	1.03
7	132	126	129.0	119	122	120.5	124.75	97.00
8	116	121	118.5	112	118	115.0	116.75	98.00
9	130	132	131.0	135	129	132.0	131.50	97.00
10	124	127	125.5	125	122	123.5	124.50	97.00
11	135	130	132.5	125	122	123.5	128.00	96.00
12	114	121	117.5	107	124	115.5	116.50	95.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS** ON 2ND LANE							**123.67**	**96.67**
STANDARD DEVIATION FOR NRWS ON SECOND LANE							6.02	1.03
1	295	300	297.5	297	297	297.0	297.25	*95.00*
2	151	159	155.0	156	152	154.0	154.50	*100.00*
3	140	141	140.5	159	158	158.5	149.50	80.00
4	184	179	181.5	50	56	53.0	117.25	*50.00*
5	24	27	25.5	79	84	81.5	53.50	*35.00*
6	106	113	109.5	91	92	91.5	100.50	*50.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON H.S.L.							**145.42**	**68.33**
STANDARD DEVIATION FOR TAPE ON HIGH SPEED LANE							82.96	26.96
7	128	122	125.0	105	106	105.5	115.25	*90.00*
8	137	145	141.0	137	142	139.5	140.25	*96.00*
9	164	172	168.0	149	147	148.0	158.00	*93.00*
10	116	119	117.5	125	124	124.5	121.00	96.00
11	131	131	131.0	138	140	139.0	135.00	97.00
12	133	133	133.0	138	139	138.5	135.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE** ON 2ND LANE							**134.21**	**95.17**
STANDARD DEVIATION FOR TAPE ON SECOND LANE							15.10	3.19

APPENDIX H

EVALUATION DATA FOR 500 FT EXIT RAMP TEST SECTION

DECEMBER 30, 1996 - 500 FT. EXIT RAMP SECTION

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	365	372	368.5	366	359	362.5	365.50	100.00
2	348	349	348.5	335	334	334.5	341.50	100.00
3	368	360	364.0	367	367	367.0	365.50	100.00
4	362	366	364.0	351	352	351.5	357.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR FRWS							**357.56**	**100.00**
STANDARD DEVIATION FOR FR							11.31	0.00
1	292	292	292.0	268	271	269.5	280.75	100.00
2	321	320	320.5	261	268	264.5	292.50	100.00
3	344	349	346.5	321	317	319.0	332.75	100.00
4	311	320	315.5	295	301	298.0	306.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR SRWS							**303.19**	**100.00**
STANDARD DEVIATION FOR SR							22.39	0.00
1	329	326	327.5	324	324	324.0	325.75	100.00
2	285	288	286.5	334	332	333.0	309.75	100.00
3	173	170	171.5	206	209	207.5	189.50	98.00
4	332	333	332.5	300	302	301.0	316.75	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR TRWS							**285.44**	**99.00**
STANDARD DEVIATION FOR TRW							64.29	1.15
1	207	203	205.0	149	151	150.0	177.50	99.00
2	195	199	197.0	161	170	165.5	181.25	99.00
3	156	154	155.0	321	316	318.5	236.75	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR NRWS							**198.50**	**98.67**
STANDARD DEVIATION FOR NRW							33.18	0.58

APRIL 9, 1997 - 500 FT. EXIT RAMP SECTION

STRIPE NUMBER	FIRST THIRD 1ST	2ND	AVG.	SECOND THIRD 1ST	2ND	AVG	TOTAL AVG.	PERCENT RETAINED
1	149	143	146.0	114	118	116.0	131.00	98.00
2	137	131	134.0	88	94	91.0	112.50	98.00
3	122	120	121.0	146	145	145.5	133.25	98.00
4	140	156	148.0	351	80	79.0	113.50	99.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR FRWS						**122.56**	**98.25**
				STANDARD DEVIATION FOR FR			11.09	0.50

	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	80	73	76.5	84	81	82.5	79.50	99.00
2	83	81	82.0	64	60	62.0	72.00	96.00
3	81	82	81.5	75	77	76.0	78.75	99.00
4	75	78	76.5	82	82	82.0	79.25	99.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR SRWS						**77.38**	**98.25**
				STANDARD DEVIATION FOR SR			3.60	1.50

	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	89	94	91.5	111	112	111.5	101.50	99.00
2	60	60	60.0	54	55	54.5	57.25	99.00
3	42	48	45.0	55	59	57.0	51.00	96.00
4	97	99	98.0	93	98	95.5	96.75	97.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR TRWS						**76.63**	**97.75**
				STANDARD DEVIATION FOR TRW			26.18	1.50

1	81	79	80.0	75	82	78.5	79.25	98.00
2	93	89	91.0	96	98	97.0	94.00	95.00
3	91	88	89.5	112	123	117.5	103.50	92.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR NRWS						**92.25**	**95.00**
				STANDARD DEVIATION FOR NRW			12.22	3.00

JULY 30, 1997 - 500 FT. EXIT RAMP SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	57	53	55.0	60	63	61.5	58.25	98.00
2	45	52	48.5	53	59	56.0	52.25	98.00
3	28	35	31.5	61	58	59.5	45.50	98.00
4	39	44	41.5	65	70	79.0	60.25	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS**							**54.06**	**98.25**
STANDARD DEVIATION FOR FR							6.64	0.50
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	44	49	46.5	59	63	61.0	53.75	99.00
2	56	57	56.5	66	62	64.0	60.25	95.00
3	54	60	57.0	62	61	61.5	59.25	99.00
4	51	46	48.5	63	56	59.5	54.00	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**56.81**	**97.75**
STANDARD DEVIATION FOR SR							3.42	1.89
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	58	61	59.5	59	51	55.0	57.25	99.00
2	61	68	64.5	70	65	67.5	66.00	99.00
3	42	48	45.0	48	46	47.0	46.00	96.00
4	66	66	66.0	73	66	69.5	67.75	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS**							**59.25**	**97.75**
STANDARD DEVIATION FOR TR							9.96	1.50
1	55	52	53.5	53	45	49.0	51.25	96.00
2	69	76	72.5	82	84	83.0	77.75	95.00
3	84	91	87.5	63	63	63.0	75.25	92.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**68.08**	**94.33**
STANDARD DEVIATION FOR NR							14.63	2.08

November 19, 1997 - 500 FT. EXIT RAMP SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	125	115	120.0	133	134	133.5	126.75	100.00
2	145	144	144.5	156	158	157.0	150.75	100.00
3	136	144	140.0	136	134	135.0	137.50	98.00
4	116	121	118.5	140	138	79.0	98.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRW**							**128.44**	**99.25**
STANDARD DEVIATION FOR F							22.09	0.96
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	177	177	177.0	171	166	168.5	172.75	100.00
2	163	167	165.0	164	162	163.0	164.00	95.00
3	140	152	146.0	153	163	158.0	152.00	100.00
4	151	159	155.0	151	154	152.5	153.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRW**							**160.63**	**98.75**
STANDARD DEVIATION FOR S							9.66	2.50
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	158	164	161.0	141	139	140.0	150.50	100.00
2	170	168	169.0	177	182	179.5	174.25	100.00
3	141	155	148.0	166	166	166.0	157.00	95.00
4	165	159	162.0	161	163	162.0	162.00	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**160.94**	**98.00**
STANDARD DEVIATION FOR T							10.05	2.45
1	197	202	199.5	192	200	196.0	197.75	95.00
2	220	217	218.5	212	210	211.0	214.75	94.00
3	241	237	239.0	265	278	271.5	255.25	93.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRW**							**222.58**	**94.00**
STANDARD DEVIATION FOR NR							29.54	1.00

July 2, 1998 - 500 FT. EXIT RAMP SECTION								
STRIPE	**FIRST THIRD**			**SECOND THIRD**			**TOTAL**	**PERCENT**
NUMBER	**1ST**	**2ND**	**AVG.**	**1ST**	**2ND**	**AVG**	**AVG.**	**RETAINED**
1	126	127	126.5	140	139	139.5	133.00	100.00
2	136	142	139.0	130	137	133.5	136.25	99.00
3	140	141	140.5	138	139	138.5	139.50	98.00
4	119	118	118.5	134	136	79.0	98.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRW**							**126.88**	**99.25**
STANDARD DEVIATION FOR F							18.94	0.96
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	141	142	141.5	135	128	131.5	136.50	100.00
2	132	135	133.5	119	115	117.0	125.25	96.00
3	131	132	131.5	128	135	131.5	131.50	100.00
4	128	126	127.0	129	121	125.0	126.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRW**							**129.81**	**99.00**
STANDARD DEVIATION FOR S							5.26	2.00
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	142	141	141.5	132	128	130.0	135.75	100.00
2	148	149	148.5	147	146	146.5	147.50	100.00
3	136	130	133.0	141	140	140.5	136.75	96.00
4	130	121	125.5	143	135	139.0	132.25	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**138.06**	**98.00**
STANDARD DEVIATION FOR T							6.58	2.31
1	167	169	168.0	153	154	153.5	160.75	94.00
2	185	190	187.5	181	183	182.0	184.75	93.00
3	194	197	195.5	220	223	221.5	208.50	90.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRW**							**184.67**	**92.33**
STANDARD DEVIATION FOR NR							23.88	2.08

	December 7, 1998 - 500 FT. EXIT RAMP SECTION							
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	79	73	76.0	79	80	79.5	77.75	100.00
2	86	90	88.0	85	92	88.5	88.25	98.00
3	129	129	129.0	131	136	133.5	131.25	98.00
4	122	128	125.0	120	119	79.0	102.00	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FR**							**99.81**	**99.00**
STANDARD DEVIATION FOR							23.19	1.15
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	150	149	149.5	137	137	137.0	143.25	100.00
2	138	139	138.5	138	139	138.5	138.50	96.00
3	126	126	126.0	127	131	129.0	127.50	100.00
4	130	131	130.5	131	135	133.0	131.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRW**							**135.25**	**99.00**
STANDARD DEVIATION FOR S							7.00	2.00
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	135	144	139.5	145	145	145.0	142.25	100.00
2	135	128	131.5	138	133	135.5	133.50	100.00
3	158	153	155.5	181	177	179.0	167.25	96.00
4	170	176	173.0	162	163	162.5	167.75	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**152.69**	**98.00**
STANDARD DEVIATION FOR T							17.47	2.31
1	159	158	158.5	142	136	139.0	148.75	94.00
2	175	169	172.0	166	162	164.0	168.00	93.00
3	133	130	131.5	134	121	127.5	129.50	90.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NR**							**148.75**	**92.33**
STANDARD DEVIATION FOR N							19.25	2.08

JUNE 30, 1999 - 500 FT. EXIT RAMP SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	91	98	94.5	84	90	87.0	90.75	100.00
2	84	93	88.5	82	88	85.0	86.75	98.00
3	93	87	90.0	100	92	96.0	93.00	98.00
4	98	99	98.5	97	98	79.0	88.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS**							**89.81**	**99.00**
STANDARD DEVIATION FOR FRWS							2.68	1.15
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	94	92	93.0	101	104	102.5	97.75	100.00
2	104	96	100.0	111	108	109.5	104.75	93.00
3	100	94	97.0	93	94	93.5	95.25	99.00
4	89	79	84.0	87	94	90.5	87.25	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**96.25**	**97.50**
STANDARD DEVIATION FOR SRWS							7.22	3.11
	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	
1	103	97	100.0	103	102	102.5	101.25	99.00
2	106	107	106.5	108	111	109.5	108.00	100.00
3	109	109	109.0	115	122	118.5	113.75	93.00
4	97	98	97.5	116	114	115.0	106.25	95.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS**							**107.31**	**96.75**
STANDARD DEVIATION FOR TRWS							5.16	3.30
1	128	124	126.0	133	135	134.0	130.00	92.00
2	153	155	154.0	148	150	149.0	151.50	87.00
3	171	171	171.0	151	158	154.5	162.75	85.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**148.08**	**88.00**
STANDARD DEVIATION FOR NRWS							16.64	3.61

APPENDIX I

EVALUATION DATA FOR 500 FT CURVED TEST SECTION

JANUARY 6, 1997 - 500 FT. CURVED HIGHWAY SECTION

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	380	384	382.0	375	359	367.0	374.50	100.00
2	344	346	345.0	327	325	326.0	335.50	100.00
3	354	347	350.5	341	332	336.5	343.50	100.00
4	304	353	328.5	349	343	346.0	337.25	100.00
5	320	337	328.5	349	254	301.5	315.00	100.00
6	325	346	335.5	353	370	361.5	348.50	100.00
7	331	335	333.0	307	309	308.0	320.50	100.00
8	287	303	295.0	286	294	290.0	292.50	100.00
9	295	302	298.5	293	296	294.5	296.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR FRWS							**329.31**	**100.00**
STANDARD DEVIATION FOR FRW							26.05	0.00
1	291	296	293.5	283	287	285.0	289.25	100.00
2	354	357	355.5	377	378	377.5	366.50	100.00
3	328	329	328.5	365	366	365.5	347.00	100.00
4	293	295	294.0	316	283	299.5	296.75	100.00
5	330	349	339.5	331	337	334.0	336.75	100.00
6	329	337	333.0	336	332	334.0	333.50	100.00
7	302	303	302.5	295	302	298.5	300.50	100.00
8	290	290	290.0	288	294	291.0	290.50	100.00
9	301	306	303.5	258	277	267.5	285.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR SRWS							**316.25**	**100.00**
STANDARD DEVIATION FOR SRW							29.90	0.00
1	344	337	340.5	375	375	375.0	357.75	100.00
2	375	380	377.5	370	377	373.5	375.50	100.00
3	358	364	361.0	338	328	333.0	347.00	100.00
4	312	318	315.0	318	320	319.0	317.00	100.00
5	321	330	325.5	319	315	317.0	321.25	100.00
6	308	314	311.0	328	332	330.0	320.50	100.00
7	310	315	312.5	293	298	295.5	304.00	100.00
8	302	296	299.0	293	296	294.5	296.75	100.00
9	284	280	282.0	280	278	279.0	280.50	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR TRWS							**324.47**	**100.00**
STANDARD DEVIATION FOR TRW							30.46	0.00

JANUARY 6, 1997 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	367	371	369.0	376	378	377.0	373.00	100.00
2	348	348	348.0	369	368	368.5	358.25	100.00
3	321	323	322.0	355	362	358.5	340.25	100.00
4	322	330	326.0	333	334	333.5	329.75	100.00
5	331	335	333.0	355	353	354.0	343.50	100.00
6	330	331	330.5	353	354	353.5	342.00	100.00
7	295	288	291.5	281	281	281.0	286.25	100.00
8	304	326	315.0	304	308	306.0	310.50	100.00
9	305	323	314.0	303	316	309.5	311.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**332.81**	**100.00**
STANDARD DEVIATION FOR NRW							26.54	0.00
1	0	0	0.0	0	0	0.0	0.00	2.00
2	0	0	0.0	0	0	0.0	0.00	4.00
3	0	0	0.0	0	0	0.0	0.00	0.00
4	525	524	524.5	461	476	468.5	496.50	100.00
5	574	579	576.5	419	432	425.5	501.00	97.00
6	475	458	466.5	503	490	496.5	481.50	99.00
7	0	0	0.0	281	0	0.0	0.00	5.00
8	0	0	0.0	304	0	0.0	0.00	6.00
9	437	435	436.0	293	296	294.5	365.25	70.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE**							**204.92**	**42.56**
STANDARD DEVIATION FOR TAP							246.18	47.29

APRIL 9, 1997 - 500 FT. CURVED HIGHWAY SECTION

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	252	242	247.0	259	263	261.0	254.00	99.00
2	239	234	236.5	258	257	257.5	247.00	99.00
3	254	246	250.0	245	236	240.5	245.25	99.00
4	225	227	226.0	190	197	193.5	209.75	100.00
5	201	203	202.0	218	220	219.0	210.50	100.00
6	225	222	223.5	225	228	226.5	225.00	99.00
7	179	181	180.0	173	186	179.5	179.75	100.00
8	173	168	170.5	173	178	175.5	173.00	100.00
9	177	174	175.5	178	171	174.5	175.00	100.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS**						**213.25**	**99.56**
	STANDARD DEVIATION FOR FRW						31.99	0.53
1	187	193	190.0	160	164	162.0	176.00	98.00
2	210	208	209.0	255	252	253.5	231.25	99.00
3	183	176	179.5	190	184	187.0	183.25	98.00
4	177	175	176.0	154	151	152.5	164.25	100.00
5	220	222	221.0	218	225	221.5	221.25	99.00
6	218	228	223.0	217	227	222.0	222.50	100.00
7	155	151	153.0	140	145	142.5	147.75	100.00
8	170	182	176.0	164	175	169.5	172.75	100.00
9	160	159	159.5	146	139	142.5	151.00	100.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**						**185.56**	**99.33**
	STANDARD DEVIATION FOR SRW						31.75	0.87
1	136	146	141.0	182	182	182.0	161.50	99.00
2	236	222	229.0	162	172	167.0	198.00	99.00
3	214	206	210.0	174	169	171.5	190.75	100.00
4	210	214	212.0	200	195	197.5	204.75	100.00
5	180	185	182.5	205	205	205.0	193.75	100.00
6	181	194	187.5	215	214	214.5	201.00	100.00
7	165	166	165.5	120	130	125.0	145.25	100.00
8	132	137	134.5	127	138	132.5	133.50	99.00
9	140	146	143.0	146	148	147.0	145.00	99.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS**						**174.83**	**99.56**
	STANDARD DEVIATION FOR TRW						28.24	0.53

APRIL 9, 1997 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	179	179	179	168	172	170.0	174.50	99.00
2	170	186	178	208	211	209.5	193.75	99.00
3	155	158	156.5	204	206	205.0	180.75	99.00
4	190	202	196	185	198	191.5	193.75	100.00
5	180	190	185	210	216	213.0	199.00	99.00
6	174	180	177	175	183	179.0	178.00	98.00
7	178	174	176	160	160	160.0	168.00	99.00
8	156	160	158	161	163	162.0	160.00	99.00
9	174	181	177.5	176	181	178.5	178.00	99.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**						**180.64**	**99.00**
	STANDARD DEVIATION FOR NRW						12.84	0.50
1	0	0	0	0	0	0.0	0.00	1.00
2	0	0	0	0	0	0.0	0.00	1.00
3	0	0	0	0	0	0.0	0.00	0.00
4	341	340	340.5	333	339	336.0	338.25	97.00
5	397	400	398.5	314	302	308.0	353.25	93.00
6	0	0	0	0	0	0.0	0.00	20.00
7	0	0	0	281	0	0.0	0.00	1.00
8	0	0	0	304	0	0.0	0.00	3.00
9	188	196	192	202	210	206.0	199.00	65.00
	AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE**						**98.94**	**31.22**
	STANDARD DEVIATION FOR TAP						154.39	41.72

JULY 30, 1997 - 500 FT. CURVED HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	46	53	49.5	56	57	56.5	53.00	99.00
2	50	54	52.0	73	77	75.0	63.50	99.00
3	79	82	80.5	66	62	64.0	72.25	99.00
4	30	37	33.5	36	35	35.5	34.50	100.00
5	42	48	45.0	60	54	57.0	51.00	100.00
6	60	52	56.0	74	70	72.0	64.00	99.00
7	53	46	49.5	72	64	68.0	58.75	100.00
8	51	62	56.5	64	59	61.5	59.00	100.00
9	62	53	57.5	56	60	58.0	57.75	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS**							**57.08**	**99.56**
STANDARD DEVIATION FOR FR							10.55	0.53
1	43	50	46.5	57	50	53.5	50.00	98.00
2	56	58	57.0	72	73	72.5	64.75	99.00
3	83	84	83.5	78	73	75.5	79.50	98.00
4	48	53	50.5	72	69	70.5	60.50	100.00
5	27	33	30.0	55	57	56.0	43.00	99.00
6	19	16	17.5	29	29	29.0	23.25	100.00
7	56	57	56.5	64	65	64.5	60.50	100.00
8	70	67	68.5	71	64	67.5	68.00	100.00
9	78	70	74.0	68	73	70.5	72.25	100.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**57.97**	**99.33**
STANDARD DEVIATION FOR SR							17.03	0.87
1	59	67	63.0	76	72	74.0	68.50	99.00
2	54	54	54.0	69	73	71.0	62.50	99.00
3	59	67	63.0	86	87	86.5	74.75	100.00
4	65	66	65.5	61	58	59.5	62.50	100.00
5	45	47	46.0	68	65	66.5	56.25	100.00
6	24	37	30.5	71	63	67.0	48.75	100.00
7	59	54	56.5	65	69	67.0	61.75	100.00
8	67	62	64.5	76	64	70.0	67.25	99.00
9	53	52	52.5	45	45	45.0	48.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS**							**61.22**	**99.56**
STANDARD DEVIATION FOR TR							8.74	0.53

JULY 30, 1997 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	52	57	54.5	56	63	59.5	57.00	99.00
2	57	66	61.5	76	66	71.0	66.25	99.00
3	48	44	46	81	75	78.0	62.00	99.00
4	59	56	57.5	77	75	76.0	66.75	100.00
5	37	40	38.5	49	47	48.0	43.25	99.00
6	42	41	41.5	45	49	47.0	44.25	98.00
7	67	59	63	76	73	74.5	68.75	99.00
8	58	58	58	53	49	51.0	54.50	99.00
9	54	52	53	73	64	68.5	60.75	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**58.17**	**99.00**
STANDARD DEVIATION FOR NR							9.38	0.50
1	204	205	204.5	240	224	232.0	218.25	*100.00*
2	189	196	192.5	175	174	174.5	183.50	*100.00*
3	177	193	185	222	223	222.5	203.75	*100.00*
4	68	74	71	77	78	77.5	74.25	90.00
5	76	74	75	78	78	78.0	76.50	88.00
6	134	147	140.5	136	130	133.0	136.75	*100.00*
7	96	94	95	130	115	122.5	108.75	*100.00*
8	125	113	119	126	118	122.0	120.50	*100.00*
9	180	183	181.5	161	150	155.5	168.50	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE**							**143.42**	**97.56**
STANDARD DEVIATION FOR TA							53.04	4.88

November 19, 1997 - 500 FT. CURVED HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	287	287	287.0	314	304	309.0	298.00	99.00
2	266	279	272.5	309	315	312.0	292.25	99.00
3	267	280	273.5	293	294	293.5	283.50	98.00
4	216	227	221.5	209	212	210.5	216.00	99.00
5	243	250	246.5	234	247	240.5	243.50	99.00
6	242	245	243.5	234	225	229.5	236.50	98.00
7	141	151	146.0	139	122	130.5	138.25	99.00
8	148	143	145.5	133	123	128.0	136.75	99.00
9	135	143	139.0	117	131	124.0	131.50	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRW**							**219.58**	**98.78**
STANDARD DEVIATION FOR FR							68.58	0.44
1	224	246	235.0	222	227	224.5	229.75	95.00
2	253	256	254.5	305	321	313.0	283.75	98.00
3	227	235	231.0	200	207	203.5	217.25	97.00
4	201	217	209.0	190	186	188.0	198.50	99.00
5	208	219	213.5	224	226	225.0	219.25	99.00
6	190	212	201.0	222	226	224.0	212.50	99.00
7	135	151	143.0	119	136	127.5	135.25	98.00
8	132	147	139.5	152	159	155.5	147.50	97.00
9	151	158	154.5	147	148	147.5	151.00	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**199.42**	**97.78**
STANDARD DEVIATION FOR SR							47.53	1.30
1	224	220	222.0	227	235	231.0	226.50	97.00
2	289	280	284.5	246	245	245.5	265.00	96.00
3	230	239	234.5	253	264	258.5	246.50	97.00
4	189	215	202.0	199	196	197.5	199.75	97.00
5	188	181	184.5	193	195	194.0	189.25	97.00
6	166	180	173.0	184	193	188.5	180.75	97.00
7	170	158	164.0	147	161	154.0	159.00	97.00
8	175	172	173.5	161	154	157.5	165.50	97.00
9	174	184	179.0	157	157	157.0	168.00	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**200.03**	**96.78**
STANDARD DEVIATION FOR T							37.87	0.44

November 19, 1997 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	220	233	226.5	236	241	238.5	232.50	97.00
2	216	226	221	268	262	265.0	243.00	97.00
3	218	218	218	254	258	256.0	237.00	97.00
4	157	153	155	181	191	186.0	170.50	98.00
5	177	184	180.5	188	192	190.0	185.25	96.00
6	173	187	180	196	201	198.5	189.25	96.00
7	161	165	163	162	165	163.5	163.25	96.00
8	159	173	166	153	149	151.0	158.50	96.00
9	152	161	156.5	161	165	163.0	159.75	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**193.22**	**96.56**
STANDARD DEVIATION FOR NR							34.92	0.73
1	760	767	763.5	854	860	857.0	810.25	*100.00*
2	789	785	787	816	824	820.0	803.50	*100.00*
3	771	774	772.5	805	812	808.5	790.50	*100.00*
4	243	235	239	228	231	229.5	234.25	95.00
5	268	268	268	215	213	214.0	241.00	95.00
6	740	752	746	715	720	717.5	731.75	*100.00*
7	591	598	594.5	649	665	657.0	625.75	*100.00*
8	699	713	706	632	643	637.5	671.75	*100.00*
9	787	796	791.5	804	812	808.0	799.75	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAP**							**634.28**	**98.89**
STANDARD DEVIATION FOR T							233.73	2.20

July 2, 1998 - 500 FT. CURVED HIGHWAY SECTION								
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	148	151	149.5	150	152	151.0	150.25	100.00
2	149	155	152.0	196	201	198.5	175.25	100.00
3	141	146	143.5	170	166	168.0	155.75	100.00
4	145	150	147.5	150	149	149.5	148.50	100.00
5	154	160	157.0	147	151	149.0	153.00	100.00
6	128	133	130.5	154	155	154.5	142.50	100.00
7	149	149	149.0	151	151	151.0	150.00	99.00
8	152	152	152.0	198	198	198.0	175.00	98.00
9	143	143	143.0	168	168	168.0	155.50	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRW**							**156.19**	**99.56**
STANDARD DEVIATION FOR FR							11.45	0.73
1	153	158	155.5	152	159	155.5	155.50	99.00
2	160	155	157.5	167	163	165.0	161.25	100.00
3	161	168	164.5	160	159	159.5	162.00	100.00
4	152	162	157.0	150	149	149.5	153.25	100.00
5	148	150	149.0	151	153	152.0	150.50	100.00
6	148	150	149.0	155	151	153.0	151.00	100.00
7	155	155	155.0	155	155	155.0	155.00	98.00
8	157	157	157.0	165	165	165.0	161.00	97.00
9	164	164	164.0	159	159	159.0	161.50	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**156.78**	**99.11**
STANDARD DEVIATION FOR SR							4.71	1.17
1	169	165	167.0	164	157	160.5	163.75	100.00
2	181	190	185.5	181	177	179.0	182.25	100.00
3	162	169	165.5	170	164	167.0	166.25	100.00
4	177	170	173.5	167	166	166.5	170.00	100.00
5	159	159	159.0	166	164	165.0	162.00	100.00
6	170	174	172.0	174	175	174.5	173.25	100.00
7	167	167	167.0	179	179	179.0	173.00	97.00
8	185.5	185.5	185.5	182	182	182.0	183.75	97.00
9	173.5	173.5	173.5	166	166	166.0	169.75	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**171.56**	**99.00**
STANDARD DEVIATION FOR T							7.53	1.50

July 2, 1998 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	SECOND THIRD AVG	TOTAL AVG.	PERCENT RETAINED
1	166	166	166	178	179	178.5	172.25	90.00
2	169	162	165.5	163	162	162.5	164.00	97.00
3	163	165	164	170	162	166.0	165.00	98.00
4	147	145	146	158	165	161.5	153.75	100.00
5	158	163	160.5	154	163	158.5	159.50	100.00
6	173	175	174	174	180	177.0	175.50	99.00
7	166	166	166	178	178	178.0	172.00	96.00
8	165	165	165	162	162	162.0	163.50	96.00
9	146	146	146	166	166	166.0	156.00	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR NRWS							**164.61**	**96.89**
STANDARD DEVIATION FOR NR							7.51	3.06
1	375	380	377.5	383	389	386.0	381.75	*90.00*
2	190	188	189	454	462	458.0	323.50	*60.00*
3	289	292	290.5	188	183	185.5	238.00	*75.00*
4	168	175	171.5	162	162	162.0	166.75	95.00
5	196	199	197.5	182	179	180.5	189.00	90.00
6	229	227	228	248	245	246.5	237.25	*93.00*
7	377.5	377.5	377.5	381	381	381.0	379.25	*100.00*
8	189	189	189	323	323	323.0	256.00	*100.00*
9	290	290	290	238	238	238.0	264.00	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR TAP							**270.61**	**89.22**
STANDARD DEVIATION FOR T							76.51	13.48

December 7, 1998 - 500 FT. CURVED HIGHWAY SECTION

1.1

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	AVG	TOTAL AVG.	PERCENT RETAINED
1	173	171	172.0	187	190	188.5	180.25	98.00
2	190	185	187.5	192	189	190.5	189.00	98.00
3	175	174	174.5	213	205	209.0	191.75	98.00
4	194	194	194.0	197	197	197.0	195.50	98.00
5	210	207	208.5	194	200	197.0	202.75	98.00
6	189	198	193.5	183	183	183.0	188.25	98.00
7	172	172	172.0	188	188	188.0	180.00	99.00
8	187	187	187.0	190	190	190.0	188.50	98.00
9	174	174	174.0	209	209	209.0	191.50	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRW**							**189.72**	**98.22**
STANDARD DEVIATION FOR F							7.06	0.44
1	211	212	211.5	199	197	198.0	204.75	98.00
2	209	207	208.0	198	198	198.0	203.00	100.00
3	200	201	200.5	203	203	203.0	201.75	100.00
4	204	204	204.0	196	198	197.0	200.50	98.00
5	199	207	203.0	204	199	201.5	202.25	100.00
6	216	215	215.5	218	215	216.5	216.00	100.00
7	211	211	211.0	198	198	198.0	204.50	98.00
8	208	208	208.0	203	203	203.0	205.50	97.00
9	200	200	200.0	197	197	197.0	198.50	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRW**							**204.08**	**98.78**
STANDARD DEVIATION FOR S							4.98	1.20
1	206	200	203.0	205	198	201.5	202.25	98.00
2	231	229	230.0	229	230	229.5	229.75	98.00
3	217	217	217.0	211	207	209.0	213.00	98.00
4	207	209	208.0	196	192	194.0	201.00	98.00
5	203	199	201.0	213	220	216.5	208.75	98.00
6	201	198	199.5	216	211	213.5	206.50	100.00
7	203	203	203.0	201	201	201.0	202.00	97.00
8	230	230	230.0	229	229	229.0	229.50	97.00
9	217	217	217.0	209	209	209.0	213.00	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRW**							**211.75**	**97.89**
STANDARD DEVIATION FOR T							11.07	0.93

December 7, 1998 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	AVG	TOTAL AVG.	PERCENT RETAINED
1	194	197	195.5	228	228	228.0	211.75	90.00
2	222	218	220	205	206	205.5	212.75	97.00
3	216	209	212.5	212	211	211.5	212.00	98.00
4	190	184	187	198	194	196.0	191.50	100.00
5	189	188	188.5	190	192	191.0	189.75	100.00
6	189	184	186.5	202	197	199.5	193.00	98.00
7	195	195	195	228	228	228.0	211.50	96.00
8	220	220	220	205	205	205.0	212.50	96.00
9	212	212	212	211	211	211.0	211.50	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR NRW							**205.14**	**96.78**
STANDARD DEVIATION FOR N							10.33	2.99
1	201	194	197.5	306	287	296.5	247.00	*90.00*
2	87	85	86	370	344	357.0	221.50	*60.00*
3	256	250	253	363	346	354.5	303.75	*70.00*
4	284	270	277	227	217	222.0	249.50	90.00
5	169	168	168.5	171	161	166.0	167.25	90.00
6	276	255	265.5	236	217	226.5	246.00	*90.00*
7	197	197	197	200	200	200.0	198.50	*100.00*
8	86	86	86	110	110	110.0	98.00	*100.00*
9	253	253	253	260	260	260.0	256.50	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR TAP							**220.89**	**87.78**
STANDARD DEVIATION FOR							59.94	13.94

JUNE 30, 1999 - 500 FT. CURVED HIGHWAY SECTION

STRIPE NUMBER	FIRST THIRD 1ST	FIRST THIRD 2ND	FIRST THIRD AVG.	SECOND THIRD 1ST	SECOND THIRD 2ND	AVG	TOTAL AVG.	PERCENT RETAINED
1	118	117	117.5	129	127	128.0	122.75	98.00
2	128	127	127.5	127	129	128.0	127.75	98.00
3	133	135	134.0	128	136	132.0	133.00	98.00
4	119	119	119.0	108	107	107.5	113.25	98.00
5	**68**	**75**	71.5	**51**	**54**	52.5	62.00	98.00
6	**57**	**51**	54.0	**53**	**54**	53.5	53.75	98.00
7	121	125	123.0	131	133	132.0	127.50	99.00
8	136	127	131.5	137	135	136.0	133.75	98.00
9	130	138	134.0	134	135	134.5	134.25	99.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **FRWS**							**112.00**	**98.22**
STANDARD DEVIATION FOR FRWS							31.44	0.44
NOTE: NUMBERS IN BOLD INDICATES STRIPES COVERED BY SKID MARKS								
1	123	121	122.0	117	125	121.0	121.50	98.00
2	139	140	139.5	132	128	130.0	134.75	100.00
3	125	120	122.5	124	122	123.0	122.75	100.00
4	**66**	**65**	65.5	**57**	**58**	57.5	61.50	98.00
5	**90**	**90**	90.0	**59**	**74**	66.5	78.25	100.00
6	**49**	**52**	54.0	**54**	**54**	54.0	54.00	100.00
7	135	138	136.5	124	127	125.5	131.00	98.00
8	142	134	138.0	137	137	137.0	137.50	97.00
9	131	133	132.0	128	129	128.5	130.25	98.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **SRWS**							**107.94**	**98.78**
STANDARD DEVIATION FOR SRWS							33.49	1.20
NOTE: NUMBERS IN BOLD INDICATES STRIPES COVERED BY SKID MARKS								
1	112	124	118.0	126	128	127.0	122.50	98.00
2	128	133	130.5	130	128	129.0	129.75	98.00
3	120	121	120.5	120	119	119.5	120.00	98.00
4	**63**	**68**	65.5	**57**	**67**	62.0	63.75	98.00
5	**63**	**65**	64.0	**66**	**66**	66.0	65.00	98.00
6	**86**	**83**	84.5	**80**	**81**	80.5	82.50	100.00
7	122	125	123.5	129	130	129.5	126.50	97.00
8	129	131	130.0	133	135	134.0	132.00	97.00
9	115	123	119.0	127	128	127.5	123.25	97.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TRWS**							**107.25**	**97.89**
STANDARD DEVIATION FOR TRWS							28.35	0.93
NOTE: NUMBERS IN BOLD INDICATES STRIPES COVERED BY SKID MARKS								

JUNE 30, 1999 - 500 FT. CURVED HIGHWAY SECTION (CONT.)

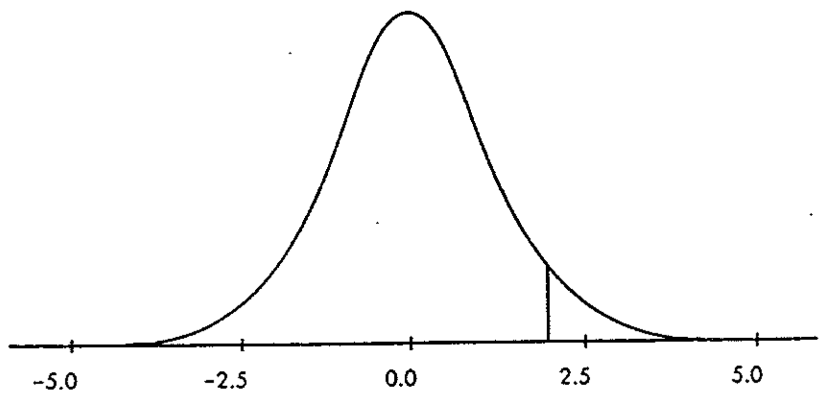
STRIPE	FIRST THIRD			SECOND THIRD			TOTAL	PERCENT
NUMBER	1ST	2ND	AVG.	1ST	2ND	AVG	AVG.	RETAINED
1	119	120	119.5	123	122	122.5	121.00	90.00
2	124	125	124.5	127	128	127.5	126.00	98.00
3	115	109	112	117	119	118.0	115.00	98.00
4	95	90	92.5	94	94	94.0	93.25	100.00
5	78	82	80	70	78	74.0	77.00	100.00
6	76	83	79.5	83	89	86.0	82.75	98.00
7	111	113	112	117	120	118.5	115.25	96.00
8	115	108	111.5	100	99	99.5	105.50	96.00
9	97	91	94	89	85	87.0	90.50	96.00
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **NRWS**							**102.92**	**96.89**
STANDARD DEVIATION FOR NRWS							17.64	3.02
1	192	192	192	159	159	159.0	175.50	*75.00*
2	51	51	51	181	183	182.0	116.50	*55.00*
3	194	198	196	152	153	152.5	174.25	*60.00*
4	120	119	119.5	114	115	114.5	117.00	90.00
5	104	104	104	101	101	101.0	102.50	90.00
6	103	97	100	131	131	131.0	115.50	*90.00*
7	190	189	189.5	177	180	178.5	184.00	*90.00*
8	90	106	98	109	110	109.5	103.75	*77.00*
9	198	200	199	203	205	204.0	201.50	*100.00*
AVERAGE RETROREFLECTIVITY/DURABILITY FOR **TAPE**							**143.39**	**80.78**
STANDARD DEVIATION FOR TAPE							39.45	15.22

APPENDIX J

t-TABLE

t-DISTRIBUTION CRITICAL VALUES

The table reports the critical value for which the area to the right is as indicated.



Area to right	0.2	0.1	0.05	0.025	0.01	0.005	0.001	0.0005
Conf. level	60%	80%	90%	95%	98%	99%	99.80%	99.90%
d.f.								
1	1.376	3.078	6.314	12.706	31.821	63.657	318.317	636.607
2	1.061	1.886	2.920	4.303	6.965	9.925	22.327	31.598
3	0.978	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.941	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.920	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.906	1.440	1.943	2.447	3.143	3.708	5.208	5.959
7	0.896	1.415	1.895	2.365	2.998	3.500	4.785	5.408
8	0.889	1.397	1.860	2.306	2.897	3.355	4.501	5.041
9	0.883	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.879	1.372	1.812	2.228	2.764	3.169	4.144	4.587