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16. Abstract <p>This report summarizes research activities regarding the delineation of concrete safety-shaped barriers (CSSBs) in situations where the barrier is located close to the travel lane. Included in this report are a summary of current barrier delineation practices in Texas; review of past CSSB research; discussion of results of field studies of CSSB delineation treatments on urban freeways in Austin and Houston, TX; and discussion of several mechanisms suggested for cleaning CSSB delineators.</p> <p>Field study results at a lighted urban freeway site in Houston suggest that some delineation treatments may have a small effect upon the distance at which drivers travel from the barrier as compared to a no-delineation condition under nighttime dry-weather conditions. However, it was not possible to determine whether this effect is of practical significance in terms of traffic safety and operations.</p> <p>It was also found that dirt and road film affect delineation types differently. In particular, the visibility of cube-corner delineators did not deteriorate as quickly or as extensively as did high-intensity reflective sheeting applied to brackets or wrapped around cylinders.</p>					
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DELINEATION OF CONCRETE SAFETY-SHAPED BARRIERS

by

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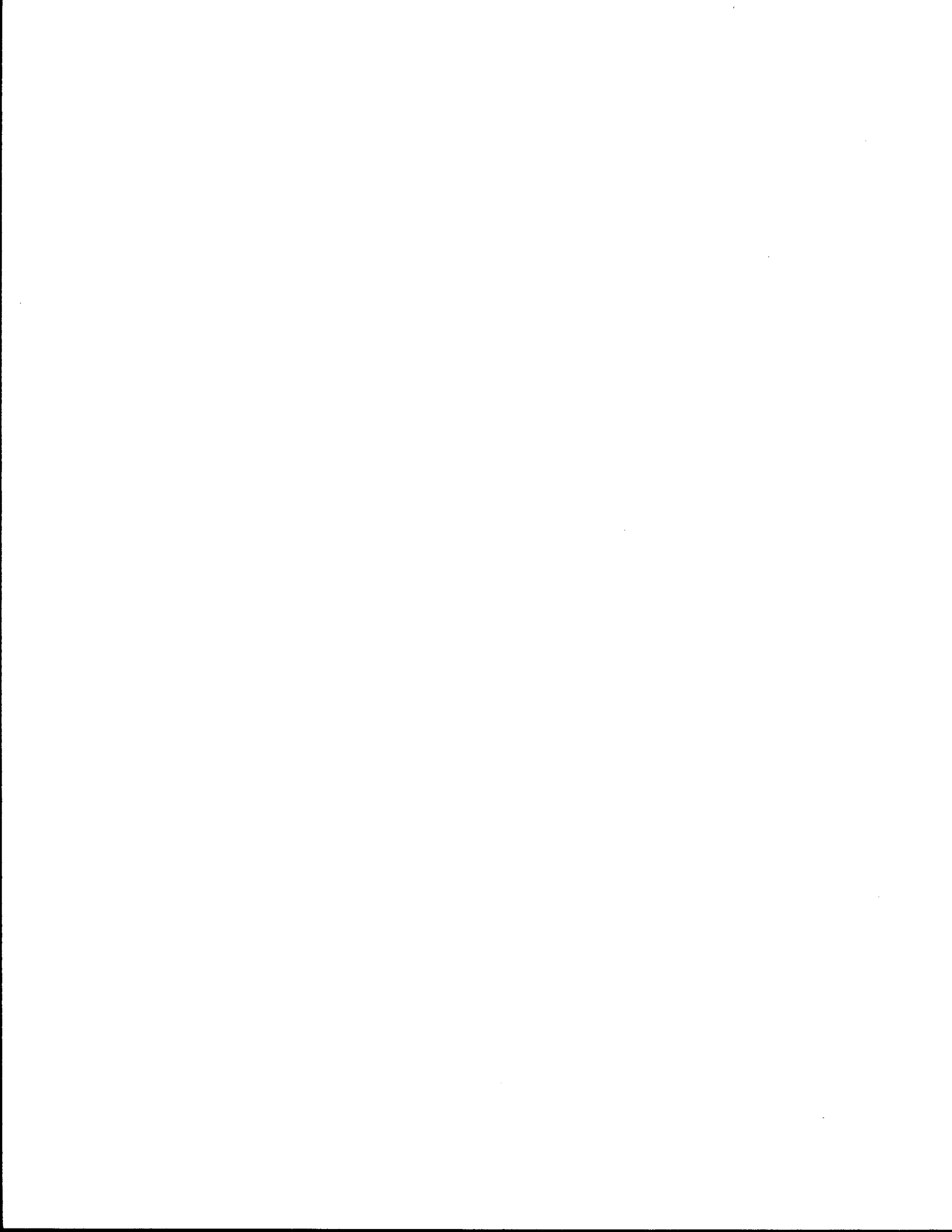
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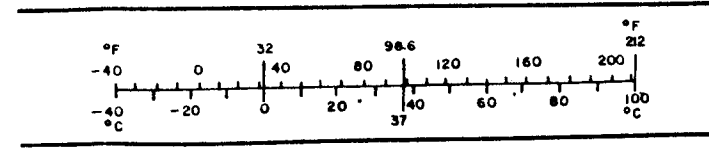
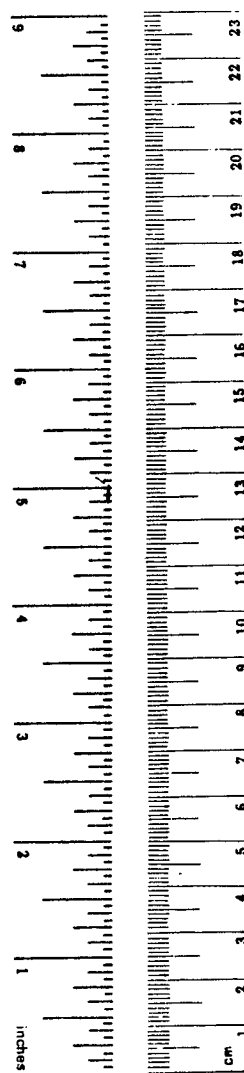
METRIC CONVERSION FACTORS

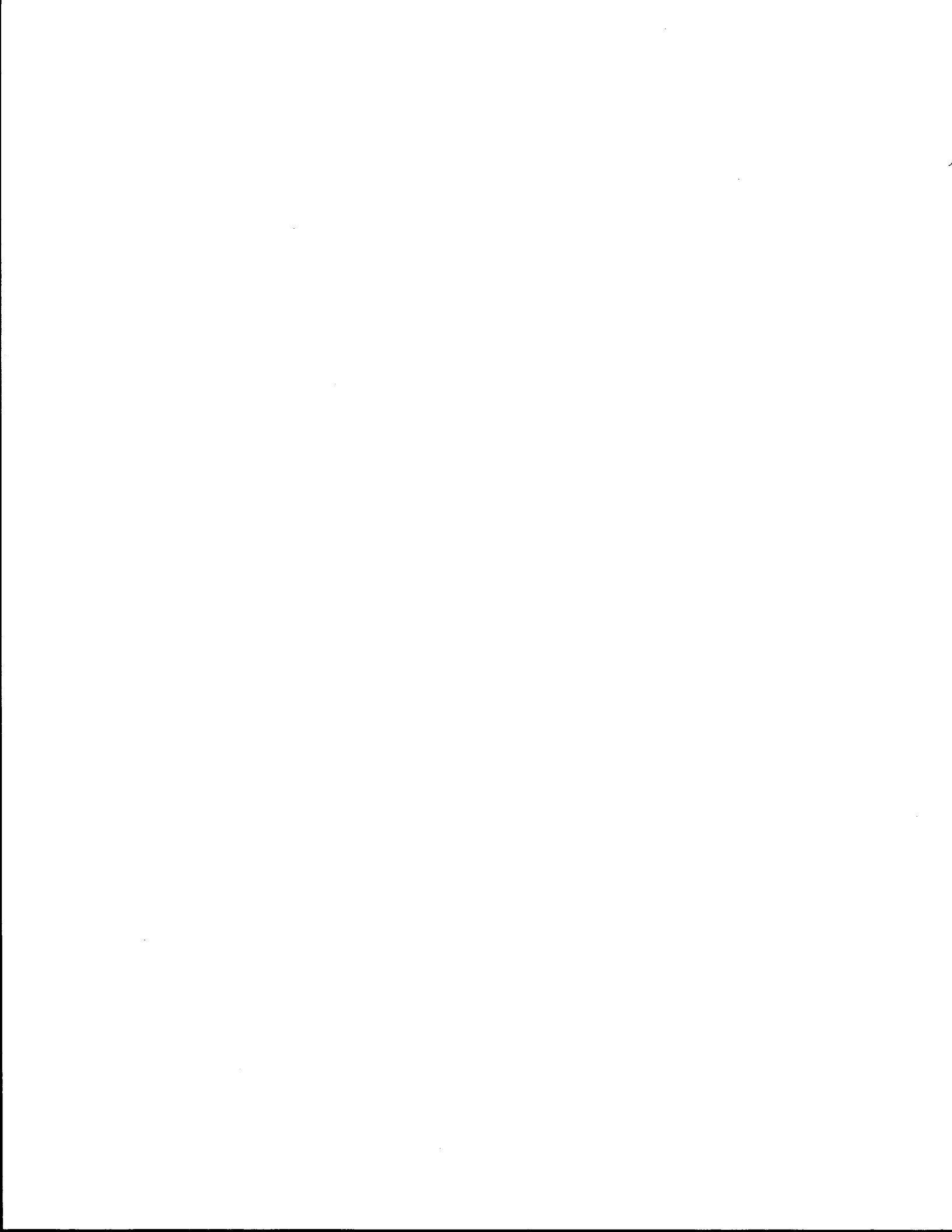
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	36	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F





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The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

SUMMARY OF FINDINGS

State-of-the-Art of CSSB Delineation

This report documents the result of a study of delineation treatments for concrete safety-shaped barrier (CSSB) where the barrier is placed very close to the travel lanes and where it is important that drivers are made aware of the location of the barrier and of the proper travel path next to the barrier.

As part of this study, existing CSSB delineation practices in Texas and previous research conducted on CSSB delineation were reviewed. Considerable variation was found in the types and amounts of delineation used on CSSBs. Most of the Texas State Department of Highways and Public Transportation (SDHPT) Districts do delineate CSSBs when they are used in highway work zones (since work zones generally have more severe geometric and visibility constraints). On the other hand, only a few Districts choose to delineate CSSBs when used in narrow freeway median applications. The choice of the particular delineation treatment varies from District to District, and is currently a matter of District preference.

There have been a few studies previously conducted in Texas and in other states on CSSB delineation. These studies have primarily involved evaluations of the cost and visibility (reflectivity) of the different types of delineators available. Visibility is generally measured by the researchers themselves or inferred from evaluations by subject drivers viewing the specific delineation treatments. The results of the different studies vary, apparently due to differences in the study designs (i.e. the types, mounting position on the barrier, and spacings of delineators that are evaluated) and measures-of-effectiveness used.

Evaluation of CSSB Delineation

Field studies of five CSSB delineation treatments were conducted on a section of illuminated urban freeway in Houston, TX. These treatments consisted of:

1. Cube-corner lens-type delineators mounted on top of the CSSB at 200-ft intervals
2. Cube-corner delineators mounted on the side of the CSSB (6-in from the top) at 50-ft intervals
3. Angle brackets covered with high-intensity (HI) reflective sheeting mounted on top of the CSSB at 50-ft intervals

4. Angle brackets covered with HI sheeting mounted on the side of the CSSB (6-in from the top) at 200-ft intervals
5. Cylinders covered with HI sheeting mounted on top of the CSSB at 50-ft intervals

Nighttime traffic performance data were collected at each treatment segment before and after the treatment was installed to obtain the following measures-of-effectiveness (MOEs):

1. Changes in lane distribution of the two inside lanes next to the CSSBs
2. Changes in the rate of vehicles observed straddling the lane stripe between the two inside lanes
3. Changes in the lateral distance of vehicles from the CSSBs.

None of the treatments appeared to have a major effect upon the traffic MOEs examined. A small but statistically significant increase in the lane straddling rate was noted after the side-mounted cube-corner delineators at 50-ft spacings were installed. Also, some slight changes were detected in the lateral distance drivers traveled from the barrier, but it did not appear that these changes were significant from a practical standpoint.

A group of subject drivers evaluated the delineation treatments under nighttime dry-weather conditions when the delineators were clean and also when they were covered with dirt and road film. As a group, the subjects stated that a 50-ft delineator spacing was preferable to a 200-ft spacing, and that mounting delineators on the side of the barrier was preferable to mounting them on top. In both the clean and dirty conditions, the side-mounted cube-corner lenses at 50-ft spacings were ranked as the brightest and most effective delineation treatment.

Visibility measurements of the five delineation treatments taken periodically while the treatments were in place at the study site showed that the visibility of the cube-corner lenses did not deteriorate (due to dirt and road film) as fast or as extensively as did the brackets and cylinders covered with HI sheeting. It was also noted that, as expected, delineation mounted on the side of the barrier lost its visibility at a faster rate than top-mounted delineation.

The features and faults of a few innovative mechanisms for cleaning CSSB delineation quickly and easily were analyzed with regard to each one's future development, production, and implementation. The results suggest that a truck-mounted mast-arm brush assembly would be the most practical and effective system of those analyzed, and would allow either top-mounted or side-mounted delineators to be cleaned in a slow-moving maintenance (similar to a street sweeping) operation. This system would be applicable to CSSB delineation in both freeway median and highway work zone locations.

IMPLEMENTATION STATEMENT

The studies documented in this report were conducted on CSSBs in urban freeway median locations where the inside travel lanes were less than 1 ft from the bottom of the CSSBs. The studies were conducted under nighttime, dry pavement conditions. Hence, the results obtained are directly applicable to these limited study conditions. However, the recommendations made are suggested for sites with somewhat similar characteristics.

Where delineation of CSSBs in narrow freeway medians are deemed necessary, it is recommended that acrylic cube-corner lenses be mounted on top of the CSSBs at spacings no greater than 200 ft. Closer spacings may be necessary, particularly if there are sharp horizontal curves present. These recommendations are also suggested for delineating CSSBs in highway work zones until additional objective driver performance data can be collected for work zone conditions. Because of study limitations, it was not possible to determine under what traffic and geometric conditions CSSB delineation is effective and useful. However, there was some evidence that CSSB delineation may be useful to drivers in nighttime wet-pavement conditions, even at sites where fixed lighting is present. Additional research is needed to either confirm or refute this evidence.

TABLE OF CONTENTS

1. INTRODUCTION	1
Background	1
Statement of the Problem	1
Research Objectives	2
Research Scope	2
2. STATE-OF-THE-ART IN CSSB DELINEATION	4
CSSB Delineation Practices in Texas	4
Extent of Delineation Use	4
Types of Delineators Used	5
Delineation Problems Encountered	6
Summary	9
Previous Delineation Research	10
CSSB Delineation at Freeway Median Installations	10
CSSB Delineation at Highway Work Zones	10
Summary	13
3. BARRIER DELINEATION STUDY, IH-35 (AUSTIN)	15
Background	15
Method of Study	16
Results	19
Lane Distributions	19
Shoulder Encroachments	21
Lateral Distances	21
Summary	24
4. BARRIER DELINEATION STUDY, IH-45 (HOUSTON)	25
Study Design	25
Delineation Treatments	25
Site Description	27
Driver Performance Analysis	30
Objective	30
Method of Study	30
Results	31
Subjective Evaluations	35
Objective	35
Method of Study	35
Results	38
Delineation Visibility over Time	45
Objective	45
Method of Study	45
Results	46
Summary	50

5. BARRIER DELINEATION CLEANING 52

 Current Methods of Cleaning Barrier Delineators. 52

 Potential Barrier Delineator Cleaning Systems. 53

 Self-Propelled Rotating Brush Cleaning System. 53

 High Pressure Water Sprayer. 54

 Truck Mounted Brush Head Cleaner 54

 Summary. 56

6. SUMMARY AND RECOMMENDATIONS. 58

 State-of-the-Art of CSSB Delineation 58

 Evaluation of CSSB Delineation 58

 Recommendations. 60

REFERENCES 61

- APPENDIX A: INSTRUCTIONS GIVEN TO SUBJECTS DURING BARRIER DELINEATION EVALUATION
- APPENDIX B: INDIVIDUAL SUBJECT RANKINGS AND COMMENTS DURING BARRIER DELINEATION EVALUATION (DIRTY CONDITION)
- APPENDIX C: INDIVIDUAL SUBJECT RANKINGS AND COMMENTS DURING BARRIER DELINEATION EVALUATION (CLEAN CONDITION)
- APPENDIX D: TECHNIQUE FOR DETERMINING VISIBILITY DISTANCE FOR BARRIER DELINEATORS
- APPENDIX E: SURVEY OF DISTRICT BARRIER DELINEATION CLEANING PROCEDURES

LIST OF TABLES

Table 2-1.	Summary of District Delineation Practices of Concrete Safety-Shaped Barriers	5
Table 2-2.	Summary of Previous CSSB Delineation Research	11
Table 2-3.	Average Field-Measured Reflectivity After 1 Month Exposure (Washington).	13
Table 3-1.	Lane Distribution Summary - IH-35, Austin	20
Table 4-1.	Summary of Delineation Treatments	29
Table 4-2.	Comparison of Lane Distribution Data: Before Vs. After Delineation - IH-45, Houston	32
Table 4-3.	Comparison of Lane Straddling Data: Before Vs. After Delineation - IH-45, Houston	33
Table 4-4.	Subject Evaluation of Delineation Treatments: Dirty Condition - IH-45, Houston	39
Table 4-5.	Summary of Subject Comments: Dirty Condition - IH-45, Houston	41
Table 4-6.	Subject Evaluation of Delineation Treatments: Clean Condition - IH-45, Houston	42
Table 4-7.	Summary of Subject Comments: Clean Condition - IH-45, Houston	44
Table 4-8.	Visibility Distance Measurements Over Time - IH-45, Houston	47

LIST OF FIGURES

Figure 2-1.	Examples of Cube-Corner Lenses	7
Figure 2-2.	High-Intensity Reflective Sheeting on 3-inch Square Plates	8
Figure 2-3.	High-Intensity Reflective Sheeting Wrapped Around 1.5-inch by 3-inch Cylinders	8
Figure 2-4.	Reflective Pavement Markers and Reflective Pavement Taper Applied to the Side of the CSSB.	9
Figure 3-1.	CSSB Delineation in Place at IH-35 Study Site, Austin (After the Delineators had been Cleaned)	15
Figure 3-2.	Video Equipment Used to Collect Nighttime Data	17
Figure 3-3.	Schematic Layout of IH-35 Study Site	18
Figure 3-4.	Comparison of Lateral Distance Distributions for Dirty Vs. Clean Delineators: Tangent Section, IH-35 (Austin)	22
Figure 3-5.	Comparison of Lateral Distance Distributions for Dirty Vs. Clean Delineators: Curve Section, IH-35 (Austin)	23
Figure 4-1.	Types of Delineators Studied, IH-45 (Houston).	26
Figure 4-2.	Layout of Delineation Treatments at Study Site, IH-45 (Houston).	28
Figure 4-3.	IH-45 (Houston) Study Site	29
Figure 4-4.	Comparison of Lateral Distance Distributions for Before Vs. After Delineation: High Nighttime Volume Hours (9 p.m. to Midnight), IH-45 (Houston).	36
Figure 4-5.	Comparison of Lateral Distance Distributions for Before Vs. After Delineation: Low Nighttime Volume Hours (9 p.m. to Midnight), IH-45 (Houston).	37
Figure 4-6.	Effect of Dirt and Road Film Upon Delineators Studied, IH-45 (Houston).	48
Figure 4-7.	Effect of Dirt and Road Film Upon Delineators Studied at Different Mounting Positions, IH-45 (Houston)	49
Figure 5-1.	Truck-Mounted Mast-Arm Barrier Delineator Cleaning Mechanism.	55
Figure 5-2.	Flexible Base Barrier Delineator	57

1. INTRODUCTION

Background

Longitudinal traffic barriers are used to minimize the severity of potential accidents involving vehicles leaving the traveled way (1). They are used where it is considered less hazardous to redirect an errant vehicle by means of the barrier than to allow the vehicle to leave the road and possibly strike an object or an oncoming vehicle. Barriers are classified according to the amount of lateral deformation they sustain upon impact; flexible, semi-rigid, or rigid. In situations where lateral clearance between the travel lanes and a hazard is limited, a rigid barrier design (one that does not deflect) is required. Currently, the only operational barrier design that is classified as rigid is the concrete safety-shaped barrier (CSSB) (2).

CSSBs are commonly used in the narrow median of freeways and high-volume expressways where it is necessary to keep errant vehicles from crossing over to the opposing lanes and into oncoming traffic. In some cases, a normal (i.e., 8 to 10 ft) median shoulder exists between the travel lanes and the barrier; in more restricted cases, the barrier may be located immediately next to the edgeline of the median (inside) travel lane.

CSSBs are also being used more and more extensively at highway work zone locations to separate traffic from the work activity. Space limitations at highway work zones usually dictate that the barrier be placed immediately next to the travel lanes. The Texas Manual of Uniform Traffic Control Devices (MUTCD) (3) specifies that temporary CSSBs used at work zones under nighttime driving conditions should have standard delineation or channelization devices affixed to them. However, there is no guidance regarding the mounting position of the devices on the CSSB or regarding the spacing between delineation.

While CSSBs (and longitudinal barriers in general) can reduce the severity of run-off-the-road accidents, it is generally accepted that they do not reduce the frequency of these accidents (2). Because CSSBs are used in situations where lateral clearance between them and the travel lane is limited, impacts with concrete barriers may actually occur quite often. Many of the less severe impacts with the CSSB are not reported, when drivers are redirected back into the travel lane with only slight damage to the vehicle and no injury to the driver or passengers. However, more severe impacts also occur, with considerable vehicular damage and occupant injuries (2).

Statement of the Problem

Because CSSBs are generally used in restricted lateral clearance situations, drivers must have adequate visual control and guidance information so that they may maintain a safe travel path and avoid impacts with the barriers. Unfortunately, CSSBs are difficult to see at night and in the rain, due to poor contrast between the barrier and the roadway pavement (4,5). As a result, many states, including Texas, are looking into ways of delineating concrete barriers.

Currently, very little information is available about how to best delineate CSSBs. There exists a wide variety in delineators available for use on CSSBs, but past experiences with delineation and the types and amount of delineation currently being used throughout Texas are not known. In addition, the effects of delineation upon traffic traveling next to the barrier in narrow median and work zone applications have yet to be determined. Finally, there is a lack of information about the effects of weather and road film on the different types of delineation. Depending on traffic and weather conditions, for instance, the reduction in delineator visibility can be quite severe even after a few week's time (6).

The lack of good standard delineation procedures often results in inconsistent and inefficient applications, with an inadequate amount of delineation used in some cases while redundant or excessive delineation is used in others (7).

Research Objectives

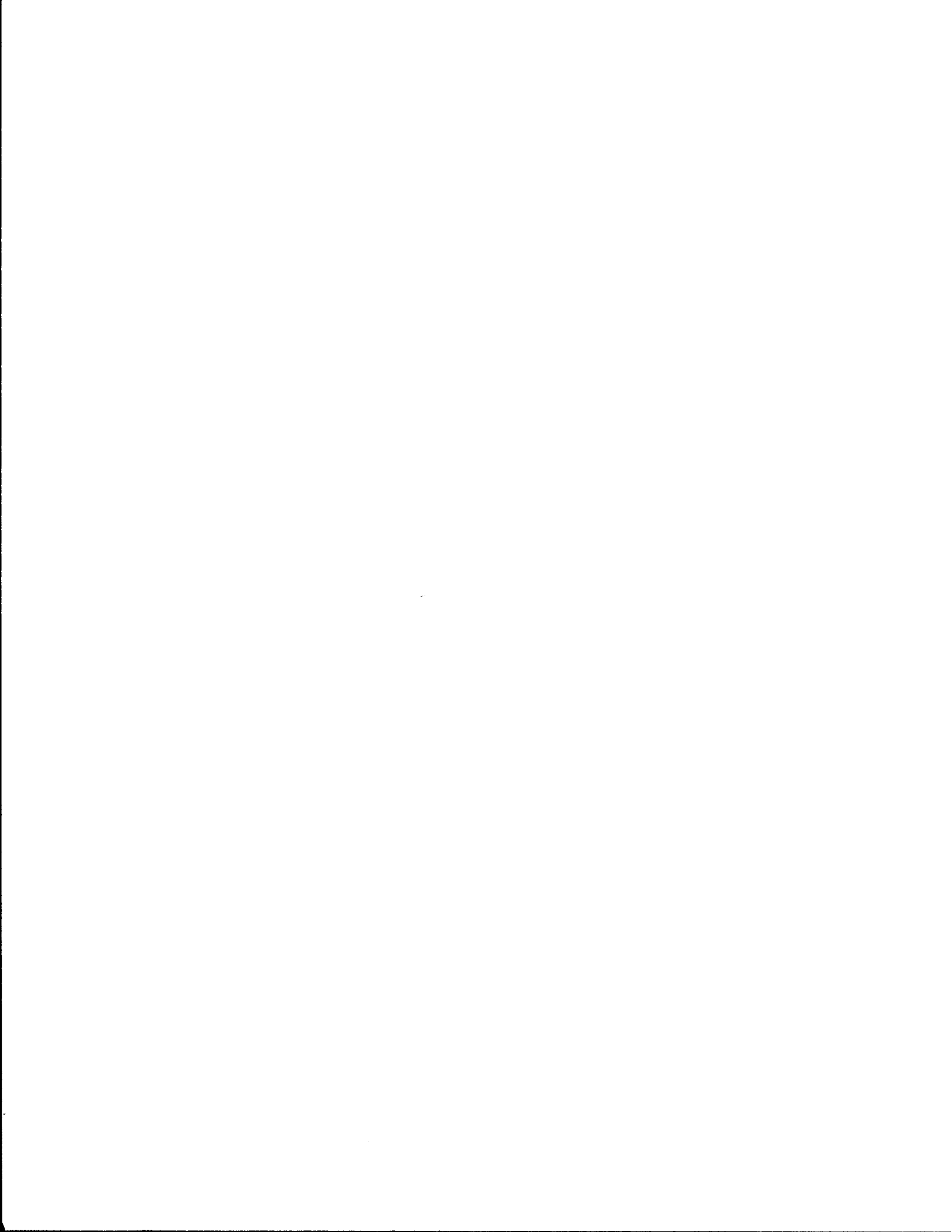
The specific objectives of the research reported herein were to:

1. Determine the current state of the art in concrete barrier delineation.
2. Evaluate the effects and relative performance characteristics of some of the more promising CSSB delineation treatments available at actual highway locations.
3. Examine the problems associated with cleaning CSSB delineation and identify and analyze feasible cleaning mechanisms.

Research Scope

The scope of the research reported herein was limited to a comparative evaluation of several CSSB delineation treatments in restricted lateral clearance situations where the barrier was located less than one foot from the travel lane edgeline. The evaluation is based on analyses of traffic operating next to the barrier, of subjective ratings of the delineation treatments, and of visibility measurements of the treatments over time. Due

to the limited funds and time frame over which the study was conducted, it was not possible to examine the effects of delineation on accident rates or to subsequently determine the cost-effectiveness of installing and maintaining CSSB delineation at a location.



2. STATE-OF-THE-ART IN CSSB DELINEATION

This chapter summarizes the CSSB delineation practices in Texas and the review of published literature available nationwide on previous CSSB delineation research. As will be seen, there exists a wide variety in the types of delineation being used on concrete barriers. Previous delineation research reviewed as part of this study also shows considerable variation in the results obtained and recommendations made. This is due largely to differences in study designs and in the measures of effectiveness (MOEs) upon which the recommendations were based. The review suggests that delineation type, spacing, and mounting position on the barrier must be considered and analyzed together when evaluating candidate barrier delineation treatments.

CSSB Delineation Practices in Texas

As the initial step in this study, a telephone survey of 23 of the 24 SDHPT Districts was conducted to determine current practices regarding CSSB delineation. The survey provided useful information as to the different types of delineation being used across the state as well as the similarities, differences, and problem areas with current delineation procedures. Site visits were made to some of the Districts to examine and further document the different types of delineation currently in use.

Extent of Delineation Use

District personnel were questioned about their delineation practices of CSSBs that are installed permanently in narrow medians of freeways, and those installed in temporary situations to protect workers and separate two-way traffic at highway work zones. Nineteen Districts stated that they have some CSSBs installed permanently. The majority (12) of these Districts do not use any type of delineation directly on the permanently installed CSSB, and feel that painted edgelines are sufficient. Of the remaining seven Districts that delineate permanent CSSBs, personnel from three indicated that all of their permanent CSSB was delineated, while the four other Districts delineated permanently installed CSSB only at locations where it was deemed necessary by District personnel.

With respect to CSSBs in temporary work zone applications, all of the 23 Districts surveyed have used CSSBs on a temporary basis at some work zones. The survey results found that seven Districts always delineated temporary CSSBs, while the remaining Districts used delineation on temporary CSSBs when deemed necessary.

Types of Delineators Used

District personnel surveyed reported a wide variety of different types of items that had or were being used as CSSB delineation. A summary of the survey responses regarding the type of delineator used is shown in Table 2-1. Several manufacturers and distributors sell small retro-reflective devices specifically designed to be mounted on CSSBs. These retro-reflective delineators (mounted either on top or on the side of CSSBs) were found to be the most common types of delineators used. The spacing of the delineators varied dramatically from District to District, from approximately 20-ft to about 200-ft intervals. Additional types of delineation that had been used on CSSBs included object markers (Type 2, Type 3) (8), chevron alignment signs (W1-8) (8), battery-powered flashers, and raised reflective pavement markers and reflective pavement tape applied to the side of the barrier. A total of five Districts reportedly had used several types of delineation on different sections of CSSBs within their Districts.

TABLE 2-1. SUMMARY OF DISTRICT DELINEATION PRACTICES OF CONCRETE SAFETY-SHAPED BARRIERS

Type of Delineation	Number of Districts ^a Using on:	
	Permanent Barriers	Temporary Barriers
Retro-Reflective Delineators		
mounted on top of barriers	4	7
mounted on side of barriers	4	4
Object Markers	1	3
Chevrons (on curves)	2	2
Battery-Powered Flashers	0	3
Reflective Pavement Tape	0	2
	Total	
	11	21

a Some Districts use more than one type of delineator on concrete barriers

Pictorial examples of some of the various types of CSSB delineators used by the Districts in permanent and temporary installations are shown in Figures 2-1 through 2-4. Although retro-reflective delineators come in many shapes and sizes, they all have one of two basic types of materials: 1) acrylic cube-corner lenses, or 2) high-intensity (HI) reflective sheeting attached to a plate, bracket, or cylinder.

Acrylic cube-corner lenses reflect more light (and thus appear brighter) than HI reflective sheeting when viewed from a straight-on position (12). However, the acrylic material is very brittle, subject to breakage from flying rocks or other objects. In addition, cube-corner lenses that are not aimed directly back at the observer have a reduced reflectivity (12). HI reflective sheeting, while generally less bright than cube-corner lenses, is not as brittle. Because it is a flexible material, it can be cut, bent, and attached to a variety of mounting objects.

Delineation Problems Encountered

The most common problem reported by the Districts was with dirt and road film quickly covering the delineators and reducing their reflectivity. The Districts must currently clean delineators by hand, and they generally do not have the manpower to clean delineators. Also, any cleaning that is done requires the worker to be next to high-speed traffic, increasing the possibility of an injury.

Also, there has been little District-to-District communication about delineation techniques/devices that had been tried and the subsequent results. Some Districts were aware of the delineation efforts of another District, but widespread knowledge of the general activities throughout the state was absent.

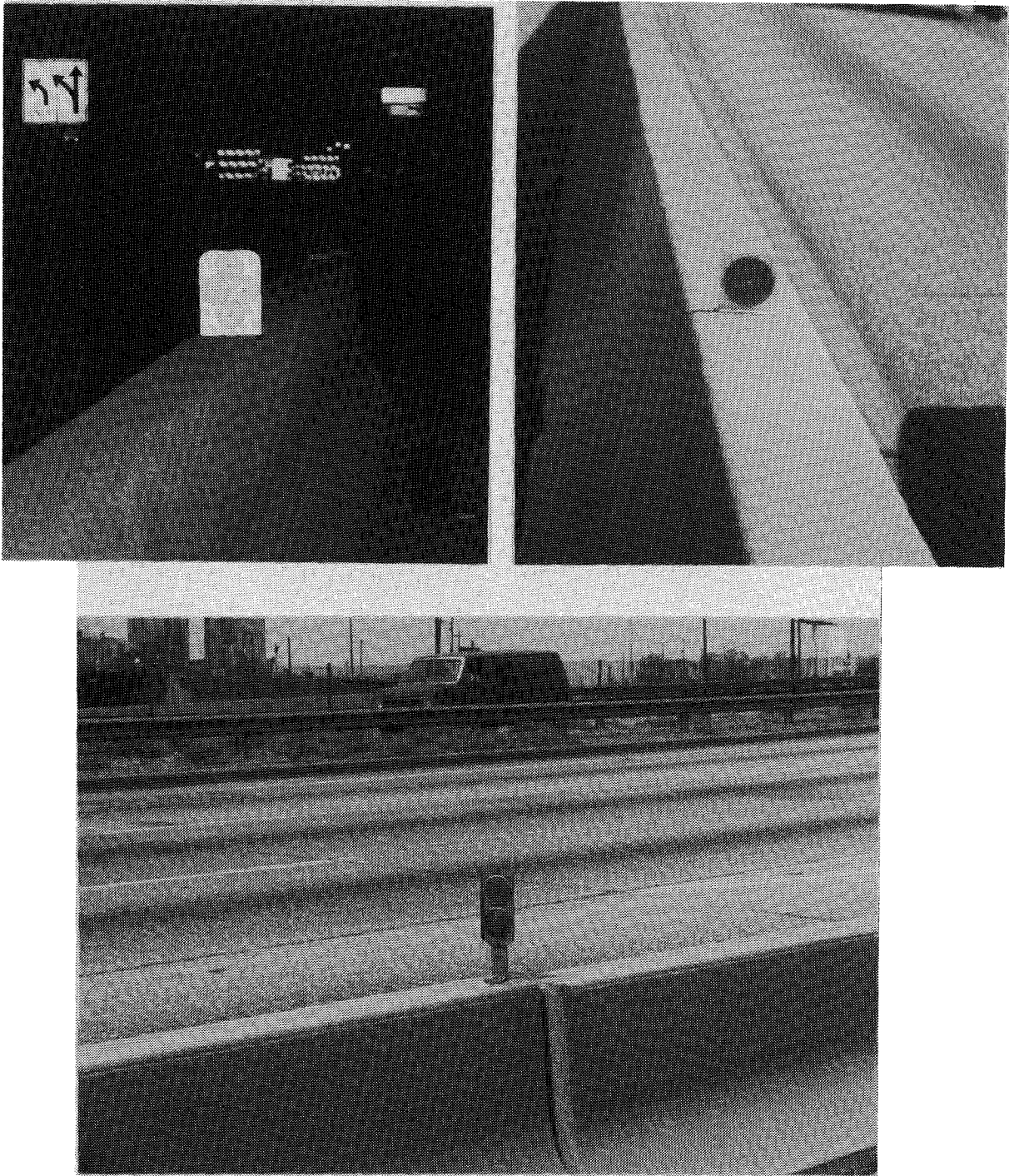


Figure 2-1. Examples of Cube-Corner Lenses.

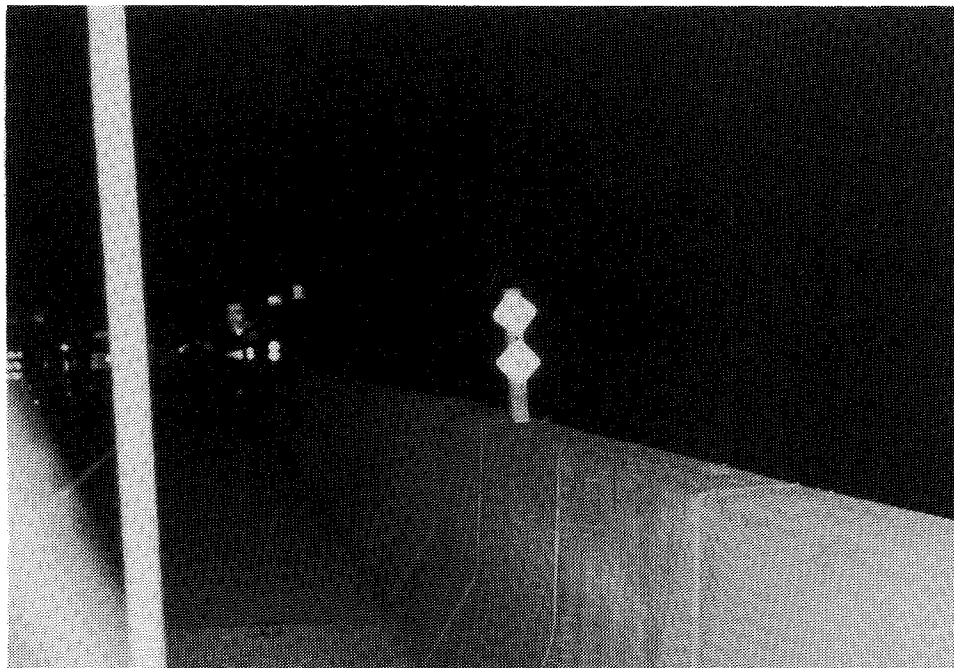


Figure 2-2. High-Intensity Reflective Sheeting on 3-inch Square Plates.

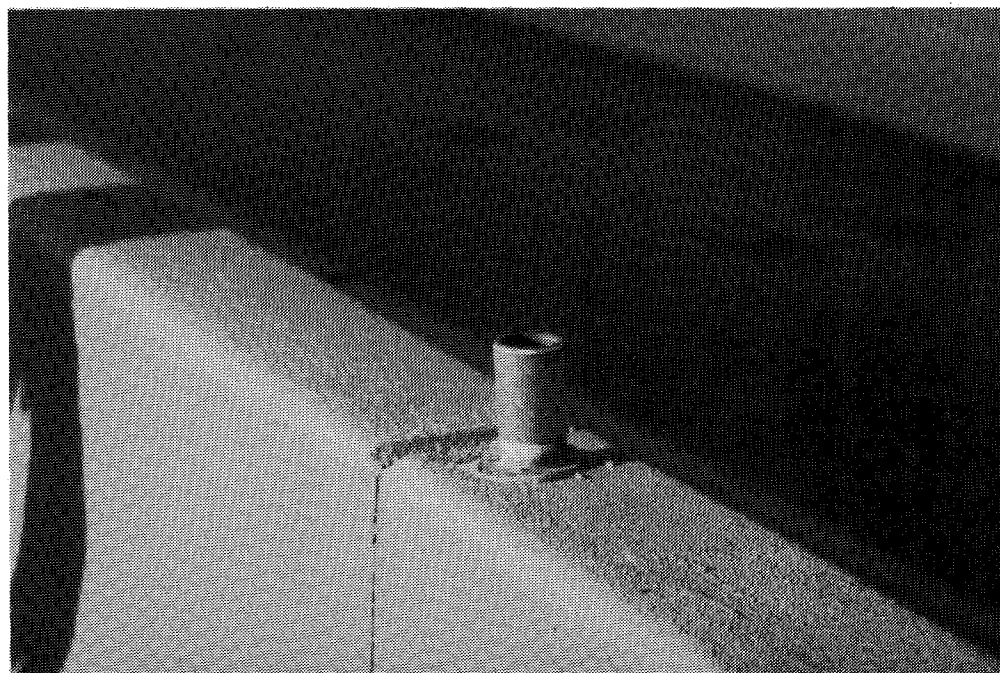


Figure 2-3. High-Intensity Sheeting Wrapped around 1.5-inch by 3-inch Cylinders.

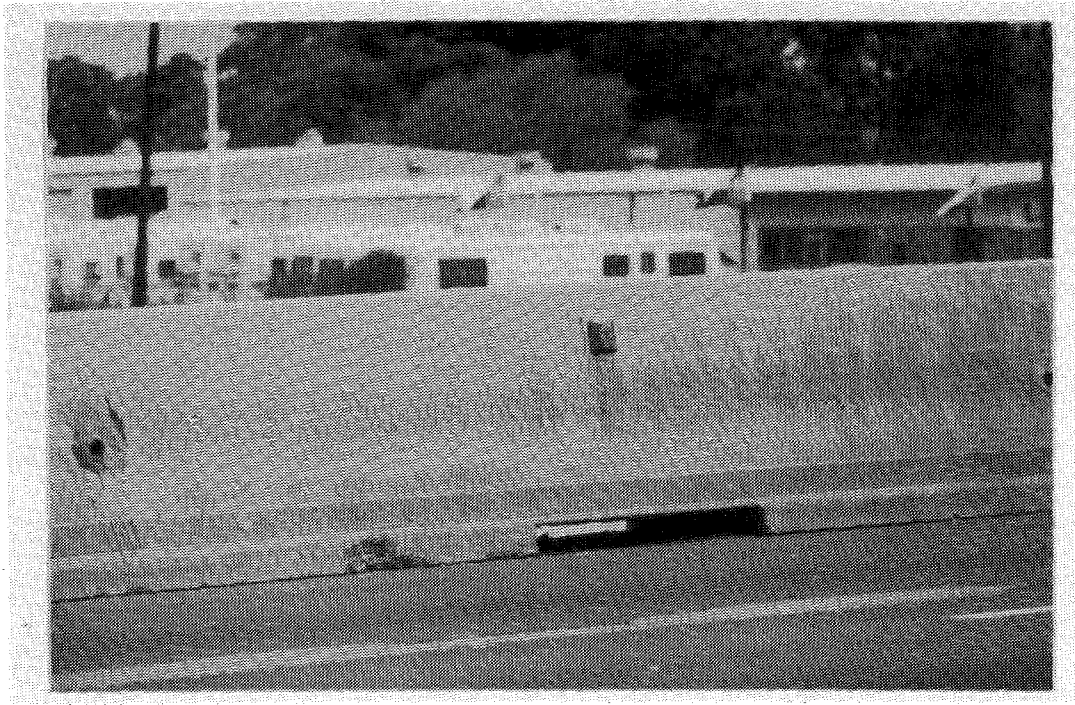


Figure 2-4. Reflective Pavement Markers and Reflective Pavement Tape applied to the Side of the CSSB.

Summary

Based on the results of this survey, there is considerable variety in delineation procedures statewide. However, a few similarities do exist in terms of the type of delineation used, as most Districts use some type of manufactured retro-reflective CSSB delineators where the decision is made to delineate CSSBs, although items such as object markers and battery-powered flashers have been used on occasion.

Although a few similarities do exist, there are by far more differences among delineation practices across the state. In particular, delineator spacing varies dramatically, as does the choice of whether to place the delineator on the top or the side of the barrier.

Several problem areas in CSSB delineation were identified. The problem of dirt accumulation on delineators, and the related need to periodically clean them, was cited as a major problem by the Districts. There is also a lack of guidelines or widely accepted practices as to the amount and type of delineation that should be used.

Previous Delineation Research

The methods and results of previous and on-going CSSB delineation research conducted throughout the country are presented in the following sections. These reviews were useful in identifying the important factors to consider when evaluating CSSB delineation and some appropriate MOEs for delineation evaluation. The reviews are presented in two sections. The first is devoted to CSSB delineation usage at narrow freeway median applications while the other discusses CSSB delineation studies at highway work zones. The results from all of the previous studies have been synthesized and are presented in tabular format in Table 2-2.

CSSB Delineation at Freeway Median Installations

In 1978 and 1979, Mallowney performed studies to establish a satisfactory delineation system for concrete barriers in narrow freeway medians in New Jersey (4,9). Specific types of delineators examined were acrylic cube-corner lenses, silvered glass lenses, and HI reflective sheeting on angle brackets. These studies included photometric tests of the reflectivity of the barrier delineators, and laboratory and field studies of the more promising delineators at three positions on a barrier: bottom-side, top-side, and top-mounted positions.

Performance criteria used in the field tests included the ranking of the reflectivity of the delineators by a group of experts and photometric reflectivity measurements of the delineators after they had weathered through one or two years. Based on the study results, Mallowney recommended the acrylic cube-corner lenses as the best delineators to use on CSSBs in the median of the freeway. He concluded that mounting delineators on top of the CSSBs was superior to mounting them on the side because a higher mounting height reduced weathering (dirt and grime accumulation, abrasion, etc.).

Based partly on Mallowney's work, Powers is currently completing a study to determine the best spacing of acrylic cube-corner lenses on CSSBs in freeway medians in New Jersey (10,11). Subjects are inspecting photographs of different delineator spacings under various geometric conditions, with and without roadway illumination, and asked whether the delineation is adequate. Based on an analysis of photographs, subject indicated a preference for spacings less than 160 ft. They also indicated a preference for reduced spacings on curves. It appears that some spacing criteria related to curve radius or degree of curvature will result from these studies.

CSSB Delineation at Temporary Installations

In addition to extensive use in narrow freeway median applications, CSSBs are often used at highway work zones to separate traffic and protect the workers. Often, geometric and visibility constraints are quite severe at

TABLE 2-2. SUMMARY OF PREVIOUS CSSB DELINEATION RESEARCH

Researcher	Delineation Treatments Studied	Study Site Conditions	Methods of Study	Recommendations
Mulloyney	Acrylic Cube-Corner and Glass Lenses, Brackets covered with HI Sheeting; Top and Side-Mounted (6 and 14-in from Top); 80-Ft Spacings on Tangents, 40-Ft on Curves	CSSB in a Narrow Freeway Median	Laboratory Photometric Measurements, Subject Evaluations (lab), Expert Evaluations (Field), Cost Considerations	Cube-Corner Delineators, Top-Mounted
Powers	Cube-Corner Delineators, Top-Mounted at Spacings from 160-Ft (Tangent) to 40-Ft (Curve)	CSSB in a Narrow Freeway Median	Subject Evaluations of Photographs taken at Study Site	160-Ft Spacing (Max) on Tangents, Closer Spacing on Curves
Brackett et. al.	Several Cube-Corner Delineators, Top and Side-Mounted (6-in from top) at 50 and 100-Ft Spacings; 6-in x 12-in Reflective Cylinders, Top-Mounted at 100-Ft Spacing; 8-in x 24-in Vertical Panel, Top-Mounted at 100 and 150-Ft Spacing	Temporary CSSBs in Work Zones	Subject Evaluations of Photographs, Limited Proving Ground Studies, Cost Considerations	Vertical Panels, Reflective Cylinders, (Top-Mounted); Spacings less than 200-Ft
11 Khan	Cube-Corner and HI sheeting Delineators, Side-Mounted (6, 12, 18, and 24-in from top) at 100 and 25-Ft Spacings; 6-in x 12-in Reflective Cylinders, Top-Mounted at 180, 120, 90, 60, 45, and 25-Ft Spacings; 6-in x 27-in Vertical Panels, Top-Mounted at 60 and 100-Ft Spacings; Spinning Delineator, Top-Mounted at 50 and 25-Ft Spacings	Temporary CSSBs in Rural and Suburban Work Zones	Laboratory Photometric Measurements, Researcher Evaluation of Brightness in the Field, Durability, Installation Methods, Cost Considerations	Vertical Panels, Reflective Cylinders, (Top-Mounted) at 25-Ft Spacings; May use Small Delineators to Supplement Panels and Cylinders
Ugwoaba	Cube-Corner Delineators, Top and Side-Mounted at 40-Ft Spacings; Raised Reflective Pavement Markers, Side-Mounted at 40-Ft Spacings; Brackets with HI sheeting, Top Mounted at 40-Ft Spacings; Reflective Cylinders, Top-Mounted at 100-Ft Spacings; 8-in x 24-in Vertical Panels, Top-Mounted at 100-Ft Spacings	Temporary CSSBs in a Suburban Work Zone	Photometric Measurements in the Field, Subject Evaluations of Brightness, Cost Considerations	Cube-Corner Delineators, Side-Mounted (6-in from top)

HI = High-Intensity

these installations, making it even more vital that drivers are made aware of the presence of the barrier and of the correct travel path through the work zone.

Brackett et. al. completed a study of several types of concrete barrier delineation for work zones (7). Based primarily on subject evaluations of photographs of a number of delineation treatments (see Table 2-2), it was recommended that 8-in x 24-in striped vertical panels or 6-in x 12-in reflective cylinders spaced no greater than 200 feet apart be used on CSSBs in work zones. Both of these systems provided a low cost (\$5-\$12 per 100 ft of barrier) relative to the other treatments tested and high acceptability (at least 85% of the subjects viewing the photographs judged them to be acceptable delineation treatments). It was noted that the cylinders provide 360 degrees of reflectivity, making them visible to drivers at all viewing angles.

Field studies of barrier delineation treatments at actual work zone locations have been completed in two states. In Ohio, Khan (5) examined a number of different types of delineators mounted both on top of and on the side of CSSBs in work zones spacings from 25 to 180-ft. The types of delineators evaluated were 6-in x 18-in vertical panels, 6-in x 12-in reflective cylinders, a large delineator which spins in the wind (creating a "flashing" appearance), and several smaller acrylic cube-corner lenses and HI reflective sheeting delineators. Khan used delineator durability, visibility (subjectively determined by the researchers), and laboratory-measured reflectivity as MOEs. He concluded that the smaller cube-corner lenses and HI sheeting delineators were not adequate as stand-alone delineation of CSSBs in work zones. The larger delineation devices (panels, cylinders) were suitable but only when installed at very short (i.e., 25 ft or less) spacings.

Ugwoaba (6) conducted a similar-type study in a work zone in the state of Washington, looking at cube-corner lenses and HI sheeting delineators, reflective cylinders, and vertical panels as was done in Ohio. In addition, raised pavement markers, mounted to the side of the barrier, were also examined. The cylinder and panels were attached to the top of the CSSB at 100-ft spacings, while the cube-corner and HI sheeting delineators were tested both on the top and the side of the CSSB at 40-ft spacings. The primary MOEs included delineation cost, brightness, and visibility. Visibility was determined by a group of 100 subject drivers from towns near the study site. The acrylic cube-corner lenses, mounted on the side of the barrier, were judged the best system by the subject drivers for identifying a correct travel path next to the CSSB.

Ugwoaba also made photometric readings after the delineators had been in place in the field for about 1 month. The photometric readings were taken both in a "dirty" condition as the delineators existed in the field and after they had been cleaned by wiping them off with a towel. The average reflectivity values of the delineators are shown in Table 2-3. After only 1 month, approximately 70 to 85 percent of the reflectivity of the devices were blocked by dirt. Ugwoaba noted that this data points to the strong need to clean the delineators regularly in order to keep them functional.

**TABLE 2-3. AVERAGE FIELD-MEASURED REFLECTIVITY
AFTER 1 MONTH EXPOSURE (WASHINGTON)**

(Candelas/foot-candle/ft²)

Delineator Type	Cleaned Condition	Dirty Condition	% Loss of Reflectivity
Acrylic Cube-Corner Lenses	1482	257	83%
Brackets with HI Reflective Sheeting	378	75	80%
Vertical Panels/ Reflective Cylinders (with HI Sheeting)	50	15	70%

Adapted from Reference (6)

Both North Carolina and Virginia have also conducted work zone CSSB delineation studies (12,13). These studies have focused strictly on the manufacturing and/or the hardware necessary for the installation of reflective cylinders, vertical panels, and other delineation devices. No performance or evaluation data has been collected.

Summary

Previous research studies have evaluated a wide variety of delineators (several small cube-corner lenses and HI sheeting delineators, vertical panels, and reflective cylinders), mounted on the top and on the side of the CSSB at spacings from 25 to 200-ft. The studies have used mainly subjective evaluations by observers and objective photometric measurements of reflectivity to determine which delineation treatments were preferable and/or more visible to drivers. The results have been mixed. For example, Mallowney, Khan, and Brackett all suggest that top-mounted delineation works best. Conversely, Ugwoaba recommends side-mounted delineation; the effect of delineation in the side position is not washed out by oncoming headlight glare as sometimes happens with top-mounted delineation.

With respect to delineation type, there is also some disagreement. Larger but less bright (in terms of specific intensity) delineators are recommended by Brackett and Kahn, while Ugwoaba and Mallowney recommend the use of the smaller, brighter cube-corner delineators. Even the spacings of

the delineators is not without debate. Although shorter spacings were generally preferred, actual distances recommended in the studies varied from 25 to 200 ft.

Differences in the design and conduction of the studies makes it difficult to compare their results. However, past research does provide a starting point for selecting appropriate delineator types, spacings, and mounting positions on CSSBs for field evaluations as part of this study. It is obvious that research is especially needed on the effects of delineation upon drivers traveling next to the barrier and upon long-term delineation performance. The types of data that need to be collected include objective driver performance data to determine whether different delineation treatments affect traffic operations next to the barrier. Data is also needed on the long-term differences in the effects of dirt accumulation on the various types of delineators available. Finally, driver likes and dislikes regarding CSSB delineation should be investigated further.

3. BARRIER DELINEATION STUDY, IH-35 (AUSTIN)

Background

As an initial attempt in Study 408 to document what effect CSSB delineation has upon traffic, TTI conducted a study of CSSB delineation installed in the narrow median on a lighted section of urban freeway (IH-35) in Austin, TX. The delineation treatment consisted of a top-mounted 1.5-in x 3-in cylinder covered with reflective sheeting and a side-mounted 2.5-in x 5-in rectangular cube-corner delineator, both spaced at 120-ft intervals, as shown in Figure 3-1. At the time of this study, the delineators had been in place on the barrier for over a year. Dirt and grime had accumulated on the delineators to the point that they were completely covered and no longer visible at night. Traffic performance data were collected with the delineators in the dirt-covered condition, after which the SDHPT cleaned the delineators and replaced any that were broken or missing. Data were collected again, and compared to that obtained before the delineators were cleaned.

IH-35 is a north-south freeway running directly through the middle of Austin. At the location selected for study, the freeway is three lanes (12-ft) wide per direction. CSSB installed in the median of the freeway separates the opposing traffic flows, while a narrow median shoulder (2 to 5 ft) separates the inside travel lanes from the barrier. The freeway section is illuminated at night and heavily traveled throughout the day, with the 1985 Annual Average Daily Traffic (AADT) equal to 149,000 vehicles. Almost 20 percent of the nighttime traffic consists of large semi-trailer trucks.

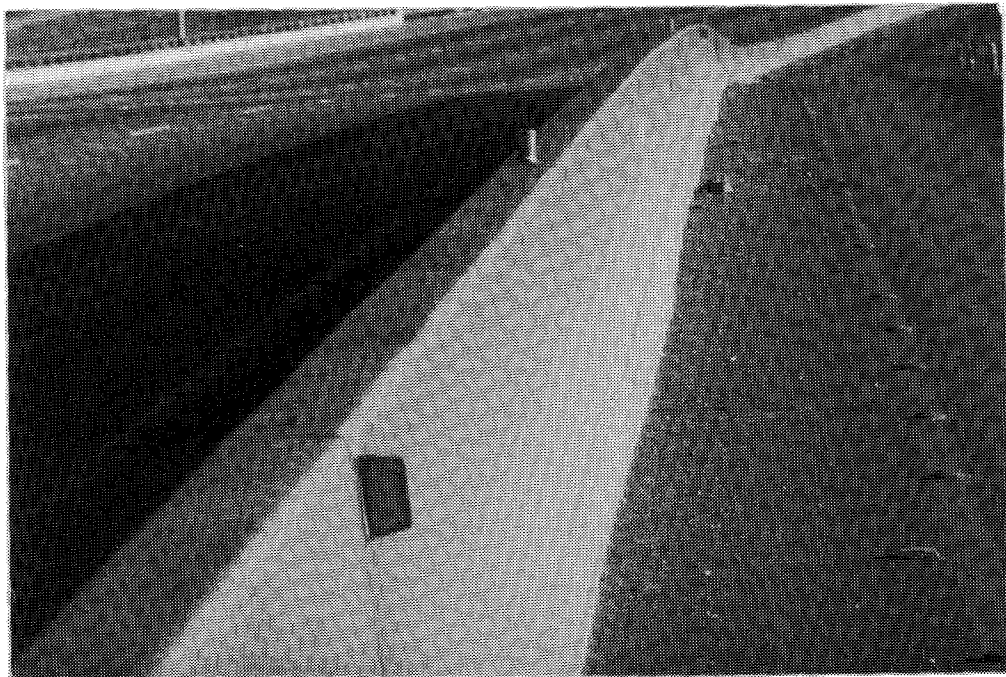


Figure 3-1. CSSB Delineation in place at IH-35 Study Site (after the delineators had been cleaned).

Method of Study

A nighttime video data collection system was used to collect driver performance data at tangent and right-handed curve segments in the northbound direction. A low light level camera housed in an environmental enclosure was mounted on a sign bridge immediately above the median barrier and positioned to provide a top-down view of traffic traveling northbound. A time-lapse video recorder and monitor were placed in a signal control cabinet off to the side of the freeway and connected to the camera. The data collection equipment used in the study is shown in Figure 3-2. A schematic of the site layout is shown in Figure 3-3.

Data were collected with the delineators in the dirt-covered condition beginning at the tangent segment of the study site. Data were collected on Tuesday through Thursday nights. The following week, the camera was turned to collect data at the right-hand curve segment. Again, data were collected Tuesday through Thursday nights. The following Sunday morning, SDHPT maintenance personnel closed the inside northbound travel lane and manually cleaned the delineators with wet sponges and paper towels. Data were then collected for one week at the curve and one week at the tangent segments, both over the Tuesday-Thursday time period each week.

The data collected with the delineators in a dirty condition were compared to that collected after they had been cleaned. Three traffic operations MOEs were used in the comparison. These measures were:

1. Lane Distribution -- The percent of traffic in the inside (median) and middle travel lanes (combined) that traveled in the inside lane. The outside shoulder lane traffic was not considered in this analysis because it was felt that vehicles in this lane would not be affected by the presence or absence of delineation on the CSSB.
2. Shoulder Encroachments -- The number of vehicles encroaching between the inside travel lane and the barrier (i.e., in the shoulder) were recorded.
3. Lateral Placement -- The lateral distance from the barrier that automobiles and trucks traveled. Estimates were made using short tape marks placed on the shoulder and inside lane in the view of the camera as shown in Figure 3-2. Estimates were made to the nearest foot. Because of the rather large traffic volumes on the facility, a sampling procedure was used, recording the lateral distance of 5 automobiles and 5 trucks in each 15 minute time period.

Data were reduced for a nine hour period each night (9 p.m. to 6 a.m.). Subsequent examination of the data showed that traffic volumes reduced substantially after midnight and increased after 5 a.m. Therefore, the data were divided into two time periods. The first period began at 9 p.m. and

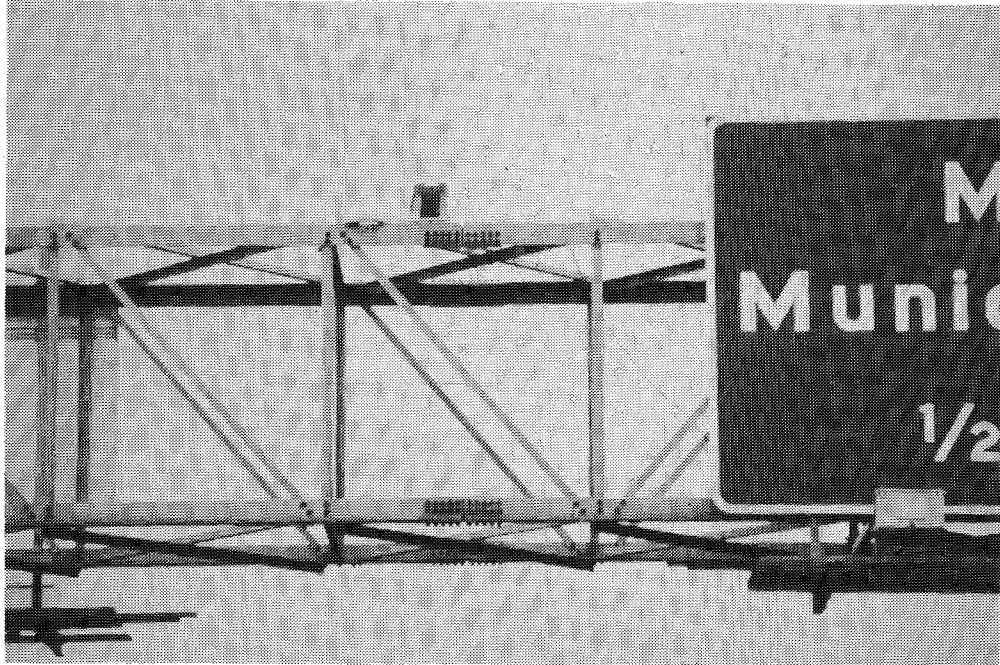


Figure 3-2. Video Equipment Used to Collect Nighttime Data.

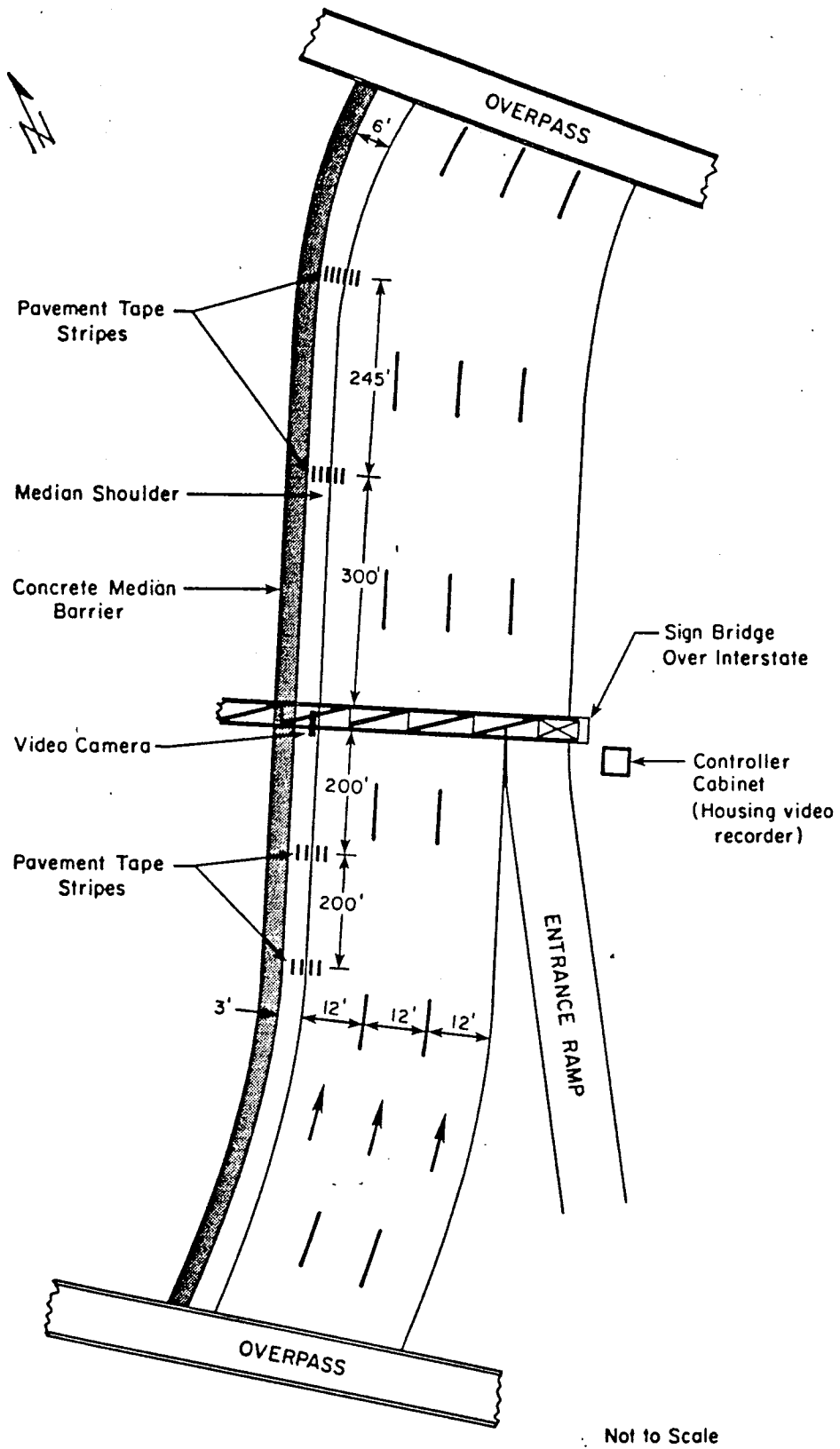


Figure 3-3. Schematic Layout of IH-35 Study Site.

ended at midnight, during which time the volume was fairly high (approximately 400 and 600 vph for the inside and adjacent travel lanes, respectively). The second period began at midnight and continued to 5 a.m. Volumes were much lower during these early morning hours, averaging 70 and 250 vph in the inside and adjacent lanes.

The nighttime hours were divided into two time periods because of the different driving conditions that existed during these times. When higher volumes are present, drivers have the additional visual cues of vehicle taillights traveling in the same direction to guide upon. However, drivers must also cope with more headlight glare from oncoming vehicles. When traffic volumes are low, drivers have fewer taillights to guide upon or headlights to cope with. In addition, driver lane choice and lateral position may be influenced by other traffic more so under high volume than low volume conditions.

Results

One of the major difficulties of this study was with determining what the possible changes in the MOEs might mean. Obviously, shoulder encroachments were an undesirable event, and a reduction of them would signal an improvement to the driving environment. However, for changes in the proportion of traffic using the inside lane and the lateral distance of vehicles from the barrier, the implication was not as clear. Better barrier visibility may make drivers more comfortable and confident driving next to the barrier, suggesting that the proportion of vehicles in the inside lane might increase and that the lateral distance from the barrier might decrease. However, it is also possible that increased barrier visibility might cause drivers to be more apprehensive of the barrier, which would show up as a decrease in the proportion of traffic in the median and an increase in the lateral distance of vehicles from the barrier. Since it is not known which response is more desirable from a safety standpoint, it was decided to report the effects of the clean delineators on the lane distribution and lateral distance measures without categorizing these effects in terms of improvements or problems.

Lane Distributions

Table 3-1 summarizes the comparison of the proportion of traffic (the middle and inside lanes combined) that used the travel lane next to the barrier before and after the delineation was cleaned. The results are categorized for both the tangent and curve stations during the high and low nighttime volume periods. Statistical significance was measured by a Chi-Square Test of Independence between lane volumes recorded before and after delineator cleaning.

TABLE 3-1. LANE DISTRIBUTION SUMMARY
IH-35, AUSTIN

PERCENT OF INSIDE AND MIDDLE LANE TRAFFIC IN LANE NEXT TO BARRIER LANE

	TANGENT SECTION			CURVE SECTION		
	Before	After	Change	Before	After	Change
High Volume Nighttime Hours (9 p.m. to Midnight)						
Autos	40.2 [7998]	36.4 [9929]	-3.8*	38.8 [9547]	38.0 [9817]	+0.2
Trucks	36.2 [759]	41.4 [606]	+5.2	39.2 [564]	41.3 [559]	+2.1
Low Nighttime Volume Hours (Midnight to 5 a.m.)						
Autos	22.4 [3766]	23.3 [3942]	+0.9	24.4 [4075]	23.4 [4066]	-1.0
Trucks	16.9 [833]	19.4 [867]	+2.5	18.6 [972]	18.0 [889]	-0.6

[] Numbers in brackets are sample sizes in number of vehicles

* Different at 0.05 Level of Significance

For the most part, few significant changes were detected between the dirty and clean delineator conditions. A smaller proportion of automobile drivers was found to travel in the inside lane at the tangent section during the higher volume hours after the delineators were cleaned. Truck drivers did not behave similarly, however. In fact, the proportion in the inside lane actually increased, although not enough to be statistically significant. Overall, though, no basic trends were evident from the data, suggesting that the clean delineators had little effect on this MOE.

Shoulder Encroachments

Encroachments into the shoulder next to the CSSB proved to be a very rare event. Only 2 automobiles and 2 trucks encroached into the shoulder during 108 hours of videotaped data. Three of these occurred at the curve section, and all occurred when the delineators were dirty. Due to the low sample size, no statistical tests could be performed on this data. It is interesting to note, though, that no encroachments occurred in either the tangent or the curve segments after the delineators had been cleaned.

Lateral Distances

Because the estimates of lateral distance were made at discrete (i.e., 1-ft) intervals rather than on a continuous scale, changes in this MOE between the dirty and clean delineation conditions could not be measured simply by comparing the average or standard deviation of the measurements. Instead, the frequency and cumulative distributions at 1-ft increments were determined and plotted. A non-parametric (Kilmogorov-Smirnoff) test was then used to compare the data. This test compares the maximum difference in the cumulative frequency distribution to a critical value to determine whether the after data distribution differs from that of the before data. If they are different, however, the test does not distinguish the reason. The difference could be due to 1) a shift in the entire distribution closer or farther from the barrier, or 2) a change in the variation or dispersion of the data.

Statistically significant differences between the before and after lateral distance distributions were found at both the tangent and curved segments. Plots of the lateral distance distributions with the delineators in the dirty and the clean conditions are shown in Figures 3-4 and 3-5 for the tangent and curve segments. The data collected in the tangent segment (Figure 3-4) suggest that both automobile and truck drivers drove slightly farther away from the barrier once the delineators had been cleaned. The opposite effect was found at the curve segment. As Figure 3-4 indicates, both automobiles and trucks appeared to be farther away from the barrier than when the delineators were dirty. The same trends are evident in both the higher volume (9 p.m. to midnight) and lower volume (midnight to 5 a.m.) periods.

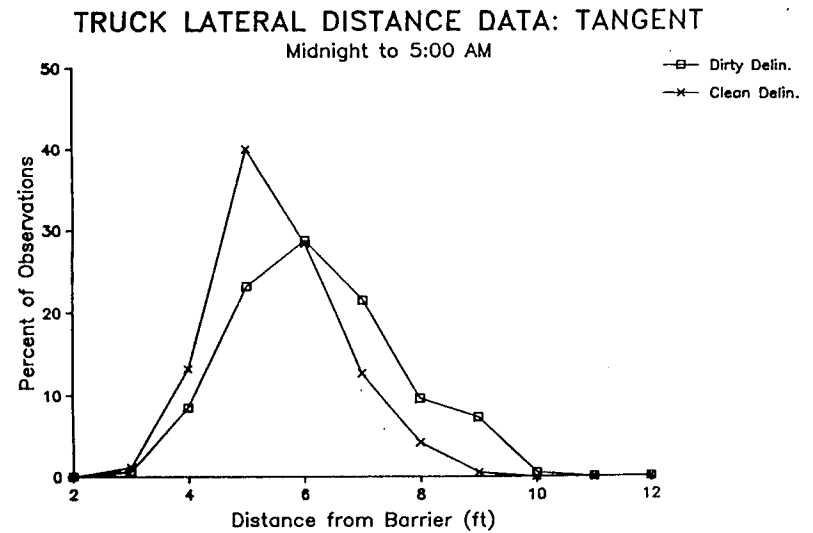
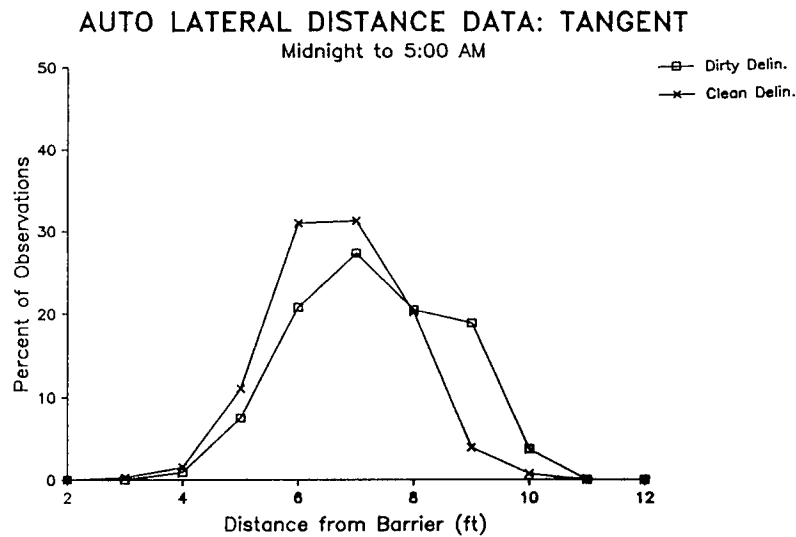
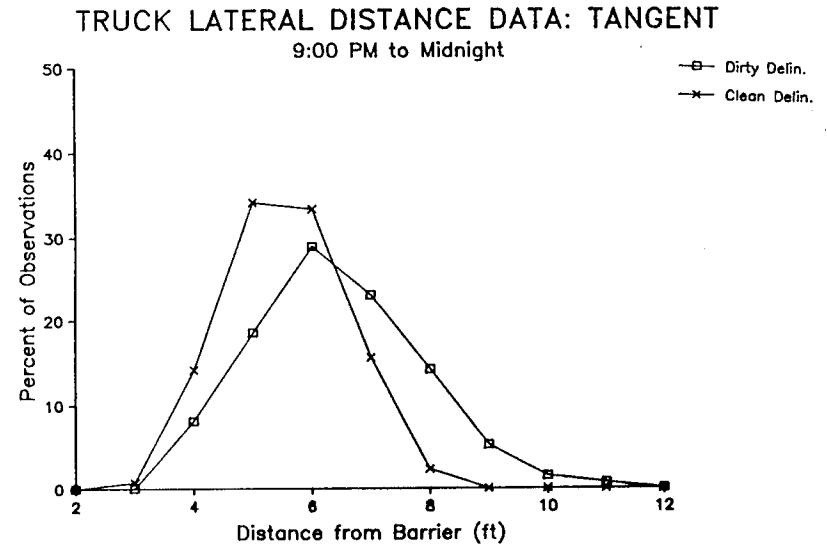
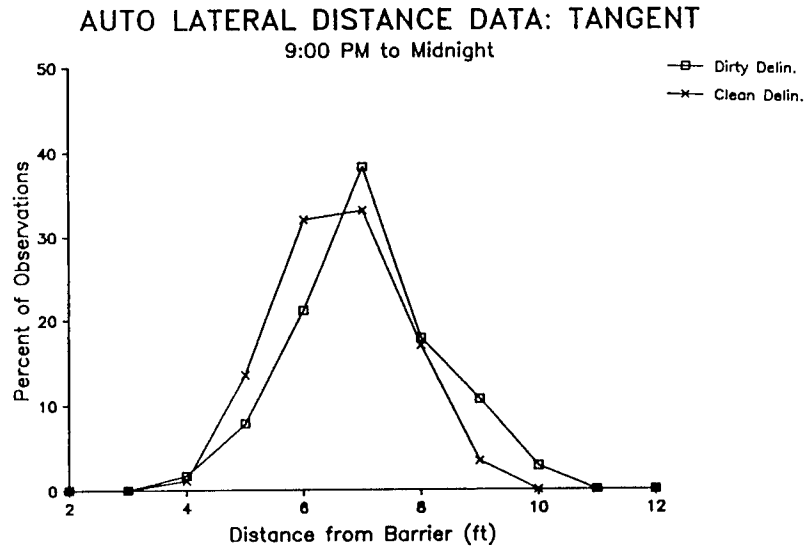


Figure 3-4. Comparison of Lateral Distance Distributions for Dirty Vs. Clean Delineators: Tangent Section, IH-35 (Austin)

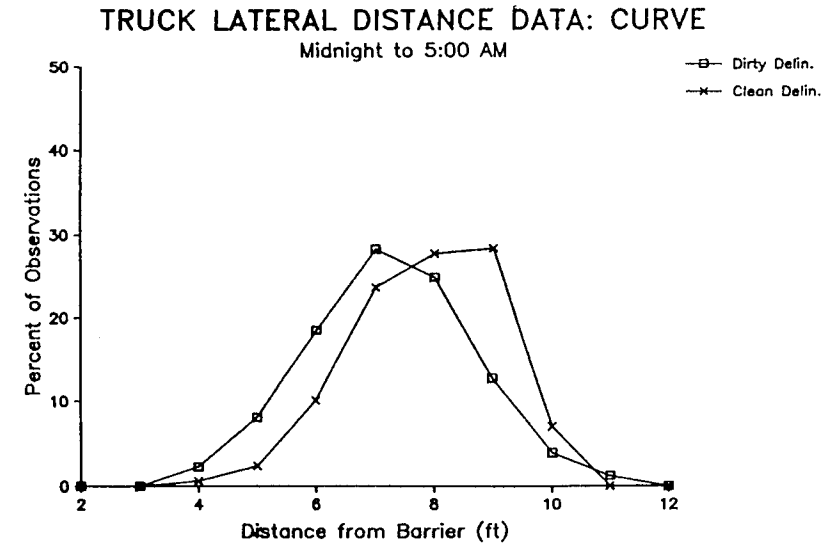
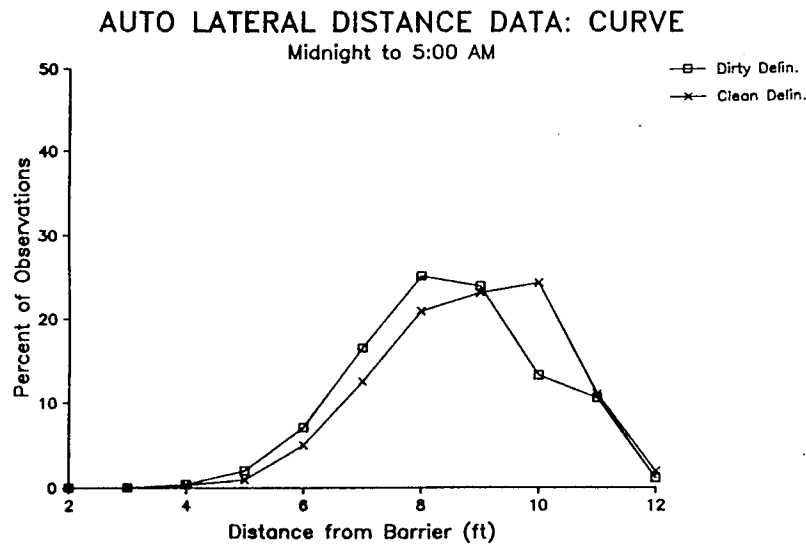
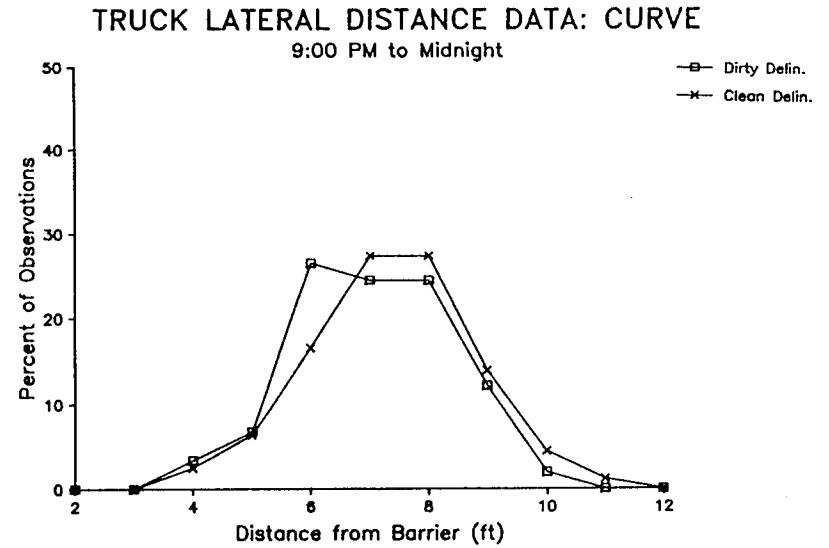
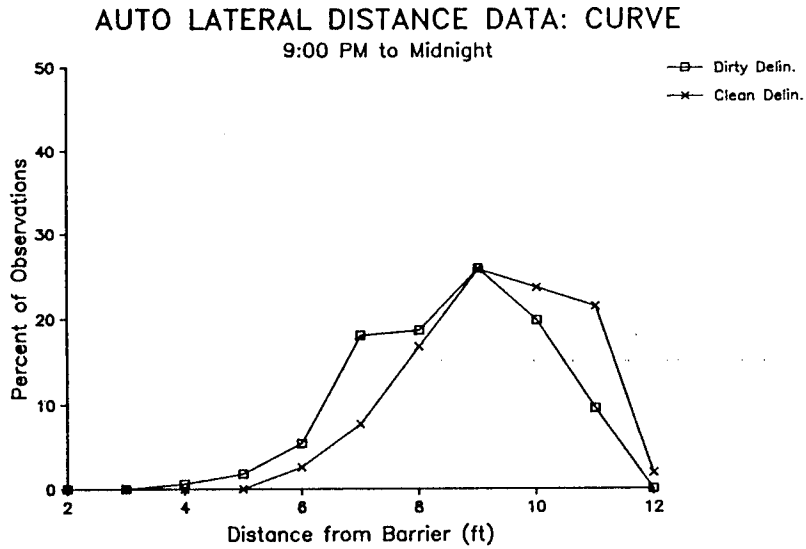


Figure 3-5. Comparison of Lateral Distance Distributions for Dirty Vs. Clean Delineators: Curve Section, IH-35 (Austin)

Summary

Of the three traffic MOEs examined, the only statistically significant changes between the clean and dirty delineator conditions occurred in lateral distance. Drivers appeared to have shifted closer to the barrier in the tangent segment after the delineators were cleaned, but shifted farther away from the barrier in the curve segment. The data suggest that delineation, when visible, may affect traffic in the lane next to the barrier. The data also suggest that these effects differ depending on whether the CSSBs are located on a tangent or a curve. However, as Figures 3-4 and 3-5 illustrate, the magnitude of this effect may be fairly small.

Due to the short period of time in which this particular study was conducted, additional data such as reported accidents with the barrier and tire/vehicle scrapes on the barrier could not be collected. Consequently, it was not possible to determine at this site the effects of delineation cleaning on traffic safety.

4. BARRIER DELINEATION STUDY, IH-45 (HOUSTON)

The study at the IH-35 (Austin) site provided an initial assessment of some effects delineation may have upon drivers traveling in the inside lane next to a CSSB. Since the barrier at the Austin site had already been delineated prior to the study, it was not possible to examine the effects of different delineator types, spacings, and mounting positions. Consequently, the next step in this research was to conduct a more extensive study of several CSSB delineation treatments in order to compare them and determine the relative effects of these different factors.

Original study plans called for studies to be performed on CSSBs at 1) a narrow freeway median location, and 2) a highway work zone. Unfortunately, it was not possible to locate a work zone location with characteristics suitable for this study. Consequently, the study was conducted only at a narrow freeway median location. However, because the CSSB was located very close to the inside lane as it is for many typical work zone situations, it is believed that some of the study results obtained in this study are applicable to work zone applications.

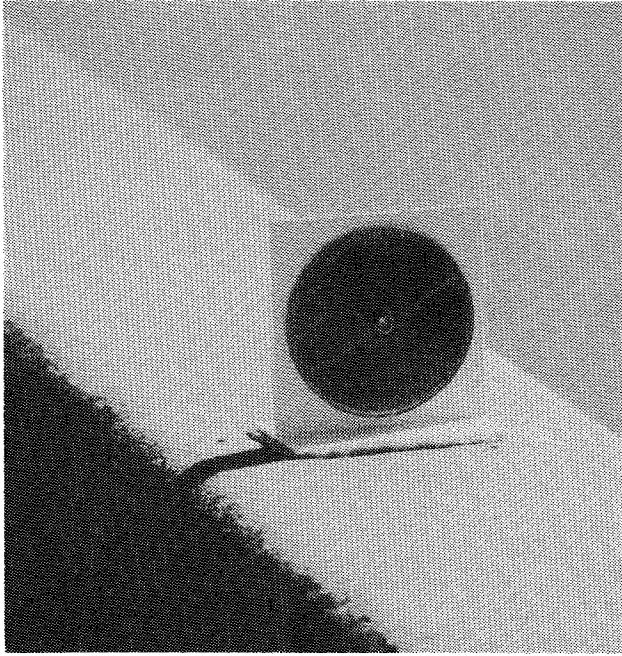
This second detailed study of CSSB delineation was conducted on a section of IH-45 (Gulf Freeway) in Houston, TX. At this particular site, five different delineation treatments were examined. These are identified and discussed in the following "Study Design" section. Three types of data were collected on the delineation treatments: 1) driver performance, 2) subjective evaluations, and 3) visibility. The objectives for collecting each type of data, the methods by which each was collected, and the results are described following the "Study Design" section.

Study Design

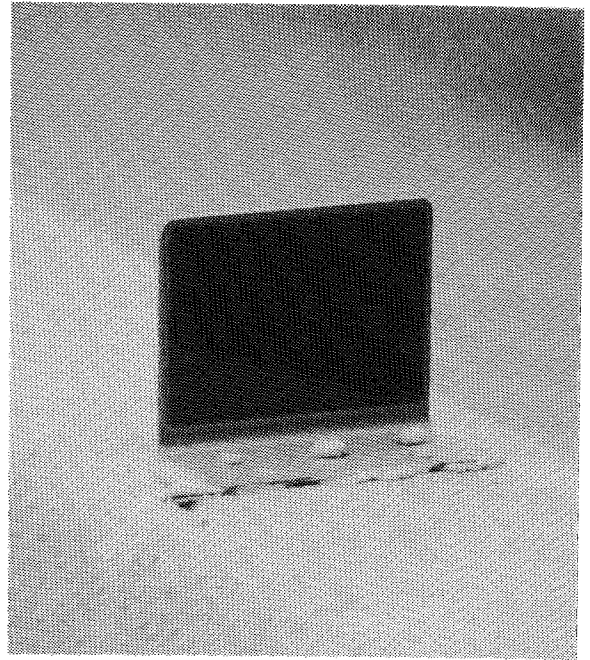
The following sections present information regarding the delineation treatments evaluated at the study site and the general description of the study site.

Delineation Treatments

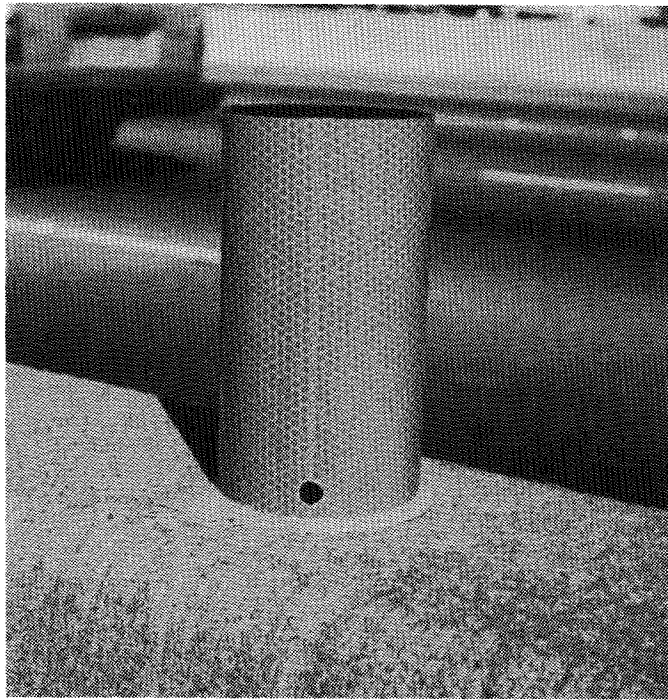
For this study, three specific types of delineators representing a range of shapes, sizes, and reflective material were examined. The first was a round (3.25-in diameter) acrylic cube-corner lens. The second delineator consisted of microprism (HI) reflective sheeting applied to a small plastic bracket (approximately 3 in high and 4.25 in wide). The third delineator evaluated was a cylindrical tube (3 in diameter by 6 in high) wrapped with HI reflective sheeting. Examples of each of these delineators are shown in Figure 4-1.



(a) Acrylic Cube-Corner Reflector



(b) Reflective Bracket



(c) Reflective Cylinder

Figure 4-1. Types of Delineators Studied
IH-45 (Houston)

In addition to the type of delineator used, consideration was also given to the spacing between delineators and the mounting position on the CSSB. Study site and funding limitations allowed for only a small number of delineator type/spacing/mounting position combinations to be examined. Five different combinations of delineator types, spacings, and mounting positions were selected for study. These treatment combinations were installed along a 3-mi section of an 8-lane illuminated urban freeway in Houston, TX, where CSSBs are located less than 1 ft away from the inside (median) travel lane. The layout of the treatments at the study site is shown in Figure 4-2.

Each delineation treatment was installed over a 0.5-mi segment of CSSB. A 0.5-mi segment between each treatment was not delineated to provide separation between the treatments. Acrylic cube-corner lenses were mounted on top of one segment of CSSB at 200-ft intervals (Treatment 1), and on the side of the CSSB (6-in from the top) at 50-ft intervals at another segment (Treatment 2). Conversely, the brackets covered with HI reflective sheeting were installed on top of one segment of barrier at 50-ft intervals (Treatment 3) and on the side of the barrier (also 6 in from the top) spaced 200-ft apart at another (Treatment 4). Since the reflective cylinders are not practical when mounted on the side of a CSSB, they were installed at 50-ft spacings on top of a final segment of barrier (Treatment 5). Specific details for each treatment are included in Table 4-1.

Site Description

The study site was located on a recently reconstructed section of IH-45 (Gulf Freeway) in Houston. The study section began at the IH-610 (South Loop) interchange and extended north for three miles. A typical cross section of the study site is shown in Figure 4-3. Throughout the study section, the freeway has three to four 12-ft lanes in each direction. Traffic through this freeway as of 1985, was 180,000 AADT. The entire study section is illuminated. A number of motels and businesses are located along the one-way frontage roads on each side of the freeway. The signs and lights of the businesses add to the general visual complexity. Overhead sign supports span the freeway at several locations. The freeway alignment is fairly straight with gentle horizontal curves and vertical rises and drops as the freeway passes over numerous cross-street arterials. Entrance ramps are metered during peak periods.

A reversible lane transitway has been retro-fitted in the median of the reconstructed freeway. On either side, CSSBs separate the transitway from the travel lanes, with the bottom of the barrier located less than 1 ft from the inside freeway lane in each direction.

DELINEATION TREATMENTS

- 1 Top-Mounted Cube-Corner Lenses at 200-Ft Spacings
- 2 Side-Mounted Cube-Corner Lenses at 50-Ft Spacings
- 3 Top-Mounted Reflective Brackets at 50-Ft Spacings
- 4 Side-Mounted Reflective Brackets at 200-Ft Spacings
- 5 Top-Mounted Reflective Cylinders at 50-Ft Spacings

- ▨ Delineated Barrier
- Non-Delineated Barrier

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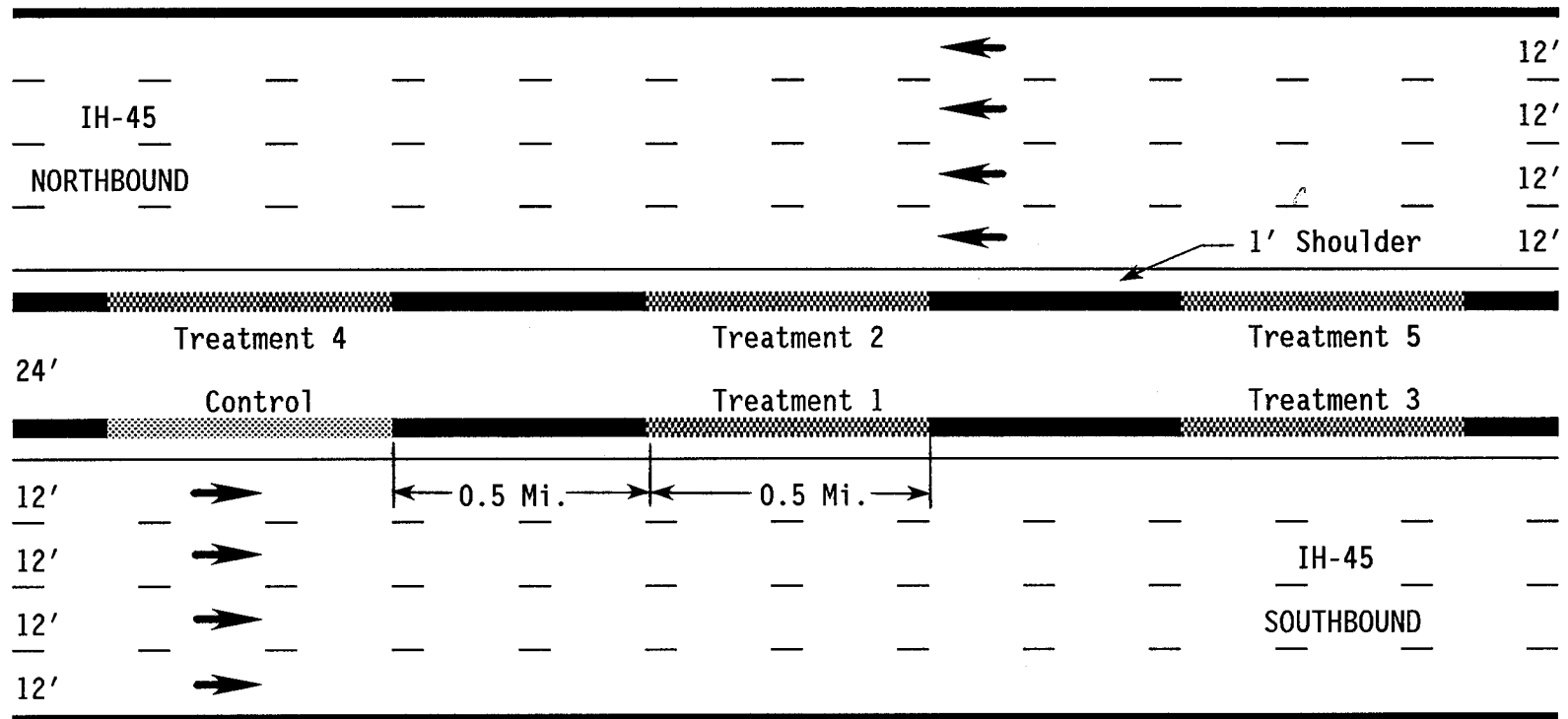


Figure 4-2. Layout of Delineation Treatments at the IH-45 (Houston) Study Site.

TABLE 4-1. SUMMARY OF DELINEATION TREATMENTS

Treatment	Delineator	Mounting Position	Spacing (ft)	Cost/Delineator (\$)	Cost/mi of Barrier (\$)
1	Cube-Corner	Top	200	2.50	66
2	Cube-Corner	Side	50	2.50	264
3	Brackets w/ HI Sheeting	Top	50	1.50	158
4	Brackets w/ HI Sheeting	Side	200	1.50	40
5	Reflective Cylinder	Top	50	4.50	475

HI = High-Intensity Reflective Sheeting



Figure 4-3. IH-45 (Houston) Study Site.

Driver Performance Analysis

Objective

The objective of this phase of the study was to evaluate the effects of CSSB delineation on traffic traveling past the segments of delineated barrier. The data were needed to determine whether the delineation treatments differed with respect to their effects on traffic.

Methods of Study

Data Collection

Data were collected at each of the delineation treatment segments using the low-light level video camera mounted on overhead sign supports spanning the freeway. Data were collected on week nights (Monday, Tuesday, Wednesday, or Thursday). Two nights worth of data were collected at each treatment segment both before and immediately after the delineators were attached to the CSSB. The treatments were installed and data collected in the following order (see Figure 4-2): 3, 1, 4, 2, and 5. This was done so that drivers were not influenced by any upstream delineation before reaching the section under study at that particular time. This entire process of delineator installation and data collection took approximately 3 months to complete.

Measures-Of-Effectiveness

Data were reduced from the videotapes for two time periods as was done for the IH-35 (Austin) study: The first period, representing high nighttime volume conditions, began at 9 p.m. and ended at midnight. The second period started at midnight and ended at 5 a.m. This period represented low nighttime volume conditions. The data were reduced to obtain three traffic MOEs:

1. Lane Distribution - The percent of traffic in the inside (median) and adjacent travel lanes (combined) that traveled in the inside lane. The outer two lanes were not considered in this analysis because it was felt that vehicles in these lanes would not be affected by the presence of delineation on the CSSB.
2. Lane Straddling - The number of vehicles straddling the lane stripe between the inside and adjacent travel lanes. These were counted as a measure of serious guidance or barrier avoidance problems for drivers. Shoulder encroachments next to the barrier, used as an MOE in the IH-35 (Austin) study, were also to be used in this study. However, no encroachments were recorded at any of the treatment segments before or after delineation was installed. Consequently, only the lane straddling measure is reported.

3. Lateral Distance - The lateral distance from the CSSBs that vehicles in the inside lane traveled. These were used as an indication of more subtle changes in vehicle lateral position within the inside lane. Distances were estimated using short tape marks placed on the pavement at 1-ft intervals.

Results

Lane Distribution

Table 4-2 presents the results of the lane distribution analysis. Asterisks next to the values indicate a statistically significant change in the proportion of traffic in the two inside lanes that used the inside travel lane. As expected, no statistically significant changes were detected at the control (non-treated) segment during either the high volume or low volume periods.

Because of the fairly large vehicle sample sizes obtained during the high nighttime volume periods, small but statistically significant changes occurred in the proportion of drivers using the inside travel lane after delineation was installed at several delineation treatment segments. As can be seen in Table 4-2, the proportion of vehicles in the inside lane decreased significantly (based on a Chi-Square Test Independence) by 3% at Treatment 1 (top-mounted cube-corner lenses at 200-ft spacings) and by 1% at Treatment 2 (side-mounted cube-corner at 50-ft spacings). In contrast, however, the proportion of drivers in the inside lane increased 2% at Treatment 5 (the top-mounted cylinders at 50-ft spacings).

Similar changes in the inside lane proportion were also detected at Treatments 1 and 5 during the low nighttime volume periods. The proportion of the inside and adjacent lane vehicles traveling in the inside travel lane decreased by 2% at Treatment 1, but increased 3% at Treatment 5.

It is important to note that these statistically significant proportional changes actually represent very small volume changes in the inside lane next to the barrier. For instance, the proportional changes at Treatments 1, 2, and 5 during the high nighttime volume periods correspond to average changes in the inside lane volumes of only 13, 5, and 5 vph, respectively. In the low nighttime volume periods, changes at Treatments 1 and 5 amounted to average changes of only 2 and 6 vph. Practically speaking, then, the delineation treatments did not appear to have much of an effect on lane distributions during either time period.

Lane Straddling

Table 4-3 summarizes the comparison of lane straddling rates at the control and treatment locations. During the high nighttime volume periods, statistical comparisons of the rates found only one significant change, that

**TABLE 4-2. COMPARISON OF LANE DISTRIBUTION DATA: BEFORE VS. AFTER DELINEATION
IH-45, HOUSTON**

Percent (%) of Inside and Middle Lane Traffic in Lane Next to Barrier

Treatment	High Nighttime Volume Periods			Low Nighttime Volume Periods		
	Before Delin.	After Delin.	Difference	Before Delin.	After Delin.	Difference
Control (No Delineation)	40.4 [6963]	41.4 [6304]	+ 1.0	22.8 [2823]	24.0 [2570]	+ 1.2
1 Top-Mounted Cube-Corner 200-ft Spacings	41.4 [6612]	38.3 [5539]	- 3.3**	23.8 [2650]	21.7 [2044]	- 2.1*
2 Side-Mounted Cube-Corner 50-ft Spacings	38.5 [6829]	36.3 [5534]	- 1.2**	25.4 [2925]	26.0 [2310]	+ 0.6
3 Top-Mounted Brackets 50-ft Spacings	39.2 [5726]	38.7 [5627]	- 0.5	24.4 [1951]	26.2 [2040]	+ 1.8
4 Side-Mounted Brackets 200-ft Spacings	34.7 [6598]	33.5 ^a [3040]	- 1.2	22.0 [2568]	20.3 ^{a,b} [1596]	- 1.7
5 Top-Mounted Cylinders 50-ft Spacings	35.9 [4927]	37.5 [5395]	+ 1.6**	22.7 [1800]	25.8 [2157]	+ 3.1**

[] Numbers in brackets represent sample sizes in number of vehicles

** Statistically Different at 0.05 Level of Significance

* Statistically Different at 0.10 Level of Significance

a This data represents only one night

b This data collected in rainy, wet pavement conditions

TABLE 4-3. COMPARISON OF LANE STRADDLING RATES: BEFORE VS. AFTER DELINEATION
IH-45, HOUSTON

Lane Straddling Rate per 1000 Vehicles in Inside Lane

Treatment	High Nighttime Volume Periods			Low Nighttime Volume Periods		
	Rate Before Delin.	Rate After Delin.	Change	Rate Before Delin.	Rate After Delin.	Change
Control (No Delineation)	1.5 [4]	0.8 [2]	- 0.7	4.7 [3]	6.5 [4]	+ 1.8
1 Top-Mounted Cube-Corner 200-ft Spacings	0.7 [2]	2.4 [5]	+ 1.7	7.9 [5]	6.8 [3]	- 1.1
2 Side-Mounted Cube-Corner 50-ft Spacings	0.0 [0]	1.4 [3]	+ 1.4**	1.3 [1]	5.0 [3]	+ 3.7
3 Top-Mounted Brackets 50-ft Spacings	0.4 [1]	0.0 [0]	- 0.4	4.2 [2]	3.7 [2]	- 0.5
4 Side-Mounted Brackets 200-ft Spacings	0.9 [2]	2.0 ^a [2]	+ 1.1	3.5 [2]	15.4 ^{a,b} [5]	+11.9**
5 Top-Mounted Cylinders 50-ft Spacings	0.6 [1]	0.5 [1]	- 0.1	4.9 [2]	0.0 [0]	- 4.9

[] Numbers in brackets represent sample sizes in number of lane straddlings observed

** Statistically Different at 0.05 Level of Significance

a This data represents only one night

b This data collected in rainy, wet pavement conditions

being an increase in the lane straddling rate at Treatment 2 (side-mounted cube-corner lenses at 50-ft spacings).

Lane straddling rates during the low nighttime volume periods were generally higher than they were during the high nighttime volume periods, as Table 4-3 illustrates. However, a comparison of the before delineation and after delineation rates during the low volume periods found statistically significant changes only at Treatment segments 4 (side-mounted brackets with HI sheeting) at 200-ft spacings) and 5 (top-mounted cylinders at 50-ft spacings). Lane straddling appeared to be reduced slightly at Treatment 5 but increased at Treatment 4.

An increase in the lane straddling rate was also evident at Treatment segment 2 (side-mounted cube-corner at 50-ft spacings), although this increase was not found to be statistically significant. Nevertheless, it does suggest that lane straddling rates increased at this treatment during both high and low volume periods. It may be that mounting the delineators on the side of the CSSB at the 50-ft spacing tends to make some drivers too apprehensive of the CSSBs when they are located so close to the travel lanes.

The increase in the lane straddling rate (during the low volume periods) after delineation was quite dramatic at Treatment 4. In fact, the rate is almost 5 times greater than in the before condition. However, the after data at this segment was collected in rainy, wet pavement conditions. The video recordings showed a significant glare problem off of the pavement from the roadway lighting and vehicle headlights, making it difficult to see the edgeline and lane stripes. Consequently, the straddling rate at this segment is not necessarily an indication of the effect the delineators had upon traffic. Instead, it suggests that some drivers may have difficulty staying in their lanes in nighttime adverse weather conditions where fixed illumination is present.

It may be that CSSB delineation is indeed quite useful to drivers in these wet-weather conditions and may become the primary control and guidance information (since the pavement markings may not be visible). Since no data were collected during nighttime wet-weather conditions before the delineation was installed, it is not known whether or not this delineation treatment was effective in reducing lane straddling rates at this segment. Similarly, it was not possible to collect data during wet-weather conditions at any of the other treatment segments so that a comparison of the relative effectiveness of each under rain conditions could be made.

Lateral Distance

Statistical comparison of the lateral distance data was based on the same Kolmogorov-Smirnoff Goodness-of-fit (14) test used in the analysis of the Austin data. During the high nighttime volume periods statistically significant differences were found for Treatments 4 (side-mounted brackets with HI sheeting at 200-ft spacings) and 5 (top-mounted cylinders at 50-ft spacings). The lateral distance distributions for these segments are shown in

Figure 4-4. Vehicles appear to have shifted slightly away from the barrier at Treatment 4. In contrast, vehicles at Treatment 5 seem to have shifted closer to the barrier.

Results of the before-after comparisons at each treatment segment during low nighttime volume periods indicate that the lateral distance distributions were different at Treatments 1 (top-mounted cube-corner lenses at 200-ft spacings), 2 (side-mounted cube-corner lenses at 50-ft spacings), and 5 (top-mounted cylinders at 50-ft spacings). Plots of the lateral distance distributions for all of these treatments are presented in Figure 4-5. The plots suggest that vehicles shifted away from the barrier at Treatment 1. Conversely, vehicles seem to have shifted closer to the barrier at Treatments 2 and 5.

Subjective Evaluations

Objective

The objective of the subject evaluations was to determine driver perception of the 1) relative "brightness" (reflectivity) of each of the treatments, and 2) relative effectiveness of each treatment in guiding drivers along a safe travel path next to the CSSB.

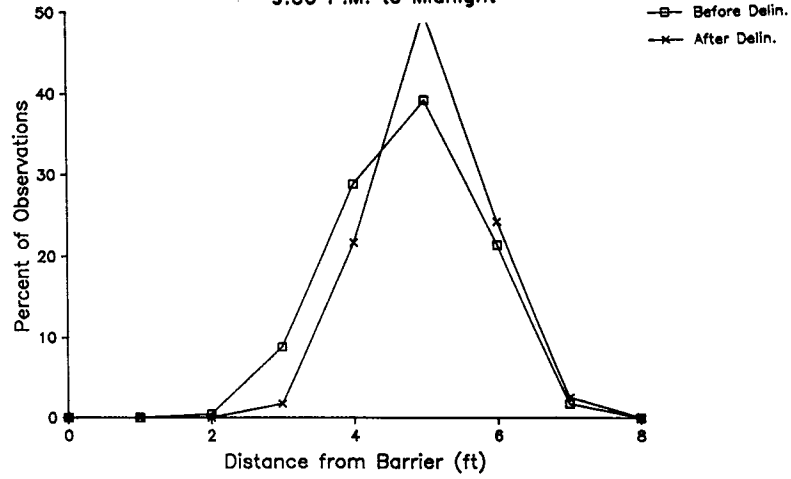
Method of Study

Each subject drove a test vehicle (1985 full-size sedan), with the test administrator sitting in the passenger seat, through the freeway section past each delineation treatment in succession. Subjects traveled in the inside lane next to the barrier. As they drove, subjects responded to questions from the test administrator about the treatments. Appendix A documents the instructions given verbally to the subjects by the test administrator.

Subjects made two drive-throughs past the treatments. On the first pass, they were asked to concentrate on the relative "brightness" of each treatment, (the term "brightness" was not defined by the test administrator). After the first pass, subjects ranked all five treatments in terms of their relative brightness, and also decided if they felt each treatment's brightness was adequate (again, the term adequate was not defined by the administrator). Subjects then made the second drive-through past the treatments, concentrating on each treatment's effectiveness in guiding them and helping them maintain a safe travel path. After the second pass, subjects again ranked the treatments, this time on the basis of effectiveness.

The delineation treatments were evaluated in both a dirty and a clean condition. The same subjects were used for both evaluations, as it was felt that no learning effects would be present to bias the results, while the use of the same subjects provided a stronger statistical study design. The subjects were divided into two groups that drove past the treatments in

(TREATMENT 4)
 REFLECTIVE BRACKETS: SIDE-MOUNTED @ 200 FT
 9:00 P.M. to Midnight



(TREATMENT 5)
 REFLECTIVE CYLINDERS: TOP-MOUNTED @ 50 FT
 9:00 P.M. to Midnight

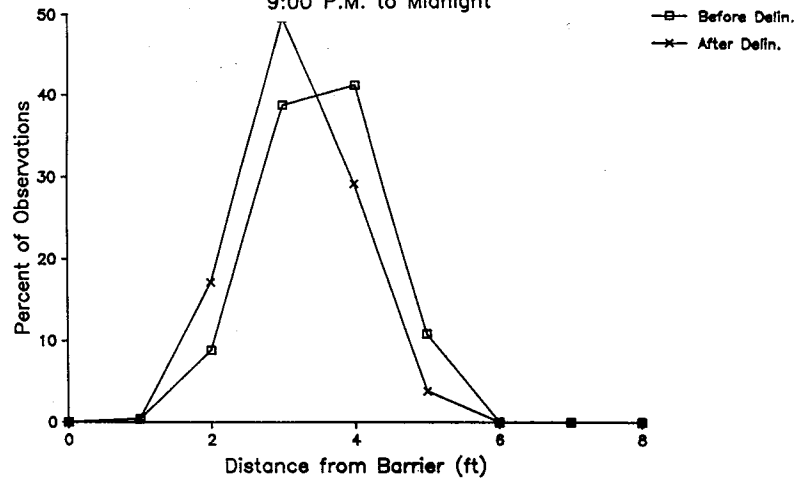
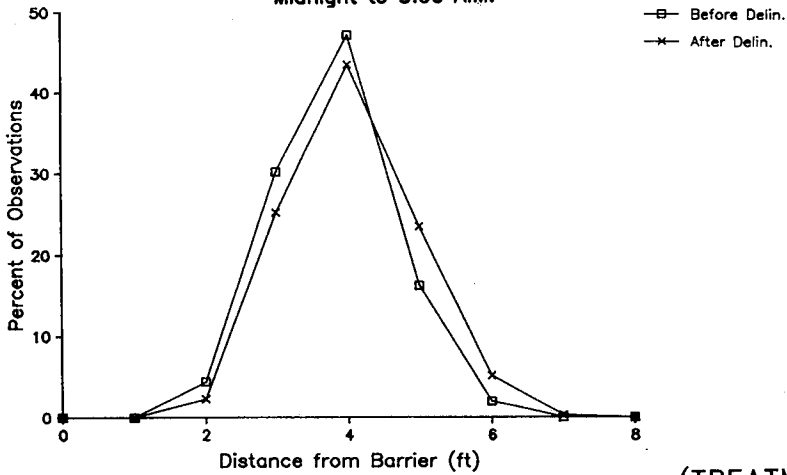
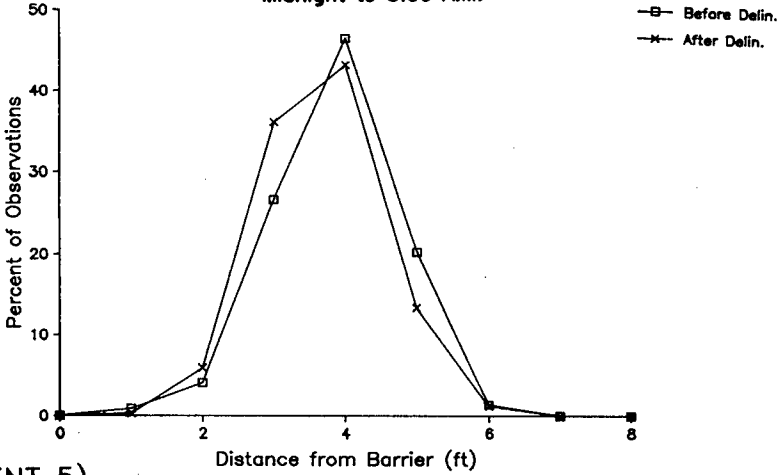


Figure 4-4. Comparison of Lateral Distance Distributions for Before Vs. After Delineation: High Nighttime Volume Hours (9 p.m. to Midnight), IH-45 (Houston)

(TREATMENT 1)
CUBE-CORNER LENSES: TOP-MOUNTED @ 200 FT
Midnight to 5:00 A.M.



(TREATMENT 2)
CUBE-CORNER LENSES: SIDE-MOUNTED @ 50 FT
Midnight to 5:00 A.M.



(TREATMENT 5)
REFLECTIVE CYLINDERS: TOP-MOUNTED @ 50 FT
Midnight to 5:00 A.M.

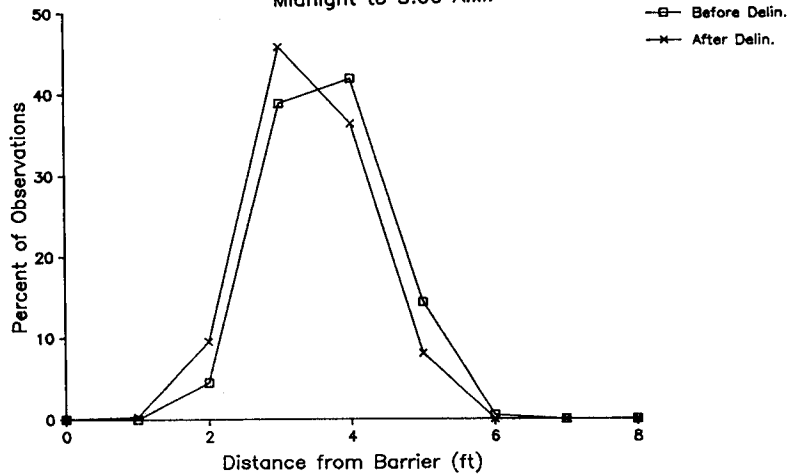


Figure 4-5. Comparison of Lateral Distance Distributions for Before Vs. After Delineation: Low Nighttime Volume Hours (9 p.m. to Midnight), IH-45 (Houston)

different sequences in an attempt to offset any effects of presentation order on the evaluations. The first group traveled southbound past Treatments 1 and 3, turned around and traveled northbound past Treatments 5, 2, and 4. The other group traveled northbound first, then southbound.

A total of eleven subjects from the Houston area participated in the study. Subjects first viewed and evaluated the treatments when the delineators were dirty. The delineators were then cleaned with a wet sponge. All but one of these subjects returned and evaluated the treatments with the delineators clean.

The demographic characteristics of the subjects are presented in Appendix A. The study sample included more women than men, with ages ranging from 19 to 56 years old. The subjects were generally well educated, experienced drivers. None of the subjects lived close to the study site, so their familiarity with the location was limited to occasional (once a month to once a year) trips through the section.

Results

Evaluation of Dirty Delineators

Subjects first evaluated the different delineation treatments after the treatments had been in place on the CSSB for four to six months. The rankings subjects gave for each treatment's brightness and effectiveness in the dirty condition are shown in Table 4-4. Also shown is the proportion of subjects who felt the brightness of each particular delineation treatment was adequate. A Friedman Analysis of Variance (ANOVA) test (15) for ranked data found the rankings to differ significantly. Subjects ranked Treatment 2 (the side-mounted cube-corner lenses at 50-ft spacings) as the brightest, and Treatment 5 (the top-mounted cylinders at 50-ft spacings) as the dimmest. Scores for the remaining treatments show that Treatments 1 (top-mounted cube-corners at 200-ft spacings), 4 (side-mounted brackets at 200-ft spacings), and 3 (top-mounted brackets at 50-ft spacings) were ranked the second, third, and fourth brightest treatments, respectively.

Adequacy ratings given by the subjects generally support the results of the relative treatment rankings. Treatment 2, ranked overall as the brightest treatment, received an adequate rating by all 11 subjects (100%). The second ranked treatment, Treatment 1, received an adequate rating by 7 subjects (64%). Treatments 4, 3, and 5 (ranked third, fourth and fifth) were given adequate ratings by 4 subjects (36%), 1 subject (9%), and 0 subjects (0%), respectively.

The second part of Table 4-4 summarizes how subjects ranked the effectiveness of each delineation treatment (with the delineators dirty) in guiding drivers and helping them maintain a center position in the travel lane. The rankings between the treatments were again found to be significantly different. Treatment 2 (side-mounted cube-corner lenses at 50-

**TABLE 4-4. SUBJECT EVALUATION OF DELINEATION TREATMENTS: DIRTY CONDITION
IH-45, HOUSTON**

Treatment	<u>Brightness^a Evaluation:</u>			<u>Effectiveness^a Evaluation:</u>	
	Total Rank Score	Relative Relative Ranking	Number Rating Brightness Adequate	Total Rank Score	Relative Ranking
1 Top-Mounted Cube-Corner 200-ft Spacings	23	2	7 (64%)	31	2
2 Side-Mounted Cube-Corner 50-ft Spacings	13	1	11 (100%)	13	1
3 Top-Mounted Brackets 50-ft Spacings	40	4	1 (9%)	35	3
4 Side-Mounted Brackets 200-ft Spacings	33	3	4 (36%)	36	4
5 Top-Mounted Cylinders 50-ft Spacings	55	5	0 (0%)	53	5

^a Rankings based on 1 = brightest or most effective, 2 = second most bright or effective, etc.

39

ft spacings) was again ranked the best, just as it had been for the brightness rankings. Treatment 1 (top-mounted cube-corner lenses at 200-ft spacings) was ranked the second most effective. Treatments 3 (top-mounted brackets with HI sheeting at 50-ft spacings) and 4 (side-mounted brackets with HI sheeting at 200-ft spacings) were ranked third and fourth most effective.

It is interesting to note that the effectiveness rankings of Treatments 3 and 4 differed from the brightness rankings. Even though Treatment 3 was ranked as less bright than Treatment 4, it was ranked as slightly more effective. This could be due in part to the closer spacings of the delineators (50-ft vs. 200-ft spacings). As with the brightness rankings, Treatment 5 was ranked as the least effective treatment.

Subjects also responded to three questions about each treatment as they drove past each section.

1. Do you feel or don't you feel this treatment pattern tends to encourage you to maintain a center position in the lane you are driving?
2. What is it about the treatment pattern that makes it particularly effective or ineffective?
3. Is there anything about the treatment pattern you dislike?

Individual subject responses to these questions for each treatment are shown in Appendix B. The comments were categorized and are summarized in Table 4-5. Treatment 5 was disliked by 8 of the 11 subjects (73%), primarily because the cylinders were not bright enough. The 200-ft spacing of Treatment 1 was disliked by 10 of the 11 subjects (91%); subjects stated that the large spacing was too great to be effective. Conversely, 9 subjects (82%) had positive comments about the side-mounted position of Treatment 2. Subjects stated that side-mounted delineation provided a better indication of the location of the barrier and helped guide them better.

Evaluation of Clean Delineators

Following the evaluation of the dirt-covered delineators, the delineators were cleaned with a wet sponge. Ten of the original eleven subjects then returned to evaluate the treatments in the clean condition. After cleaning, the visibility of each treatment was essentially the same as when the delineators were newly installed. When clean, all delineators were visible from at least 1050 ft, and only 300 ft separated the most visible (cube-corners) from the least visible (reflective cylinders) treatments.

Table 4-6 presents the total rank scores and adequacy ratings of the clean delineation treatments by the 10 subjects. Overall, the brightness rankings showed very little difference between the high and low scoring treatments. In fact, a Friedman ANOVA test on the ranked data found no

TABLE 4-5. SUMMARY OF SUBJECT COMMENTS: DIRTY CONDITION
IH-45, HOUSTON

Treatment	Delineator Type (Includes size, shape brightness)		Delineator Mounting Position		Delineator Spacing	
	Good	Poor	Good	Poor	Good	Poor
1 Top-Mounted Cube-Corner 200-ft Spacings	0	2	2	2	0	4
2 Side-Mounted Cube-Corner 50-ft Spacings	0	1	⑨	1	3	0
3 Top-Mounted Brackets 50-ft Spacings	2	5	0	2	4	3
4 Side-Mounted Brackets 200-ft Spacings	2	3	2	1	0	<u>10</u>
5 Top-Mounted Cylinders 50-ft Spacings	0	<u>8</u>	0	1	5	1

41

___ = Large Number of Negative Comments

○ = Large Number of Positive Comments

TABLE 4-6. SUBJECT EVALUATION OF DELINEATION TREATMENTS: CLEAN CONDITION
IH-45, HOUSTON

Treatment	Total Rank Score	Brightness ^a Evaluation:		Effectiveness ^a Evaluation:	
		Relative Ranking	Number Rating Brightness Adequate	Total Rank Score	Relative Ranking
1 Top-Mounted Cube-Corner 200-ft Spacings	30	3	10 (100%)	35	4
2 Side-Mounted Cube-Corner 50-ft Spacings	23	1	9 (90%)	19	1
3 Top-Mounted Brackets 50-ft Spacings	32	4	10 (100%)	27	2
4 Side-Mounted Brackets 200-ft Spacings	29	2	8 (80%)	36	5
5 Top-Mounted Cylinders 50-ft Spacings	36	5	5 (50%)	33	3

^a Rankings based on 1 = brightest or most effective, 2 = next brightest or most effective, etc.

statistically significant differences between the treatments indicating the subjects, as a group, ranked the treatments all about equal. Given the fact that the delineators in each treatment were all visible for a distance of 1050 to 1350 ft, the equality of the treatment rankings are understandable.

As with the evaluation in the dirty condition, subjects also indicated whether they thought each treatment was adequate in terms of brightness. Treatments 1 through 4 received an adequate rating from at least 8 of 10 subjects (80%); However, Treatment 5 received an adequate rating from only 5 subjects (50%). The subjects as a group did not consider the top-mounted reflective cylinders, even when clean, to be adequate in terms of brightness.

The second part of Table 4-6 contains the total rank scores from the subjects with respect to each treatment's relative effectiveness in guiding drivers and helping them maintain a center position in the travel lane. A Friedman ANOVA test found that the rankings did not differ significantly.

Subjects were again asked to respond to questions about the specific treatments in the same manner as they did for the evaluation of the treatments in the dirty condition. Comments (which can be found in Appendix C) are summarized in Table 4-7.

No clear trend is evident with regards to delineator type as all received a few positive and negative comments from the subjects. The comments did reveal a general dislike for delineation mounted on top of the barrier (Treatments 1, 3, and 5), and a corresponding liking for those treatments mounted on the side (Treatments 2 and 4). Subjects indicated that the treatments mounted on top of the barrier seemed to make the travel lanes appear wider than they were, and made it feel as though the delineation was drawing them closer to the barrier. However, this perceived reaction was not evident in the driver performance data (discussed previously) which showed vehicles were slightly closer to the barrier at Treatment 5 (top-mounted cylinders at 50-ft spacings) but farther away from the barrier at Treatment 1 (top-mounted cube-corners at 200-ft spacings).

The subjects stated several reasons for liking side-mounted delineation, including a more direct line of sight, a better indication of the location of the barrier wall, and more realistic perception of lane width. Subjects also disliked the 200-ft spacings of Treatments 1 and 4, and liked the 50-ft spacings of Treatments 2 and 4. Even though Treatment 5 (top-mounted cylinders at 50-ft spacings) was also spaced at 50-ft intervals, subjects generally did not comment about the spacing of this treatment.

TABLE 4-7. SUMMARY OF SUBJECT COMMENTS: CLEAN CONDITION
IH-45, HOUSTON

Treatment	Delineator Type (Includes size, shape brightness)		Delineator Mounting Position		Delineator Spacing	
	Good	Poor	Good	Poor	Good	Poor
1 Top-Mounted Cube-Corner 200-ft Spacings	0	1	1	<u>5</u>	0	<u>6</u>
2 Side-Mounted Cube-Corner 50-ft Spacings	2	2	⑥	1	⑥	0
3 Top-Mounted Brackets 50-ft Spacings	1	1	0	3	⑧	1
4 Side-Mounted Brackets 200-ft Spacings	1	3	3	0	0	<u>7</u>
5 Top-Mounted Cylinders 50-ft Spacings	1	2	2	2	4	0

44

___ = Large Number of Negative Comments

○ = Large Number of Positive Comments

Delineation Visibility Over Time

Objective

The objective of this phase of the study was to monitor, over a period of time, the loss of visibility of each type of CSSB delineator as dirt and road film accumulated on the reflective surfaces. From this data, it would be possible to estimate the relative maintenance requirements of the different delineators and delineation treatments. Delineators that lose their reflectivity faster must be cleaned more often to keep them serving their intended purpose.

Method of Study

The collection process of nighttime driver performance data discussed previously required that the installation of the delineation treatments be performed over a three-month period, and so the treatments were not exposed to the same traffic and weather conditions. TTI researchers considered cleaning all of the other treatments at the time the final delineation treatment was installed and starting the evaluation of treatment visibility over time at that point. However, it was not known whether factors such as sun and abrasion (from windblown sand) had already reduced the brightness and visibility of the delineators. As an alternative, TTI researchers decided to install a new delineator at each treatment segment at the time of the final treatment installation. The new delineator was placed in front of one of the delineators previously installed. The previously installed delineators were left in place and allowed to continue to become dirty. Subsequent measurements of visibility distances for each delineation treatment, however, were made with the newer delineators.

The researchers decided to measure visibility distances in terms of how far a driver, sitting in a vehicle next to the delineated barrier, would be able to see the test delineator. Since there was not a full shoulder between the barrier and the inside travel lane, the measurements had to be made from within the Transitway itself, which was not yet opened to traffic. While it was possible to measure the visibility distance for those delineators mounted on top of the barrier, those on the outside of the barrier obviously could not be seen from a vehicle within the Transitway. For those delineators mounted on the side of the barrier, TTI researchers were forced to use a five-cell D flashlight, lean over the side of the barrier, and measure how far away the test delineator could be seen. Since two different light sources were used, a conversion factor had to be developed that related the delineator visibility distances of these two sources. Discussion of this factor is found in Appendix D.

Results

The visibility distances of the delineators were determined at the time of installation and at 2, 6, 10, and 16 weeks after installation. Table 4-8 and Figures 4-6 and 4-7 summarize these results. For those delineators mounted on the side of the CSSB, the visibility distances have been adjusted (using the factor described in Appendix D) to represent auto headlights as the light source so that direct comparisons of the distances would be possible.

In Figure 4-6, the graphs show the visibility of each type of delineator over the time period studied. Regardless of mounting position, the cube-corner delineators did not lose visibility as quickly or as extensively as the reflective brackets or the cylinders. Much of the loss in visibility distance for the brackets and cylinders occurred in the first six weeks after installation. For instance, measurements made six weeks after installation showed that the top-mounted bracket with HI sheeting (Treatment 3) could be seen only from a distance of 250 ft, and the side-mounted bracket with HI sheeting (Treatment 4) and top-mounted cylinder (Treatment 5) were visible for a distance of only 150 ft. The loss experienced by cube-corner lenses was much more gradual and less severe. At six weeks time, the top-mounted cube-corner lens (Treatment 1) was visible for a distance of 900 ft, while the side-mounted lens (Treatment 2) was visible for a distance of 750 ft.

As Figure 4-6 also shows, the data collected 16 weeks after initial installation showed that the visibility of the delineators was better than it was at 10 weeks time. The improvement was especially noticeable in the cube-corner lenses. Extremely heavy rains the week preceding the 16 week evaluation may have washed some of the dirt from the delineators, explaining the improved visibility. It should be noted that the dramatic improvement by the cube-corner lenses was not matched by the brackets with HI sheeting or the cylinders (in fact the cylinders showed no improvement).

As expected, mounting position (top or side) on the barrier effected the rate at which the visibility of both the cube-corner lenses and brackets with HI sheeting deteriorated. As shown in Figure 4-7, the visibility of delineators mounted on the side of the CSSB deteriorated at a faster rate than those mounted on top of the CSSB. This effect was more pronounced for the brackets with HI sheeting than for the cube-corner lenses. The cylinders were not mounted on the side of the barrier, and so have not been included in this figure.

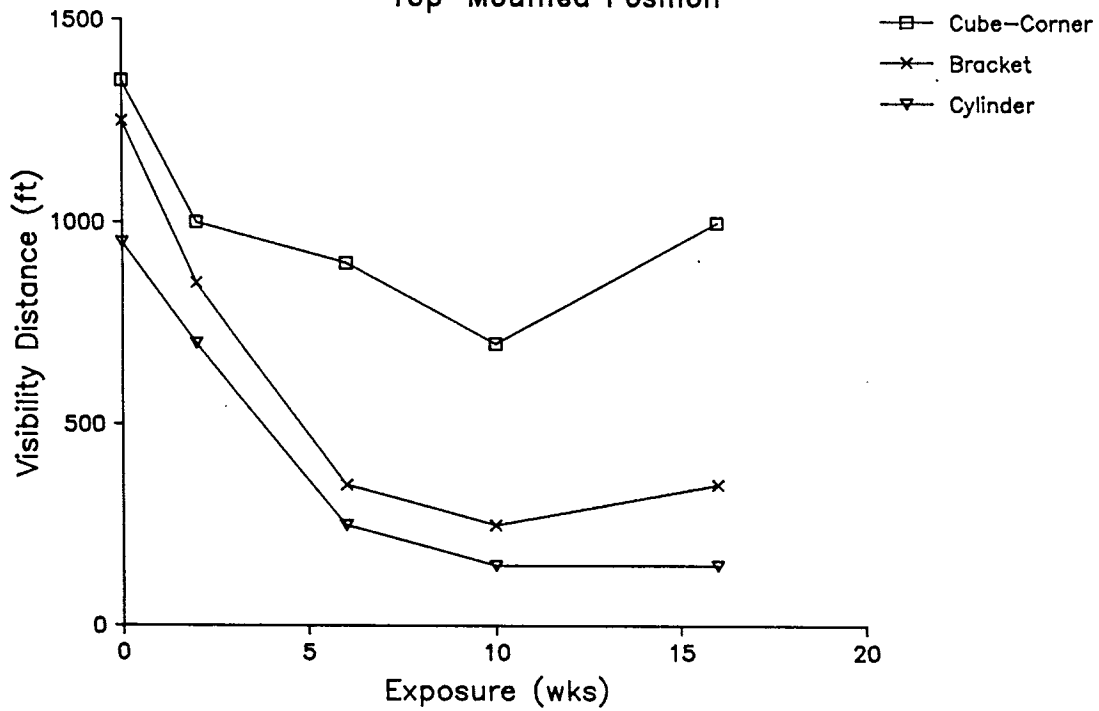
TABLE 4-8. VISIBILITY DISTANCE MEASUREMENTS OVER TIME

Maximum Distance at Which Delineator is Visible (ft)

Treatment	Length of Exposure (Weeks after Treatment Installation)				
	0	2	6	10	16
1 Top-Mounted Cube-Corner 200-ft Spacings	1350	1000	900	700	1000
2 Side-Mounted Cube-Corner 50-ft Spacings	1350	950	750	450	750
3 Top-Mounted Brackets 50-ft Spacings	1250	850	350	250	350
4 Side-Mounted Brackets 200-ft Spacings	1250	650	100	80	150
5 Top-Mounted Cylinders 50-ft Spacings	1050	700	200	100	100

COMPARISON OF DELINEATORS

Top-Mounted Position



COMPARISON OF DELINEATORS

Side-Mounted Position

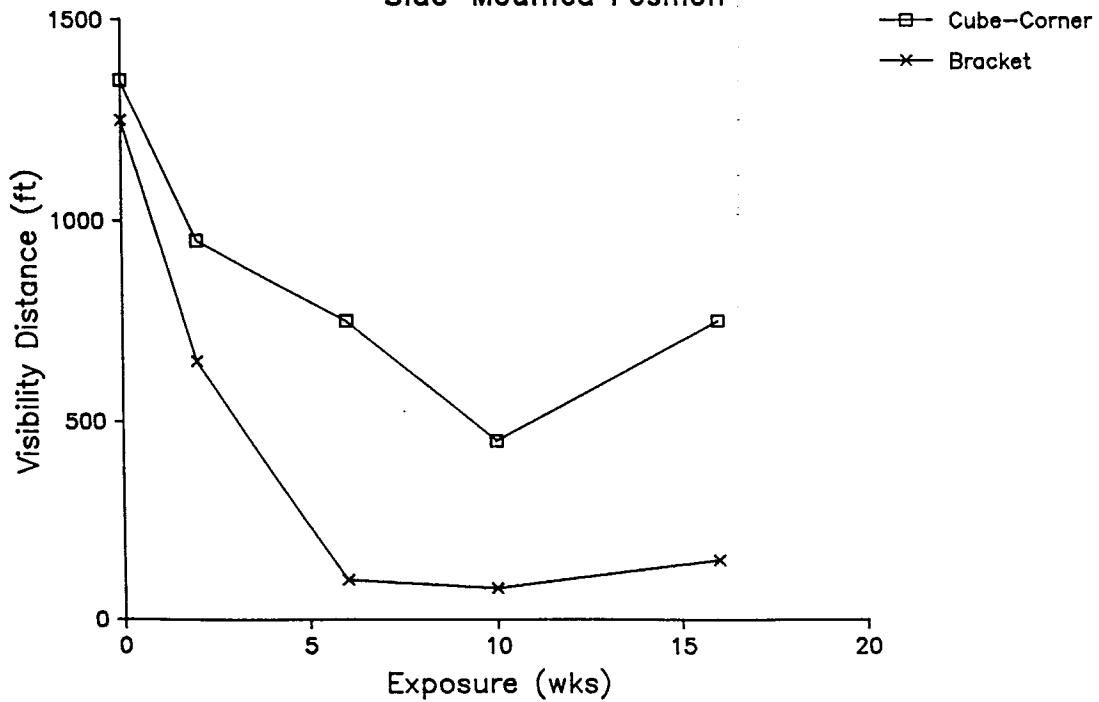
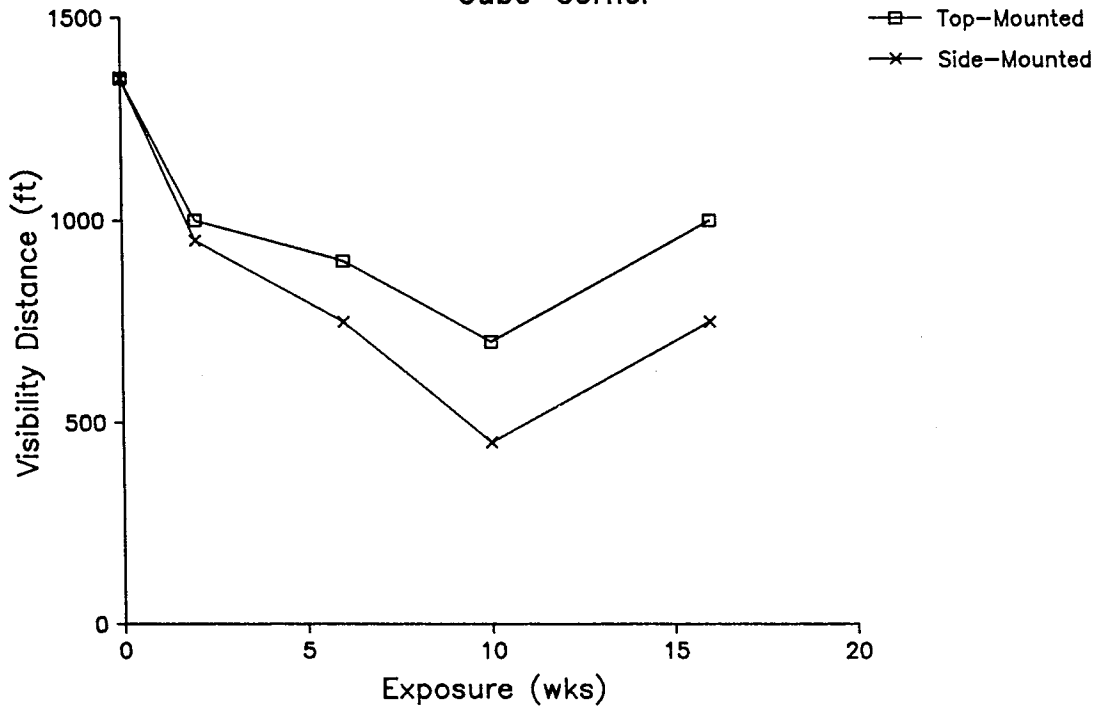


Figure 4-6. Effect of Dirt and Road Film Upon Delineators Studied, IH-45 (Houston)

EFFECT OF MOUNTING POSITION

Cube-Corner



EFFECT OF MOUNTING POSITION

Bracket

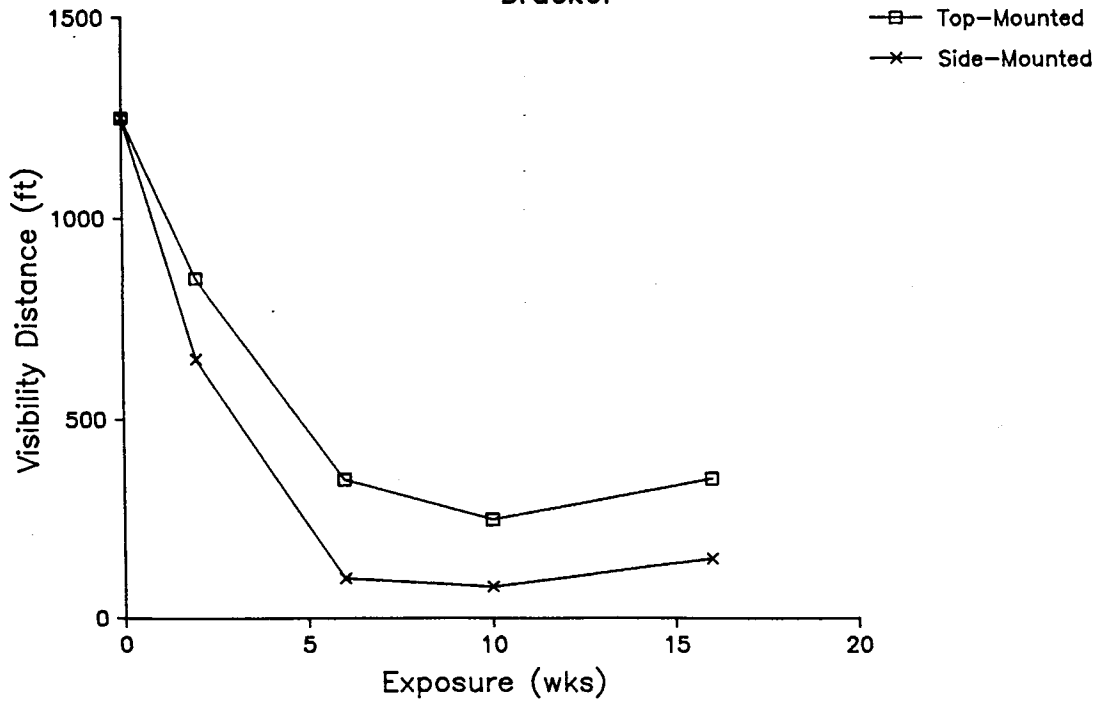


Figure 4-7. Effect of Dirt and Road Film Upon Delineators Studied at Different Mounting Positions, IH-45 (Houston)

Summary

The field study conducted in Houston examined the effects and performance of five CSSB delineation treatments under lighted urban freeway conditions where the bottom of the CSSBs were located less than 1-ft away from the inside travel lane. The results of the driver performance analysis conducted under nighttime, dry-pavement conditions show that lane distributions were not affected to any practical degree by the installation of the different treatments on the barrier.

Lane straddling rates were found to be slightly higher for Treatment 2 (side-mounted cube-corner lenses at 50-ft spacings), suggesting that this treatment may make some drivers apprehensive of the barrier. Lane straddling rates also appeared to be higher for the other side-mounted treatment, Treatment 4 (side-mounted brackets with HI sheeting at 200-ft spacings), although this increase was more likely due to the fact that the data was collected in rainy, wet pavement conditions.

The measurements of vehicle lateral distances from the barrier showed drivers traveled slightly closer to the barrier after the installation of the top-mounted cylinders at 50-ft spacings (Treatment 5) and side-mounted cube-corner lenses at 50-ft spacings (Treatment 2). Conversely, drivers were found to travel slightly farther away from the barrier after the installation of the top-mounted cube-corner lenses at 200-ft spacings (Treatment 1) and side-mounted brackets with HI sheeting at 200-ft spacings (Treatment 4). However, these shifts were also not extremely dramatic, and may not be significant from a practical standpoint.

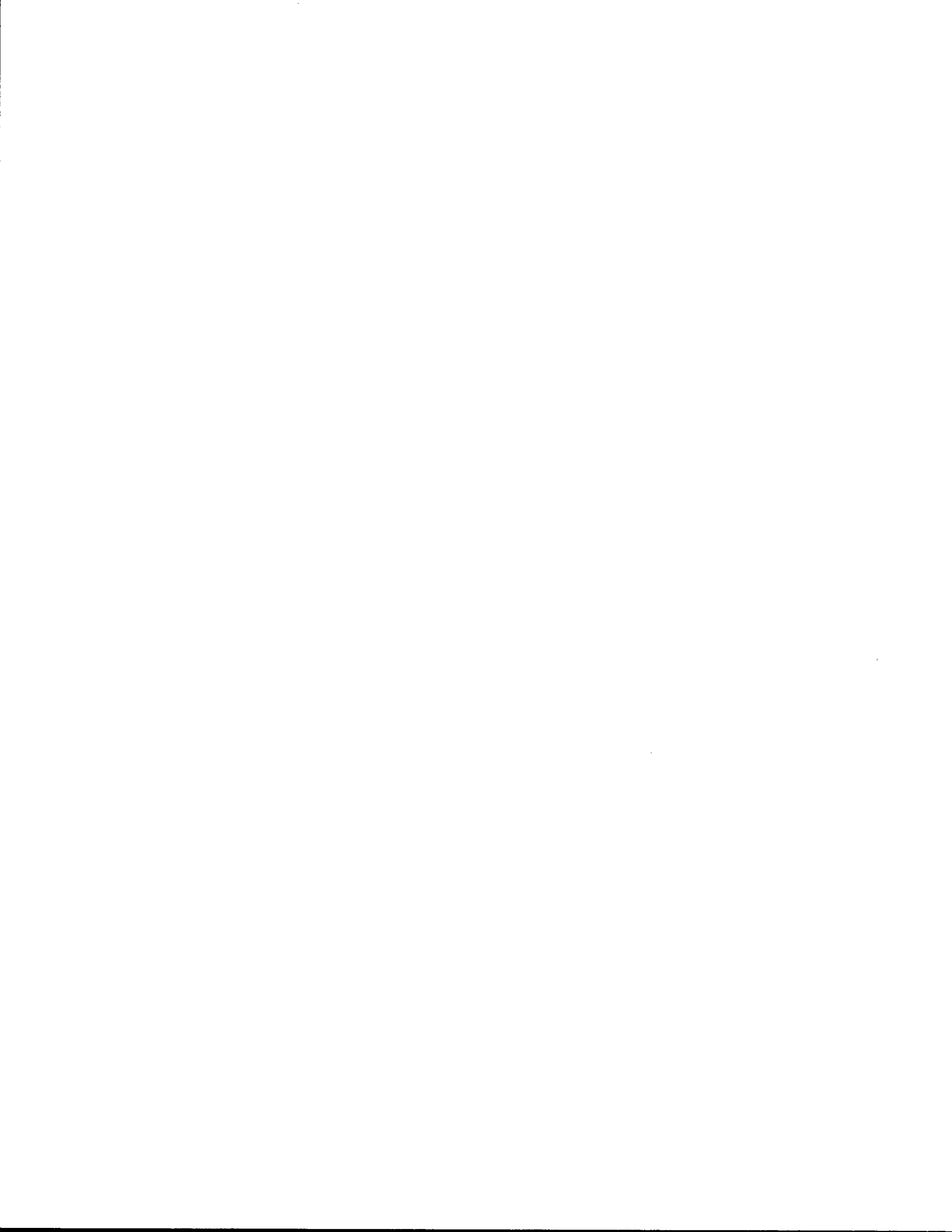
If it had been possible to collect more data under nighttime wet-weather conditions, these results may have been quite different. The small amount of data collected in the rain at Treatment 4 suggests that drivers may have a control and guidance problem in wet weather at locations where fixed illumination is present. The illumination, while beneficial during normal dry conditions, can create glare problems that apparently make it difficult to see the existing pavement markings. Barrier delineation is mounted above the pavement, and may not be as susceptible to the glare from fixed lighting. In these instances, barrier delineation could serve as a major source of control and guidance information. Unfortunately, further research under wet weather conditions was beyond the scope and funding of this study.

The nighttime dry weather subjective evaluations conducted with the delineators in dirty and clean conditions provided some insight into driver perception and preference for the five CSSB delineation treatments investigated. In a clean condition, all of the treatments examined except for the reflective cylinders appeared to be equally bright and effective to subjects, based on a relative ranking of each. However, subject comments suggested a preference for the side-mounted cube-corner lenses at 50-ft spacings over the other treatments. More prominent differences between treatments developed over time as dirt accumulated on the delineators and reduced their visibility. With the treatments dirty, the side-mounted cube-

corner lenses at 50-ft spacings were ranked as both the brightest and most effective under nighttime dry weather conditions. Subject comments indicate that, for both clean and dirty conditions, the 50-ft spacing was preferred over the 200-ft spacing, and that the side-mounted position was preferred over the top-mounted position.

Visibility measurements of the delineation treatments over time showed that different types of delineators are not affected the same by dirt and road film. The brackets with HI sheeting and the cylinders were found to lose their initial visibility quite rapidly, while the cube-corner lenses were less affected by the dirt accumulation process. Also, as expected, side-mounted delineation became dirty and lost visibility at a faster rate than top-mounted delineation.

As stated previously, the lack of a suitable study site prevented an analysis of the delineation treatments in a highway work zone location. However, it is believed that some of the results just presented have applicability to work zone locations. In particular, the data on delineator visibility over time suggest that cube-corner lenses are better suited to work zone locations, since dirt accumulation impacts the visibility of cube-corner lenses the slowest. Similarly, a top-mounted position also helps to minimize the effects of dirt accumulation. While the actual rate at which delineation becomes dirty will depend on the specific site where it is installed, it is expected that the relative effects of dirt upon the different types of delineators and upon the mounting position on the barrier would remain consistent, whether the barrier is in a narrow urban freeway median or a rural highway work zone.



5. BARRIER DELINEATION CLEANING

Several studies (2,4) as well as District personnel surveyed (see Chapter 2) have cited the accumulation of dirt and road grime on the reflective surface of delineators as a major problem associated with the use of barrier delineation. Data concerning the loss in delineator visibility as documented in Chapter 4 also illustrate the extent of this problem. Although some delineators appear to lose their visibility less quickly than others, none are immune to the constant dirt accumulation process. The dirt that collects on these delineators is made up of a number of things including dust, oil, ground tire rubber, and vehicle exhaust emissions. During rainy, wet pavement conditions, this mixture combines with rain water on the pavement and is splashed onto the delineators by passing vehicles. This process repeats over and over until the delineators have lost all reflectivity and are not visible to drivers.

Because of the constant loss of visibility over time, there has been a reluctance by some Districts to install delineators on CSSBs at some locations in narrow freeway medians. There is also a reluctance to put men at risk and to spend the time to clean barrier delineators with the methods currently available. This chapter is devoted to the barrier delineation cleaning problem. As part of Study 408, the current methods available for delineator cleaning have been identified and documented. In addition, innovative methods of cleaning CSSB delineation have been identified and examined.

Current Methods of Cleaning Barrier Delineators

A telephone survey of the Districts with large urban areas was performed to determine how the different Districts currently clean CSSB delineators. The specific responses are found in Appendix E. The most common method of cleaning delineators by the Districts was by hand using a brush and soapy water. One District has tried to use a compressed air sprayer to squirt cleaning solvent on the delineators. This process has proved to be unsatisfactory and so the District has returned back to the hand cleaning method.

No set pattern exists as to when and how often the delineators are cleaned. Cleaning is generally performed during normal daylight hours, unless traffic volumes are too high to allow a lane to be closed next to the barrier where necessary. The frequency of delineator cleaning varies among Districts. Most Districts stated that they make occasional nighttime inspections of the delineators, but usually clean them in response to citizen complaints about poor visibility. On roadway reconstruction projects where CSSB is used and delineated, the Districts sometime require (specifically stated in the contract) the contractor to periodically clean the delineators. Within the Districts, though, there does not seem to be a set schedule for delineator cleaning nor is there any one crew in the Districts that is typically responsible for the cleaning.

Most of the Districts surveyed did not have to close a travel lane or otherwise disrupt traffic in order to clean the delineators. In Houston (District 12), maintenance personnel are able to clean delineators from within an authorized vehicle lane (AVL) during the hours the lane is not open to traffic. Other Districts often have a shoulder that separates the CSSBs from the travel lanes from which the delineators are cleaned. However, when no AVL or shoulder is available, the Districts have no choice but to close the travel lane next to the CSSBs in order to clean the delineators. Generally, this must be done during low volume hours (such as early on a Sunday morning).

In addition to the Districts that were surveyed, a number of northern locations were polled to find out what provisions were taken to clean barrier delineators. Among these locations were the cities of Chicago, IL and Boston, MA as well as the states of Illinois and Massachusetts. These were chosen because of the severe winters which they commonly endure. However, those northern locations surveyed all indicated that they made no provisions for cleaning CSSB delineators.

Potential Barrier Delineator Cleaning Systems

Currently, the only documented method for cleaning the delineators is to go into the field and clean them by hand, using wet brushes or paper towels. It is believed that some type of mechanized delineator cleaning system would be quite useful. As part of this study, TTI has identified several alternative mechanisms for cleaning delineators. These mechanisms include a self-propelled rotating brush system, a truck-mounted brush head system, and a high pressure water sprayer. The self-propelled and truck-mounted systems do not as yet exist. None of the systems have been field tested to determine their effectiveness at cleaning barrier delineators. Even though they have not been tested, each system's theory of operation is presented and discussed here to determine their potential features and faults.

Self-Propelled Rotating Brush Cleaning System

The proposed self-propelled rotating brush cleaning system is a self-contained system of rotating brushes that would ride on top of a CSSB. The system would have its own water supply and motor to operate the rotating brushes and propel the machine along the top of the barrier. The system would have brushes on both the top and the side of the barrier.

Features:

- 1) The unit would have its own propulsion so it could be put on a barrier and left alone to do its work. Thus, it would reduce man-hours required.
- 2) The unit would not require a lane closure, as it would fit over the barrier. Also, it would be out of the way of traffic, and should not be a hazard to motorists.

- 3) It would reduce work crew exposure to traffic.
- 4) The unit would be capable of cleaning both top and side mounted delineators.

Faults:

- 1) The unit is not in existence, and would be expensive to develop and construct.
- 2) The machine would require a large motor to perform a number of tasks, including propelling the machine and its water supply uphill while rotating the cleaning brushes.
- 3) The unit would not work on discontinuous barriers or on barriers that have luminaire or sign supports mounted on top.

High Pressure Water Sprayer

The high pressure water sprayer would be used in much the same way as a wand type car wash, using the pressurized water stream to spray the delineator. The only known sprayer of this type is mounted on a trailer in District 12 (Houston), but would theoretically operate in the same manner whether mounted on a trailer or on a truck.

Features:

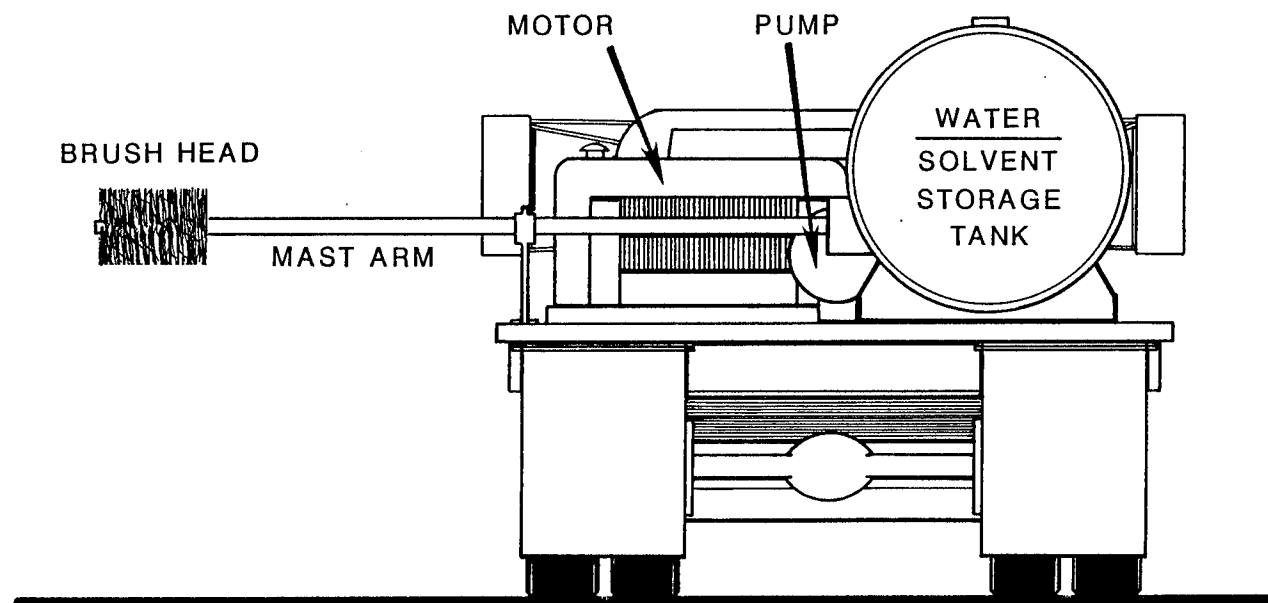
- 1) It has the capability to clean all types of delineators, both those top and side mounted.
- 2) The operation should be faster than hand cleaning.
- 3) The work could be done as a moving maintenance operation.
- 5) The equipment and technology are already available, so no development cost would be required.

Faults:

- 1) The work would have to be done from a travel lane if no AVL or shoulder is available.
- 2) The water overspray could possibly go into a travel lane on the opposite side of the delineator, causing a potentially hazardous situation for an oncoming driver. The use of a spray shield or shadow vehicle may be necessary.
- 3) It is not known how well the water spray would clean the delineators without some type of scrubbing mechanism.

Truck Mounted Brush Head Cleaner

This cleaning system would use a brush or another type of cleaning surface mounted on the end of a rotating mast arm to clean the delineators. The system would be mounted on a truck for mobility (Figure 5-1). The truck would carry the motor, pumps, and water supply for the unit. It is believed



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Figure 5-1. Truck-Mounted Mast-Arm Barrier Delineator Cleaning Mechanism

that this is system and the self-propelled brush system both would work better with a flexible base delineator, such as the one shown in Figure 5-2. However, the system should also work satisfactorily on most of the barrier delineators currently installed in the field.

Features:

- 1) The system would reduce the amount of exposure of workers to traffic.
- 2) The system could be used in a moving maintenance operation.
- 3) Using adjustable arm lengths, heights and interchangeable cleaning heads, the system should work on all types of delineators, both top and side mounted.
- 4) The cleaner would work on all types of barriers, regardless of sign and luminaire supports.
- 5) The system could be mounted on existing vehicles, such as herbicide trucks.

Faults:

- 1) The system would have to operate from a travel lane if no AVL or shoulder is available.
- 2) The machine would have to be developed and built. A preliminary estimate of the cost of the system is approximately \$4,000.

Summary

Delineator cleaning has been cited as a major concern by many Districts in the state. Currently, the only means available to clean delineators is by hand using buckets of water and brushes. This technique is slow, tedious, labor-intensive, and potentially hazardous. As a result, delineators may be used in some locations rather than try to periodically clean and maintain them. What is needed is a safe, efficient method to clean delineators.

A few innovative cleaning devices have been suggested and examined for their potential application in the field. Each has its own features and faults, however. A truck-mounted cleaning mechanism appears to have considerable promise and should be capable of cleaning delineators as a slow-moving maintenance operation. Such a system could make it safer and more cost-effective to clean delineators and, in turn, make delineator usage on barriers a more attractive idea to District personnel.

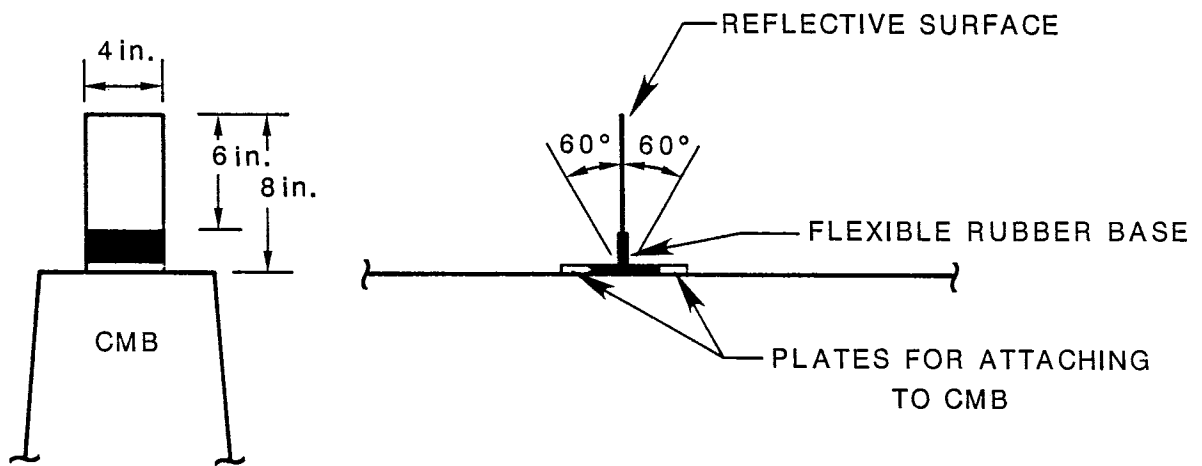


Figure 5-2. Flexible Base Barrier Delineator.

6. SUMMARY AND RECOMMENDATIONS

State-of-the-Art of CSSB Delineation

A review of existing CSSB delineation practices in Texas and of previous research conducted on CSSB delineation has been performed as part of this study and is documented in this report. The results of the review indicate that, because of a lack of available standards or guidelines on how to delineate CSSBs, there is considerable variation in the types and amounts of delineation used on CSSBs. The survey of delineation practices in Texas found that most Districts do delineate CSSBs that are used in highway work zones (since work zones generally have more severe geometric and visibility constraints), but that only a few choose to delineate CSSB in narrow freeway median applications. The choice of the particular delineation treatment to use varies from District to District, and is currently a matter of District preference.

There have been a few studies previously conducted on CSSB delineation. The studies have generally involved evaluations of the cost and visibility (reflectivity) of the different types of delineators available. Visibility is generally measured by the researchers themselves or inferred from evaluations by subject drivers viewing the specific delineation treatments. Different delineator types (such as cube-corner lenses or brackets with HI sheeting), spacings, or mounting positions on the CSSBs affect the results obtained in each study so that it is difficult to compare results or to draw any solid conclusions regarding CSSB delineation.

Evaluation of CSSB Delineation

An initial field study of CSSB delineation in a narrow freeway median was conducted on an illuminated section of freeway in Austin, TX. The data showed that the delineation did have a small effect on lateral distance that traffic traveled from the CSSB when the delineators were clean as opposed to when they were dirty. Drivers traveled slightly closer to the CSSB in a tangent section when the delineation was clean, but traveled slightly farther away from the CSSB when the delineators were clean in the curve section. These effects, as already stated, were small and may not be significant from a practical standpoint. In addition, the limited time frame of the study did not allow for an analysis of the effects of delineation on accidents or accident potential at this site.

The second study of CSSB delineation was conducted at a narrow urban freeway median site in Houston, TX where the CSSB was located less than 1-ft from the inside travel lane. Five delineation treatments were examined:

1. Top-mounted cube-corner lenses at 200-ft spacings
2. Side-mounted cube-corner lenses at 50-ft spacings

3. Top-mounted brackets covered with HI sheeting at 50-ft spacings
4. Side-mounted brackets covered with HI sheeting at 200-ft spacings
5. Top-mounted reflective cylinders at 50-ft spacings

Three types of data were collected at each segment where delineation was installed:

1. Driver performance
2. Subject evaluations
3. Visibility distances

Driver performance data suggested that some delineation treatments had a small effect upon vehicle lateral distance from the CSSB when compared to a non-delineated condition, but it did not appear that these were significant from a practical standpoint. An increase in lane straddling rates was detected for Treatment 2 (side-mounted cube-corner lenses at 50-ft spacings), suggesting that this treatment may make some drivers too apprehensive of the CSSB.

When the different delineation treatments were clean, subjects ranked them all (except for the top-mounted reflective cylinders at 50-ft spacings) about equal in terms of brightness and effectiveness. After the treatments were in place for a period of time and had become dirty, though, the side-mounted cube-corner delineators at 50-ft spacings were ranked as the brightest and most effective. Generally speaking, subjects preferred the 50-ft spacing over the 200-ft spacing, and also preferred side-mounted delineation over top-mounted delineation.

Visibility measurements of the delineation treatments taken periodically while the treatments were in place at the study site showed that the cube-corner lenses were not affected by dirt and road film accumulating on the delineators and reducing their visibility as fast or as extensively as were the brackets covered with HI sheeting or the cylinders. Also, as expected, delineation mounted on the side of the barrier became dirty and lost its visibility at a faster rate than top-mounted delineation.

Some innovative mechanisms for cleaning CSSB delineation quickly and easily were presented. The features and faults of each cleaning mechanism were analyzed with regard to their future development, production, and implementation. The analysis suggests that a truck-mounted mast-arm brush assembly would be the most practical and effective system of those examined, and would allow either top-mounted or side-mounted delineators to be cleaned in a slow-moving maintenance (similar to a street sweeping) operation. This system would be applicable to CSSB delineation in both freeway median and highway work zone locations.

Recommendations

Based on the results of this study, cube-corner delineators are recommended for use on CSSBs in narrow freeway median locations. These delineators do not become dirty and less visible as fast as delineators covered with HI sheeting.

Subjects ranked Treatment 2 (side-mounted cube-corner lenses at 50-ft spacings) as the brightest and most effective delineation treatment. However, driver performance data collected for this treatment under nighttime, dry-pavement conditions showed an increase in lane straddling. The combination of the close (50-ft) spacing and the side-mounted position may make some drivers too apprehensive of the barrier when it is located so close to the travel lane. Lane straddling could result in conflicts between vehicles or other operational problems. Consequently, for CSSB applications with site and lateral distance conditions similar to those studied here, it is recommended that top-mounted delineation be used. An added benefit to the use of top-mounted delineation is that it does not become dirty as fast as side-mounted delineation.

Only two levels of delineator spacings were evaluated in this study, 50-ft and 200-ft. Subject drivers comments indicated a preference for the shorter spacings, but the traffic data collected did not suggest that one spacing was better than the other. Therefore, it is recommended that a 200-ft spacing be considered as a maximum. Closer spacings may be warranted, however, on CSSBs on extremely sharp curves in order to insure adequate control and guidance information for drivers.

The Texas MUTCD (3) specifies that temporary CSSBs used in work zones at night should be delineated with some type of delineation or channelization markers or devices. However, there is no guidance as to the location of the markers or devices on the CSSBs or of the spacing between them. Since no data is available as to the effects of delineation upon traffic at highway work zone locations, the above recommendations are suggested for use when CSSBs in work zones are to be delineated. Since most CSSBs in work zones are located very close to the travel lanes (as they were for these field studies), it is believed that the results of these studies may have some application to work zone situations. However, future research should investigate the effect of this and other delineation treatments at work zones.

In addition to objective studies of driver performance next to CSSBs delineation at work zones, research is also needed to determine what effects delineation has upon traffic safety in terms of accident potential and costs. It is recommended that further study of the above delineation treatment be performed at several freeway median and highway work zone locations be conducted to determine whether the increased cost associated with installing and cleaning CSSB delineation results in reduced accident costs.

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APPENDIX A: INSTRUCTIONS GIVEN TO SUBJECTS DURING
BARRIER DELINEATION EVALUATION



TABLE A-1. SUBJECT DEMOGRAPHIC INFORMATION

Subjects	<u>Number of Subjects in each Category</u>	
	Dirty Condition Evaluation	Clean Condition Evaluation
Total	11	10
Gender:		
Male	3	3
Female	8	7
Age:		
< 25	3	2
25 - 50	4	4
> 50	4	4
Education:		
High School	3	2
College	8	8
Yearly Mileage Driven:		
0 - 10,000	1	1
10,000-20,000	6	5
> 20,000	4	4

INSTRUCTIONS GIVEN TO SUBJECTS DURING EVALUATION

GENERAL INSTRUCTIONS

"Your task is to evaluate several different ways of modifying the concrete median barrier so that drivers on freeways or interstate highways can see the barriers adequately at night (and particularly not sideswipe it). These modifications are called barrier delineation treatments. They consist of small reflective devices glued to the top or the side of the barrier.

You will see and be asked to evaluate a total of five different delineation treatments. You will actually drive a test vehicle down the lane next to the barrier and observe the characteristics of the delineation pattern. Three patterns are one side of the highway, and the other two are on the other, so you will drive down and back. There will be a separation between these patterns which is untreated so you will be able to easily tell when a new section of patterns begins."

(Start tape recorder, document date, subject name, weather, etc. and identify drive through order No. 1 or 2)

BRIGHTNESS EVALUATION

"Your first task is to observe and estimate relatively speaking, the brightness of each pattern. As you drive through, try to recall the pattern characteristics. You will be asked to compare the brightness with other treatments you see later, so try to recall it. At the end you will be asked to rank treatments from brightest to dimmest. Do you have any questions at this time?

(Give instructions to start car, enter freeway and move to lane next to the barrier)

(As each treatment pattern is encountered)

"This is treatment pattern _____. Please note its characteristic brightness.

(After the last treatment is seen, exit freeway, stop car, and give subject brightness evaluation from).

"Here is a sketch of the highway section and the location of the treatments you just saw. Also, here are sketches of the treatments labeled A through E to help refresh your memory. On your evaluation form, please mark beside each section your ranking of each treatment (1 to 5), from brightest to dimmest."

(Wait for subject to fill out form)

"Now that you have finished ranking them, please decide whether each treatment provided an adequate amount of brightness. These treatment patterns may all be adequate, all be inadequate, or some may be adequate and others inadequate. Underneath your ranking of each section on the form please mark an A for adequate or I for inadequate, with respect to brightness."

(For those treatments they marked inadequate, ask the subjects why)

ADEQUACY EVALUATION

"Next, I would like to have you drive through again and this time concentrate on two things: (1) the pathway of your vehicle; (2) detailed characteristics of the barrier delineation treatment, other than overall brightness.

An "adequate" delineation of a safe path at night means:

- (a) not driving too close to the barrier (to risk contact).
- (b) not driving too far away from the barrier (and possibly crossing over your lane stripe into the next lane to the right.)
- (c) in general, maintaining a relatively consistent pathway between the two stripes, as you would in daylight driving.

I also want you to note how the pattern of light is produced and its effects on you. Is it too much, too little or just right?"

(Start car again, and travel through section in same order as for the brightness evaluation.)

(As each treatment pattern is encountered . . .)

"This is treatment pattern _____. Do you feel the pattern tends to encourage you to maintain a center position in the lane you are driving in?" (If not, ask them why not).

"What is it about the treatment pattern that makes it particularly effective or ineffective?"

"Is there anything about the pattern you dislike?"

(For each treatment pattern after the first).

"Comparing this pattern with the previous one, would you say it is more effective, less effective, or about the same?"

(After all treatments are seen, exit freeway, stop car, and give them adequacy evaluation form.)

"Now that you have seen all 5 delineation patterns, I would now like you to rank them in terms of their adequacy and effectiveness, placing a 1 by the section most effective, 2 by the next most effective section, and so on. You have done this already for relative brightness, but this time your rankings are based on each treatment's patterns' effectiveness in maintaining a safe path."



APPENDIX B: INDIVIDUAL SUBJECT RANKINGS AND COMMENTS DURING
BARRIER DELINEATION EVALUATION (DIRTY CONDITION)



INDIVIDUAL SUBJECT RANKING
BRIGHTNESS RANKINGS: DIRTY CONDITION

Treatment	Subject Number:											Total Rank Score
	1	2	3	4	5	6	7	8	9	10	11	
Top-Mounted Cube-Corner 200' Spacings	1 (A)	3 (A)	2 (A)	2 (I)	2 (I)	2 (A)	2 (A)	5 (I)	1 (A)	2 (A)	4 (I)	27
Side-Mounted Cube-Corner 50' Spacings	2 (A)	1 (A)	1 (A)	1 (A)	1 (A)	1 (A)	1 (A)	1 (A)	2 (A)	1 (A)	1 (A)	13
Top-Mounted Brackets 50' Spacings	4 (I)	4 (I)	3 (I)	4 (I)	4 (I)	4 (I)	3 (I)	4 (I)	3 (A)	4 (I)	3 (I)	40
Side-Mounted Brackets 200' Spacings	3 (I)	2 (A)	4 (I)	3 (I)	3 (I)	3 (A)	4 (I)	3 (I)	4 (I)	2 (A)	2 (A)	33
Top-Mounted Cylinders 50' Spacings	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	5 (I)	55

(A) = Treatment rated as adequately bright
(I) = Treatment rated as inadequately bright

EFFECTIVENESS RANKINGS: DIRTY CONDITION

Treatment	Subject Number:											Total Rank Score
	1	2	3	4	5	6	7	8	9	10	11	
Top-Mounted Cube-Corner 200' Spacings	1	2	4	4	2	3	2	2	4	3	4	31
Side-Mounted Cube-Corner 50' Spacings	3	1	1	1	1	1	1	1	1	1	1	13
Top-Mounted Brackets 50' Spacings	2	4	3	2	4	4	3	4	3	4	2	35
Side-Mounted Brackets 200' Spacings	4	3	2	5	3	2	4	4	2	2	3	36
Top-Mounted Cylinders 50' Spacings	5	5	5	3	5	5	5	5	5	5	5	53

SUBJECT COMMENTS

Question 1: Do you feel this pattern tends to encourage you to maintain a center position in the lane you are driving?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "Yes"
- S- 2: "Yes"
- S- 3: "Somewhat"
- S- 4: "No"
- S- 5: "Yes, I guess so"
- S- 6: "I move too close to the barrier, thinking I have more room next to the barrier"
- S- 7: "Yes"
- S- 8: "Yes"
- S- 9: "No, it wants to pull me closer to the barrier"
- S-10: "Yes, it helps"
- S-11: "Yes"

Top-Mounted Reflexite @ 50' Spacings

- S- 1: "No, they're not bright enough"
- S- 2: "Yes"
- S- 3: "No, because it doesn't illuminate"
- S- 4: "Yes, but the reflectivity is poor"
- S- 5: "Yes"
- S- 6: "I still shy towards the wall, I think. It makes me feel that I can get closer to it"
- S- 7: "Yes"
- S- 8: "Yes"
- S- 9: "No, I still want to get too close"
- S-10: "Its's fighting me. It seems to be coming at me."
- S-11: No comment

Top-Mounted Cylinders @ 50' Spacings

- S- 1: "No, because you barely notice it"
- S- 2: "Yes"
- S- 3: "No, it doesn't give me any help"
- S- 4: "No, they're too invisible"
- S- 5: "Yes"
- S- 6: "Yes"
- S- 7: "I guess so"
- S- 8: "They're very ineffective. They have no influence on my driving behavior whatsoever"
- S- 9: "No, they pull me closer to the barrier"
- S-10: "No"
- S-11: "Sort of"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "Yes"
- S- 2: "Yes"
- S- 3: "Yes"
- S- 4: "Yes"
- S- 5: "Yes"
- S- 6: "Yes, very much so"
- S- 7: "Yes"
- S- 8: "Yes, I can see 20 to 25 yards in front of me, that's good"
- S- 9: "Yes"
- S-10: "Yes, this would"
- S-11: "Yes"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "No, they're spaced too far apart"
- S- 2: "Yes"
- S- 3: "Only somewhat. The distance is too far apart"
- S- 4: "No, they're so widely spaced"
- S- 5: "Yes, I guess so"
- S- 6: "No, I probably shy away. They're spaced kind of far apart. I don't know when the next one's coming"
- S- 7: "Yes"
- S- 8: "Yes"
- S- 9: "They're not bad, but they're too far apart"
- S-10: "Not really"
- S-11: "Sort of, when they (the delineators) are there"

Question 2: What is it about the treatment pattern that makes it particularly effective or ineffective?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "It's at eye level"
- S- 2: "The delineator is too small"
- S- 3: No comment
- S- 4: "The spacing is too great to be effective"
- S- 5: No Comment
- S- 6: "The pattern was spaced more, but I could still follow the train of thought"
- S- 7: "Sitting on top like it is, you can tell how tall the barrier is"
- S- 8: "I can see two of them at once"
- S- 9: "They're bright enough, and they're spaced okay"
- S-10: "It's not in my way. It wouldn't wake one up, though"
- S-11: "I think they could be a little closer together"

Top-Mounted Reflexite @ 50' Spacings

- S- 1: "The brightness makes them ineffective. The spacing is good, but not the brightness"
- S- 2: "There is no reflection to it"

- S- 3: "It does not illuminate, but the spacing is good"
- S- 4: "The pattern is good and close enough"
- S- 5: "It's close together, I think its effective"
- S- 6: No Comment
- S- 7: No Comment
- S- 8: "I think its effective because it is square, not the usual round delineator"
- S- 9: "I think the squares are more effective than the round"
- S-10: No Comment
- S-11: No Comment

Top-Mounted Cylinders @ 50' Spacings

- S- 1: "They're ineffective because there's no brightness to it"
- S- 2: "I can't see them"
- S- 3: "They're not illuminating"
- S- 4: "They're close enough spaced, but not bright enough"
- S- 5: "It seems like they're close together"
- S- 6: "They're spaced pretty well. I know where the pattern's going"
- S- 7: "I say they're ineffective. They look like sticks. Are you sure those things have lights on them?"
- S- 8: "They look like part of the cement"
- S- 9: "There's no reflection, they're ineffective"
- S-10: "They're close together. There's no light (reflection) though"
- S-11: "I can't see them. If you could see them I think they would be pretty good"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "You know the barrier's there, you can see it"
- S- 2: "The reflectors are lower (on the side), I can see them"
- S- 3: "It shows me where the edge is. It's on my side of the barrier, I think that's helpful"
- S- 4: "They're closely enough spaced so I don't wonder if I'm wandering over (close to the barrier)"
- S- 5: "I like it on the side. The spacing is ok, too"
- S- 6: "I like the height where it is about car level. The spacing is fine"
- S- 7: "They're brighter you can see them. They're to the side, it gives you a perception of the wall being there. I feel more comfortable on the side"
- S- 8: "I can see a whole line of them. They show me the wall"
- S- 9: "I like them on the side. It keeps me away from the barrier"
- S-10: "I like the location. I know where the wall is"
- S-11: "They're good on the side of the barrier"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "They're ineffective, too far apart"
- S- 2: "They're too far apart"
- S- 3: "The spacing makes it ineffective"
- S- 4: No Comment
- S- 5: "They seem to be too far apart"

- S- 6: "The distance is too great. I like the position"
- S- 7: "I think they're ineffective. I can't even see them"
- S- 8: "I do like the squares"
- S- 9: "I like the way it is built (square). It catches my eye"
- S-10: "I like where they are (on the side)"
- S-11: "There aren't enough of them to make them too effective"

Question 3: Is there anything about the treatment pattern you dislike?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "They're too far apart. You could put another in between each one"
- S- 2: "No"
- S- 3: "The distance is too far apart"
- S- 4: "They're too far apart"
- S- 5: "They're too far apart. It seems like they're a little small"
- S- 6: "No"
- S- 7: "No"
- S- 8: "Not being all that bright"
- S- 9: "I want to get too close to the barrier"
- S-10: "No"
- S-11: "They would be harder to see if you had a smaller car"

Top-Mounted Reflexite @ 50' Spacings

- S- 1: "The brightness is too poor"
- S- 2: "No"
- S- 3: "No"
- S- 4: "No"
- S- 5: "I'm not particularly crazy about its shape"
- S- 6: "I think these are a little too close together"
- S- 7: "I don't like the 'square'. I can't see them as well"
- S- 8: "They're too close together. That's kind of irritating"
- S- 9: "I don't like them on top"
- S-10: "They're more nauseating because they're closer together. They draw my eyes to the barrier instead of the road."
- S-11: "Again, headlights would not hit them as well when they're on top."

Top-Mounted Cylinders @ 50' Spacings

- S- 1: "It doesn't let me know how far away I am from the wall. I feel I tend to shy away from it"
- S- 2: "No"
- S- 3: "Just its ability to guide me down the road"
- S- 4: "No"
- S- 5: "No"
- S- 6: "No"
- S- 7: "No"
- S- 8: No Comment
- S- 9: No Comment
- S-10: No Comment
- S-11: "There maybe a few too many of them"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "I don't like them on the side"
- S- 2: "No"
- S- 3: "No"
- S- 4: "No"
- S- 5: "No"
- S- 6: "No"
- S- 7: "No"
- S- 8: "No"
- S- 9: "No"
- S-10: "No"
- S-11: "I think they could be a little bit bigger"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "I wish they were mounted higher. They're also too far apart"
- S- 2: "I don't like the spacing. They're kind of hard to see that far apart"
- S- 3: "No"
- S- 4: "They're much too far apart"
- S- 5: "I don't like the spacing"
- S- 6: "The distance is too great. Also, the square is not as good as the circle"
- S- 7: "I can't see them"
- S- 8: "They're too far apart"
- S- 9: "Too far apart"
- S-10: "There needs to be a few more"
- S-11: "No"

APPENDIX C: INDIVIDUAL SUBJECT RANKINGS AND COMMENTS DURING
BARRIER DELINEATION EVALUATION (CLEAN CONDITION)



BRIGHTNESS RANKINGS: CLEAN CONDITION

Treatment	Subject Number:										Total Rank Score
	1	2	3	4	5	6	7	8	9	10	
Top-Mounted Cube-Corner 200' Spacings	4 (A)	5 (A)	2 (A)	3 (A)	3 (A)	4 (A)	2 (A)	4 (A)	1 (A)	2 (A)	30
Side-Mounted Cube-Corner 50' Spacings	2 (I)	4 (I)	4 (A)	1 (A)	2 (A)	2 (A)	4 (A)	3 (A)	3 (A)	1 (A)	23
Top-Mounted Brackets 50' Spacings	3 (A)	2 (A)	1 (A)	5 (A)	4 (A)	5 (A)	3 (A)	2 (A)	2 (A)	5 (A)	32
Side-Mounted Brackets 200' Spacings	5 (I)	3 (I)	3 (A)	2 (A)	1 (A)	3 (A)	4 (A)	1 (A)	4 (A)	3 (A)	29
Top-Mounted Cylinders 50' Spacings	1 (A)	1 (A)	5 (I)	4 (A)	5 (A)	1 (A)	5 (I)	5 (I)	5 (I)	4 (A)	36

(A) = Treatment rated as adequately bright
(I) = Treatment rated as inadequately bright

EFFECTIVENESS EVALUATION: CLEAN CONDITION

Treatment	Subject Number:										Total Rank Score
	1	2	3	4	5	6	7	8	9	10	
Top-Mounted Cube-Corner 200' Spacings	4	4	2	5	5	4	2	3	4	2	35
Side-Mounted Cube-Corner 50' Spacings	3	3	4	1	1	2	1	1	2	1	19
Top-Mounted Brackets 50' Spacings	2	2	1	2	2	3	3	4	3	5	27
Side-Mounted Brackets 200' Spacings	5	5	5	3	3	5	4	2	1	3	36
Top-Mounted Cylinders 50' Spacings	1	1	3	4	4	1	5	5	5	4	33

SUBJECT COMMENTS:

Question 1: Do you feel this pattern tends to encourage you to maintain a center position in the lane you are driving?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "No, not really. Spacing is too great"
- S- 2: "Yes"
- S- 3: "Not particularly. It's helpful, but not much"
- S- 4: "No, they're too far apart"
- S- 5: "Yes"
- S- 6: "No, I think it might make me move closer to the wall. I think maybe I've got more room."
- S- 7: "Yes"
- S- 8: "No, it tends to want to pull me to it"
- S- 9: "They're pulling me to the left I think"
- S-10: (No comments obtained due to a recorder malfunction)

Top-Mounted Reflexite @ 50' Spacings

- S- 1: "Yes"
- S- 2: "Yes"
- S- 3: "Yes"
- S- 4: "Yes"
- S- 5: "Yes"
- S- 6: "Yes, because they're so close together"
- S- 7: "Yes"
- S- 8: "It tends to pull me to the center median"
- S- 9: "Better than the previous one (Top-Mounted Stimsonite). You can see where you're going"

Top-Mounted Reflective Cylinders @ 50' Spacings

- S- 1: "Yes"
- S- 2: "Yes"
- S- 3: "Yes"
- S- 4: "Yes"
- S- 5: "I guess"
- S- 6: "Yes"
- S- 7: "Yes, I guess so"
- S- 8: "It makes me want to get too close to the barrier"
- S- 9: "Well, it tends to"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "Yes, but on the side I feel a little uncomfortable, like its making me move a little to the right"
- S- 2: "Yes"
- S- 3: "Yes"
- S- 4: "Yes"
- S- 5: "Yes, it's better for me"

- S- 6: "Yes"
- S- 7: "Yes"
- S- 8: "Yes, it does. It keeps me away from the barrier and does not force me too far to the right"
- S- 9: "Yes"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "No, there's not enough of them"
- S- 2: "Yes"
- S- 3: "Not really. I don't think there's any effect"
- S- 4: "Yes"
- S- 5: "Its okay"
- S- 6: "Yes"
- S- 7: "Yes"
- S- 8: "Yes"
- S- 9: "Yes"

Question 2: What is it about the treatment pattern that makes it particularly effective or ineffective?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "They're too far apart. I tend to veer out (away from the barrier)"
- S- 2: "Ineffective. They're not bright enough and too far apart"
- S- 3: No Comment
- S- 4: "Too far apart"
- S- 5: "They're too far apart"
- S- 6: "I don't think they're close enough, and shouldn't be on top. When they're spaced out, I have a hard time making a judgement about how far away I am from the wall."
- S- 7: "You can tell how tall the wall is, that makes it effective"
- S- 8: "It's not bright enough"
- S- 9: "There's something strange about them, maybe it's their distance apart"

Top-Mounted Reflexite 50' Spacings

- S- 1: "Effective because they're close together"
- S- 2: "They're effective close together and bigger, brighter. You can see them easily"
- S- 3: "They're spaced close together. If they were sidemounted they'd be even more effective"
- S- 4: "The spacing is great, but was obliterated by the wash of oncoming traffic at times"
- S- 5: "They're nice and real close together"
- S- 6: "I can see them. Spacing is good too"
- S- 7: No Comment
- S- 8: "I think with it closely spaced makes it effective. You can definitely see the wall"
- S- 9: No Comment

Top-Mounted Reflective Cylinders @ 50' Spacings

- S- 1: "They're effective because there's enough of them and they stand out real soon (you can see them from a distance)"
- S- 2: "You can see they're on top at eyelevel. That's just right"
- S- 3: "They're less illuminated than the previous pattern"
- S- 4: "The fact that they are a light color and mounted on top of the barrier makes them quite visible"
- S- 5: "That they're close together"
- S- 6: "It's close together, and its a big reflector. I like its size"
- S- 7: "It's ineffective. It's not bright to me"
- S- 8: "It's got enough light, and they're close together"
- S- 9: "I do not know what they were telling me what to do (I don't understand them)"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "They're effective because of their spacing and brightness. I do feel a little uncomfortable with them on the side."
- S- 2: "They're ineffective, they're not bright enough. The spacing's okay."
- S- 3: "The spacing makes it effective"
- S- 4: "They're close enough spaced and located on the side of the barrier. Positioned below the top of the barrier you don't have the interference of oncoming headlights."
- S- 5: "It's close enough together, also side-mounted"
- S- 6: "Being level with the headlights makes it effective. I like them on the side of the barrier"
- S- 7: "It's on the side so I can see that wall, how far away I am. And I can tell its height too."
- S- 8: "I like it on the inside of the wall. There's enough of them and good reflectors."
- S- 9: "I like them on the side"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "Ineffective because of the spacing"
- S- 2: "Aren't bright enough and too far apart"
- S- 3: "They're spaced too far apart"
- S- 4: "They're better than nothing. But the spacing is inadequate"
- S- 5: "I like the round ones instead of the square ones"
- S- 6: "I like it on the side, but they're not close enough together"
- S- 7: "Not as bright, but I can see them"
- S- 8: "It's on the side, it's got good reflection, and the reflectors are a little bigger"
- S- 9: "They're bright but not too bright. And they're on the side. I think these are my favorite"

Question 3: Is there anything about the treatment pattern you dislike?

Top-Mounted Stimsonite @ 200' Spacings

- S- 1: "No"
- S- 2: "No"
- S- 3: "I'd rather it not be on top. I'd rather it be side-mounted. I get the illusion the lane is wider than it is."

- S- 4: "No"
- S- 5: "(When there are) oncoming headlights even with them, I couldn't see them"
- S- 6: "No"
- S- 7: "I don't think you can see them as well as when they're on the side"
- S- 8: "Not really"
- S- 9: "The spacing. I also think I don't like them on the top"

Top-Mounted Reflexite @ 50' Spacings

- S- 1: "No"
- S- 2: "No"
- S- 3: "No"
- S- 4: "No"
- S- 5: "I don't like them on top, but if they're going to be there, I like that one"
- S- 6: "The 'square'. It tends to 'wash out' when they get closer"
- S- 7: "No"
- S- 8: "No"
- S- 9: "No"

Top-Mounted Reflective Cylinders @ 50' Spacings

- S- 1: "No, I like it"
- S- 2: "No"
- S- 3: "No, just their location (on top)"
- S- 4: "No"
- S- 5: "I don't like them on top"
- S- 6: "No"
- S- 7: "I don't like them at all. They look like sticks sticking up"
- S- 8: "Not really"
- S- 9: "No, but I don't know what they are when I am looking at them"

Side-Mounted Stimsonite @ 50' Spacings

- S- 1: "No"
- S- 2: "No"
- S- 3: "No"
- S- 4: "No"
- S- 5: "Not really"
- S- 6: "No"
- S- 7: "No"
- S- 8: "No"
- S- 9: "No"

Side-Mounted Reflexite @ 200' Spacings

- S- 1: "Nothing other than spacing"
- S- 2: "No"
- S- 3: "No"
- S- 4: "No"
- S- 5: "Not close enough together"
- S- 6: "No"
- S- 7: "They're not as bright as the previous pattern"
- S- 8: "No"
- S- 9: "No"



APPENDIX D: TECHNIQUE FOR DETERMINING VISIBILITY
DISTANCE FOR BARRIER DELINEATORS



Table D-1 shows the maximum visibility distances of the three types of delineators examined in this study. The delineators were brand new and completely clean. Data collection personnel measured these distances using both the car headlights and the flashlight as light sources with the delineators sitting on top of the barrier. Since the delineator was the same regardless of the light source used, the difference in visibility distances between the headlight and flashlight sources was due to the difference in the intensity of the sources themselves. The ratio of these intensities is directly proportional to the ratio of the visibility distances, as shown below:

$$\frac{\text{Intensity}_{\text{Flashlight}}}{\text{Intensity}_{\text{Auto Headlights}}} = \frac{\text{Visibility Distance}_{\text{Flashlight}}}{\text{Visibility Distance}_{\text{Auto Headlights}}}$$

This ratio is shown in the last column of Table D-1. The ratio of measured distances was consistent across all types of delineators as would be expected. This ratio was used to normalize subsequent evaluations where the flashlight was used as the light source (necessary for the side-mounted delineators) to approximate a visibility distance that would have been possible had auto headlights been used.

TABLE D-1. VISIBILITY DISTANCES OF CLEAN DELINEATORS

Maximum Distance Delineator is Visible (ft)			
Delineator Type	<u>Light Source:</u>		
	Automobile Headlight	Flashlight	Ratio
Cube-Corner Lenses	1350	800	0.6
Bracket with HI Sheeting	1250	750	0.6
Reflective Cylinders	1050	600	0.6



APPENDIX E: SURVEY OF DISTRICT BARRIER
DELINEATION CLEANING PROCEDURES



SUMMARY OF DISTRICT RESPONSES CONCERNING BARRIER DELINEATOR CLEANING

District 2 - Ft. Worth

The only barrier-mounted delineators are those in construction zones on IH-35W. The contractor is responsible for the cleaning of these delineators. The contractor uses crews of two to three men with buckets of soapy water and brushes to clean the delineators and barricades. They are usually cleaned every month. Nighttime inspections are made every month to determine if cleaning is necessary. The contractor must keep the delineators clean or use steady-burn lights instead of delineators. The contractor feels it is cheaper to clean the delineators than to maintain lights.

District 4 - Amarillo

District 4 has a few permanent barrier delineation devices. They are cleaned by hand from the median shoulder as needed. They are checked every 2 to 3 weeks to determine if cleaning is required. As can be expected, the delineators require more cleaning in the winter months. Maintenance personnel perform the cleaning during normal working hours.

District 12 - Houston

District 12's Incident Management Team personnel have performed the task of cleaning barrier-mounted delineators. They tried several methods for cleaning the delineators, including a compressed air sprayer with water, soap and water, and with cleaning solvent. In all cases, the personnel resorted back to cleaning the delineators by hand, using buckets of water and nylon brushes. In District 12, the permanently mounted delineators are generally found on barriers adjacent to Authorized Vehicle Lanes (AVLs) retro-fitted in the median of the major radial freeways. The barrier delineator cleaning process has been performed from within the AVL when not in use. Cleaning was not found to be on any type of set schedule. Rather, it generally took place when a number of citizen complaints about the dirty delineators were received. Houston's Metro System is now contracting out the task of delineator cleaning along the AVLs.

District 13 - Yoakum

This District has only one location where delineators are mounted on concrete barrier, that being a narrow bridge. The delineators on the bridge are cleaned once a week by hand. A squirt bottle with water and a mild soap solution along with a rag are used to clean the delineators.

District 15 - San Antonio

Barrier delineators are seldom used in the District. Some delineators were placed on barriers in curves at a previous time. These are occasionally cleaned by hand from the shoulder. The personnel use brushes and buckets of water. The delineators are not cleaned on a regular schedule. Nighttime visibility checks are made of the roadway signs every three months. If the personnel notice that the delineators are dirty, they may be cleaned if there is time and personnel available.

District 18 - Dallas

There are no permantly-mounted barrier delineators used within the District.

District 24 - El Paso

For the most part, the only barrier-mounted delineators are temporary ones located in construction zones. These are cleaned by the contractor.