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Work Zone Traffic Management Synthesis:

Barrier Delineation Treatments Used In Work Zones

Research, Development, and Technology
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16. Abstract

This report is a synthesis of research findings on current practices in the delineation of portable concrete safety-shaped barriers (CSSBs) in work zones. The information is based on a review of research reports and work zone manuals from a selection of state and city highway agencies, discussions with highway officials, and field observations of selected highway construciton projects. The report presents an assessment of the state-of-the-practice and makes recommendations for further research and future revisions of the Manual on Uniform Traffic Control Devices.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

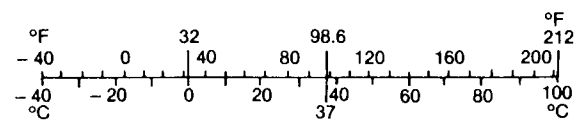
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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I. INTRODUCTION

A. Use of Portable Concrete Safety-Shaped Barriers. Portable concrete safety-shaped barriers (CSSBs) have become an accepted device for protecting motorists, pedestrians, and workers in highway construction zones. CSSBs are used by most state highway agencies, and their use among city and county highway agencies is on the increase. The primary function of CSSBs is protection. While CSSBs may not reduce the frequency of accidents, they have proven to be effective in reducing the severity of accidents involving vehicles leaving the traveled way and in accidents involving the intrusion of construction activities into the traveled way.

B. Need for Delineating Portable Concrete Safety-Shaped Barriers. In spite of their massive size and rigidity, CSSBs are not easily seen at night and during inclement weather and have been found to blend with the pavement and work surroundings (1, 2, 3, 4). During conditions of adverse visibility -- dust, fog, rain, snow, low contrast and glare -- motorists are deprived of many visual cues which are normally used for guidance (path delineation) through work zones, and as a consequence, workers, pedestrians, and motorists are in greater danger of work zone accidents. Recognizing this loss of visibility, most states have adopted a number of devices for delineating CSSBs in order to provide adequate path definition for motorists. Delineators give drivers a line of discrete visual cues along a defined path during darkness and adverse weather conditions. The Manual on Uniform Traffic Control Devices (MUTCD) (5) and several research reports (1, 2, 7, 8, 12) have recognized the value of delineation devices in improving the visibility of CSSBs in work zones.

C. Current MUTCD Standards on CSSB Delineation. Section 6D-2 of the MUTCD (5) defines delineators as "reflector units capable of clearly reflecting light under normal atmospheric conditions from a distance of 1000 feet when illuminated by the upper beam of standard automobile lights." The minimum standard dimension of delineators is three inches, and they must be mounted on suitable supports to be four feet above the near edge of the roadway (5). Type A low-intensity flashing warning lights are recommended for mounting on barricades, drums, vertical panels, and advance warning signs and are intended to continuously warn drivers that they are approaching or passing through a hazardous area. Type C steady-burn lights are recommended for delineating the path through work areas. Their mounting height is 36 inches to the bottom of the lens (MUTCD, Section 6E-5). Vertical panels along with Type A and Type C warning lights are allowed for warning and channelizing devices, respectively (MUTCD, Section 6C-5).

Section 6C-10 of the MUTCD recognizes the need for increasing barrier visibility by giving them a color and installing standard delineation or channelization markings or devices. What constitutes standard delineation devices is unclear. Delineation devices treated in Section 3D apply to open roadways and are primarily reflectors with mounting height of four feet above the near edge of the roadway (Section 3D-5, MUTCD) with a normal spacing of 200 to 528 feet on tangents and spacing on curves to be based on the formula, $S = 3 \cdot \sqrt{R-50}$, where S is the spacing in feet and R is the curve radius in feet. Section 6C-10 requires barriers used at night to be delineated. Warning lights, reflectors, and vertical panels are especially mentioned as delineators in Part VI of the MUTCD. Section 6C-10 allows <u>optional</u> use of two Type A yellow flashing lights at the start of the continuous barrier for warning of hazard but <u>requires</u> all subsequent warning lights for path delineation, if needed, to be of Type C steady burn.

The standard height of portable CSSBs is 32 inches. To obtain the four-foot height above pavement elevation, reflectors used on CSSBs would require a mounting attachment about 16 inches high; an uncommon practice. Glare, cost, and maintenance problems have discouraged the attachment of elevated reflector supports on top of CSSBs. Moreover, the MUTCD provides no clear guidelines regarding the mounting height and separation of warning lights on portable CSSBs. Section 6D-2 advises that spacing of delineators should be such that several can always be seen. Current information in the MUTCD implies that reflectors should not be directly attached to CSSBs, and that warning lights are to be treated as reflectors from a placement standpoint. Guidelines on the use of delineators on CSSBs in work zones should cover the following areas:

1. A comprehensive definition of delineators.

2. Purpose of barrier delineation.

3. Definition of devices used as barrier delineators: warning lights, reflectors, paint, markers, etc.

4. Mounting height of reflectors and warning lights.

5. Spacing of reflectors and warning lights on tangents, curves, and tapers.

6. Treatment of the barrier approach terminal.

7. Recommended applications.

8. Illustrated applications.

9. Supplementary role of delineators.

D. CSSB Delineation Devices. The quest for effective CSSB delineation has generated numerous examples of delineation devices which vary in size, type, reflective qualities, maintenance, durability, and damage-resistance. Figure 1 displays a number of delineation devices and reflects the variation in practice among and within the states. Some of these devices are still being used, and their spacing, maintenance and effectiveness will be discussed in later sections of this synthesis. The following types of devices for delineating portable CSSBs have evolved over the years.

1. **Top-Mounted Reflectors.** These include simple reflectors such as reflective sheeting mounted on small plates with a minimum dimension of three inches as well as those based on cube-corner retro-reflectance principles. Top-mount is used by some states and their jurisdictions. A sample of top-mounted installations is presented in Figure 2.

2. **Side-Mounted Reflectors.** These have the same features as top-mounted. A popular position of side-mounted reflectors is five-to-sixteen inches down from the top of the barrier as illustrated in Figure 3.

3. **Paints.** Painting segments of portable CSSBs is practiced by some states. The paint is made highly reflective with glass beads. Colorado paints the first two barrier segments in orange. Covering all barrier segments with a reflective white pigment is also practiced in Maryland. Use of diagonal orange and black stripes at a 45-degree angle on the approach of barrier segments is an occasional practice in New York.

4. **Raised Pavement Markers on the Pavement.** Raised markers are placed on the pavement next to the barrier or on the barrier itself as indicated in Figure 4. Yellow markers are used for barriers on the left and white for barriers on the right. Davis (9) found raised pavement markers to be effective as a supplement to painted lines located next to CSSBs in work zones.

5. **Warning Lights on Top Surface of Barriers.** Use of Type C warning lights on portable CSSBs has been approved by the MUTCD. Steady burn warning lights mounted on the top surface of CSSBs are a popular delineation method as illustrated in Figure 5.

6. **Warning Lights Above Top Surface of Barrier.** In this case the base of the lens is mounted above the barrier such that it is more than one foot above the top of the barrier. See Figure 5.

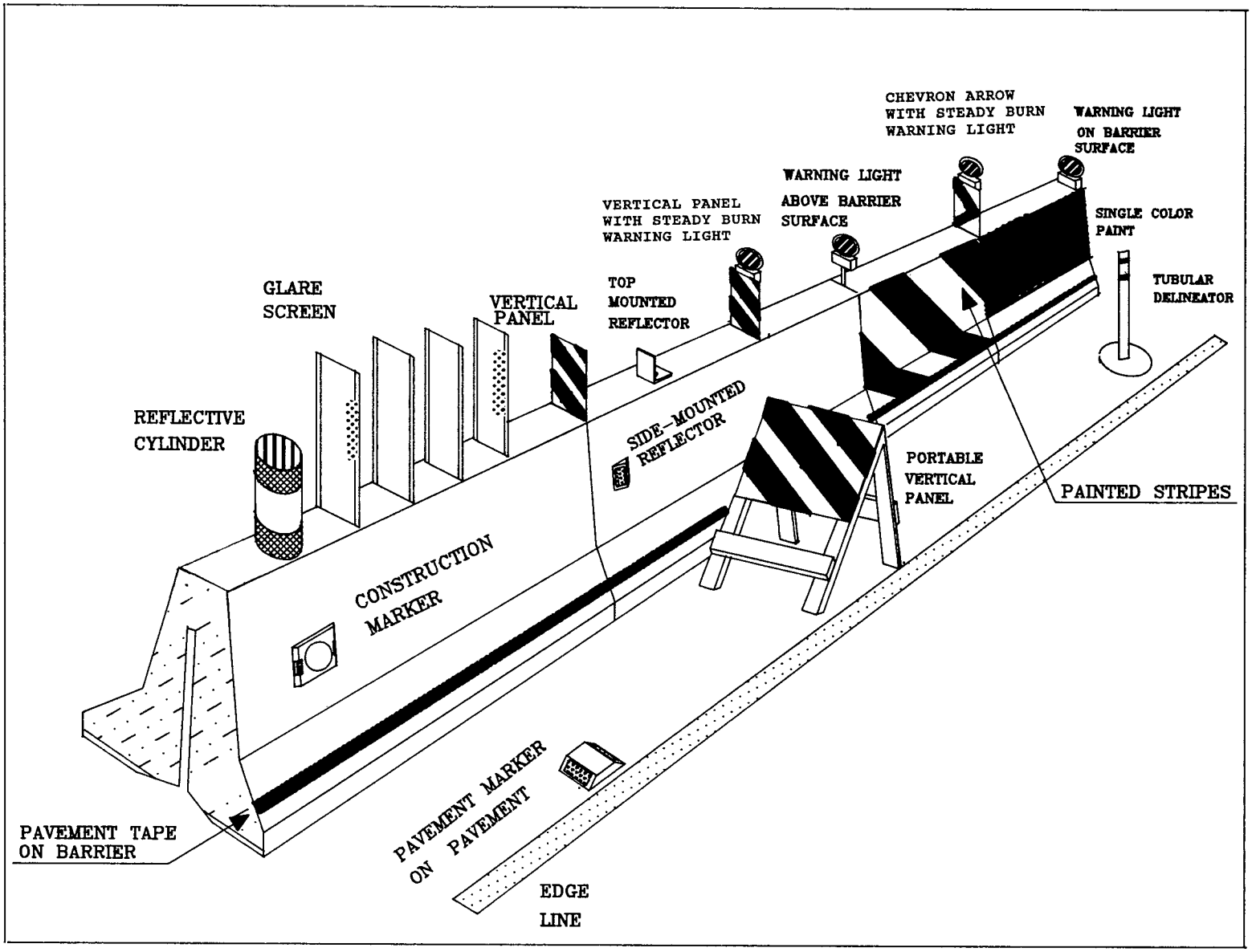


Figure 1. Sample of devices for delineating portable concrete safety-shaped barriers

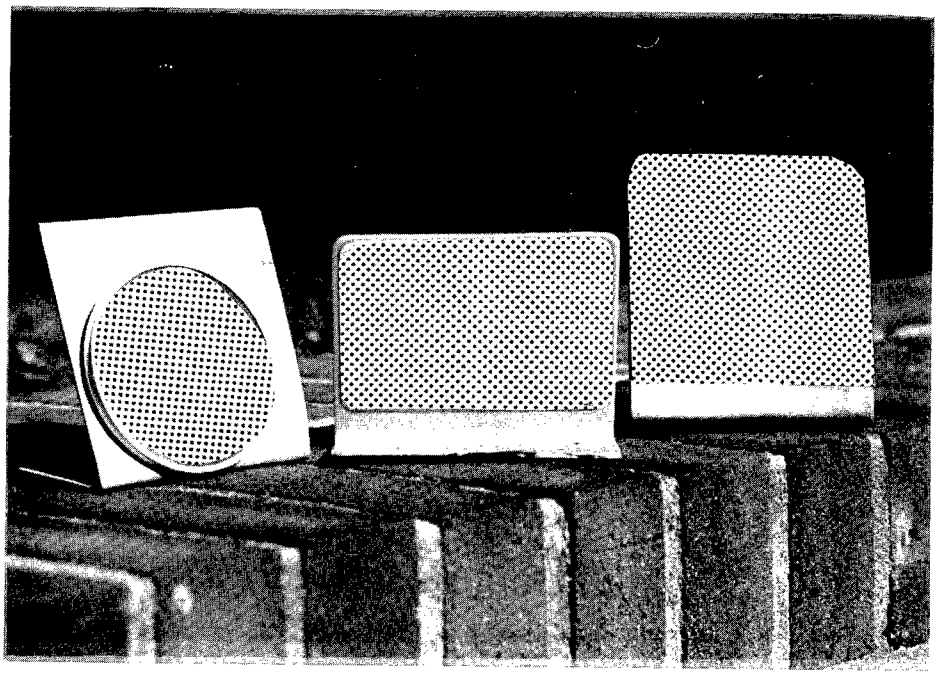
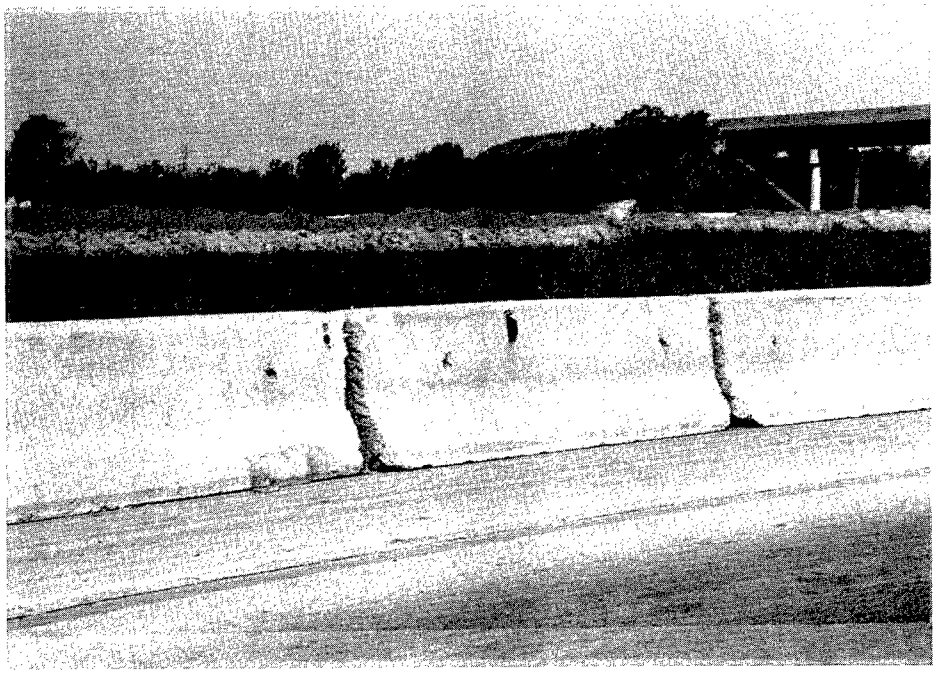


Figure 2. Sample of reflectors used on top of portable CSSBs



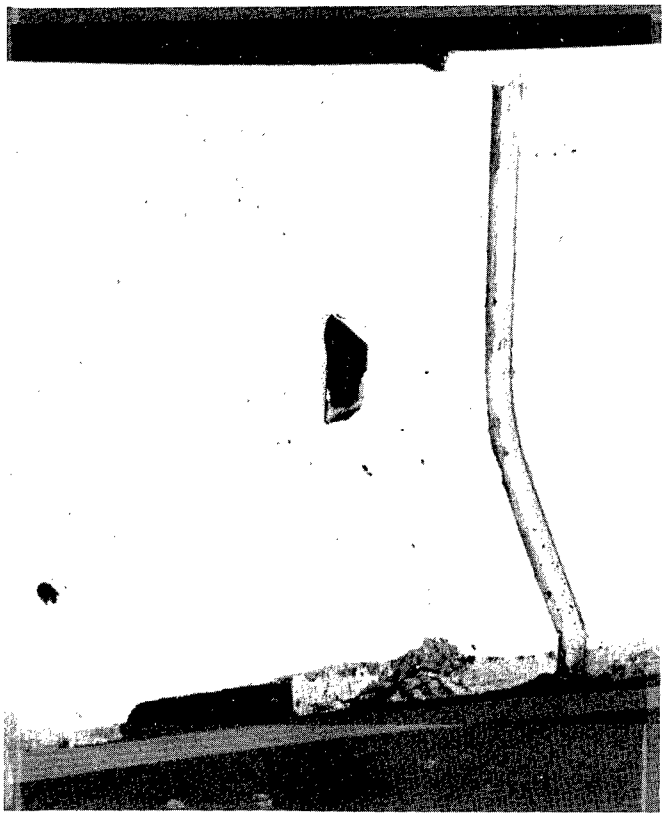
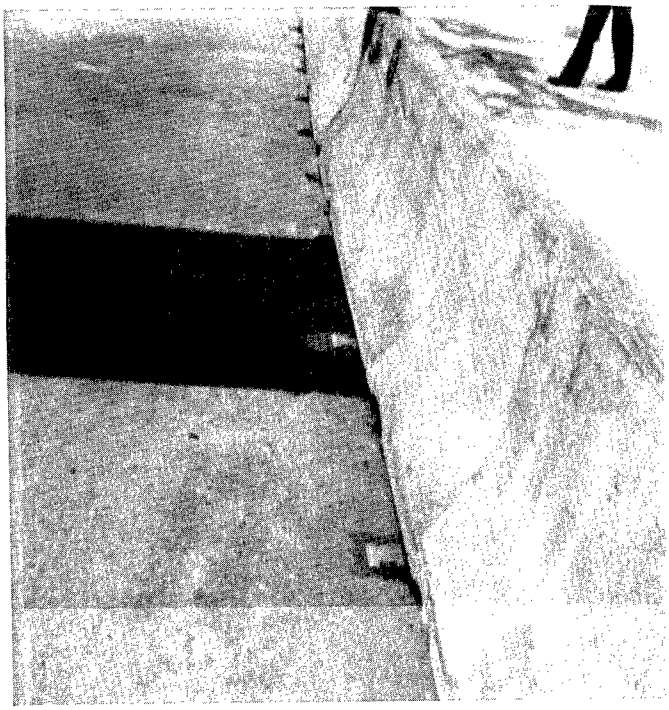
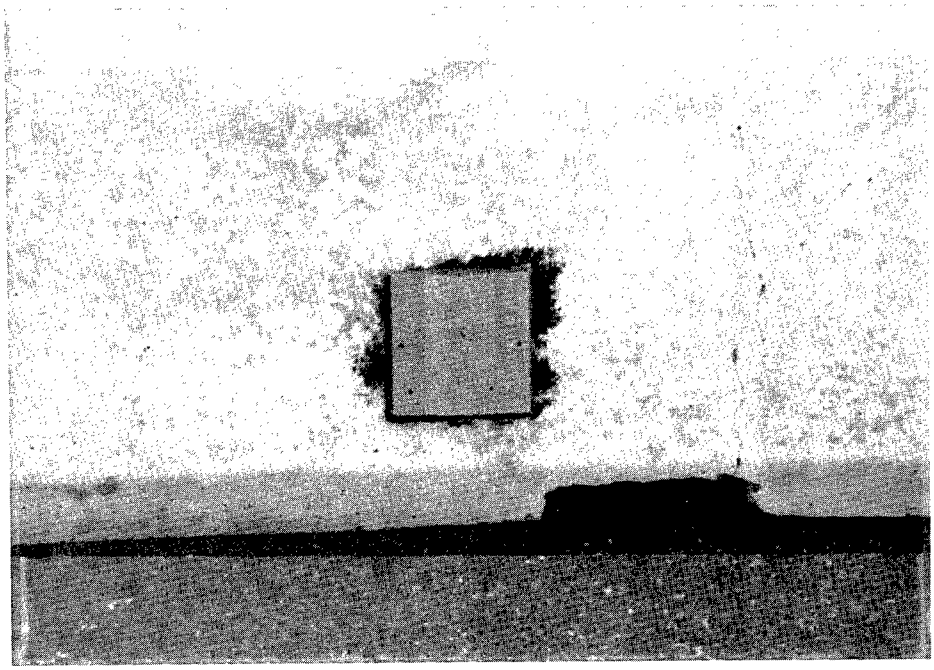


Figure 3. Side-mounted reflectors



Pavement marker on pavement close to barrier



Pavement marker on face of barrier

Figure 4. Delineating with pavement markers

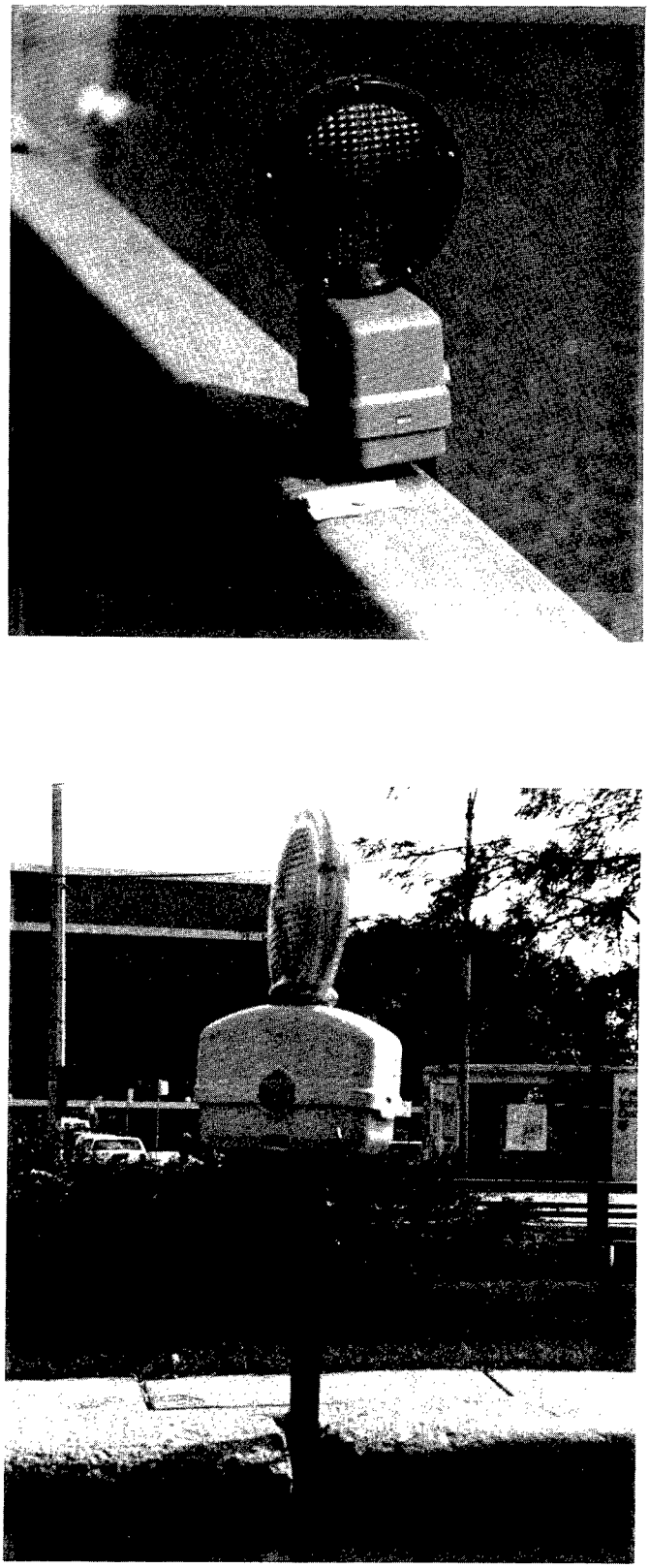


Figure 5. Warning lights on and above top surface of barrier

7. **Vertical Panels**. These panels are made of aluminum or plastic sheets about 5 to 12 inches wide and 10 to 48 inches high. They are generally covered with high intensity reflective sheeting. Color codes of panels used on top of or near portable CSSBs in work zones include 45 degree stripes in black and yellow or orange and white, solid yellow panels for barriers on the left, and solid white panels for barriers on the right. One study (9) recommended the use of yellow panels as a replacement for steady-burn lights in construction zones. Figure 6 illustrates the use of vertical panels.

8. **Chevron Arrows**. The black and yellow chevron alignment sign (12 inches by 18 inches) is approved for use outside of construction zones (Section 22C-10 of the MUTCD). However, this sign is often used to warn of major changes in roadway alignment through construction zones. See Figure 7. This practice is in violation of the MUTCD.

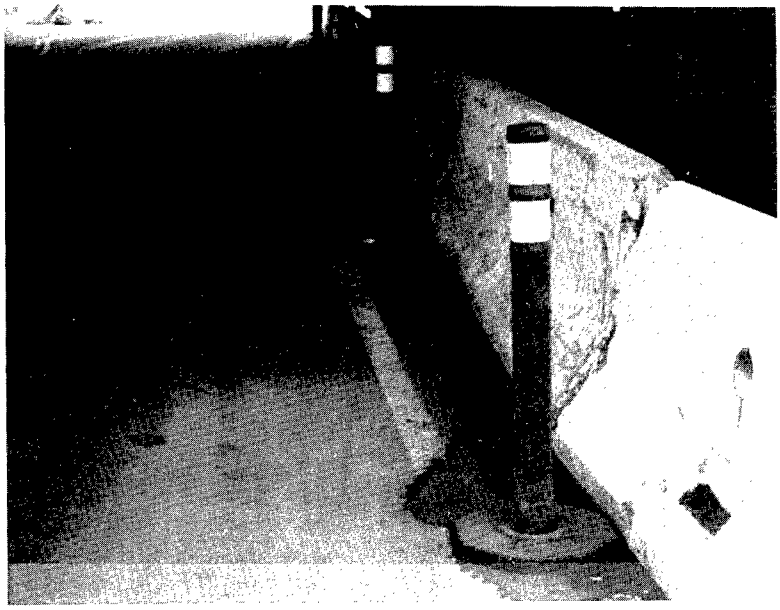
9. **Reflective Cylinders**. These cylinders are small plastic drums (typically 6 inches in diameter and 12 inches high) covered with high intensity reflective sheeting and mounted on top of portable CSSBs. Reflective cylinders have not been widely used in practice but have been the subject of several research studies (1, 2, 7, 10). The color code includes plain white as well as orange and white stripes.

10. **Pavement Marking Tape on Side of Barrier**. The placement of four-inch wide reflectorized pavement marking tape along the base of portable CSSBs has failed as an effective delineator. In his study of removable foil-backed tapes, Kahn (1) observed that the bond between the tape and the barrier failed within 24 hours.

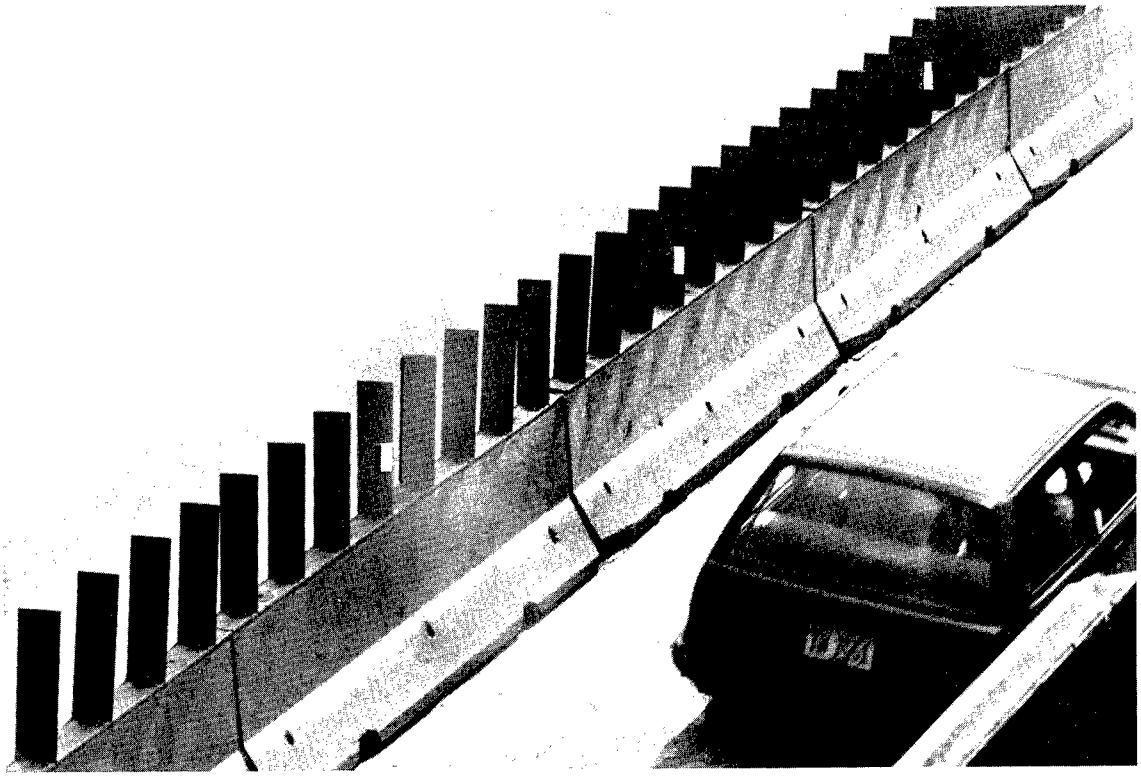
11. **Tubular Markers**. Tubular markers are primarily channelizing devices. Their minimum height is 18 inches, the width is variable. Their reflective qualities are described in Section 6C-3 of the MUTCD. Tubular markers are rarely used for delineating CSSBs. However, at an interchange construction site in California, orange tubular markers were used as barrier delineators. See Figure 8. They were placed between the right edge line and the portable CSSB. The two-lane underpass was naturally dark during the day, and the construction activity utilized both shoulders.

Figure 6. Delineating with vertical panels

Figure 7. Delineating with chevron arrows
(Application not recommended by the MUTCD)



Tubular markers



Glare blades

Figure 8. Delineating with tubular markers and glare blades

12. **Glare Blades**. The top surface of portable CSSBs is used for attaching several types of delineating devices. Devices for controlling glare from vehicle headlights and obscuring construction activities tend to monopolize this top surface area. Recently, attention is being focused on devices which will delineate portable CSSBs, channelize traffic, and obscure motorists' view of construction activities. Glare blades equipped with retro-reflective material (see Figures 8 and 9) appear to have these qualities. Modular assemblies of vertical blades have the potential for eliminating the tedious work of anchoring each glare blade in the field. Multi-blade sections can be assembled elsewhere and then transported to the work zones for mounting on barriers.

13. **Vertical Panels with Warning Lights**. Vertical panels with top-mounted steady-burn warning lights are approved in Section 6C-5 of the MUTCD as a nighttime channelization and warning option. This combination of vertical panel and steady-burn warning light was observed at a major interstate highway construction project in Chicago, Illinois. The devices were mounted on top of the portable CSSBs.

14. **Ground-Mounted Vertical Panel**. The vertical panel, mounted on a portable A-frame, was observed in use in front of portable CSSBs in the crossover area of a crossover detour on a limited-access four-lane divided roadway in Pennsylvania. The orange and white stripes on the panel aided channelization at night. See Figure 10.

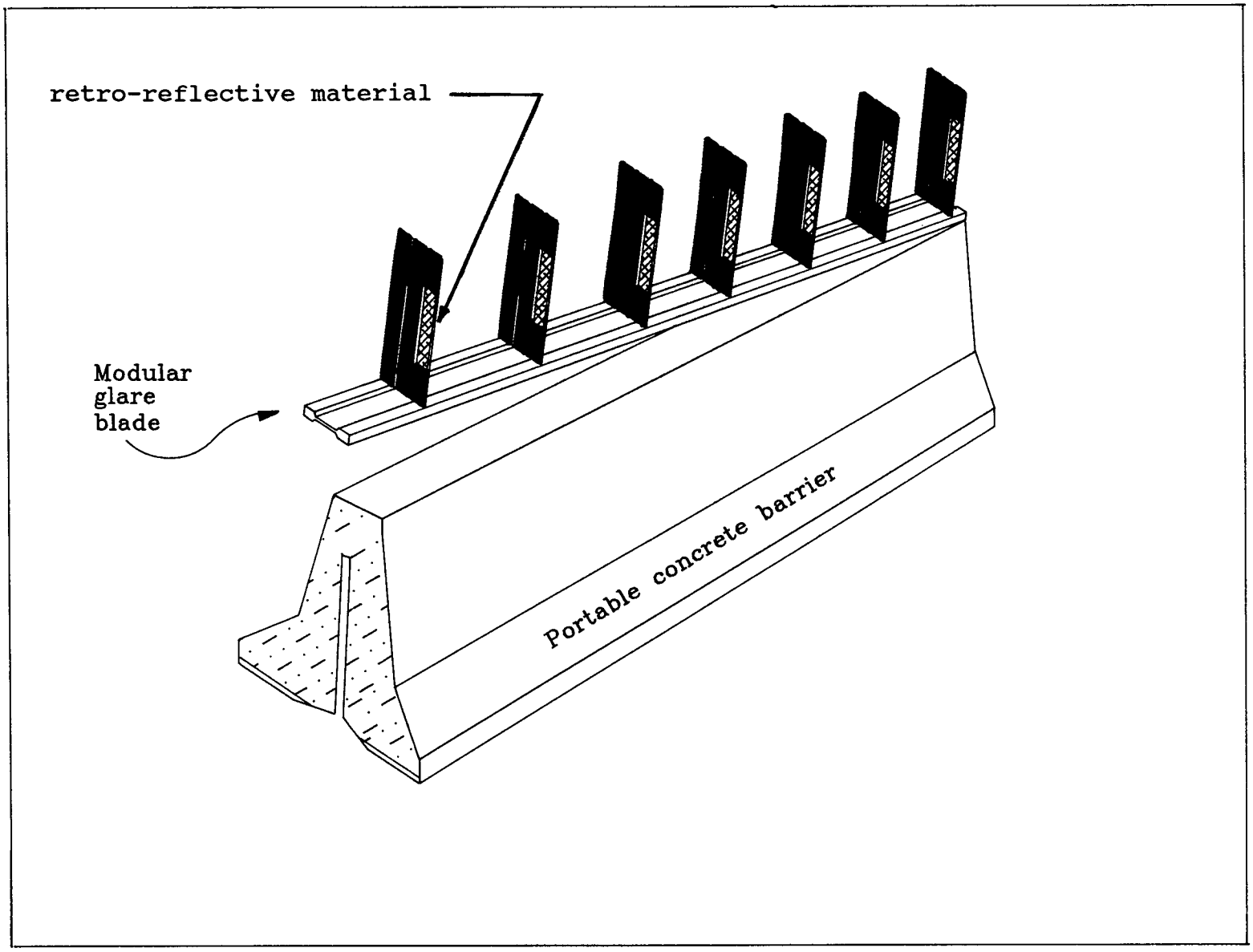


Figure 9. Modular glare blade segment with retro-reflective material

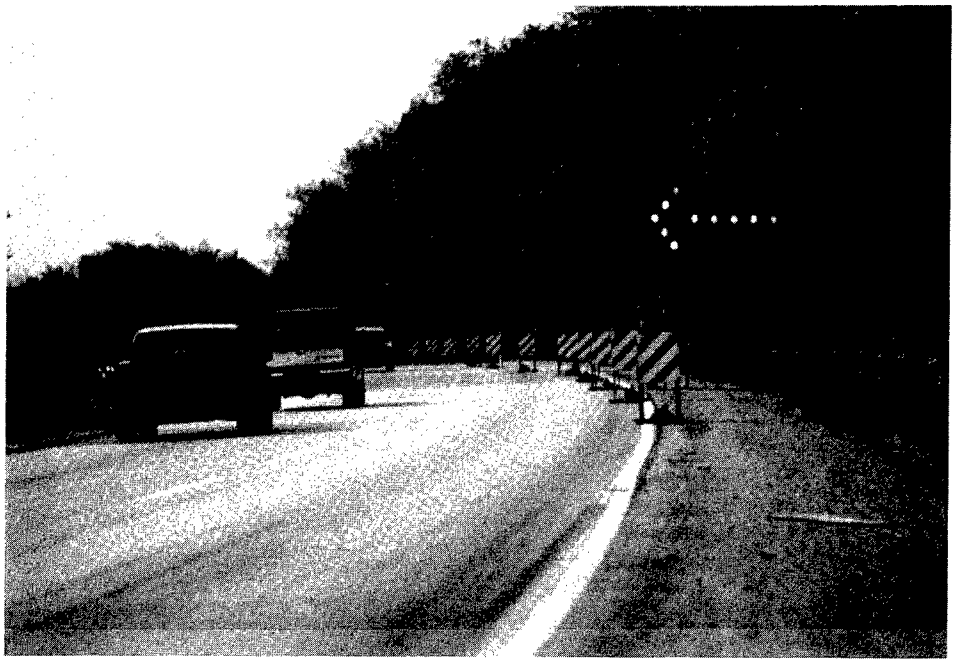


Figure 10. Ground-mounted vertical panels

II. RESEARCH FINDINGS ON BARRIER MOUNTED DELINEATORS

The long-term performance of various types of retro-reflective delineators for concrete median barriers was investigated by Mullowney (3, 10). Six different types of reflectors -- Reflexite, 3M BD-21, Stimsonite 975, Swareflex 3290, Stimsonite 2400, and Stimsonite 960 -- were installed on barriers on U.S. 1 in New Jersey and were observed over a 16-month period. Mullowney monitored the effects of weathering, destruction by debris and vandals, durability of mounting systems, effect of vertical placement, effects of opposing headlight glare, and visibility on wet nights. A team of drivers consisting of engineers, maintenance personnel, and individuals with quality control and research backgrounds rated the devices when they were new, after one winter, and after two winters of field exposure. Photometric measurements were also taken at the same intervals. Motion pictures provided additional opportunities for in-house staff of the New Jersey Department of Transportation to review the installations. The vertical positions of reflectors were at the top of barrier, on the side five inches from the top, and on the side 14 inches from the top. Among the findings: geometry, particularly left hand curves, restricted the visibility of side-mounted delineators; the reflectivity of all the devices, except the Stimsonite 975, remained adequate throughout the 16 months; and headlight glare can eliminate visibility of top-mounted reflectors. Headlight glare from a continuous stream of opposing traffic was observed to eliminate the visibility of long segments of delineators.

Mullowney (6) also studied the mounting and visibility of Swareflex 329 on top of concrete median barriers. The delineators were spaced at 80 feet on tangents and 40 feet on curves. The study team observed that the delineators were visible on right-hand curves, but left-hand curves reduced the driver's view of the delineators. Mullowney concluded that reflectors should be used in well-lit areas, and that vandal-resistant anchorage using nuts and bolts should be used in urban locations where unauthorized removal is a problem.

Davis (9) conducted field experiments to determine whether 5 x 10-inch yellow high-intensity retro-reflectors could be effective replacements for steady-burn lights. The average speed and vehicle speed variance were selected as performance measures in a before-and-after study. All devices were mounted on the top of the barrier. Davis found that at the 95 percent confidence level, the reflectors neither decreased the number of vehicles in the lane next to the barrier nor changed the average speed and variance. He concluded that yellow reflectors should be considered for use as a supplement or replacement for steady-burn lights on work zone barriers.

Bracket, et al. (11) in laboratory and proving ground studies evaluated ten methods for delineating concrete barriers in work zones. The delineators studied included top-mounted and side-mounted yellow and orange reflectors of various dimensions, cylinders covered with orange and white stripes, orange and white vertical panels, and a continuous 12-inch wide stripe painted on the side of barriers. In a preliminary screening, shoppers at a mall were asked to evaluate the devices by looking at photographs of proving ground installations. Based on interview responses Bracket, et al. identified the four delineation methods preferred by shoppers: 8 x 24-inch orange and white vertical panels with 100-foot spacing, continuous longitudinally painted stripes on barriers, 2 x 2-inch yellow side-mounted cube-corner reflectors attached 6 inches from the top and spaced at 50 feet, and 0.5 x 4-inch yellow side-mounted reflectors placed 6 inches from the top and spaced at 50 feet. These four methods were subsequently installed on barriers on a proving ground site, and 25 drivers were asked to drive the course and give their opinion of each treatment. Based on all responses, the 8 x 24-inch, orange and white vertical panel was rated to be the best by drivers.

Khan (1) evaluated the performance of six types of delineators mounted on portable CSSBs at four highway work zones in Ohio. The six delineators selected were:

1. the top-mounted Mini-Barrel (12 inches tall x 6 inches in diameter) wrapped by high intensity reflective sheeting and spaced at 25 feet;

2. the top-mounted Astro Optics J-D1 reflector (3 x 5.25 x 2.5 inches) spaced at 100 ft.;

3. the side-mounted Stimsonite Barrier Reflector (2.6 x 5.7 x 2.3 inches) spaced at 100 feet on tangents, 50 feet on curves of 3 to 5 degrees, and 25 feet on curves over 15 degrees;

4. Reflexite Guard Rail Delineator placed at eight inches above the pavement and spaced at 50 feet;

5. alternating system involving Astro Optics, Stimsonite and Reflexite reflectors at 50-foot intervals at a mounting height of 20 inches above the roadway, 6 x 27-inch hazard panels spaced from 48 to 60 feet, and

6. the Safe-T-Spin (4 x 7 inches) wrapped in reflective sheeting and spaced at 25 feet on curves and 50 feet on tangents.

Photometric measurements of retro-reflectivity were recorded. The study concluded that the Mini-Barrel and Hazard panel can provide adequate delineation, and that the Stimsonite, Astro-Optics, and Reflexite reflectors by themselves are not adequate

and should be used to supplement larger top-mounted delineators. As supplementary devices, these reflectors should not be spaced more than 25 feet apart in work zones.

Dowden (4) conducted a subjective evaluation of delineation methods applied to CSSBs at work zones in Iowa. Among the delineators studied were:

1. the Astro Optics mounted at two inches below the barrier top and spaced at 10 feet;

2. top-mounted orange and white hazard panels (8 inches by 24 inches) spaced at 100-foot and 150-foot intervals;

3. 12-inch wide continuous paint strip applied longitudinally on the vertical face of a barrier, white on the right and yellow on the left;

4. top-mounted (6 inches by 12 inches) reflective cylinder painted with four-inch horizontal orange and white stripes and spaced at 100 feet;

5. and the Safe-T-Spin, mounted on top and spaced at 100 feet.

Based on his night observations, Dowden concluded that the Astro-Optics and the cylinder gave the best visibility performance, and that hazard panels, cylinders, and the barrier tape might have value on barriers used in traffic diversions.

Ugwoaba (7) investigated the effectiveness of seven types of delineators installed on portable CSSBs on an interstate highway near Seattle, Washington. His field experiments included: Astro-Optics on the top of barrier, Reflexite on the top of barrier, reflective cylinders on the top of barrier, hazard panels, raised pavement markers on the side of barrier (12 inches above pavement), Astro-Optics on the side of barrier (26 inches above pavement), and Davidson markers on the edge line. Subject drivers negotiated the test section and subsequently indicated their preference. Eighty-eight percent, or 15 out of 17, of drivers preferred Astro-Optics placed on the side of the barrier. Installation time, luminance, and the effect of dirt and snow were also observed. Ugwoaba found that dirt accumulation on delineators decreases with increasing mounting height, that the effectiveness of delineators directly attached to the top surface of portable CSSBs is greatly diminished by headlight glare, and that the best placement of concrete barrier reflectors is on the sides. Ugwoaba recommended that the effect of snow, water, and headlight glare -- conditions under which the need for delineators is critical -- should be especially mentioned in the MUTCD.

Ullman and Dudek (2) conducted field evaluations of barrier-

mounted delineators in order to gauge the effect of mounting height, spacing, and dirt on driver performance and preference. Five high-occupancy-vehicle (HOV) barrier test sites on an illuminated freeway were studied over several months. The treatments involved the following:

1. top-mounted 3.25-inch diameter acrylic cube-corner lenses spaced at 200 feet;

2. the same device side-mounted and spaced at 50 feet;

3. top-mounted three-inch high-intensity reflective sheeting spaced at 50 feet;

4. side-mounted three-inch high-intensity reflective sheeting spaced at 200 feet;

5. and top-mounted three-inch diameter by six-inch high cylinders covered with high-intensity reflective sheeting.

The before-and-after study included time-lapse video recordings of traffic next to the barrier, visibility measurements, and drivers' evaluations of the delineators during clean and dirty conditions. Based on statistical analyses, Ullman and Dudek (2) found that none of the treatments adversely affected lane distribution, lane straddling, and lateral distance from the barrier during dry pavement conditions. However, drivers showed a marked preference for the side-mounted cube-corner reflectors spaced at 50 feet. Visibility measurements showed that the brightness of top-mounted delineators were less impaired by dirt accumulation. The top-mounted cube-corner reflector, spaced at 200 feet was indicated as being the most cost-effective treatment.

The aggregate findings within the literature clearly indicate that the proper placement of delineators on CSSBs in work zones is influenced by the following factors: drivers preference, glare, environmental conditions, and geometry. Use of supplementary delineation could eliminate such concerns as whether top-mounts are superior to side-mounts, or whether one reflector is superior to another. As will be shown later, several states use both top and side-mounted delineators on the same barrier. A few salient findings are as follows:

1. Delineator placement (height and spacing) is dependent on drivers' preference, glare, environmental conditions, and geometry.

2. Large delineators appear to be more effective than smaller ones but are not necessarily cost-effective.

3. Many of the retro-reflective delineators used in research have been determined to be more than

adequate. However, the cube-corner type of reflectors experienced less loss of reflectivity due to dirt accumulation during long-term exposure.

4. There is need for devices which can both delineate motorists path and control glare from headlights during long term installation.

5. Alternating top and side-mounted delineators could take advantage of their best virtues.

6. Delineators could be directly attached to CSSBs or placed in close proximity. They need not be four feet above the near edge of the roadway in order to be effective.

7. Delineators need periodic cleaning to maintain minimum driver visibility.

8. The availability of good nighttime illumination is not a rationale for avoiding use of delineators on CSSBs.

9. Closer spacing of delineators may be needed on curves which turn to the left; the smaller the radius the greater the need for reduced spacing.

10. Research involving the measurement of vehicle speed, lateral position, and lane distribution has not been conclusive about the selection and placement of delineators.

III. CURRENT PRACTICES

The MUTCD and the work zone traffic control manuals of several states (12, 13, 14) require portable CSSBs in night use to be delineated with "standard delineation or channelization markings or devices." What constitutes standard devices has not been defined. As a result, practitioners have not limited their choice of delineators to those mentioned in Part VI of the MUTCD, such as reflectors, warning lights, light-colored barriers, and vertical panels. Apparently, practitioners are aware that delineation, as presented in Part VI of the MUTCD, is based on experience with roadway delineation in non-work zones. Thus, plain vertical panels -- white for the right edge and yellow for the left -- pavement markers, the chevron arrow sign, painted barriers, reflective cylinders, warning lights, and cube-corner reflectors directly attached to the barrier surface have emerged as standard devices in some states. This section discusses the delineation practices of ten States: New Jersey, Ohio, Colorado, Maryland, California, New York, Virginia, Illinois, Pennsylvania, and Michigan. Delineation devices used by these states are indicated in Table 1 and are based on interviews with state and city officials, a review of state standards, and field observations by Daniel Consultants, Incorporated.

A. Delineators for Portable CSSB

1. **Warning Lights**. All the states visited allow the use of warning lights alone or warning lights together with auxiliary channelization or hazard marking devices. Type C steady burn warning lights are generally applied along transition areas and on flared and longitudinal segments. Type A and Type B flashing warning lights have been reserved for identifying hazards such as barrier terminals, impact attenuating devices, and points where barrier tangents intersect. Maryland often uses two Type A flashing warning lights at the approach terminals of portable barriers and Type C warning lights on other segments as suggested by the MUTCD. The other states are less consistent in the use of Type A and Type B flashing warning lights. Virginia uses the Type A flashing light to alert motorist to the hazard point created by the intersection of the flared and tangent sections of portable CSSBs. The cost of purchasing and maintaining warning lights has stimulated interest in less expensive delineation systems such as retro-reflectors.

Table 1. Delineators used by several states

Concrete Barrier Delineators	States										
	VA	MD	CA	NY	IL	MI	PA	NC	CO	OH	NJ
Types A and B warning lights	*	*			*	*	*			*	*
Type C warning lights	*	*		*	*	*	*			*	*
Retro-reflective delineators	*	*	*	*	*	*	*	*	*	*	*
Orange and white vertical panels	*				*	*	*				
Chevron Arrow	*				*						
Tubular Cones			*								
Paint		*	*	*					*		
Modular glare blades			*	*							
Pavement markers				*							
Reflective tapes				*		*					
Reflective cylinders								*		*	
Chevron Arrow with Type A warning light	*										
Alternating Chevron Arrow and Type C warning light	*										
Alternating vertical and Type C warning light	*										
Alternating Type C lights and reflectors		*					*				
Vertical panel with Type C warning light					*						
Alternating top-mounted and side-mounted reflectors		*								*	

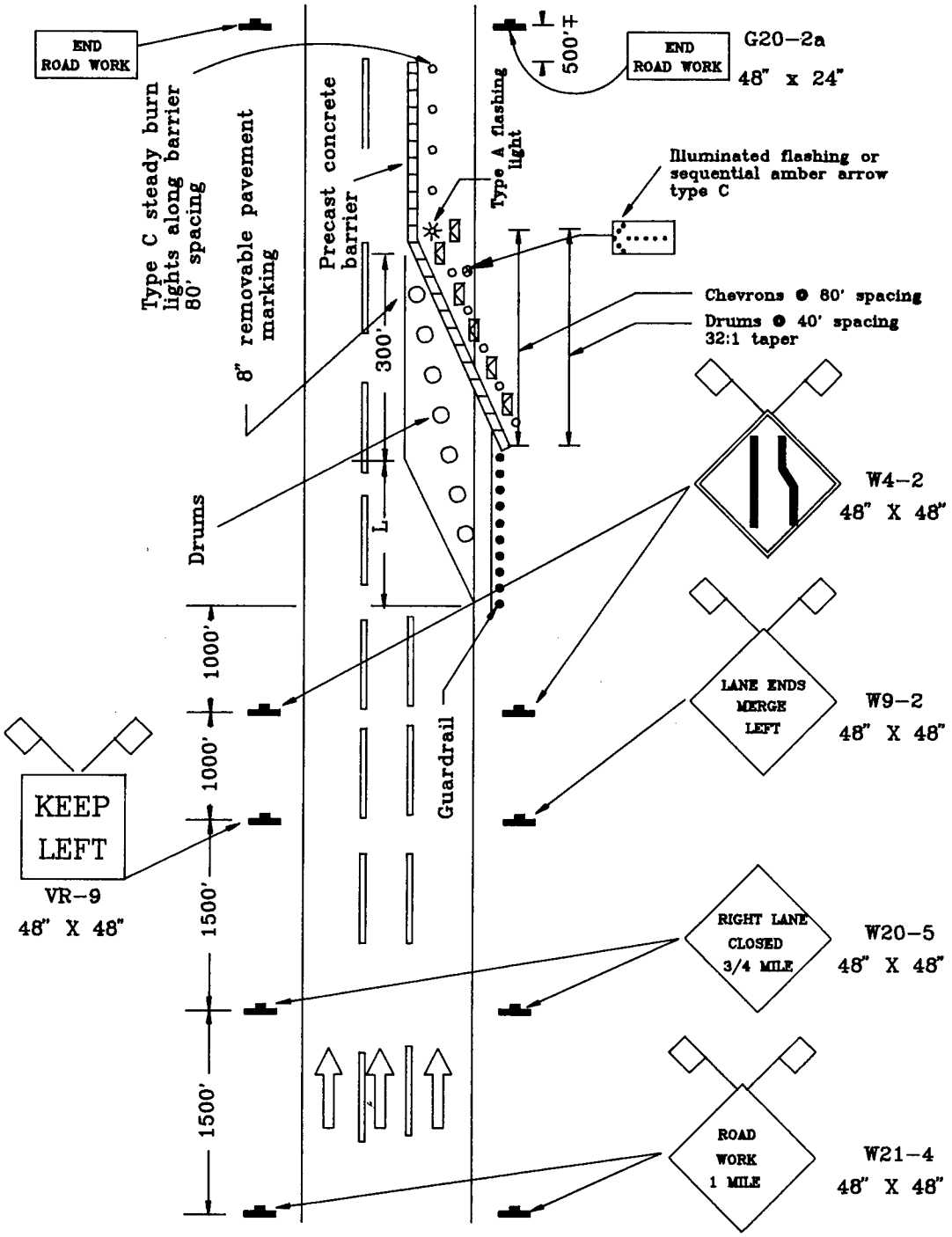
Legend: VA, Virginia; MD, Maryland; CA, California; NY, New York; IL, Illinois; MI, Michigan; PA, Pennsylvania; NC, North Carolina; CO, Colorado; OH, Ohio; NJ, New Jersey

2. **Cube-Corner Reflectors**. This group constitutes several brands of acrylic cube-corner retro-reflectors of either circular or trapezoidal shapes which are attached to the side or top of CSSBs. These reflectors are used alone as well as in conjunction with other channelizing devices.

3. **High-Intensity Sheeting Reflectors**. There is an increasing trend toward greater use of this type of device. The comparatively low acquisition and maintenance cost is the primary reason for this trend. North Carolina has been using high-intensity sheeting on both cylindrical and rectangular delineators for CSSBs. Virginia and New Jersey have experimented with high-intensity sheeting as a selective replacement for warning lights. On recent contracts where portable CSSBs are to be installed, New Jersey has required contractors to use 6-inch by 12-inch reflectors made of either white or yellow high-intensity reflective sheeting. These reflectors can be customized by any jurisdiction which purchases material for their assembly. Reflective sheeting is the predominant type and is cut to match the size and shape of aluminum attachment plates or cylinders. The minimum dimension is three inches. Those used in North Carolina are approximately four inches wide by 8 to 10 inches high. The yellow and white color codes match the edge lines.

4. **Vertical Panels**. These are rectangular plates with orange and white diagonal stripes and a minimum width of eight inches and minimum height of two feet. The predominant use of vertical panels in work zones is for identifying hazard points such as barrier terminals and impact attenuation devices. Virginia uses vertical panels for that purpose as well as to delineate transition tapers. Michigan and Illinois found it effective to use vertical panels on flares, transition areas, and longitudinal segments of CSSB sections. Illinois and Virginia often attach warning lights to vertical panels.

5. **Chevron Arrow Sign**. This black and orange sign (24 inches by 30 inches) has been observed in the field in Illinois and is officially incorporated in the Virginia Work Area Protection Manual (13). Virginia uses the chevron arrow sign at breakpoints and along barrier segments located across closed lanes. See Figure 11. Field installations in Illinois have been limited to barriers along the taper for closed lanes on freeways. Although the chevron arrow was not observed on portable CSSBs in California, it is included among the standard work zone signs for that



Source: (13)

Figure 11. Chevron arrows on portable concrete safety-shaped barriers

state (12) without illustrating application.

6. **Modular Glare Blades**. The modular design of glare blades facilitates the installation of glare blades in sets on top of CSSBs. See Figure 9. Illinois and New York are among the states which have found these devices to be effective in controlling glare from vehicle headlights. Virginia, Michigan and New Jersey have expressed interest in modular glare blades. Virginia has many non-modular installations of glare control devices on its Interstate highway system.

7. **Pavement Markers**. This is not a popular practice. Delineation with pavement markers placed at the base of portable CSSBs was observed in New York. As indicated in Figure 12, the markers are attached to the barriers and are spaced at approximately five feet.

8. **Painting**. Painting the CSSB is supplemental to the use of other delineation devices. Painting has not evolved as a routine practice even within states such as Maryland and New York where painting is an accepted practice. Colorado paints barrier terminals in orange and white stripes. Diagonal orange and black stripes were applied to some barrier approach terminals in New York. Maryland has adopted the use of a reflectorized white pigment for all CSSB segments. Field observations in Maryland indicate that this has not become a routine practice.

9. **Combination of Delineators**. To increase visibility at night and to minimize the possibility of devices being made ineffective by glare and dirt, many states have allowed use of supplementary delineators. In Maryland it is a popular practice to alternate top or side-mounted reflectors and warning lights. Vertical panels or chevron arrows are alternated with warning lights in Virginia. Ohio uses supplemental top-mounted cylindrical reflectors (6 inches in diameter and 12 inches high) between side-mounted reflectors. In Illinois, warning lights are routinely attached to vertical panels. In addition, segments of barrier sections may be treated with different delineators, for example, vertical panels on tapers and warning lights along longitudinal segments. Special barrier hazard points are often marked with paint, flashing warning lights, and vertical panels, while reflectors and steady-burn lights command other segments of a CSSB section.

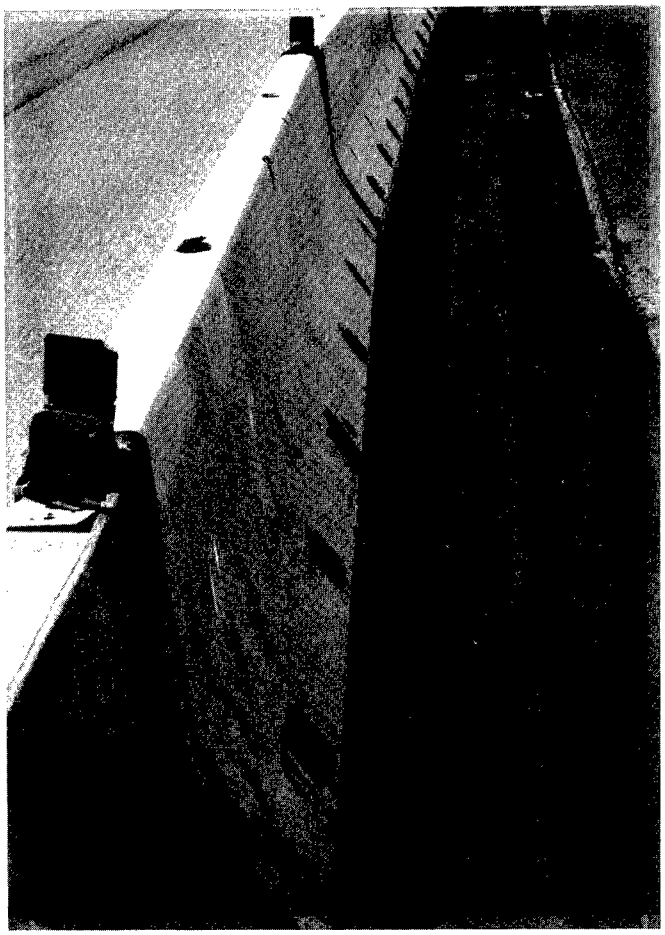


Figure 12. Pavement markers attached to base of portable CSSBs

B. Placement of Delineators on Portable CSSB

1. **Spacing of Delineators**. The information provided by the states clearly shows that they have adopted the broad minimum standard on reflector spacing as presented in Section 6D-2 of the MUTCD. That section recommends spacing delineators such that several are always visible to drivers. However, field practice and standard drawings in the work zone traffic control manuals in some states (Illinois, Ohio, and Virginia, for example) indicate a trend in using specific separation distances depending on the type of device and the site geometrics. Ohio requires 100-foot spacings for barrier reflectors on curves greater than five degrees, and reflectors must be placed on tangents such that several can be seen. Illinois recommends 50 to 100-feet spacing for vertical panels, and chevron signs, but follows MUTCD broad guidelines on the spacing of reflectors and warning lights. Virginia uses 80-foot spacing for Chevron signs, vertical panels, and Type C steady-burn lights with placement such that several devices are always visible to drivers. If the portable CSSB is within ten feet of the pavement edge, California recommends delineation using MUTCD guidelines. Maryland adopted the MUTCD guidelines, but its spacing of reflectors and warning lights is generally less than 75 feet on tangents and less than 50 feet on flared and transition segments of portable CSSBs. The large reflector paddles (6 inches by 12 inches) used by New Jersey are spaced at 100-foot intervals on portable CSSBs, except on curved segments with a radius less than 1910 feet where a 50-foot spacing is applied. Michigan claims great satisfaction with large high-intensity reflector paddles spaced at 100-150 feet on tangents, five feet on flared segments and on curves sharper than 30 degrees, and 25 feet on curves flatter than 30 degrees. Michigan also uses reflectors and steady-burn warning lights spaced at 20-30 feet, vertical panels spaced at 50 feet, and cube-corner reflectors spaced at 100-150 feet. New York uses steady-burn lights with 50 to 100- foot spacing and has joined other states in reducing the use of steady-burn lights. Several brands of reflectors are used by the State of New York. They are spaced at 10 to 20 feet on sharp curves and 50 to 100 feet on tangents. Pavement markers attached to portable CSSBs are spaced at five feet. Pennsylvania makes intensive use of steady-burn warning lights spaced at 50 to 80 feet. The spacing of reflectors is variable. Vertical panels spaced at 30 feet are often used along with portable CSSBs in crossover areas. Variations in spacing of devices for

delineating portable CSSBs are presented in Table 2.

2. **Mounting Height of Delineators**. Table 2 indicates that the placement of delineator devices on top of the barrier rather than on the side is the predominant practice among the ten states reviewed. Devices such as cylindrical reflectors, vertical panels, warning lights, chevron arrows and large reflective paddles are naturally too cumbersome for side mounting and are generally attached to the top of barriers. However, Type C warning lights are not always directly attached to the top surface of CSSBs. In Michigan, Type C lights are often attached to extended vertical supports as indicated in Figure 5. In Illinois they are attached to the top of vertical panels (see Figure 13). In Virginia, they are attached to the top of chevron arrows. It should be noted that the height of CSSBs is 32 inches, and that reflectors attached to the top surface range in height from 32 to 36 inches above the near edge of the roadway, as opposed to the general mounting height of four feet required by Section 6D-2 of the MUTCD.

   Current Ohio Department of Transportation specifications require delineators on portable CSSBs to be side-mounted at 26 inches above the rear edge of the pavement and not less than three inches below the top. Maryland and Pennsylvania often apply delineators to the top and two-to-four inches below the top of the barrier. Figure 14 illustrates the practice in Maryland and Pennsylvania of alternating top-mounted Type C warning lights with side mounted reflectors. There is a lingering uncertainty regarding the comparative long-term effectiveness of top and side-mounted reflectors. Practitioners are aware of the glare problem which is more severe with top-mounted reflectors and the tendency of side-mounted delineators to be covered with dirt and snow. A compromise is the joint use of side and top-mounted delineators. Alternating top-mounted and side-mounted reflectors is practiced in Maryland and Ohio. Ohio alternates top-mounted cylindrical reflectors with side-mounted reflectors. New York allows use of top-mounted reflectors and pavement markers attached to the base of portable CSSBs (see Figure 12).

   The information presented above reflects the more common practices of the states reviewed and should not be construed as the only practice in any of the states. Very often the choice of delineation devices used on portable CSSBs is determined by contractors and district engineers on a project-by-project basis. Autonomous jurisdictions usually establish their own

Table 2. Spacing and position of delineators on portable CSSBs

State	Device	Spacing	Position on Barrier
CA	Reflectors	MUTCD	Top
VA	Chevron arrow	80 ft.	Top
	Type C Warning lights	80 ft.	Top
	Vertical panel	80 ft.	Top
	Reflectors	MUTCD	Side
OH	Reflectors	100 ft., curves less than 5 degrees. 50 ft., curves greater than 5 deg. MUTCD	Top/Side
NJ	Type C Warning lights	20-100 ft.	Top
	Reflector paddles	100 ft. on tangents	Top
		50 ft. on sharp curves	Top
IL	Type C Warning lights	20-100 ft.	Top
	Reflectors	MUTCD	Top
	Vertical Panels	50-100 ft.	Top
	Chevron arrow	50-100 ft.	Top
MI	Reflectors	20-150 ft.	Top
	Reflective paddles	5-150 ft.	Top
	Type C Warning lights	20-50 ft.	Top
	Vertical panels	50 ft.	Top
PA	Type C Warning lights	50-80 ft.	Top
	Reflectors	40 ft.	Top/Side
	Vertical panels	40 ft.	Base
MD	Reflectors	50-80 ft. less than 50 ft. on sharp curves.	Top/Side
	Type C Warning lights	30-80 ft. less than 50 ft. on sharp curves.	Top
NY	Type C Warning lights	50-100 ft. on flat curves/tangents. 10-20 ft. on sharp curves.	Top
	Pavement markers on barrier	4-6 ft.	Base

Legend: CA, California; VA, Virginia; OH, Ohio; NJ, New Jersey; IL, Illinois; MI, Michigan; PA, Pennsylvania; MD, Maryland; NY, New York; MUTCD, Reference No. 5

Figure 13. Combined use of warning lights and vertical panels

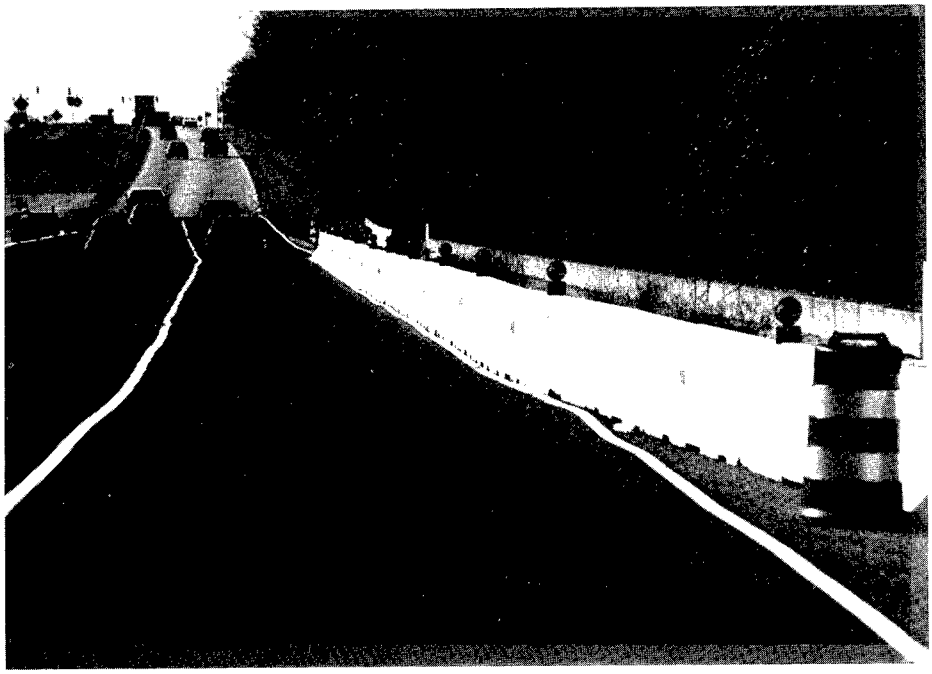


Figure 14. Delineating portable CSSBs with warning lights and side-mounted reflectors

standards for highway work zones under their control.

Moreover, it is not uncommon to find different brands and applications of delineators on similar work zones in different sections of the same highway within the same highway district.

There is a strong preference for top-mounted devices. This practice evolved out of logistical problems in maintaining side-mounted delineators. Officials claim that these delineators are difficult to access for maintenance and tend to require more service than top-mounted devices. A less common practice is the use of side-mounted delineators to supplement top-mounted devices. Most of the officials have high praise for the effectiveness of Type C steady burn warning lights, but their installation and maintenance costs have generated a trend toward greater use of passive reflective devices. Virginia Department of Transportation is conducting a study on passive alternatives to Type C steady-burn light on portable CSSBs. Preliminary results of that research, which is not yet published, indicate that vertical panels are as effective as Type C steady-burn lights.

IV. ASSESSMENT

A. Research on delineators for portable CSSBs has identified the need for considering glare, environmental conditions, maintenance logistics, cost, and geometrics in their selection and placement. Headlight glare over portable CSSBs on the median decreases the ability of motorists to recognize top-mounted delineators. The MUTCD makes no reference to this glare problem. Although the vertical panel is approved in Section 6C-5 of the MUTCD, its potential as a glare control device, when used in a closely-spaced series, has not been noted. Practitioners are responding to the glare issue through the use of special screens, large-area and closely-spaced delineators on top of barriers, and by combining top and side-mounted devices such as Type C steady-burn warning lights with side-mounted and top-mounted reflectors. While there is a need for devices which control glare by blocking light, the cost of acquisition, maintenance, and removal makes them practical for only certain hazardous locations.

B. Section 6C-10 of the MUTCD makes reference to standard delineators which are not usually attached to portable CSSBs. The practice and research are supportive of direct attachment of delineation devices to portable CSSBs, and there is no evidence that such attachments are unsafe. There is an implied assumption on the part of researchers and practitioners that direct attachments of delineators to portable CSSBs is the most practical method.

C. The practice and research indicate a wide range in the mounting heights of delineating devices for CSSBs. The stipulated delineator height of four feet above the rear edge of the roadway, as indicated in Section 6D-2 of the MUTCD, has been ignored by researchers and practitioners. The standard portable CSSB is 32 inches high. Barrier-mounted delineators have been demonstrated to be effective. There is a potential glare problem if all retro-reflectors for delineating portable CSSBs are restricted to a height of four feet. The MUTCD is not in step with this concern.

D. Section 6D-2 of the MUTCD presents a restrictive definition of delineators as being primarily reflector units. The research and practice have included signs, lights, markings, paddles, glare blades, etc. and have opened the possibility for delineators to be given color codes which do not follow those for the left and right edge lines. The practical concept of what constitutes a delineator for portable CSSBs is much broader than that presented in the MUTCD.

E. The MUTCD limits the option of using Type A flashing warning lights to the first two lights of a continuous barrier section (Section 6C-10). Virginia has found the intersection of tapers and longitudinal segments of portable CSSBs to be particularly hazardous and in need of special markings. The chevron arrow and Type A flashing warning light are used for this purpose. Officials believe that these special markings present strong visual guidance to motorists.

F. The MUTCD guidelines in Section 6D-2 state that delineators should be spaced such that several are always visible to drivers. This guideline allows for shorter spacing on curves of short radius and longer spacing on large radius curves and tangent sections. There is no consensus among practitioners or researchers regarding the optimum spacing of delineators with respect to glare, environmental conditions, geometrics, and type of devices. Spacing is critical for small reflective devices. These devices are relatively inexpensive and are more likely to be used by contractors. The maximum spacing used in practice is about 150 feet. In one research project (2) drivers showed a preference for 50- foot spacing. Moreover, very short spacing on tangents could contribute to reflective glare from wet pavement at night. Until the optimum spacing of delineators is addressed by research, the visibility guidelines in the MUTCD may be modified to indicate that they also apply during headlight glare conditions.

G. The pattern for the diagonal stripes of right and left vertical panels as presented in Section 6C-5 of the MUTCD is generally followed by the states. However, the language of the MUTCD is not mandatory with regard to the usage of specific panels. Unlike other mandatory applications, the word "shall" has been erroneously excluded.

H. Warning light vandalism was identified as a serious problem in freeway work zones in high-density residential areas. Efforts to decrease unauthorized removal of these devices by strengthening the attachment system with bolts, screws, and strong cements have not reduced the extent of deliberate damage. Since contractors are often required to maintain these devices, the cost of material and labor associated with replacement has stimulated interest in delineation devices which are less attractive to vandals. Vertical panels and large-area reflector paddles have some potential for being effective delineators and for discouraging vandals.

I. Section 6D-2 of the MUTCD establishes the dimension of the reflective element of delineators to be approximately

three inches. Since this is a minimum measure the use of the term "approximately" accommodates devices with minimum dimension of even 2.5 inches. One popular reflector has a minimum dimension of 2.3 inches and an area of 7.5 square inches. California has selected three inches as the minimum dimension for reflectors. Ohio specifies a minimum area of seven square inches. There is uncertainty about whether a single dimension is sufficient for defining the minimum size of reflectors. A combination of one dimension and an area appears to be a good compromise. Manufacturers are already providing this type of information.

J. Section 6C-10 of the MUTCD stipulates that portable CSSBs must be delineated with standard delineation and channelization markings or devices at night. Although what constitutes these standard devices is not specified in the MUTCD, they can be assumed to be those mentioned in Part VI; that is drums, cones, lights, reflectors, vertical panels, and barricades. The emerging interest in large reflectors warrants a broader definition of standard devices to include devices that can be customized using high-intensity reflective material.

K. Increasingly, portable CSSBs are being used on local projects in high-density urban areas where it is impractical to install tapered barrier segments because of the proximity of intersections, driveways, bus stops, etc. Hence, it is not uncommon to find deployments of short sections of portable CSSBs comprising less than three segments. Urban usage of CSSBs is often for the protection of pedestrians. Typical work zones include pavement and sidewalk repair and building construction. Local officials rely on the MUTCD, but the MUTCD has not yet addressed the delineation needs for portable CSSBs on city streets. There is a misconception among city officials that there is no need to delineate portable CSSBs on local projects because of existing street lights and other urban illumination. There is also some doubt that standard barrier delineation devices are appropriate for application in central business districts. Painting portable CSSBs in stripes and the use of flashing warning lights and construction ribbons are sporadic practices.

L. The loss of reflector brightness caused by dirt is a continuing problem on CSSBs in work zones.

V. CONCLUSIONS

A. Deficiencies in the MUTCD guidelines for selecting and applying delineators on portable CSSBs are recognized by state highway officials. The need for reducing the risk of work zone accidents is the primary reason for the sustained interest in improving delineation practices. Some states are making an effort to improve practices by trial-and-error.

B. Attempts to improve delineation practices are not well coordinated and are guided by experiences within each state. As a consequence, practices vary in each state.

C. Many states have not developed guidelines for portable CSSB delineation beyond those in the current MUTCD; they allow delineation determined on a project-by-project basis within each administrative district. This has resulted in non-uniform practices within such states.

D. There is variety in the choice of devices for delineating portable CSSB, but there are no well developed guidelines on their selection and application.

E. Officials of local jurisdictions are least aware of the need for barrier delineation and stand most to gain if the MUTCD guidelines are improved.

VI. RECOMMENDATIONS

A. In Part III of the MUTCD there is need for a qualifying statement indicating that Section D does not apply to work zones.

B. Section 6E-5 of Part VI of the MUTCD deals with warning lights. There is need to note that these devices can be used to delineate standard portable CSSBs and can be attached directly to the top surface of such barriers.

C. Section 6D-2 of Part VI of the MUTCD needs to be amended to:

1. Devise delineators to include the broad types of devices used to delineate portable CSSBs. The definition should also cover devices that may be made from reflective sheeting such as cylindrical reflectors and paddles.

2. Mention specific delineation devices that may be applicable to portable CSSBs in order to clarify the meaning of standard devices.

3. State mounting height options for various delineators on portable CSSBs.

4. Discuss glare in terms of safety, barrier alignment, and position of delineators on barrier.

5. Revise the minimum dimension standard of three inches so that it would apply to cube-corner reflectors and specify some minimum area for the reflective surface: 7.5 square inches may be appropriate.

6. Discuss the effect of dirt on delineators and the need for periodic washing.

D. A typical drawing of a standard portable CSSB should be included in Section 6C-10 of Part VI of the MUTCD. This drawing should include dimensions and positioning for top and side-mounted reflectors.

E. Section 6C-10 should make reference to Section 6D-2 for description of standard delineation devices applicable to work zones.

F. Section 6D-2 should clarify the concept of spacing delineators for better visibility. Factors that influence spacing need to be mentioned. A numerical guideline on

the maximum spacing for particular classes of delineators is recommended. There is a need for further human factors research to establish numerical guidelines on spacing. In the interim, a maximum spacing of 80 feet could be applied.

G. There is need for research to evaluate the effectiveness of chevron arrow signs and the combined use of Type A flashing warning light and chevron arrow or vertical panel to highlight hazardous areas along portable CSSBs.

H. There is need for research on the use of portable CSSBs in downtown areas and their appropriate delineation. Current literature does not cover these subjects.

LIST OF REFERENCES

1. Khan, M. M., Evaluation of Delineation Systems for Temporary Traffic Barriers in Work Zones, Contract DOT-FH-11-8561, Ohio Department of Transportation, Columbus, Ohio, December, 1985.

2. Ullman, G. and Dudek, C. L., "Delineation of Concrete Safety Shaped Barriers," Paper presented at the 67th Annual Meeting of the Transportation Research Board, Washington, D.C., January, 1988.

3. Mullowney, W. L., "Evaluation of Delineation Systems for the New Jersey Barrier," Transportation Research Record No. 681, Transportation Research Board, Washington, D.C., 1978.

4. Dowden, H. E., Evaluation of Delineation System for Temporary Traffic Barriers in Work Zones, Report No. FHWA-TS-86-XX, Federal Highway Administration, Washington, D.C., December, 1985.

5. Manual On Uniform Traffic Control Devices for Streets and Highways, Federal Highway Administration, Washington, D.C., 1978.

6. Mullowney, W. L., New Jersey Concrete Median Barrier Delineation, Report No. FHWA/NJ-80/007, Federal Highway Administration, Trenton, New Jersey, October, 1979.

7. Ugwoaba, G. U., Evaluation of Delineation Systems for Temporary Traffic Barriers in Work Zones, Report No. WA-RD-115.1, Washington State Department of Transportation, Olympia, Washington, May 1987.

8. Evaluation of Delineation System for Temporary Traffic Barriers in Work Zones, Iowa Department of Transportation, Contract No. FH-11-8559, Federal Highway Administration, Washington, D.C., 1985.

9. Davis, T. D., "Construction-Zone Delineation," Transportation Research Board No. 811, Transportation Research Board, Washington, D.C., 1981.

10. Mullowney, W., Concrete Barrier Visibility Study, Report No. FHWA/NJ-80/002, Federal Highway Administration, Washington, D.C., January, 1978.

11. Brackett, R. Q., et al., Delineation of Temporary Barriers in Work Zones, Report No. FHWA/RD-84/079, Federal Highway Administration, Washington, D.C., June, 1985.

12. Manual of Traffic Control for Construction and Maintenance Work Zones, California Department of Transportation, Sacramento, California, 1985.

13. Virginia Work Area Protection Manual, Michigan Department of Transportation, Richmond, Virginia, 1987.

14. Michigan Manual of Uniform Traffic Control Devices, Part VI, Construction and Maintenance, Michigan Department of Transportation, Lansing, Michigan, 1987.

15. Noel, E. C. et al., Barrier Delineation Treatments Used in Work Zones, Contract No. DTFH61-88-Z-00007, Federal Highway Administration, On-going research.

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