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16. Abstract

This report presents the findings of field studies conducted to evaluate the effects of sight distance to lane closures at urban freeway work zones. These studies investigated the interaction of sight distance with traffic volume and various work zone traffic control features (e.g., advance signing and arrowboards). The studies were conducted at 16 maintenance work zones of freeways in Houston, Dallas, Ft. Worth, San Antonio and Corpus Christi, Texas.

The studies revealed that as sight distance to a lane closure decreases, more and more drivers are "trapped" in the closed lane at the taper area. Also, sight distance is more critical as traffic volumes increase. Based on the study findings, a minimum desirable sight distance of 1500 feet was recommended for lane closure work zones on freeways.

The studies also suggested that advance signing for lane closures is only partially effective. Arrowboards were found to be effective traffic control devices for lane closures where the sight distance is adequate, as they encourage early lane changing.

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SIGHT DISTANCE REQUIREMENTS AT LANE CLOSURE WORK ZONES ON URBAN FREEWAYS

by

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Research Report 228-7

Traffic Management During Urban Freeway
Maintenance Operations
Research Study 2-18-78-228

Sponsored by

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College Station, Texas

April 1981

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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.

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SUMMARY

Background

Maintenance operations performed on urban freeways oftentimes require the temporary closing of one or more travel lanes. In these situations, motorists should be encouraged to vacate the closed lane(s) in advance of the work area using effective traffic control devices (e.g., advance signing, cone taper, arrowboard, etc.). If the traffic control system fails, severe safety and operational problems can result as high speed traffic is surprised by the lane closure and/or is "trapped" in the closed lane.

A series of field studies was conducted to evaluate current traffic control practices at lane closure work zones on urban freeways in Texas. The studies, which are documented in this report, identified problem areas and provided input for the development of improved traffic control practices.

Advance Signing

The field studies revealed that the advance signs normally used to warn drivers of freeway lane closures during maintenance operations are only partially effective in encouraging drivers to vacate the closed lane(s). The signs become less effective as traffic volumes increase.

Importance of Sight Distance

In this report, sight distance is defined as the distance from the beginning of the cone taper to where a driver can identify that his or her lane is closed, provided the line of sight is not obstructed by another vehicle. The field studies revealed that many drivers (20 to 50 percent depending on volume conditions) wait until sighting the lane closure before attempting to

merge out of the closed lane(s). Therefore, adequate sight distance to the lane closure must be provided to assure safe and efficient traffic flow. As traffic volumes increase, more and more drivers will be "trapped" at the lane closure if adequate sight distance is not provided.

Implementation

A minimum sight distance of 1500 feet should be provided at work zone lane closures on urban freeways. It is also recommended that an arrowboard (Figure 1) be used at urban freeway lane closures.

If it is not possible to provide a sight distance of at least 1500 feet, an additional arrowboard should be placed upstream of the cone taper for median and shoulder lane closures. This additional arrowboard should be positioned so that drivers are warned of the lane closure at least 1500 feet upstream of the cone taper. The advance arrowboard will encourage more drivers to vacate the closed lane before they see the closure itself. Even if an advance arrowboard is used, the sight distance to a lane closure should not be less than 1000 feet (absolute minimum).

Field Procedure for Checking Sight Distance

A field procedure for checking sight distance at work zone lane closures on urban freeways to insure that a minimum sight distance of 1500 feet is provided is presented in Appendix A.

Figure 1. Typical Arrowboard Recommended for Use at Work Zone Lane Closures

PRELIMINARY FIELD STUDIES

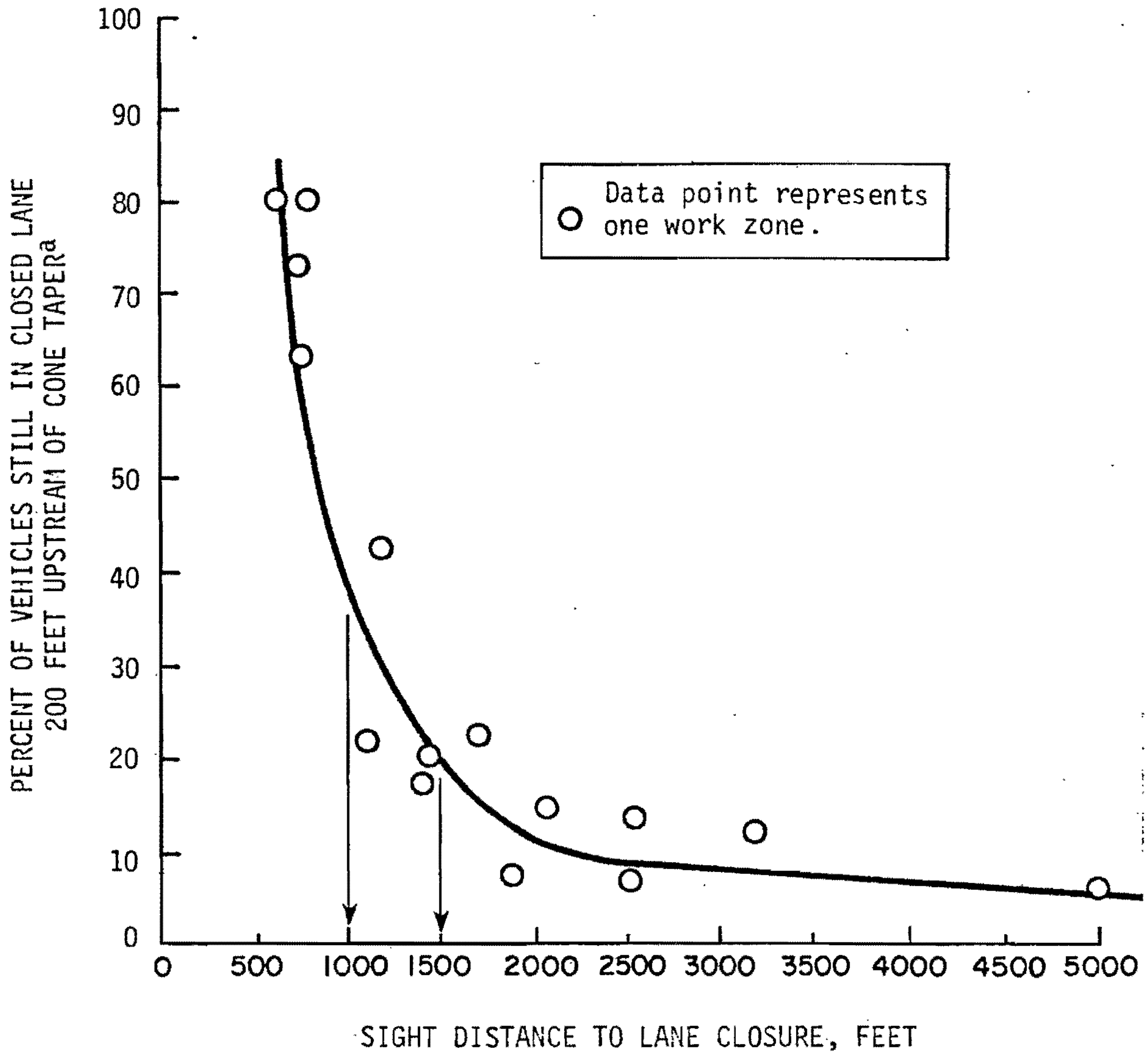
Study Description

A series of field studies was conducted at 15 lane closure work zones on urban freeways in Dallas, San Antonio, Fort Worth, and Corpus Christi. In these studies, a research team documented the geometrics and traffic control used at each worksite, and measured the sight distances to the lane closure. All 15 work zones studied involved one- or two-lane closures on three-lane sections.

A field crew was also deployed at the work zones to manually collect volume and lane distribution data at points upstream of and at the beginning of the lane closure. These data, collected for several hours at each site, were used to determine the performance of the various traffic control devices. Control device effectiveness was judged by its success in encouraging drivers in the closed lane to vacate the lane upstream of the taper area.

Study Findings

The data collected at the 15 work zones revealed that sight distance had a significant influence on driver behavior at the lane closure work zones. This influence is shown in Figure 2 which plots the percent of vehicles still in the closed lane 200 feet upstream of the cone taper versus sight distance. The figure indicates that as sight distance decreased, more and more drivers were "trapped" in the closed lane until reaching the taper area. Upon reaching the taper area, these drivers had to "force" their way into an adjacent open travel lane. These forced merge maneuvers can result in unsafe and inefficient traffic flow (e.g., increased vehicle conflicts, erratic maneuvers, large speed differentials, accidents, and reduced work zone capacity).



[a]Percent = $\frac{A}{B}$ where:

A = The number of vehicles in the closed lane 200 feet upstream of the beginning of the cone taper, corrected for ramp traffic.

B = The number of vehicles in the closed lane before entering the work zone, corrected for ramp traffic.

[b]Sight Distance was measured from the point at which a driver could identify that the lane was closed to the beginning of the cone taper.

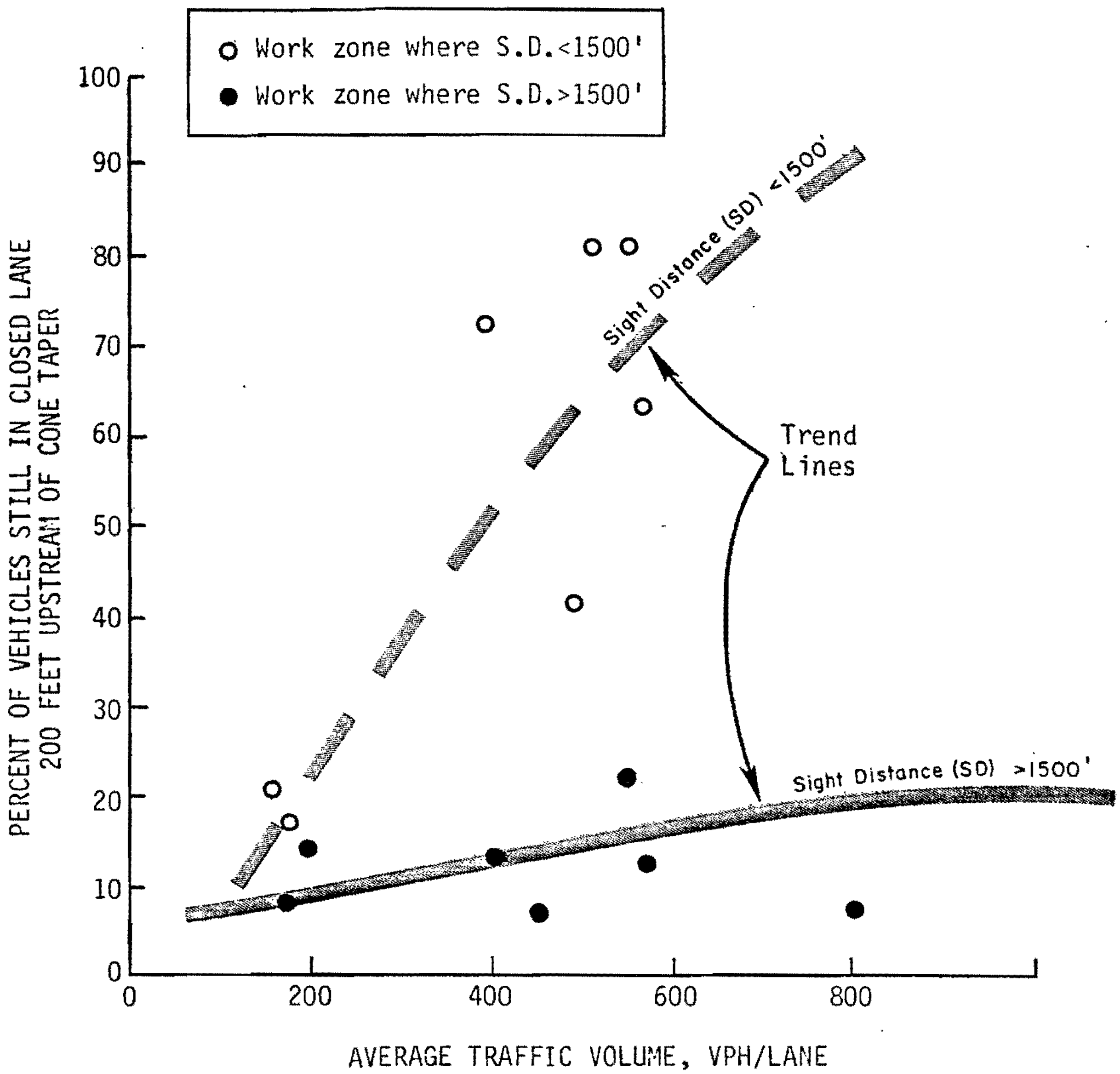
Figure 2. The Effects of Sight Distance to a Closed Lane on Occupancy of the Closed Lane

As sight distance was restricted below about 1500 feet, the percentage of "trapped" drivers increased moderately. As the sight distance was reduced even more (below 1000 feet), the percentage of "trapped" drivers rapidly increased. At those work zones with a sight distance between 600 and 800 feet, for example, up to 80 percent of the closed lane traffic still occupied the closed lane 200 feet upstream of the cone taper.

Figure 2 also shows that the sight distances at the 15 randomly selected work zones varied considerably, from 650 feet to 5100 feet. Several of the work zones had relatively short sight distances. In fact, four of the work zones had sight distances less than 1000 feet.

The preliminary field studies also provided insight into the effects of traffic volume on traffic operations at lane closure work zones, as shown in Figure 3. Figure 3 suggests that traffic volume did not significantly affect the percentage of closed lane vehicles still in the closed lane very near the taper area when sight distance was greater than 1500 feet. At work zones where sight distance was less than 1500 feet, however, traffic volume had a great effect on occupancy of the closed lane near the taper area. As traffic volume increased, the percentage of "trapped" vehicles increased very rapidly (see Figure 3).

At work zones where sight distance was over 1500 feet, most drivers had enough warning time to find a gap in the adjacent open lane and merge comfortably into it, regardless of the volume level (150-800 vph/lane). At work zones where sight distance was less than 1500 feet, however, drivers could move quickly out of the closed lane only under very low volume conditions (e.g., 200 vph/lane). As traffic volume increased, there were fewer gaps available in the adjacent lane and drivers had less time to find these gaps. Therefore, more drivers were "trapped."



Note: One of the 15 study sites was omitted from the evaluation because of inconsistencies resulting from the presence of an exit ramp near the taper area.

Figure 3. Effects of Traffic Volume on Lane Occupancy at Lane Closure Work Zones

CONTROLLED FIELD STUDIES

Study Purpose

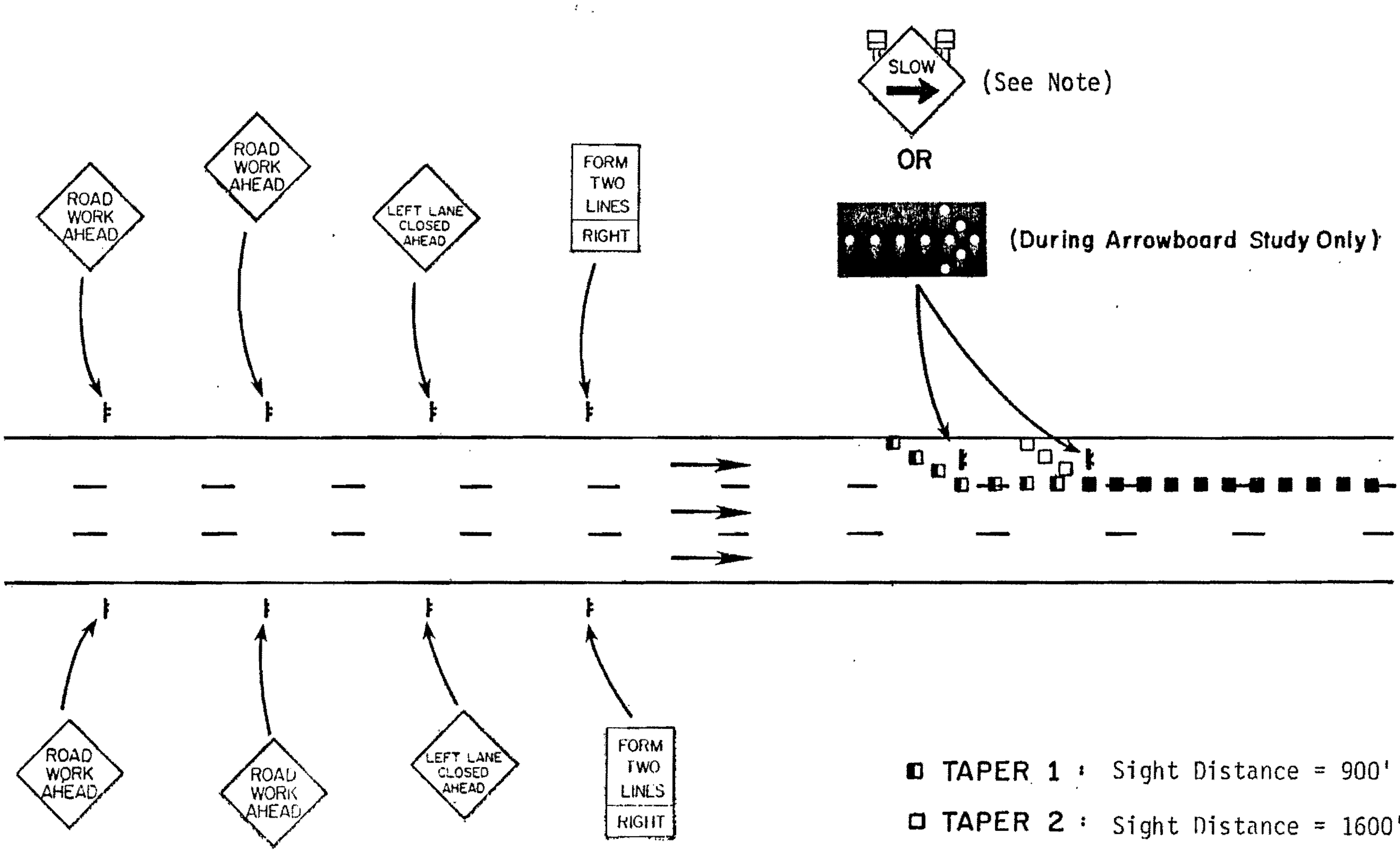
The field studies previously discussed revealed that sight distance is a critical factor at lane closure work zones. They also suggested that traffic volume becomes important when sight distance is less than about 1500 feet. It should be noted, however, that there were many differences among the work zones studies, especially in site geometrics and signing. The differences made it difficult to fully assess the effects of sight distance, and in particular, the interaction of sight distance with other traffic control features (e.g., advance signing, arrowboards, etc.). To address these concerns, a series of "controlled" field studies was developed. Using the "controlled" study approach, conditions at the work zone could be regulated and the effects of individual traffic control features determined.

Study Description

The "controlled" field studies were conducted at a median barrier repair worksite on I-10 in Houston. The repair work was performed by a District 12 maintenance crew and it required closing the median lane on a three-lane section. A 600-foot cone taper was used to close the lane, along with advance signing and an arrow sign positioned behind the taper.

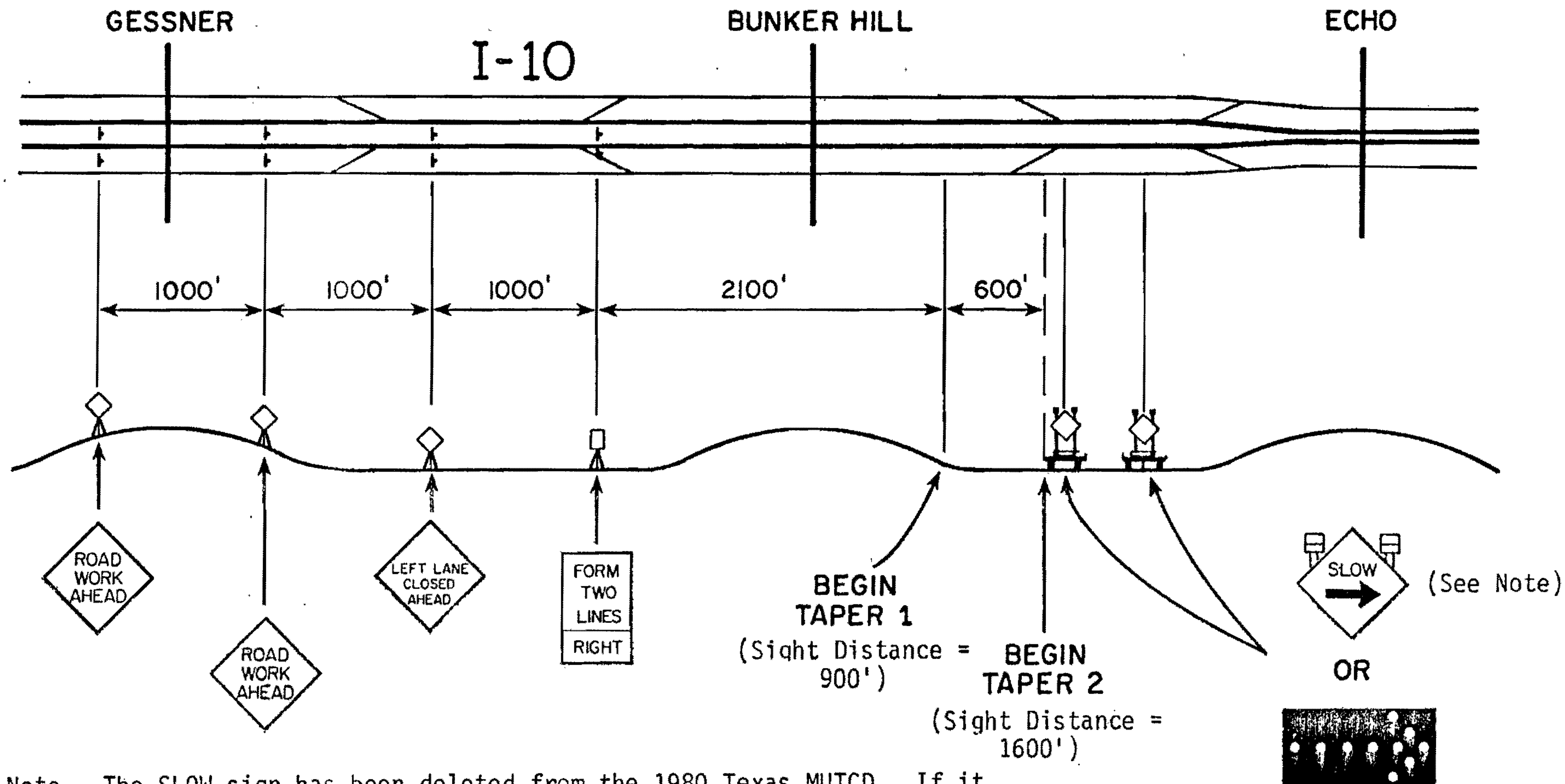
Figure 4 presents a site plan for the work zone. The figure shows that a set of four advance signs were used upstream on the taper area on each side of the affected travel lanes.

Figure 5 shows a plan-profile view of the work zone. Note from Figure 5 that a vertical curve at the Bunker Hill interchange limited sight distance to the lane closure. By moving the cone taper relative to this interchange, it



Note - The SLOW sign has been deleted from the 1980 Texas MUTCD. If it is used, it must be accompanied by an Advisory Speed sign.

Figure 4. Site Layout



Note - The SLOW sign has been deleted from the 1980 Texas MUTCD. If it is used, it must be accompanied by an Advisory Speed sign.

Figure 5. Plan-Profile View

was possible to control the sight distance. During the studies, two taper positions were evaluated (Tapers 1 and 2 in the figures), resulting in sight distances of 900 feet and 1600 feet, respectively.

A step-by-step description of the study approach is presented below:

1. First, data were collected before the work zone was set up to determine normal traffic flow patterns.
2. Next, the District 12 signing crew installed the advance signs. Data were collected with the signs in place (but no lane closure) in order to evaluate the effects of the advance signing.
3. The median lane was closed (with a cone taper and static arrow sign) and data were again collected. The taper was positioned to provide a 900-foot sight distance the first day of the studies and a 1600-foot sight distance the next.
4. Finally, the static arrow sign was replaced with a flashing arrowboard sign to determine the effects of an arrowboard, if any. The arrowboard was evaluated under both sight distance conditions.

During the two-day study, traffic volumes at the worksite varied somewhat. This made it possible to evaluate the effects of sight distance and the other factors (advance signing and use of a flashing arrowboard) under two volume conditions: 1000 vph and 3000 vph.

Data Collection

Sight distance to the lane closure was measured from a moving research vehicle using a Distance Measuring Instrument (DMI) mounted in the vehicle. Several sight distance measurements were taken and an average sight distance was calculated for each taper location. Measurements affected by traffic interferring with the line of sight were rejected.

Lane distribution and volume data were collected at the lane closure and seven locations upstream of the closure. These data were manually counted in five-minute intervals by field crews stationed along the roadside.

The studies were conducted on two consecutive Sundays. Approximately ten hours of data (5 hours per day) were collected as follows:

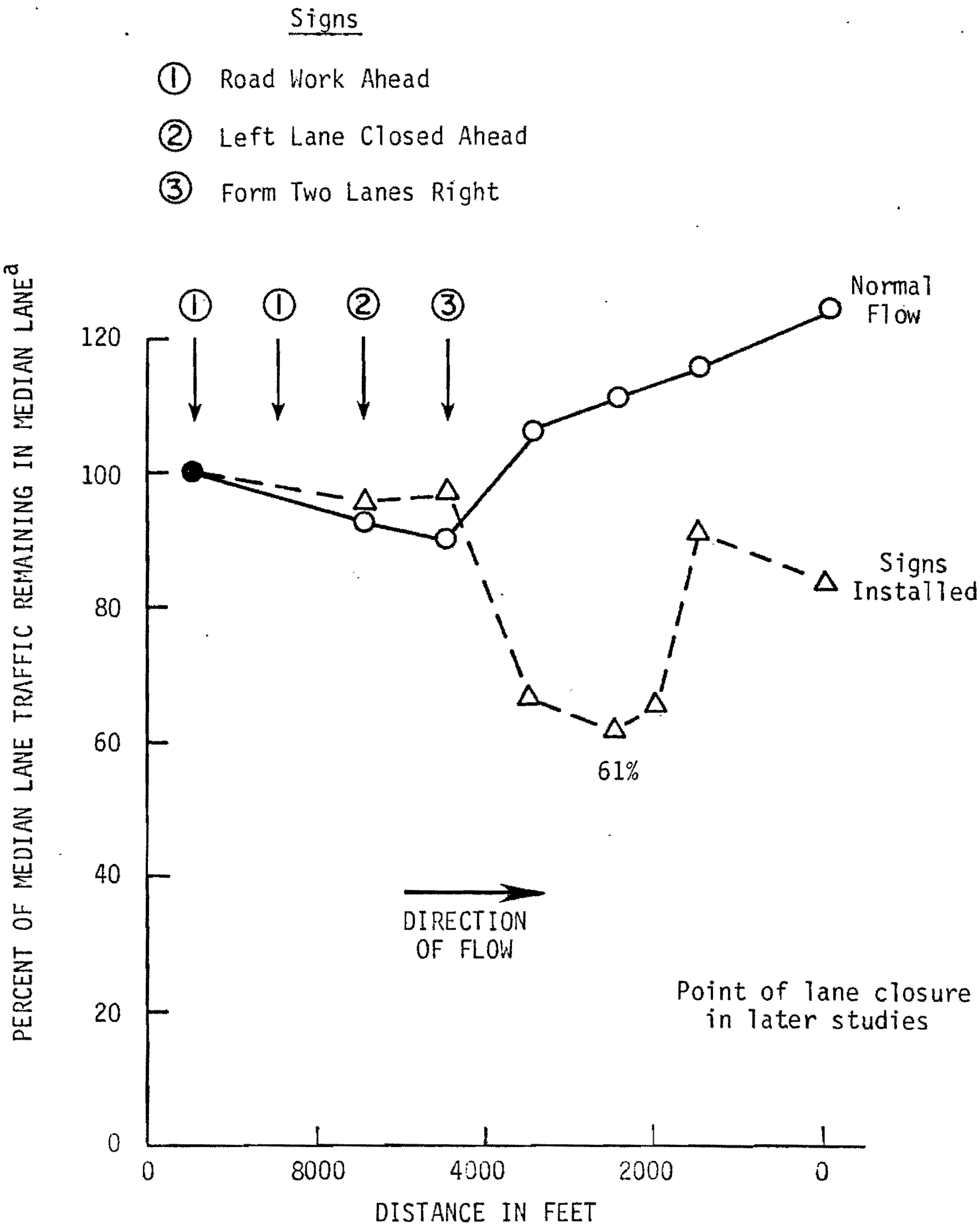
Base data	1 hr.
Signs only	3 hrs.
Signs and Taper 1	2 hrs.
Signs and Taper 2	4 hrs.
	10 hrs.

The lane distribution and volume data were reduced and analyzed to determine how much traffic was in the closed lane and when this traffic moved out of the lane in response to the signs and/or lane closure.

Study Findings

The "controlled" field studies confirmed that sight distance is an important factor at lane closure work zones. The data gathered in the studies provided input for the development of sight distance recommendations. The studies also revealed that the advance signing used by District 12 at the work zone (see Figure 4) is only partially effective in encouraging drivers to vacate a lane. Thus, the need for adequate sight distance at lane closure work zones is critical. As in the preliminary studies, the "controlled" studies revealed that traffic volume affects traffic operation more as sight distance is reduced. The studies also suggested that a flashing arrowboard, used behind the taper at lane closure work zones, can enhance traffic operations. These findings are discussed in detail below.

Advance Signing--Figure 6 shows the effects of the work zone advance signing on occupancy in the median lane. From the figure, only 39 percent (100 minus 61 percent) of the drivers observed in the median lane at the first count



● [a]Reference Point: 1st Count Station

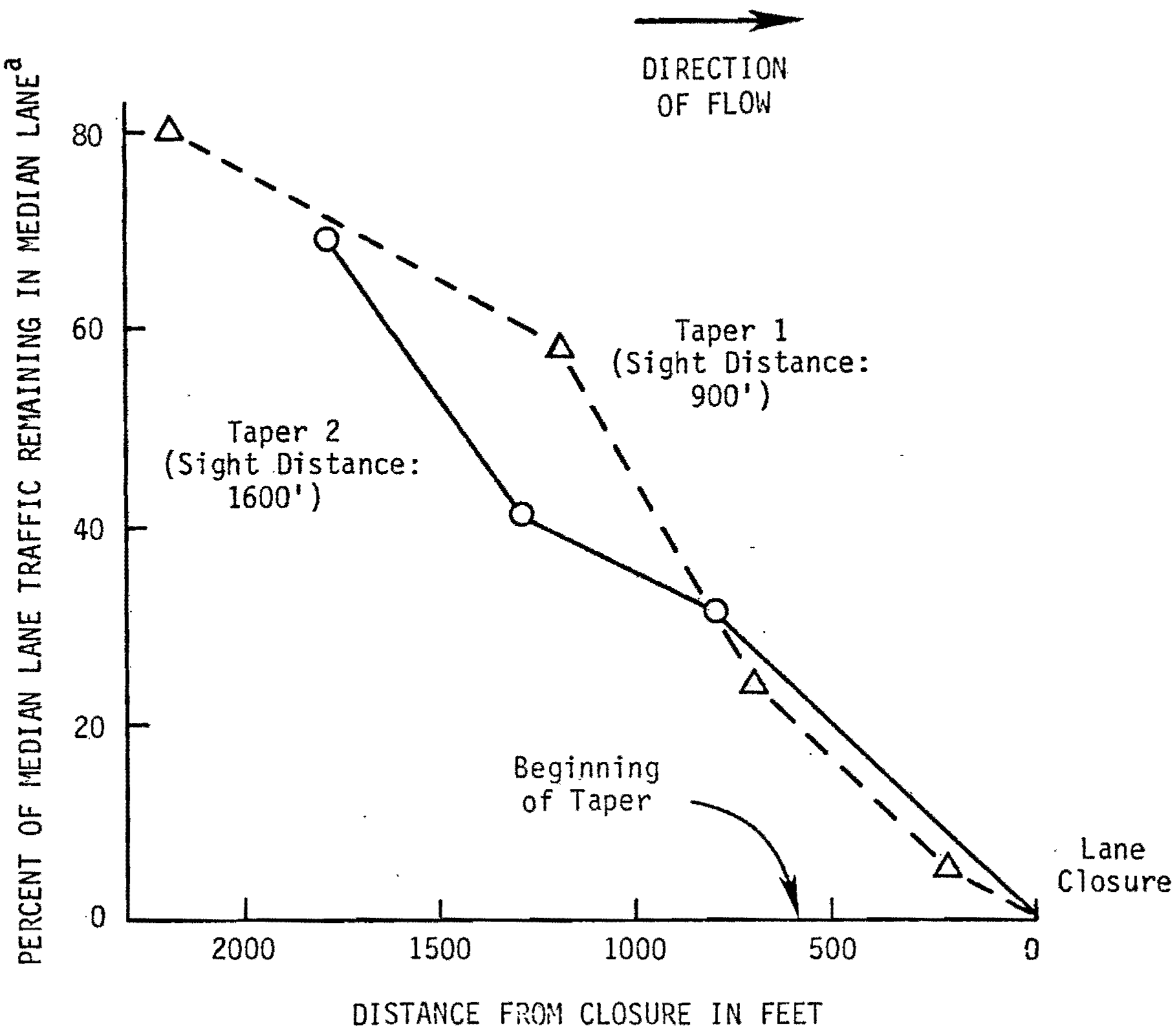
Figure 6. Effectiveness of Advance Signing Used by District 12

station vacated the median lane in response to the advance signing. All of these drivers moved out of the median lane within 2000 feet of the last sign in the series.

The advance signing was evaluated before the median lane was actually closed. From Figure 6, it is seen that many drivers started moving back into the median lane approximately 2500 feet beyond the last sign. This point coincided with the crest of the vertical curve at the Bunker Hill interchange and drivers could see that the median lane was clear for at least two miles ahead. There was also an entrance ramp just beyond the Bunker Hill interchange. Many of the ramp drivers, having not seen the advance signing, quickly made their way into the median lane.

Based on the data in Figure 6, it is apparent that advance signing alone will not encourage all drivers to vacate a closed lane. Many drivers apparently wait until they can identify that a lane is actually closed before they attempt a lane change. For this reason, adequate lane closure sight distance should be provided, regardless of advance signing. Figure 6 also suggests that advance signing can be placed too far upstream of a lane closure since drivers will begin moving back into the closed lane if they travel some distance without observing the lane closure. These studies, however, did not address the issue of sign placement relative to the point of lane closure in depth.

Sight Distance--Figure 7 shows the percentage of median lane traffic still in the median lane at various distances from the lane closure for Taper 1 (sight distance = 900 feet) and Taper 2 (sight distance = 1600 feet). From Figure 7 it can be seen that many drivers vacated the median lane sooner when the sight distance was 1600 feet compared to 900 feet.



[a]Reference Point: 1st Count Station

Figure 7. Effects of Sight Distance on Median Lane Occupancy

Under both sight distance conditions, a significant percentage of median lane drivers still occupied the lane near the taper area. This trend is shown by the data in Table 1. Table 1 gives the percentages of median lane traffic still in the median lane at 1000, 500, and 200 feet upstream of the cone taper. Note from the table that 31 percent of the median lane traffic still occupied the median lane 200 feet upstream of the cone taper under both sight distance conditions.

TABLE 1. PERCENT OF MEDIAN LANE TRAFFIC STILL IN MEDIAN LANE AT GIVEN DISTANCES FROM CONE TAPER

Sight Distance To Lane Closure In Feet	Percent of Median Lane Traffic Still in Median Lane		
	1000 Feet From Cone Taper	500 Feet From Cone Taper	200 Feet From Cone Taper
900	67	51	31
1600	58	37	31

The data presented in Figure 7 and Table 1 were collected while the advance signing used by District 12 was in place upstream of the lane closure and a static arrow sign was positioned behind the cone taper. The data represent light to moderate volume conditions at the site (1000 to 3000 vph).

The results of the "controlled" sight distance studies were consistent with those of the preliminary studies. They indicate that sight distances in the 900 - 1600 foot range are tolerable, but that greater sight distances are preferred.

Traffic Volumes--Data were collected under two volume conditions (1000 vph and 3000 vph) when only the advance signs were present. Figure 8 summarizes these data and reveals that traffic volume had a significant effect on driver response to the advance lane closure signing. From the figure, 47 percent (100 minus 53 percent) of the median lane drivers changed lanes when the flow rate was 1000 vph. When the flow rate was 3000 vph, however, only 27 percent (100 minus 73 percent) changed lanes.

These figures (47 versus 27 percent) suggest that as traffic volumes increase, drivers are less likely to respond to advance signing for a lane closure. As volume increases, there are fewer available gaps in the traffic stream. Apparently, many drivers are unable or simply hesitant to find one of these infrequent gaps to merge out of a lane signed for closure.

The effects of traffic volume on median lane occupancy in the taper area were also studied (see Table 2). From the table, 17 percent of the original median lane traffic still occupied the median lane 200 feet from the taper when the flow rate was 1000 vph. As volume increased at the site to 3000 vph, the percent of "trapped" vehicles increased to 20. These figures (17 versus 20 percent) suggest that, at the sight distances evaluated, traffic volume had an effect on drivers' responses to the lane closure. More drivers were "trapped" as volumes increased.

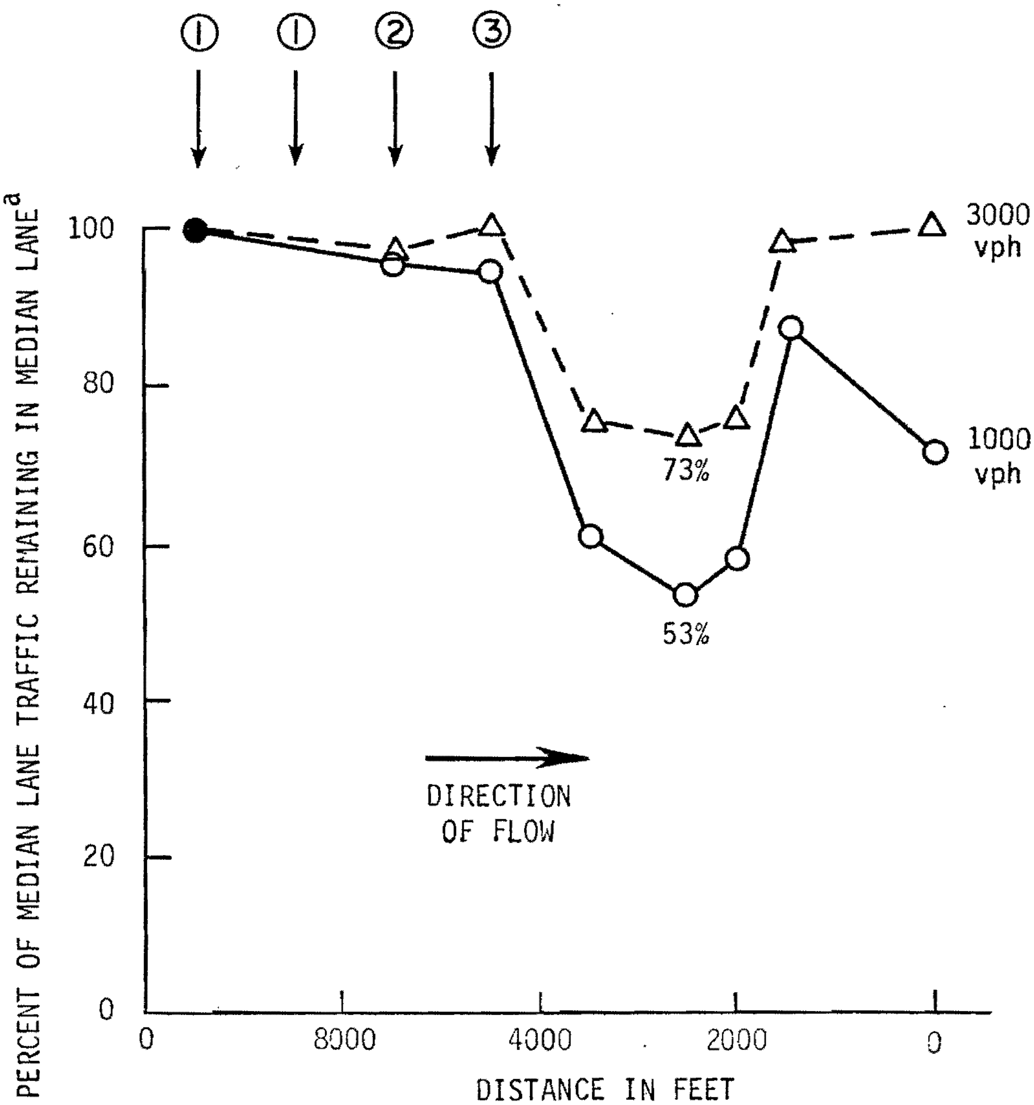
Flashing Arrowboard--The effects of flashing arrowboards at the lane closure were also studied. The flashing arrowboard was positioned behind the cone taper in place of the static arrow sign (see Figure 4). The use of the arrowboard at this site did not increase the sight distance to the lane closure since the closure was purposely positioned just downstream of a hilltop. The arrowboard did, however, greatly enhance the conspicuity of the closure.

Signs

① Road Work Ahead

② Left Lane Closed Ahead

③ Form Two Lanes Right



● [a]Reference Point: 1st Count Station

Figure 8. Influence of Traffic Volume on Median Lane Occupancy

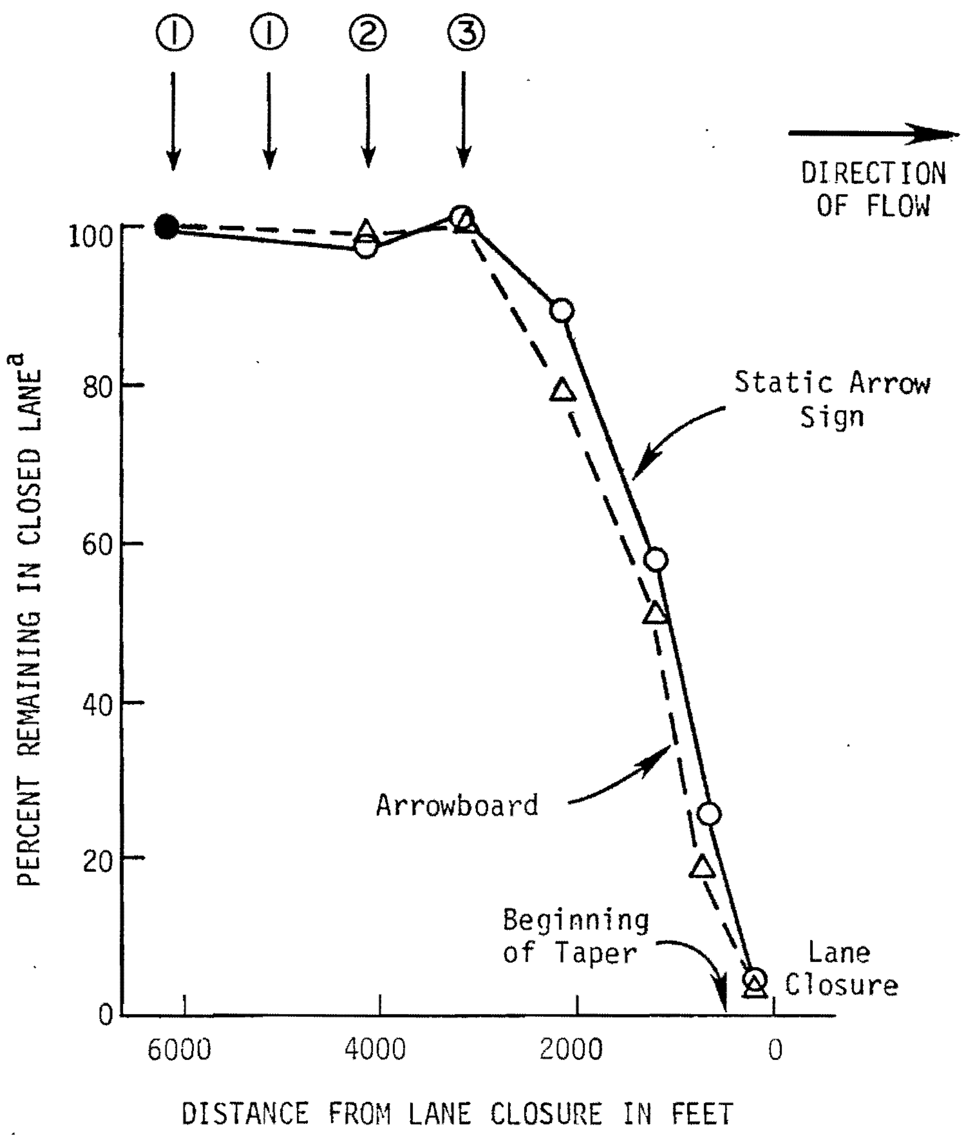
TABLE 2. EFFECTS OF TRAFFIC VOLUME ON MEDIAN LANE OCCUPANCY 200 FEET UPSTREAM OF CONE TAPER

Traffic Volume (vph)	Percent of Median Lane Traffic Still in Median Lane 200 Feet Upstream of Cone Taper
1,000	17
3,000	20

Figures 9 and 10 present the results of the arrowboard studies. These figures plot the percent of drivers remaining in the median lane versus distance from the lane closure for sight distances of 900 feet and 1600 feet, respectively. In the figures, the effects of the arrowboard are compared to those produced by the static arrow sign. Figure 9 indicates that the arrowboard had little added effect when the sight distance was only 900 feet. Traffic simply did not have time to respond, even though the arrowboard probably made the closure more conspicuous. The arrowboard did have a significant effect when the sight distance was increased to 1600 feet, however. From Figure 10, 40 percent of the median lane traffic still occupied the lane 1000 feet from the taper when the static arrow sign was used. When the arrowboard was used, this figure was reduced to only 23 percent. Thus, if sight distance is adequate at a lane closure work zone (e.g., >1500 feet), the studies suggest that the use of an arrowboard encourages better driver response to the closure.

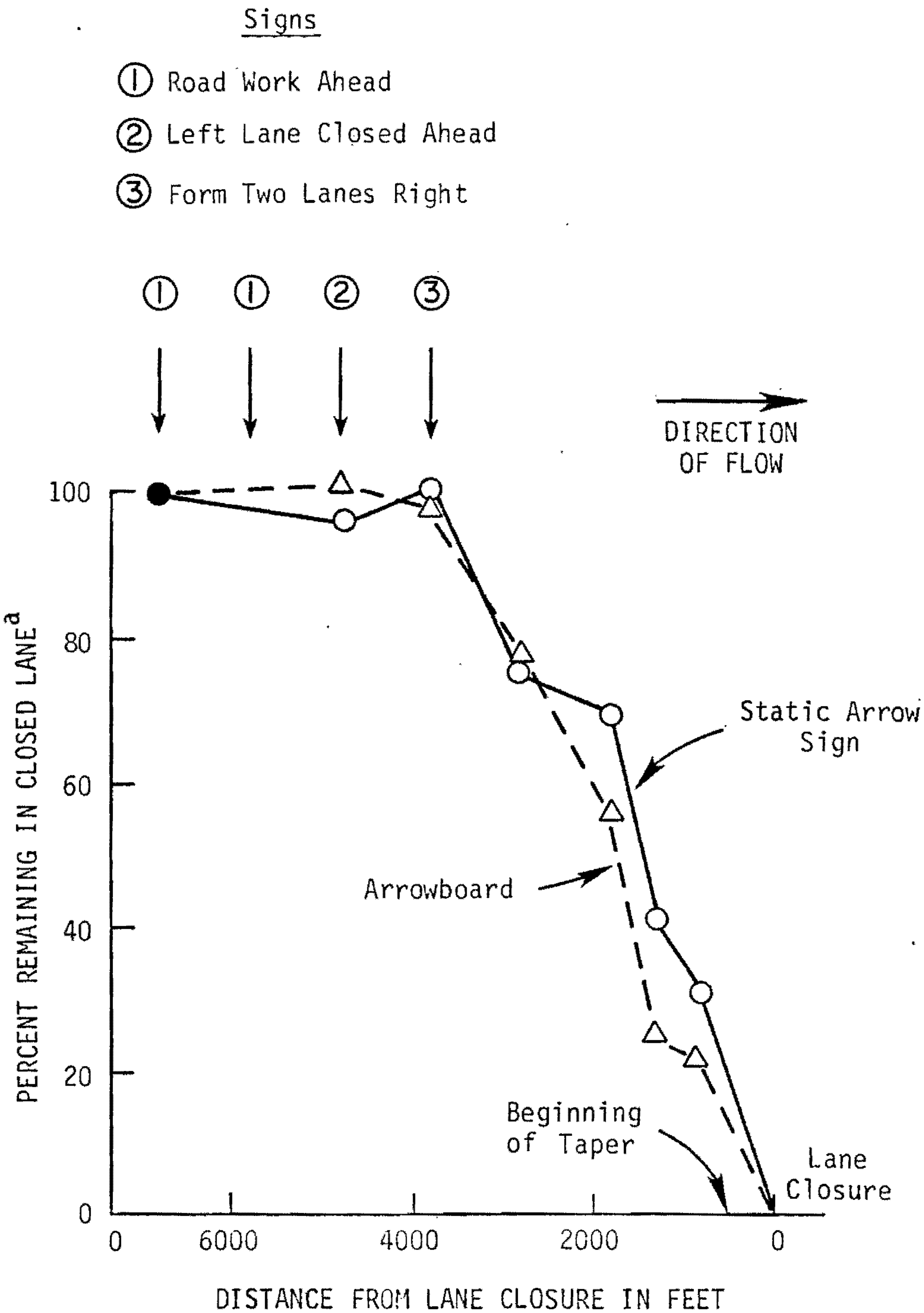
Signs

1. Road Work Ahead
2. Left Lane Closed Ahead
3. Form Two Lanes Right



● [a]Reference Point: 1st Count Station

Figure 9. Influence of Arrowboard (Sight Distance = 900 Feet)



● [a]Reference Point: 1st Count Station

Figure 10. Influence of Arrowboard (Sight Distance = 1600 Feet)

CONCLUSIONS AND RECOMMENDATIONS

Advance signing for a lane closure is only partially effective in encouraging drivers to vacate the closed lane(s). The signs become less and less effective as traffic volumes increase. Many drivers wait until sighting the lane closure before attempting to merge out of the closed lane(s). Therefore, adequate sight distance to a lane closure must be provided to assure safe and efficient traffic flow. As traffic volumes increase, more and more drivers will be "trapped" at the lane closure if adequate sight distance is not provided.

Based on the study results, it is recommended that a minimum sight distance of 1500 feet be provided at work zone lane closures on urban freeways. If the sight distance is at least 1500 feet, the number of drivers "trapped" at the taper area will be minimized, thus enhancing safety and traffic flow. It is also recommended that an arrowboard be positioned behind the cone taper at all freeway lane closures, regardless of sight distance, to help encourage traffic to merge out of the closed lane(s).

If the sight distance to a lane closure is less than 1500 feet, an arrowboard should be placed on the roadside upstream of the cone taper (1). This advance arrowboard will encourage many drivers to vacate the closed lane before seeing the lane closure. Even if an advance arrowboard is used, however, the sight distance to a lane closure should be at least 1000 feet (absolute minimum). Sight distance less than 1000 feet will result in many drivers being "trapped" in the closed lane. These drivers must force their way into an open lane and can cause severe safety and operational problems in the taper area.

REFERENCE

1. M. J. S. Faulkner and C. L. Dudek. Field Evaluation of Flashing Arrowboards as an Advance Warning Traffic Control Device at Freeway Work Zones. Texas Transportation Institute Report 228-5, April 1981.

APPENDIX A

FIELD PROCEDURE FOR CHECKING SIGHT DISTANCE

The following field procedure is recommended for checking sight distance to lane closures at work zones on urban freeways to insure that a minimum sight distance of 1500 feet is provided:

> Two vehicles are required to check sight distance (e.g., job foreman's vehicle and the sign truck which is used to deploy traffic control devices). Prior to installing the lane closure taper, the two vehicles stop together on the roadside or shoulder well upstream of the planned taper area. Driver 1 (sign truck driver) enters the roadway first and proceeds toward the taper area in the lane to be closed. As Driver 1 pulls away, he/she begins counting lane stripes. After counting 38 stripes, Driver 1 signals Driver 2 to follow, either by radio or by flashing the vehicle lights. (A normal stripe-dash combination is 40 feet long; therefore, 38 stripes x 40 feet/stripe = 1520 feet.)
>
> Driver 2 enters the roadway and follows Driver 1, keeping the same approximate spacing (1500 feet). When Driver 1 reaches the planned taper area, he/she pulls off the roadway. Driver 2 should be able to see Vehicle 1 at the point where it pulls off the road. If so, it is likely that once the lane is closed, sight distance to the closure will be 1500 feet or greater.

The procedure described above will only give a rough estimate of sight distance. After a lane is closed, the job foreman or another member of the work crew should drive through the work zone and check the sight distance to the lane closure. To do this, he/she drives in the closed lane and counts lane stripes from the point where the closure is sighted to the beginning of the taper. A minimum of 38 stripes should be counted to assure that the minimum sight distance of 1500 feet is provided. If fewer stripes are counted, the taper should be relocated to provide greater sight distance or an advance warning arrowboard should be used at the site.

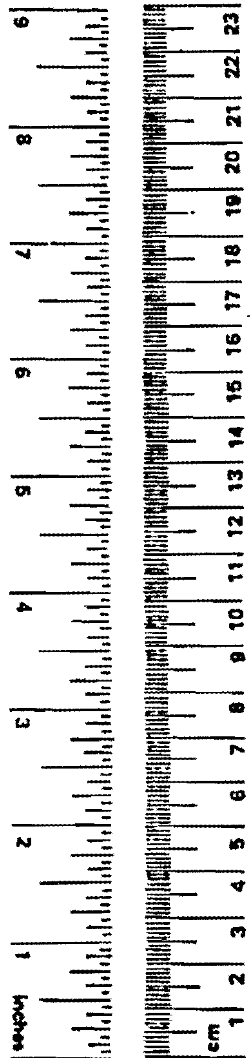
APPENDIX B

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	0.95	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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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	0.035	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	35	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