PERFORMANCE OF TEMPORARY CONCRETE TRAFFIC BARRIERS DURING THE WIDENING OF I-95

by

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Research Scientist

Prepared by the Virginia Highway & Transportation Research Council Under the Sponsorship of the Virginia Department of Highways & Transportation and the Virginia Department of Transportation Safety

(The opinions, findings and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This research effort was initiated at the request of officials of the Virginia Department of Highways and Transportation to obtain information on the performance of the precast concrete traffic barrier (PCTB) when exposed to heavy vehicles. The PCTB is a portable system used in Virginia since 1976 to separate high speed vehicular traffic and construction activities.

The PCTB system was evaluated during the widening of I-95 at Ashland. The scope of the evaluation included (1) an examination of the traffic accident data for I-95 before and during construction to determine the effects of construction on the frequency and characteristics of traffic accidents, (2) an analysis of tire marks on the barrier and barrier-involved accidents to obtain an indication of the effectiveness of the PCTB in safely redirecting vehicles, and (3) an examination of the effects of the PCTB system on traffic operations.

The research effort found that (1) the traffic accident rate in the construction zone on I-95 was 12% higher than before construction, (2) the reduction in the lateral distance between the vehicles in the median and shoulder lanes during construction appeared to contribute to an increase in the number of sideswipe type accidents, (3) 97% of the vehicles which impacted the barrier were safely redirected, (4) drivers were more at ease with the barrier located on the left edge of the roadway than when located on the right, and (5) vehicular speeds were reduced by only a few miles per hour when the barriers were in place.

A subsequent study utilizing mathematical computer modeling techniques is recommended, since the performance of the PCTB system when impacted by a heavy vehicle was not identified in this study.

ACKNOWLEDGEMENTS

The author expresses sincere appreciation to D. W. Hill and W. R. Stevens for efforts in collecting and reducing traffic operations data, to C. W. Payne, J. L. Mills, and B. F. Marshall for efforts in collecting traffic operations data, and to P. S. Harris and D. J. Green for computer processing traffic operations data.

Special thanks go to Captain E. T. Keister and his people at Division I of the Virginia Department of State Police for their efforts in providing barrier-specific information and photographs of barrier-involved traffic accidents.

Appreciation is due all personnel of the Virginia Department of Highways and Transportation who participated in this study, especially, R. E. Napier for maintaining information on the placement of the barriers on the study site, and R. M. Cleek, Jr. and his people at the Ashland Highway Residency for providing traffic control in the field data collection portion of this study.

Finally, the contributions of members of the staff of the Virginia Highway and Transportation Research Council are acknowledged. In particular, thanks go to Harry Craft for editing the report and to Ivy Carlton for typing the manuscript.

SUMMARY OF FINDINGS AND CONCLUSIONS

1. The traffic accident rate in the construction zone on I-95 was 12% higher than before construction.

2. The reduction in the lateral distance between the vehicles in the median and shoulder lanes during construction appeared to contribute to an increase in the number of sideswipe type accidents.

3. Based on observed tire marks on the barrier and reported accidents, 97% of the vehicles which impacted the temporary barrier were safely redirected.

4. Vehicles contacted the temporary concrete barriers in 26% of the reported accidents during construction.

5. The typical barrier displacement due to vehicle contact was less than 1 ft.

6. There was an average of 11.6 impacts with the temporary barrier on I-95 per million vehicle miles of exposure.

7. Driver awareness of the construction zone was evidenced by a 2 mile per hour reduction in the average speed of traffic.

8. Cars traveled 1.3 ft. closer to the barrier when it was located on the left edge of the roadway than when located on the right.

9. Based on the analysis of lane distribution, drivers were more at ease with the barrier on the left than on the right.

RECOMMENDATION

The basic query underlying this project, How will the PCTB system perform when impacted by a heavy vehicle? was not answered because no such impact occurred. The fact that this type of accident, feared by Department officials, did not happen during the widening of I-95 at Ashland suggests that there is a low probability of such an event occurring. However, as upgrading and widening projects on the aging interstate system become more prevalent, the probability of such an event will increase. Rather than gain experience through the occurrence of numerous heavy vehicle accidents involving the PCTB system, it is recommended that a subsequent project utilizing mathematical computer modeling techniques be initiated to answer the initial question.

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INTRODUCTION

The widening of an in-service freeway such as I-95 requires that construction activities take place adjacent to the traveled roadway. The interface between high speed vehicular traffic and construction activities necessitates that a barrier system be employed to provide a safe environment for both the motoring public and workmen. To provide this safe environment, the barrier should be substantial enough to protect workmen from errant vehicles, while at the same time it should not cause severe damage to a vehicle that strikes it or injuries to the occupants of the vehicle.

The barrier system employed in Virginia since 1976 to separate high speed vehicular traffic and workmen is constructed with precast concrete traffic barrier (PCTB) units. The performance of the system was evaluated during the widening of the Virginia Beach-Norfolk Expressway in 1976-77.(1) There it was found that the system performed well, with only 2% of the vehicles which impacted the barrier being involved in reported accidents and the other 98% being safely redirected. The typical barrier displacement due to vehicle contact was less than 1 ft. However, there was one incident involving a van which impacted the barrier at an estimated speed of 55 mph and an angle of 35° which resulted in a displacement of 8 ft. In this accident, (1) the structural capacity of the PCTB system was exceeded, (2) the impact conditions were severe when compared to those under which strength tests on permanent barriers are made,(2) and (3) the van rolled over after impact. This incident showed that the upper performance limits of the PCTB system were within the operating conditions found on the Virginia Beach-Norfolk Expressway where tractor-trailers represent only 1% of the traffic volume. Based on this incident, it was recommended that the barrier's performance be evaluated during the widening of I-95 where tractor-trailers make up 18% of the traffic volume. Deputy Commissioner and Chief Engineer Leo E. Busser III concurred in this recommendation and requested that the performance of the PCTB system be evaluated during the widening of I-95 at Ashland. This study was sponsored jointly by the Virginia Department of Highways and Transportation and the Virginia Department of Transportation Safety.

PURPOSE AND SCOPE

The purpose of this project was to evaluate the performance of the PCTB used as a traffic control device to separate high speed vehicular traffic and construction activities during the widening of I-95 at Ashland. The specific objectives were to evaluate —

1. the efficacy of the PCTB employed in a traffic control barrier system on the basis of the protection it provided motorists and workmen on I-95, and

2. the effects of the PCTB on the characteristics of traffic on I-95.

STUDY SITE AND BARRIER SYSTEM

Interstate 95 is a major truck route along the Eastern Seaboard from Maine to Florida. I-95 in Virginia is 151 mi. long and carries 2.4 billion vehicle miles of travel annually. The 1.3 mi. study site at Ashland was being widened from two to three lanes in each direction. The traffic volume in this section was 41,000 vehicles per day, 66% of which were passenger cars, 16% single-unit trucks, and 18% tractor-trailers and buses.(3)

The widening was performed in three phases as shown in Figure 1, and consisted primarily of upgrading the existing right shoulder and adding a median lane and shoulder in each direction to the existing four-lane roadway. The first phase included all grading operations beyond 15 ft. from the edge of pavement on both sides. The second phase called for the placement of the PCTB system on the right side of the roadway and the completion of all work on that side. The third phase required a similar operation in the median. The maximum length of barrier permissible was 5,500 ft. and placement of the barriers on both sides of the roadway at the same time was not permitted.

The PCTB units employed had the New Jersey "safety shape" profile. They were 24 in. wide, 32 in. high, and 12 ft. long and weighed approximately 4,800 lb. (see Figure 2). The joints were of the tongue and groove design. The units were of either the tenon (male-male) or mortise (female-female) type, which facilitated the removal of a member at the midsection (see Figure 3). Lateral support was provided only on bridge decks, where the units were bolted to the bridge deck as shown in Figure 4. The barrier system was introduced at the start of the work area by either a 300 ft. barrier taper or a portable impact attenuator when the barrier end could not be transitioned 20 ft. or more beyond the edge of the pavement.

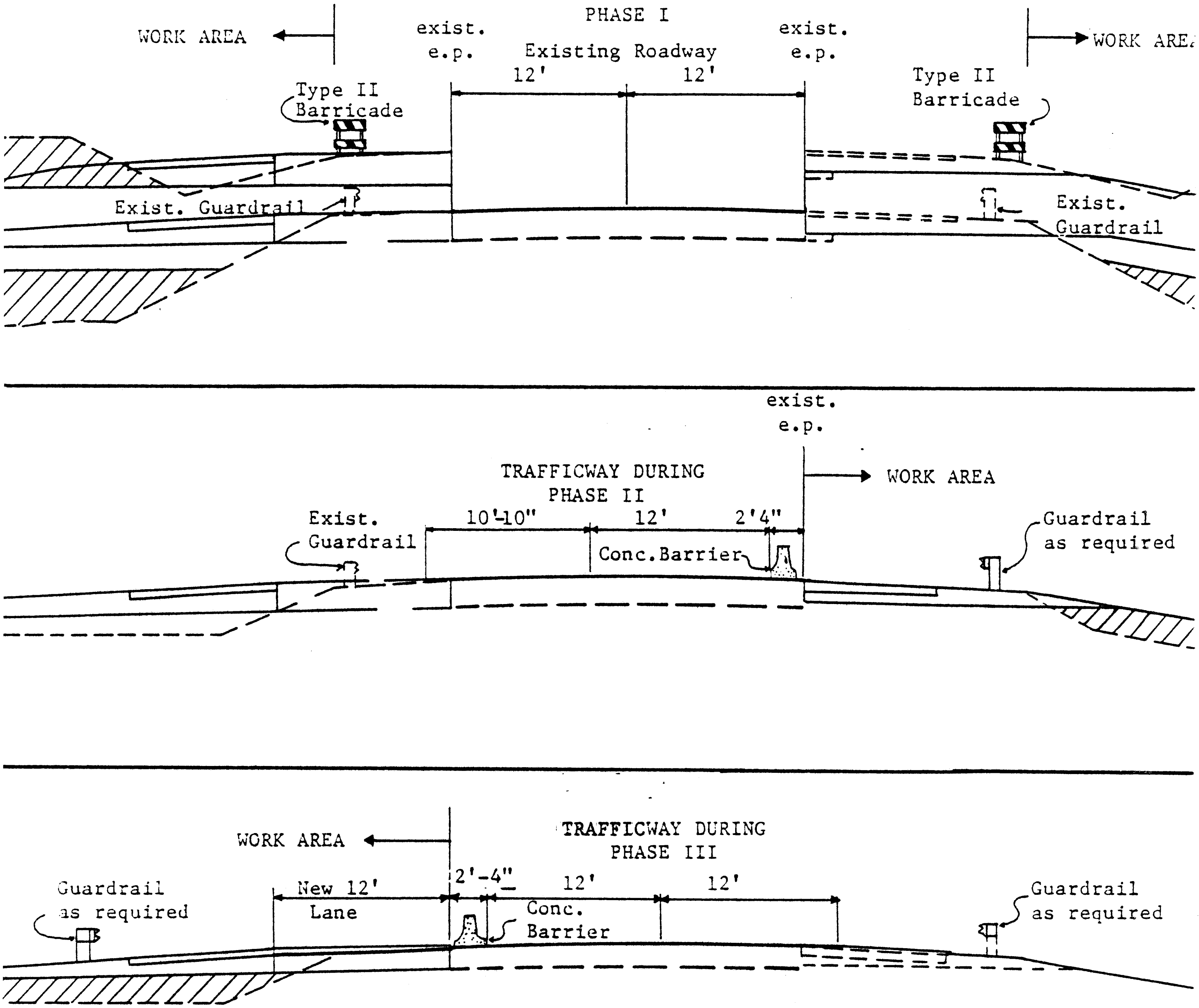

Figure 1. Cross section of I-95 for one direction of travel during construction.

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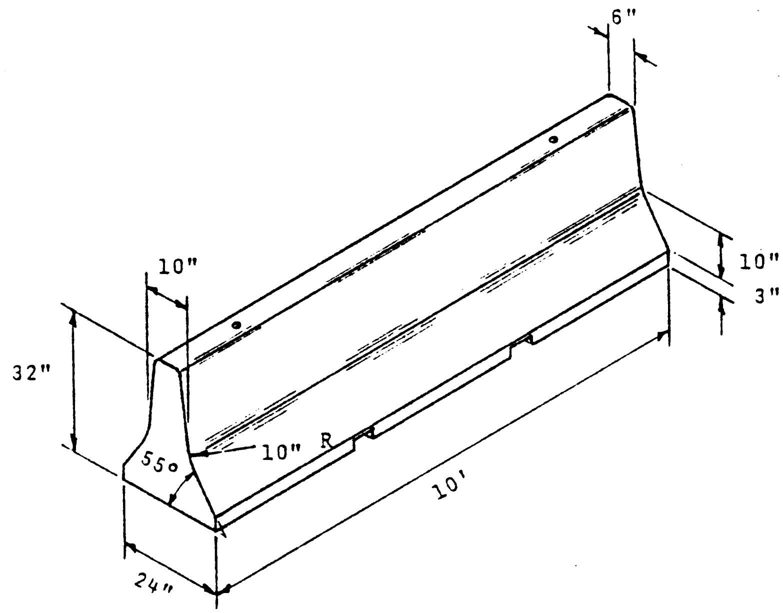

Figure 2. New Jersey type concrete safety shape median barrier.

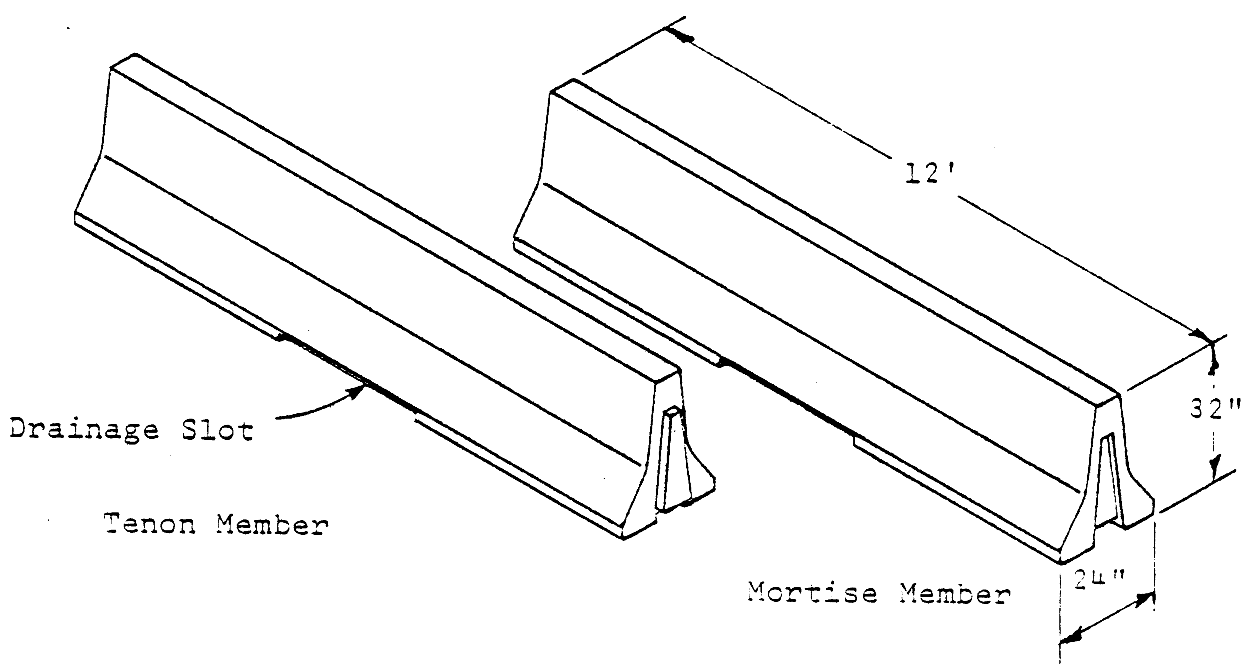

Figure 3. Tenon and mortise members.

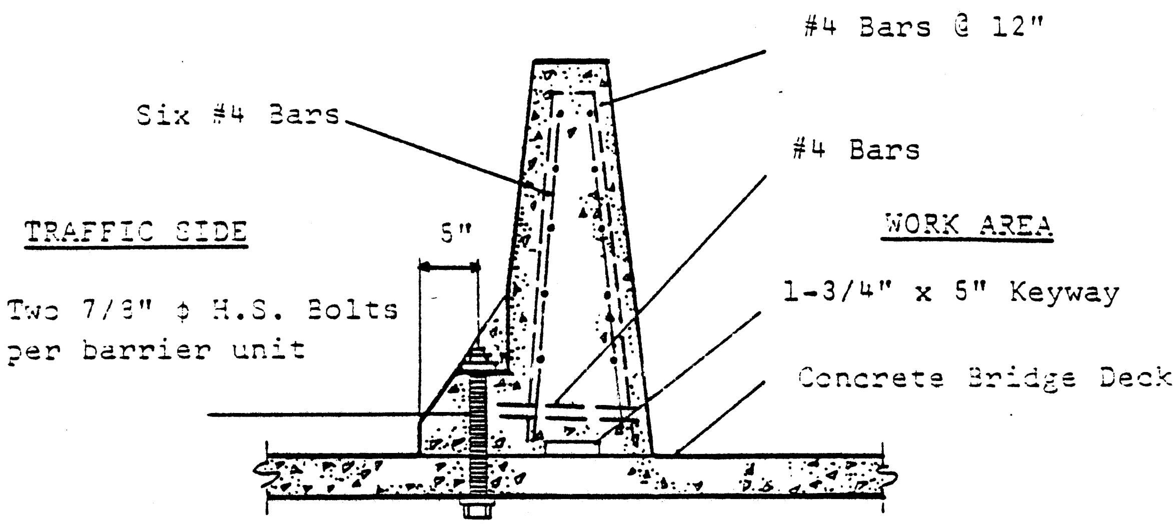

Figure 4. PCTB installation on bridge deck.

TRAFFIC SAFETY

The purpose of the traffic safety analysis was to determine the effect of the I-95 construction work on the traffic safety environment with specific emphasis on the performance of the PCTB. There were three phases in this analysis: (1) an examination of the traffic accident data for I-95 before and during construction to determine the effects of construction on the frequency and characteristics of traffic accidents; (2) a study of reported accidents on I-95 in which vehicles came into contact with the PCTB system to determine the level of safety afforded the motorist and workmen by the PCTB system in the construction zone; and (3) an analysis of the tire marks on the barrier and barrier-involved accidents to obtain an indication of the efficacy of the PCTB in safely redirecting vehicles.

Effects of the I-95 Construction on Accidents

For this phase of the traffic safety analysis, FR-300P accident reports were compiled by accident date and location to provide a comparison of crash data for periods before and during construction. The latter period extended from April 7, 1980, through December 31, 1981; and to avoid possible seasonal fluctuations, April 7, 1978, through December 31, 1979, was taken as the before period. As can be seen in Table 1, the total number of accidents increased from 18 before construction to 19 during construction. There were no fatal accidents during either period. The number of injury accidents increased from 7 to 9 and the number of property damage only accidents

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decreased from 11 to 10. The total accident rate increased from 56.6 to 63.6 per 100 million vehicle miles of travel, because of the increase in the injury rate from 22.0 to 30.1. Even though the injury rate increased by 37%, the change in the number of injury accidents was too small for this increase to be considered significant.

To gain additional insight into the nature of the injury accidents an analysis of the injuries by severity was made and the results are shown in Table 2. The injuries were divided into three classes. Class 1 injuries included visible signs of injury such as a bleeding wound or distorted member, or the individual having to be carried from the scene; class 2 injuries included other visible signs such as bruises, abrasions, swelling, and limping; while class 3 injuries produced no visible signs but were characterized by complaint of pain or momentary unconsciousness. A total of 16 people were injured in the before period and 22 during construction. The number of class 1 injuries decreased from 9 to 3 and the number of class 2 and class 3 injuries increased from 5 to 10 and from 2 to 9, respectively. The most severe type of injury, class 1, accounted for 56% of the injuries before construction and only 14% during construction. Thus, while the number of injuries in each class are small, the severity of the injuries shifted from the most severe class before construction to the least severe class during construction.

Further insight into the effects of construction on traffic crashes can be gained by studying changes in the types of collision. As shown in Table 3, for the before period the rear-end collision accounted for 39% of the total, followed by the fixed-object 22%, and the sideswipe 11%. During construction the most often noted type was the sideswipe, which accounted for 42% of the total and this was followed by fixed-object at 32%, and rear-end at 16%. The shift toward sideswipe collisions during construction may have been caused by the traffic streams traveling closer together as discussed in the Traffic Characteristics portion of this report.

The number of vehicles that impacted fixed objects increased from 5 before construction to 15 during construction. As shown in Table 4, the number impacting guardrail increased from one to five, and the increase for bridge rails was from one to three. The number of vehicles impacting the concrete barrier during construction was six. The increased number of accident-involved guardrail and bridge railings may have been caused by the close proximity of these rails to the travelway during phase II construction as shown in Figure 1.

The distribution of crash data by time, location, weather, roadway condition, and driver and vehicle characteristics was also analyzed; however, no significant deviations were found between the before and during construction periods.

Table 1

Crash Data Before and During Construction

Crash Severity	Before Construction		During Construction		Change In	
	Number	Rate*	Number	Rate*	Number	Rate*
Fatal	0	0.0	0	0.0	0%	0%
Injury	7	22.0	9	30.1	+29%	+37%
Property Damage Only	11	34.6	10	33.5	-9%	-3%
TOTAL	18	56.6	19	63.6	+6%	+12%

* 100 Million Vehicle Miles of Travel

Table 2

Distribution of Injuries by Severity

Injury Severity	Before Construction Number	Before Construction Percent of Total	During Construction Number	During Construction Percent of Total
Class 1	9	56	3	14
Class 2	5	31	10	45
Class 3	2	13	9	41
TOTAL	16	100	22	100

Table 3

Distribution of Crashes by Type of Collision

Type of Collision	Before Construction Number	Before Construction Percent of Total	During Construction Number	During Construction Percent of Total
Rear-end	7	39	3	16
Fixed-Object	4	22	6	32
Sideswipe	2	11	8	42
Other	5	28	2	10
TOTAL	18	100	19	100

Table 4

Distribution of Vehicle Collisions With Fixed Objects

Fixed Object Impacted	Before Construction Number	Before Construction Percent Of Total	During Construction Number	During Construction Percent Of Total
Bank	3	60	1	7
Guardrail	1	20	5	33
Bridge Rail	1	20	3	20
Concrete Barrier	0	0	6	40
TOTAL	5	100	15	100

Barrier — Involved Accidents

This phase of the traffic safety analysis was conducted to provide information on the interaction between impacting vehicles and the PCTB system. There were 5 reported accidents in which a total of 6 vehicles came in contact with the PCTB units between April 7, 1980, and December 31, 1981. In addition to the state FR-300 P accident reports, the Virginia Department of State Police provided a supplemental accident report form containing barrier-specific information and photographs for each of these crashes.

On the 5 reported accidents involving the barrier, 2 resulted in injury and 3 in property damage only. Two of the impacting vehicles remained in the lane adjacent to the barrier after contact with the barrier, 1 was subsequently impacted by another vehicle in the lane adjacent to the barrier, 1 infringed on the adjacent lane, and 2 crossed into the adjacent lane. The barrier was struck first in 2 of the 5 accidents, and in the remaining ones a vehicle sideswipe another before impacting the barrier. The typical barrier displacement due to vehicle contact was less than 1 ft. However, larger deflections were noted in 2 accidents, one of which involved a full-size car being forced into the barrier by a tractor-trailer changing lanes. Five barrier units were displaced in the configuration shown in Figure 5 with a maximum deflection of 3 ft. The barrier system did not fail and there were no injuries.

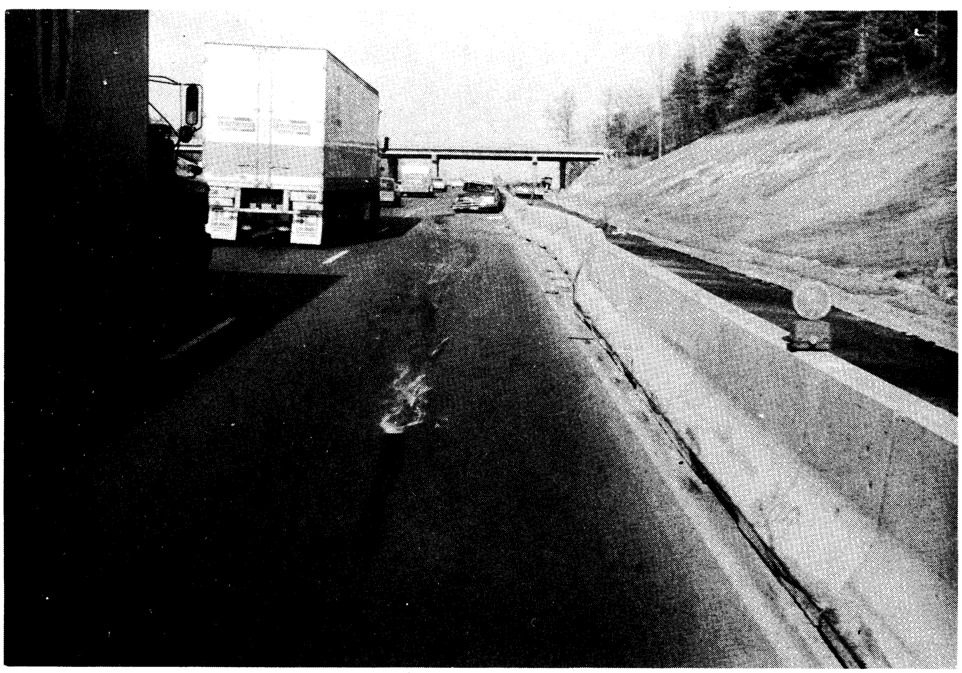

Figure 5. Car forced into barrier by tractor-trailer changing lanes displaced five units. (Virginia Department of State Police photo.)

The only reported accident in which the barrier system failed involved two compact cars that sideswiped each other on the right shoulder, then came across the roadway and impacted the barrier. One vehicle, traveling at 55 mph prior to the accident, impacted the barrier at approximately a 25° angle. The left front tire climbed up and over the barrier, and the vehicle traveled approximately 20 ft. with the left front wheel over the back side of the barrier before coming off the barrier and overturning in the roadway. The second vehicle, traveling at 75 mph prior to the accident, impacted the barrier at approximately a 20° angle and was redirected. The vehicle came to rest next to the guardrail on the opposite side of the roadway. Five people were injured in this accident, 4 in the overturned vehicle and 1 in the other vehicle. Two barrier units were knocked completely into the work area as shown in Figure 6. Three barrier joints failed. As with the accident in the construction zone on the Virginia Beach-Norfolk Expressway where the barrier system failed,(5) the impact conditions described above were severe when compared to those under which strength tests on permanent barriers are made.

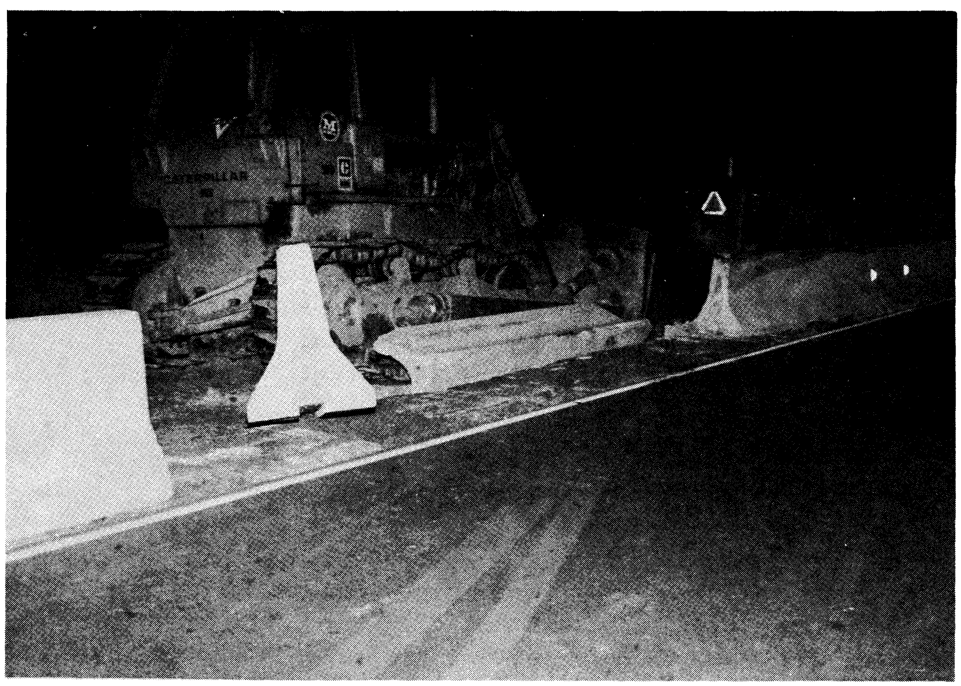

Figure 6. Two compact cars impacted the PCTB system at high speeds and large angles and caused the system to fail. (Virginia Department of State Police photo.)

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Tire Mark Surveillance

The purpose of this part of the traffic safety analysis was to determine the efficacy of the PCTB system in safely redirecting vehicles. The principle upon which this determination was based is that the profile of the PCTB is designed to redirect, with minimal damage to the vehicle or injury to the occupants, vehicles which impact it at a shallow angle of incidence. If the PCTB performed as anticipated, the accident analysis would not identify those vehicles which impacted it and were safely redirected; however, evidence of the vehicle's involvement would remain on the face of the PCTB in the form of tire marks. Thus, a correlation between vehicle involvements with the barrier and traffic accidents in which a vehicle contacted the barrier should give an indication of the efficacy of the system in safely redirecting vehicles.

The PCTB units were installed during phase II and phase III of the construction sequence as shown in Figure 1. The dates of installation were recorded for 4 continuous barrier installations, and just prior to movement of the PCTB units to new locations the tire marks on the barrier were identified, photographed, and catalogued as to roadway location and date of survey. A total of 1.8 miles of barrier with 3.2 million vehicle miles of exposure were included in this portion of the study.

There was evidence of 37 vehicle involvements with the PCTB system above the 3 in. vertical curb. Scuff marks on the curb were not included in the number of involvements, since they could have been made by the side of the tire and thus might not be an indication of vehicle climb on the barrier. Over this same time there was 1 reported accident in which a vehicle came in contact with the barrier. Thus the indication is that 97% of the impacting vehicles were safely redirected by the PCTB system during the widening of I-95. The vehicle involvement rate was 11.6 impacts above the 3 in. vertical curb per million vehicle miles of exposure. These results correspond to the results of the earlier study on the Virginia Beach-Norfolk Expressway widening project,[4] where 98% of the vehicles were safely redirected and the vehicle involvement rate was 9.7 impacts per million vehicle miles of exposure.

TRAFFIC OPERATIONS

One of the objectives of this study was to determine the effects of the barrier's presence on traffic operations. The construction zone on I-95 was particularly suited for this evaluation, since the barrier was required on each side of the roadway during different phases of construction. For this determination, data were collected before construction and during construction with the barrier on the right and then on the left under various traffic volumes and lighting conditions. Specifically evaluated were the effects of the barrier on trends in vehicular speeds, lane distribution, and lateral placement by vehicle type.

The basic hardware used for data collection consisted of pavement tape switches connected to an automatic chart recorder. For each vehicle, information was recorded and coded from the chart recorder output to determine vehicle speed, vehicle type, lateral placement, and arrival time. Data were recorded for both the median lane and the shoulder lane before construction and during construction with the barrier on the right edge of the roadway and on the left.

Vehicular Speeds

The analysis of vehicular speeds was undertaken to partially identify driver reaction to the barrier located on the right and then on the left edge of the roadway. It was assumed that any increased feeling of insecurity or discomfort by the driver would show up in this analysis. The posted speed limit before construction was 55 mph; when the barrier was located on the right edge of the roadway, it was 45 mph; and when the barrier was on the left, it was 55 mph with a maximum recommended speed of 45 mph.

As can be seen in Table 5, the average speeds decreased during construction in both lanes during all time periods. With the barrier located on the right edge of the roadway, the average speed in the shoulder lane decreased by 1.6 mph and that in the median lane by 2.1 mph. With the barrier located on the left, the average speed in the shoulder lane decreased by 0.5 mph and that in the median lane by 1.6 mph. All of these speed reductions were statistically significant (t-test, $p > 0.99$). The difference in the average vehicular speeds between the two lanes was reduced by 0.5 mph when the barrier was located on the right and by 1.1 mph when the barrier was on the left. The lower average speeds in both lanes when the barrier was on the right edge of the roadway could have been caused by either the location of the barrier or the lower 45 mph speed limit; however, neither of these factors appeared to greatly reduce vehicular speeds in the construction zone.

The small reduction in average speeds indicates that the driver's feeling of security and comfort were only slightly affected by the presence of the barrier.

Table 5

Average Vehicular Speeds in MPH

	Median Lane			Shoulder Lane		
Time (Hr.)	Before Construction	Barrier On Right	Barrier On Left	Before Construction	Barrier On Right	Barrier On Left
0400	NO DATA	56.7	58.4	NO DATA	53.7	59.1
0800	61.2	58.7	58.3	57.5	55.3	55.3
1200	62.6	59.5	59.8	57.6	56.0	56.7
1600	62.2	60.9	61.0	57.7	57.0	57.1
2000	61.0	59.5	NO DATA	57.4	55.6	NO DATA
2400	61.1	57.1	58.7	57.2	54.0	55.8
AVERAGE	61.7	59.6	60.1	57.3	55.7	56.8

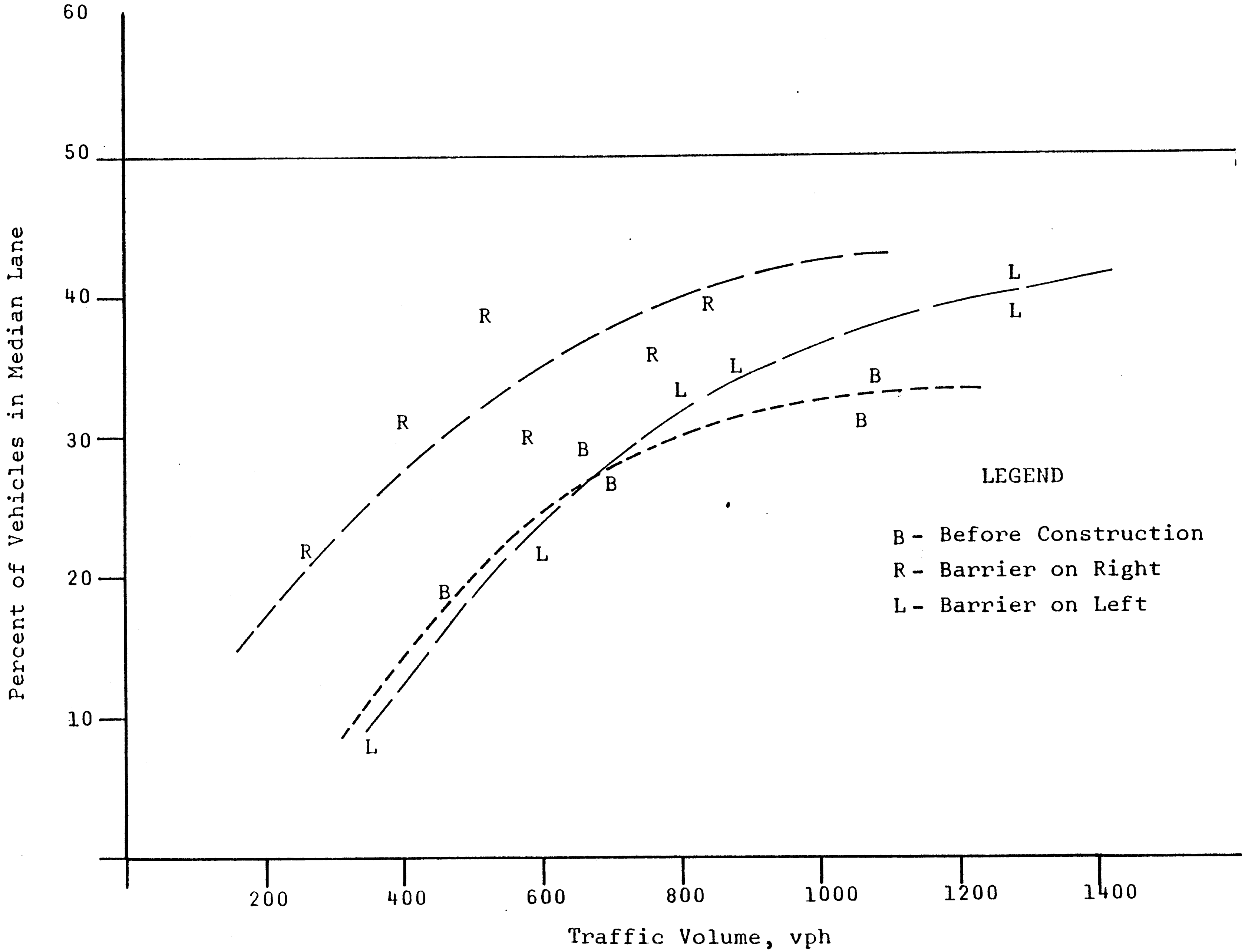
Lane Distribution

The construction zone on I-95 was ideal for the analysis of the effects of the presence of the barrier on lane selection, since the PCTB system was required on each side of the roadway during different phases of construction. It was hypothesized that any increased feeling of insecurity would show up in the analysis as a decreased use of the lane next to the barrier.

As shown in Figure 7, the percentage of vehicles using the median lane increased as the traffic volume increased. With the barrier located on the right edge of the roadway there was a definite tendency for the vehicles to travel in the median lane, even though this lane was narrower than the barrier lane (see Figure 1). This tendency did decrease as the traffic volume increased as evidenced by the distance between the "R" curve and the "B" curve in Figure 7 decreasing as the traffic increased. When the barrier was located on the left, the percentage of vehicles in the median lane at low traffic volumes was almost identical to that before construction. However, as the traffic volume increased there was an increased tendency for drivers to select the barrier lane. Thus, the information presented in Figure 7 indicates that drivers were more at ease with the barrier located on the left edge of the roadway than when it was on the right.

Lateral Placement

This analysis was concerned with the lateral position of vehicles in both lanes before construction and during construction with the barrier located on the right and then on the left edge of the roadway. Before construction and during phase III construction (barrier on the left), both lanes were 12 ft. wide. During phase II construction (barrier on the right), the lane adjacent to the barrier was 12 ft. wide and the median lane was 10 ft.-10 in. wide. Standard center- and edgelines were used under all conditions. In all cases the lateral placements were measured from the outside wheel of the vehicle to the outside of the edgeline (see Figure 8). The edgeline was located 4 in. from the toe of the barrier. Because of the difference in width between a car and a tractor-trailer, they were analyzed separately.


Percent of Vehicles in Median Lane
60
50
40
30
20
10
200
400
600
800
1000
1200
1400
Traffic Volume, vph
LEGEND
B - Before Construction
R - Barrier on Right
L - Barrier on Left

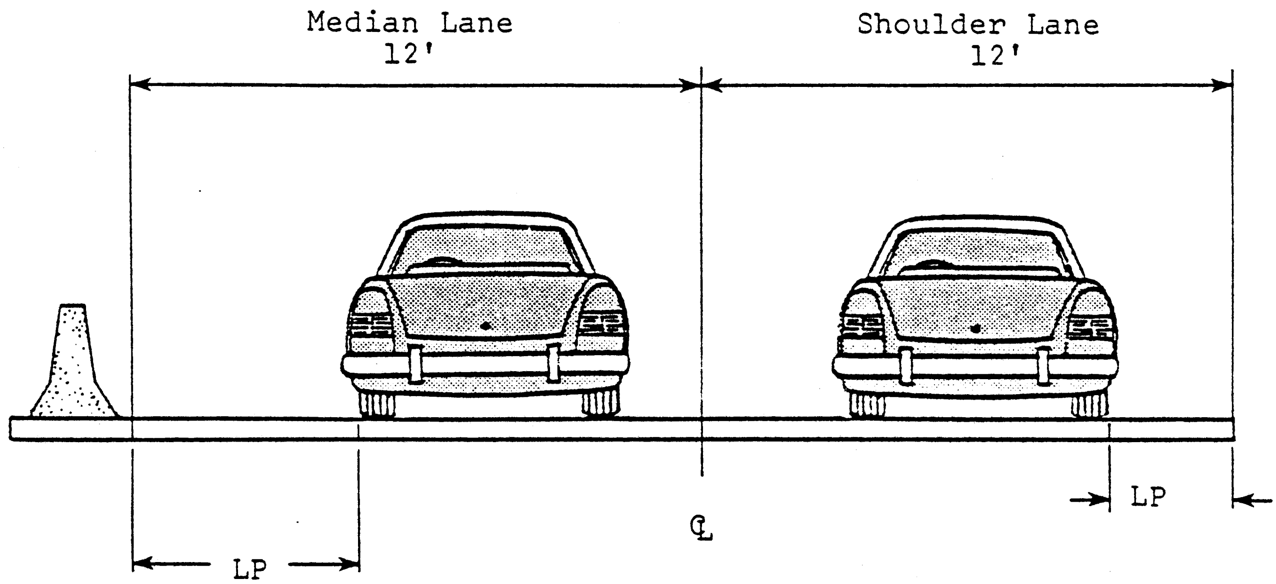


Figure 8. Lateral placement measurements during phase III construction.

Lateral Placement of Cars

As shown in Table 6, the average lateral placement of cars in the shoulder lane before construction was 3.2 ft. and in the median lane 3.1 ft. With the barrier located on the right edge of the roadway, the average lateral placement of cars in the shoulder lane increased by 2.2 ft. to 5.4 ft., and in the median lane it decreased by 0.2 ft. to 2.9 ft. Both of these movements were statistically significant (t-test, $p > 0.99$). The effect of the presence of the barrier on the right edge of the roadway and the narrower median lane during phase II construction was to reduce the average lateral distance between the two traffic streams by 3.3 ft. Assuming an overall width of 6.5 ft. for a full-size car (see Figure 9), the information presented above indicates that the average lateral distance between the two traffic streams decreased from 5.3 ft. before construction to 2.1 ft. with the barrier on the right. This fact may have contributed to the increased number of sideswipe accidents identified in the accident analysis portion of this study. This information also indicates that the average position of the left side of a vehicle in the shoulder lane was 0.3 ft. from the centerline with the barrier on the right. During the late night and early morning hours, this average position was on the centerline.

Table 6

Average Lateral Placement of Cars, in Feet

Time (Hr.)	Median Lane: Before Construction	Median Lane: Barrier On Right	Median Lane: Barrier On Left	Shoulder Lane: Before Construction	Shoulder Lane: Barrier On Right	Shoulder Lane: Barrier On Left
0400	NO DATA	3.7	4.5	NO DATA	5.7	3.2
0800	3.2	2.9	4.5	3.0	5.5	3.0
1200	3.1	3.0	4.3	3.1	5.4	2.9
1600	2.9	2.8	4.0	3.1	5.3	2.9
2000	3.2	2.8	4.2	3.1	5.4	3.2
2400	3.2	2.8	4.2	3.6	5.6	3.1
AVERAGE	3.1	2.9	4.2	3.2	5.4	3.0

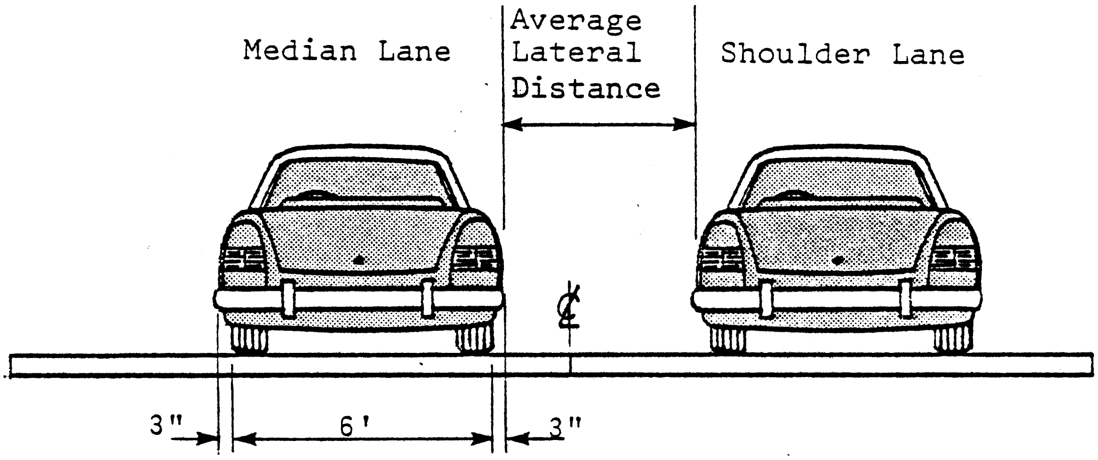


Figure 9. Average lateral distance.

With the barrier located on the left edge of the roadway, the average lateral placement of cars in the shoulder lane decreased by 0.2 ft. to 3.0 ft. and in the median lane it increased by 1.1 ft. to 4.2 ft. Both of these movements were statistically significant (t-test, $p > 0.99$). With the barrier on the left, cars in the lane adjacent to the barrier were traveling 1.3 ft. closer to the barrier than when the barrier was on the right. The effect of the presence of the barrier on the left edge of the roadway was to reduce the average lateral distance between the two traffic streams by 0.9 ft. to 4.3 ft. The wider roadway width during phase III construction and the cars tracking closer to the barrier when on the left contributed to the two traffic streams being 2.3 ft. further apart than when the barrier was on the right.

Lateral Placement of Tractor-Trailers

As shown in Table 7, the average lateral placement of tractor-trailers in both lanes before construction was 1.9 ft. With the barrier located on the right edge of the roadway, the average lateral placement of tractor-trailers in the shoulder lane increased by 1.8 ft. to 3.7 ft. and in the median lane it remained unchanged. This movement in the shoulder lane was statistically significant (t-test, $p > 0.99$). The effect of the presence of the barrier on the right edge of the roadway and the narrower median lane during phase II construction was to reduce the average distance between the two tractor-trailer streams by 2.9 ft. With an overall width of 8.0 ft. for a tractor-trailer, the information presented above indicates the average lateral distance between the two tractor-trailer streams decreased from 4.2 ft. before construction to 1.3 ft. with the barrier on the right. In addition, the average position of the left side of the tractor-trailer in the shoulder lane was within 0.3 ft. of the centerline with the barrier on the right. As with cars during the early morning hours, this average position was on the centerline.

When the barrier was placed on the left edge of the roadway, the average lateral placement of tractor-trailers in the shoulder lane decreased by 0.3 ft. to 1.6 ft. and in the median lane it increased by 0.8 ft. to 2.7 ft. Both of these movements were statistically significant (t-test, $p > 0.99$). With the barrier on the left, tractor-trailers in the lane adjacent to the barrier tracked an average of 1.0 ft. closer to the barrier than when it was on the right. The effect of the presence of the barrier on the left edge of the roadway was to reduce the average lateral distance between the two tractor-trailer streams by 0.5 ft. to 3.7 ft. The wider roadway width during phase III construction and the tractor-trailers tracking closer to the barrier when on the left contributed to the two tractor-trailer streams being 2.4 ft. further apart than when the barrier was on the right.

Table 7

Average Lateral Placement of Tractor-Trailers, in Feet

	Median Lane			Shoulder Lane		
Time (Hr.)	Before Construction	Barrier On Right	Barrier On Left	Before Construction	Barrier On Right	Barrier On Left
0400	NO DATA	3.1	2.9	NO DATA	4.3	1.9
0800	1.7	1.9	2.6	1.8	3.9	1.7
1200	1.9	1.9	2.7	1.8	3.4	1.3
1600	1.7	1.4	2.7	1.8	3.1	1.4
2000	2.4	1.8	2.9	1.7	3.7	1.5
2400	2.0	1.9	2.5	2.1	3.8	1.5
AVERAGE	1.9	1.9	2.7	1.9	3.7	1.6

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3. "Average Daily Traffic Volumes on Interstate, Arterial and Primary Routes," Virginia Department of Highways and Transportation, Richmond, Virginia, 1980.

4. Lisle and Hargroves, *op. cit.*, p. 19.

5. *Ibid.*, p. 17