occurs, it may have a very negative effect on traffic operations on the arterial street.

ACKNOWLEDGMENT

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Operational Effects of Driveway Width and Curb Return Radius

STEPHEN H. RICHARDS

Existing driveway design standards include independent design controls for throat width and curb return radius. They fail to recognize that these two driveway features may have an aggregate effect on driveway operation. In addition, current standards for driveway width and curb return radius are based primarily on vehicle turning capabilities and do not consider how drivers respond, in terms of speed and path, to various driveway designs. The results of proving-ground studies conducted to evaluate the effects of driveway width, curb return radius, and offset taper approach treatments on the speed and path of drivers entering and leaving driveways are presented. A total of 59 nonprofessional drivers participated in the studies. These motorists, driving an instrumented study vehicle, collectively performed more than 1400 driveway entry and exit maneuvers. Speed and path data were collected for each maneuver and were analyzed to determine the relative performance of 19 driveway design conditions. The studies revealed that current standards for driveway width and radius result in driveway designs that encourage very slow entry speeds and, in many cases, undesirable vehicle paths. Recommendations are presented, based on the study results, for driveway width and radii requirements. The studies also found that offset taper approach treatments do not have a significant effect on entry paths or speeds at driveways.

A primary objective of driveway regulation is to establish design controls for the physical features of driveways. Experience indicates that these design controls are needed to promote efficient traffic operation and safety (1,2). However, many of the design controls contained in existing state and local regulations are based more on intuition than on engineering evaluation. The actual effects of these controls on traffic operations and safety are not fully known and, because there is no documented evidence supporting them, it is sometimes difficult to justify or defend their use.

There is a particular need to determine how drivers respond (in terms of path and speed) to driveway throat width and curb return radius. Existing design controls for width and curb return radius are based primarily on vehicle turning capabilities and do not consider driver performance characteristics. In addition, existing regulations present independent design controls for these two driveway features. They do not recognize that width and curb return radius may have a combined effect on vehicle speed and path at driveways (3,4).

STUDY DESCRIPTION

A series of proving-ground studies was developed to evaluate driver response to various driveway features in terms of speed and path. The objectives of each study were as follows:

1. Study 1--Determine the effects of throat width and curb return radius (as individual design features and in combination) on the speed and path of drivers turning right into driveways,
2. Study 2--Determine the effects of exiting vehicle position on the speed and path of drivers turning right into driveways,
3. Study 3--Evaluate the effects of offset taper approach treatments on the speed and path of drivers turning right into driveways,
4. Study 4--Evaluate the effects of curb return radius on the speed and acceleration of drivers turning right out of driveways, and
5. Study 5--Evaluate the effects of unequal entry and exit curb return radii on the speed and path of drivers turning right into driveways.

In all five studies, a group of "off-the-street" motorists drove an instrumented study vehicle through a specially constructed driveway test track. The speed and path of these drivers as they entered or exited the various driveways under study were recorded. A comparative evaluation of the different driveways was then made based on the speed and path data.

Test Track

The studies were conducted at the Texas A&M University Proving Ground facility in Bryan, Texas. This facility is located at an abandoned U.S. Air Force base, and the unused airport runways provide an ideal environment for controlled driving studies.

A driveway test track, approximately 2000 ft long, was constructed on one of the runways. The study driveways were constructed by using canvas fire hoses, which were painted yellow and stuffed with wood shavings. The fire hoses provided a three-dimensional visual target and physical barrier very similar to concrete curbing and were flexible enough to use on both curved and tangent sections. In addition, the pliable hoses created no safety hazard and were easily repaired when damaged by a vehicle impact. Since the hoses were portable and did not scar the pavement, the test-track layout could be changed quickly and effectively in order to evaluate a new set of driveways.

The two test-track layouts used for the studies are shown in Figure 1. The first layout had eight

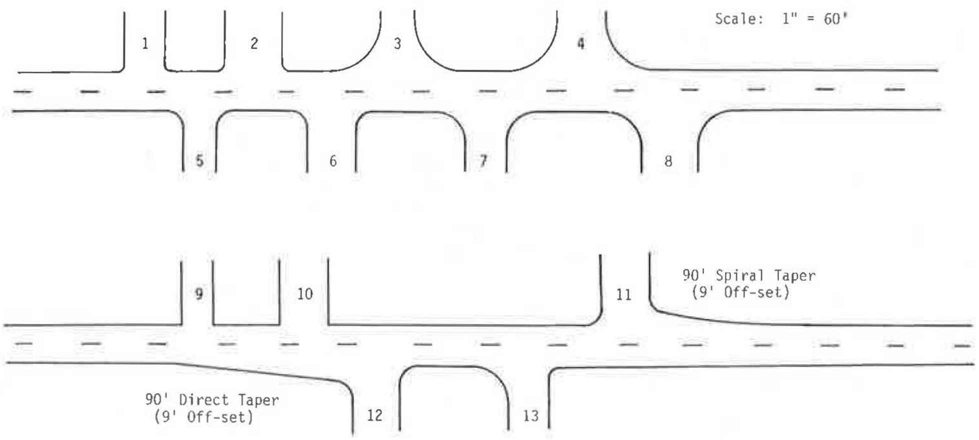


Figure 1. Test-track layouts: (top) first layout and (bottom) second layout.

Table 1. Measurements of driveways evaluated in study 1.

Test-Track Layout	Driveway	Width (ft)	Curb Return Radius (ft)	Spacing Between Driveways (ft)
First	1	25	5	35
	2	35	5	60
	3	20	30	85
	4	30	30	
	5	20	10	55
	6	30	10	65
	7	25	20	80
	8	35	20	
Second	9	20	0	40
	10	30	0	165
	11	30	10	
	12	30	10	65
	13	25	20 (entry), 5 (exit)	

driveways, and the second layout had five. Temporary centerline and stopline markings (not shown in the figure) were installed at certain driveways during some of the studies. The measurements of the driveways in both layouts are given in Table 1.

It should be emphasized that driving conditions and driver expectancies at the test track were somewhat different from those that would exist under normal driving situations. For example, there was none of the vehicle or pedestrian traffic that, under normal conditions, could influence driver behavior. In addition, the entire runway was level and there were no approach grades or changes in elevation at the driveway entrances. For these reasons, extreme caution must be used in relating the speed and path data for a test driveway to an actual driveway.

Test Vehicle

A 1977 Chevrolet Impala with a 305 V-8 engine was used as the test vehicle in all studies. This vehicle was selected as representative of a standard-sized automobile. It had an overall length of 212 in, a total width of 76 in, and a wheel base of 116 in. The vehicle was equipped with power steering and brakes and weighed approximately 3800 lb.

A Labro Track Test fifth wheel was mounted on the rear bumper of the test vehicle and positioned so that it tracked behind the left wheels. A tachometer on the fifth wheel transmitted continuous speed data to a two-channel Brush 222 strip-chart recorder mounted in the vehicle. The recorder was remote controlled from the front seat.

Test Subjects

A total of 59 paid test subjects from the Bryan-College Station, Texas, area participated in the studies. Only licensed drivers with normal driving experience and skills were selected. Most subjects participated in several of the studies, and approximately 30 drivers participated in each study.

On the average, the study sample was younger and better educated than the national driver population and included a disproportionately high percentage of female drivers. However, since the studies involved determining the "relative" performance of various driveway designs, these sampling biases probably had minimal effect on the study results (relative performance was determined by comparing a group of drivers' responses to one design with the same group's responses to another design).

Study Administration

Because a limited number of driveways could be constructed on the test track at one time, the studies were administered in three phases:

1. During phase 1, most of study 1 was conducted. The first test-track layout (Figure 1) was used, and 31 of the 59 subject drivers participated.
2. During phase 2, studies 2 and 4 were administered to 29 of the 59 participating drivers. The first test-track layout was again used. An unmanned vehicle was positioned in the two driveways used for study 2, and stopline and centerline markings were installed at the four driveways used for study 4.
3. In phase 3, studies 3 and 5 and the remainder of study 1 were administered. The second test-track layout (Figure 1) was used and 26 of the 59 subject drivers participated.

Only one driver at a time was allowed on the test track and, once a driver entered the test track, he or she drove until completing an entire study phase. Approximately 45 min of driving time was required to complete each phase. Several subjects participated in more than one phase; however, there was a two- or three-week time period between each phase.

Study Procedure

On arriving at the study headquarters, the subjects were briefed on the nature of the studies and were driven through the test track by the study administrator, who explained the study procedures and demonstrated the required maneuvers. Minimum instruction was given on how to use the driveways.

Every subject was told to use test-track driveways as he or she would normally use driveways in daily driving. Each subject was also encouraged to make comments about any of the driveways being evaluated in the studies.

The subject was then allowed to drive the test vehicle. Each subject made a few practice runs through the test track to become familiar with the study procedures, the track layout, and vehicle handling characteristics. After the subject felt comfortable with the procedures and the vehicle, he or she began the required study maneuvers. The study administrator rode with each subject throughout the studies to give instructions and operate the strip-chart recorder. The subjects performed the various study maneuvers (right-turn entry or exit) three times at each driveway. Each subject progressed through the series of maneuvers required for a given study phase in a random manner. This prevented the driver learning process from affecting the overall study results.

Right-Turn Entry Maneuvers

Studies 1, 2, 3, and 5 involved a right-turn entry maneuver. In these studies, subjects accelerated to 30 miles/h, drove to a particular driveway (identified by traffic cones placed out of the travel lanes on either side of the driveway), and made a "comfortable" right turn into the driveway. In entering the driveway, the subjects could use any speed and path they believed appropriate. After entering, they drove approximately 50 ft into the driveway throat and stopped.

Right-Turn Exit Maneuvers

Study 4 involved a right-turn exit maneuver. Stopline and centerline markings were installed at the four driveways used in the study. The stopline markings provided a common starting point for all right-turn exit maneuvers, and the centerline markings were positioned to provide a 15-ft exit lane at all driveways. To make the required exit maneuver, the subjects, after stopping on the stopline, accelerated and turned right out of the driveway into the right travel lane. They continued accelerating at a comfortable rate until reaching a speed of 30 miles/h or more.

Data Collection

The speed of the test vehicle was continuously monitored during all five studies by the fifth wheel, a tachometer, and a strip-chart recorder assembly. The strip-chart recorder provided a continuous plot of vehicle speed versus time. An event recorder connected to the strip-chart recorder enabled the study administrator, who operated the equipment, to identify the point in time (and spot speed) at which the test vehicle cleared the travel lanes. The event recorder made it possible to relate the time-speed plot to the position of the vehicle at the driveway.

Vehicle position data were recorded for all right-turn entry maneuvers (studies 1, 2, 3, and 5). These data were collected by two ground observers, who manually recorded the position of the test vehicle's right front wheel as it passed over several sets of tape reference markers on the pavement. Wheel position relative to driveway geometry was measured to the nearest foot by using the tape marker system.

RESULTS

Study 1

The first study determined the effects of throat width and curb return radius on the path and speed of drivers turning right into driveways. The 10 driveway designs evaluated are given below:

Throat Width (ft)	Curb Return Radius (ft): None	5	10	20	30
20	X		X		X
25		X		X	
30	X		X		X
35		X		X	

Figure 2 shows the mean path of the test vehicle's right front tire (and paths representing one and two standard deviations from the mean path) observed at each of the study 1 driveways. For the designs studied, the average driver tended to move toward the test-track centerline to make the required right-turn entry maneuvers. Most drivers, however, did not encroach over the test-track centerline before entering a particular driveway.

Figure 2 also shows that vehicle paths tended to parallel the entry curbline at driveways that had a curb return radius of 20 ft or more and to diverge from the entry curbline at driveways that had a radius of 10 ft or less. In the latter cases, drivers made wide turns into the driveway throat to compensate for the small radius. Once the drivers entered the driveways, they turned toward the entry curbline to reposition their vehicles on the proper (entry) side of the driveways.

Driveway width did not significantly influence vehicle path at driveways that had a curb return radius of 20 ft or more (Figure 2). Motorists generally used the entry side of driveways to perform the right-turn entry maneuvers. At driveways that had a radius of 10 ft or less, however, drivers tended to make a wider turn at the wider driveways. They encroached into the exit side of the driveway to compensate for the small curb return radius.

Figure 3 summarizes the speed data collected at the 10 driveways in study 1. The figure shows speed profiles for right-turn entry traffic at driveways 4 and 9. Driveway 4 (Figure 1) was 30 ft wide and had a 30-ft curb return radius. Driveway 9 (Figure 1) was 20 ft wide and had no curb return. The speed profiles for the other eight driveways in study 1 fall within the boundaries established by the speed profiles for these two driveways.

The results show that the speed profiles for all of the study 1 driveways have the same basic shape and almost overlap. This indicates that, in the absence of an exiting vehicle, the average speed of right-turn entry vehicles is essentially the same for driveways that have throat widths ranging between 20 and 35 ft regardless of curb radius. Drivers began slowing down (from 30 miles/h) approximately 250 ft upstream of the driveways. They began to decelerate more rapidly about 150 ft upstream of the driveways and continued decelerating in the driveways.

Drivers slowed down considerably to enter all of the driveways. The average entry speed (the speed when the test vehicle cleared the test-track travel lane) at driveway 4 was 13 miles/h, and the average entry speed at driveway 9 was 9 miles/h. It is important to note that the range of speeds observed at all of the study 1 driveways was relatively small. There was only a 4-mile/h difference in the average entry speed observed at the "fastest" and "slowest" driveways (driveways 4 and 9).

Study 2

The objective of the second study was to evaluate the effects of an exiting vehicle on the speed and path of drivers turning right into driveways. The

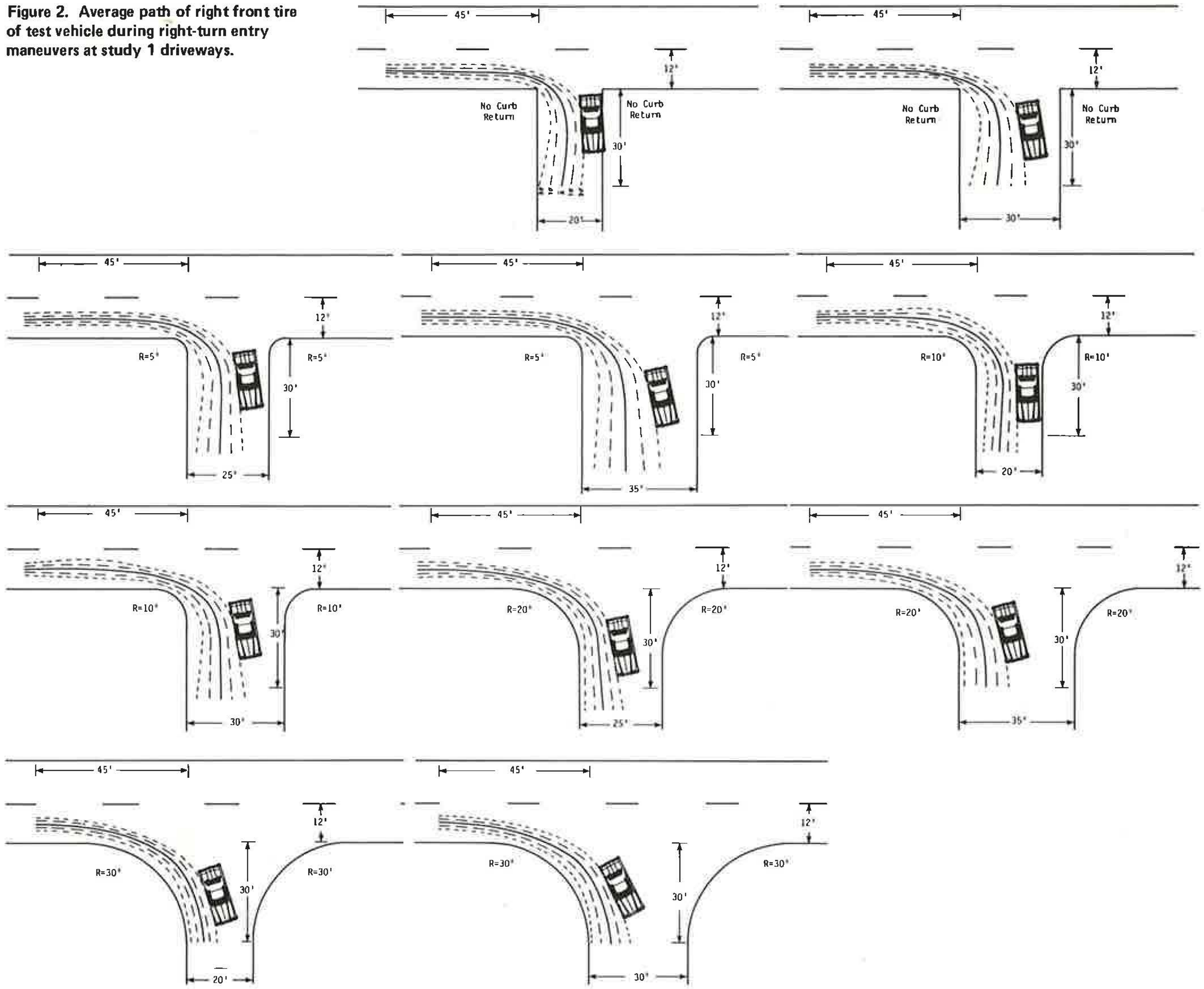


Figure 2. Average path of right front tire of test vehicle during right-turn entry maneuvers at study 1 driveways.

study also provided additional data for study 1. Figure 4 shows the six driveway situations evaluated. The various situations were created by changing the position of an exiting vehicle at two different driveways. As Figure 4 shows, the exiting vehicle was positioned in the test driveways so that the available entry widths were 10, 15, and 20 ft; the two driveways had curb return radii of 5 and 20 ft, respectively.

Figure 5 summarizes the study 2 vehicle-path data. At the driveways that had a 5-ft curb return radius, drivers tended to use as much of the available throat width as possible to complete the right-turn entry maneuvers. At the driveways that had a 20-ft curb return radius, drivers remained on the entry side of the driveway and their paths paralleled the entry curbline.

Drivers experienced extreme difficulty in turning right into the two driveways that had an available width of only 10 ft. As shown in Figure 5, many drivers ran over the curbing. Some drivers even refused to enter those driveways, saying that, if they encountered a similar situation while driving, they would stop in the travel lane and wait for the exiting vehicle to leave the driveway.

Figure 6 shows speed profiles for the six driveway situations evaluated. From the figure, average entry speeds ranged from 5 miles/h (10-ft width and 5-ft curb return radius) to 11 miles/h (20-ft width and curb return radius).

The speed profiles for the study 2 driveways are similar in shape and magnitude to those for study 1, except for the most restricted situation, in which the available width was only 10 ft and the curb return radius was 5 ft. At this driveway, drivers began rapid deceleration approximately 300 ft upstream of the driveway and reached their slowest speed (4-mile/h average speed) while still in the travel lane. Several drivers actually stopped in the travel lane before attempting to enter the severely restricted driveway opening.

Study 3

The third study evaluated the effects of offset taper approach treatments on the speed and path of drivers turning right into driveways. Two taper treatments were studied: direct and spiral. Each treatment, shown in Figure 7, had a 90-ft taper section that produced a 9-ft curbline offset at the driveway. The treatments were used at driveways that had 30-ft throat widths and 10-ft curb return radii.

Figure 8 shows vehicle paths for the two drive-

Figure 3. Summary of vehicle speed data for study 1.

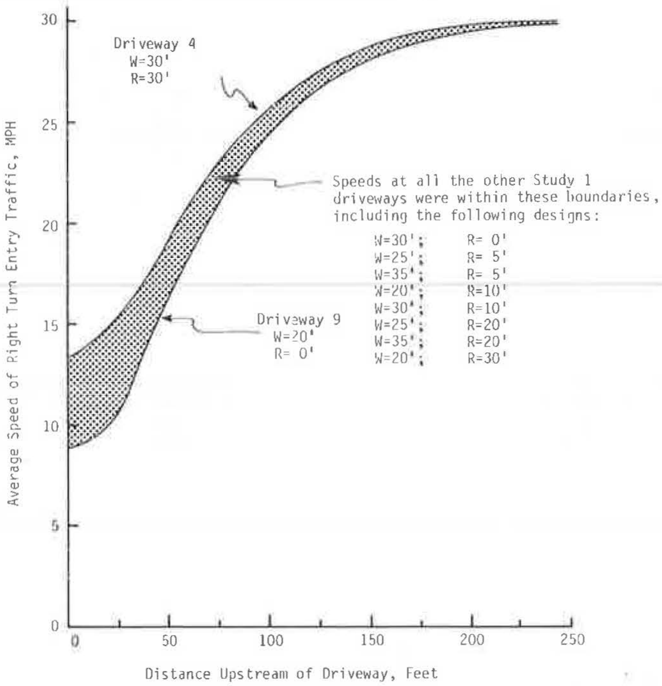


Figure 4. Driveway situations evaluated in study 2.

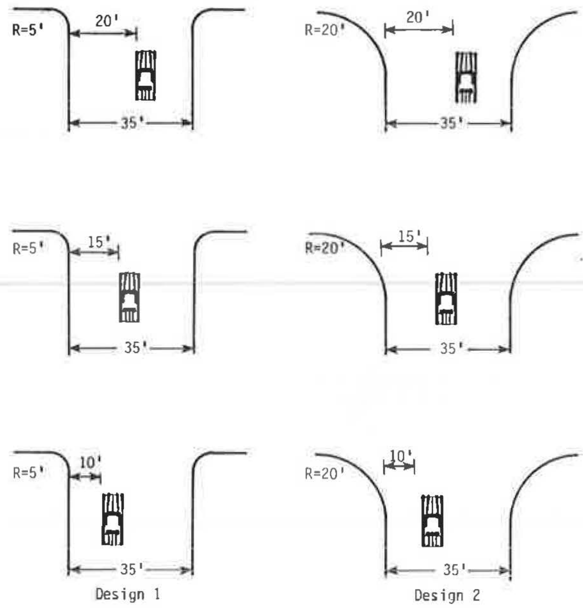
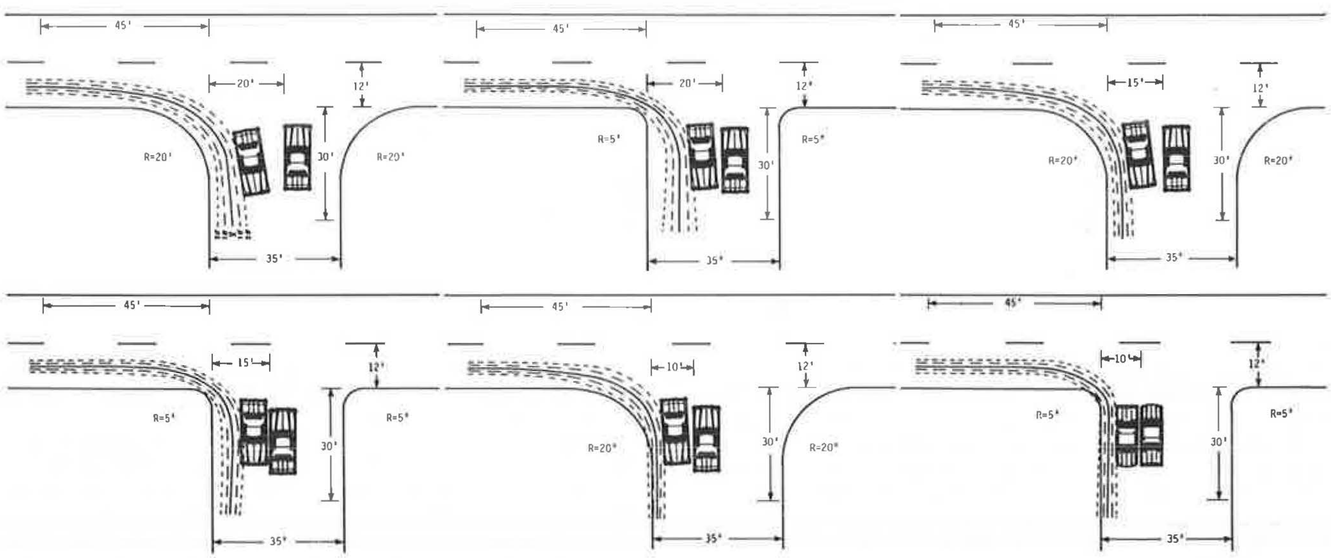


Figure 5. Average path of right front tire of test vehicle during right-turn entry maneuvers at study 2 driveways.



ways and reveals that, at both driveways, vehicle paths paralleled the tapered entry curbline. This trend was more apparent at the driveway that had the spiral taper approach treatment. Drivers also tended to use the entry side of the driveway. Encroachment into the exiting portion of the driveways was less than the encroachment observed at driveway 6 in study 1. (Driveway 6 was identical to the study 3 driveways except that it had no taper approach treatment.)

Figure 9 shows the speed profiles for the two approach treatments evaluated in study 3 and for the similar study 1 driveway. The speed profiles indicate that the offset taper approach treatments evaluated offered no advantages in terms of increased approach and entry speeds. In addition, there was no significant difference between the direct and spiral taper designs in terms of speed.

Study 4

Study 4 was designed to evaluate the effects of curb return radius on the speed and acceleration of drivers turning right out of driveways. Existing curb return radii of 5, 10, 20, and 30 ft were evaluated.

Figure 10 shows speed profiles for right-turn exiting traffic at the study 4 driveways. The profiles indicate that exit curb return radius had very little effect on the speed and acceleration of traffic turning right out of the driveways studied. For example, the average driver accelerated to a

Figure 6. Summary of vehicle speed data for study 2.

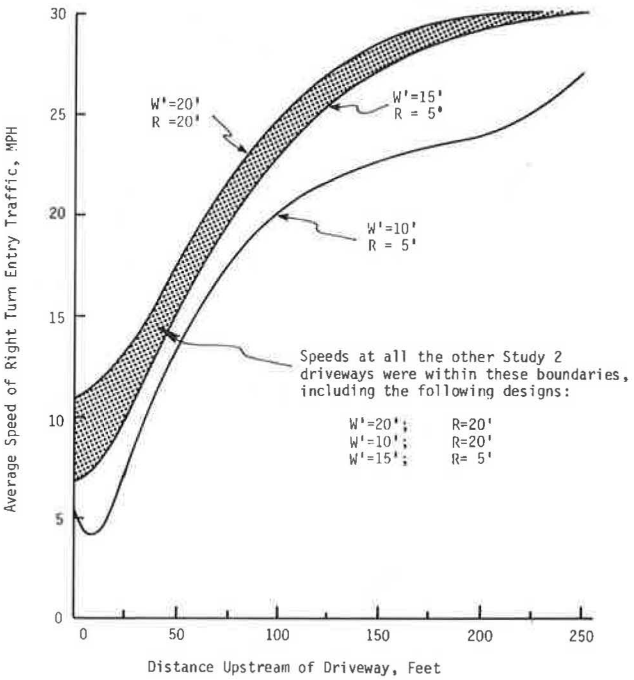


Figure 7. Offset taper approach treatments evaluated in study 3.

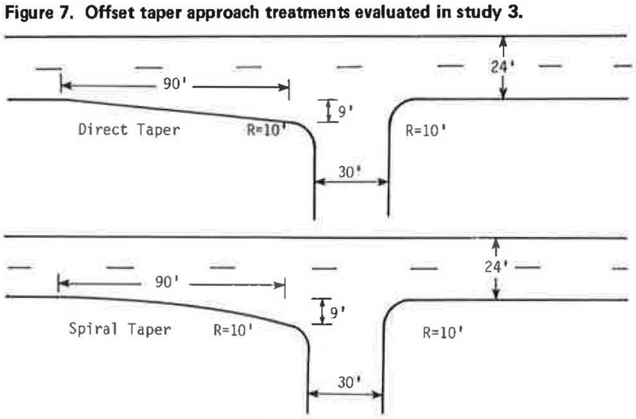


Figure 8. Average path of right front tire of test vehicle during right-turn entry maneuvers at study 3 driveways.

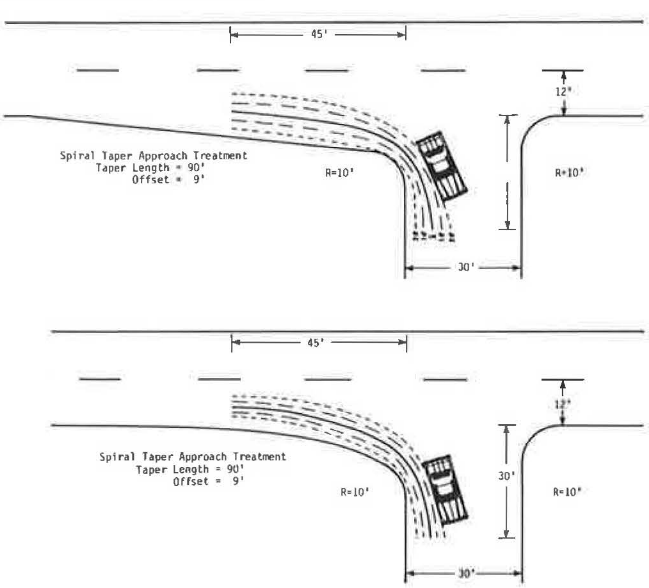


Figure 9. Effects of direct and spiral taper approach treatments on speed of right-turn entry traffic.

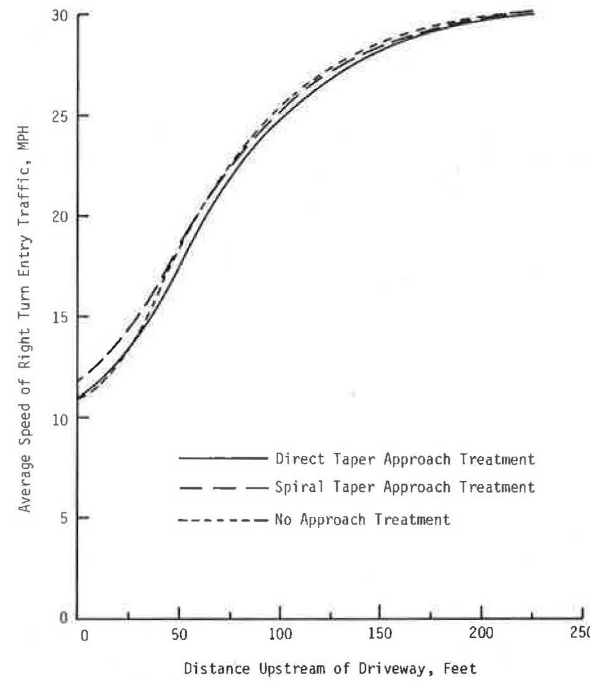


Figure 10. Influence of curb return radius on speed of right-turn exit traffic.

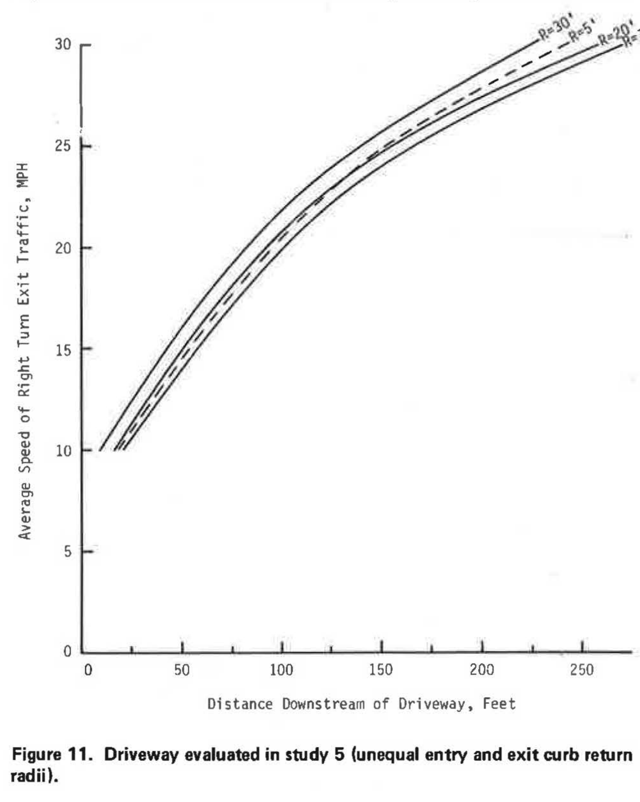
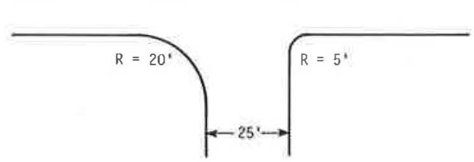


Figure 11. Driveway evaluated in study 5 (unequal entry and exit curb return radii).



speed of 20 miles/h in the first 100 ft after exiting from the driveway that had a 5-ft exit curb return radius and accelerated to 22 miles/h in the first 100 ft after exiting from the driveway that had a 30-ft exit curb return radius. In all likelihood, this relatively small difference (20 versus 22 miles/h) is not significant in terms of safety or traffic operations.

The effects of curb return radius on the positioning of right-turn exiting traffic were not evaluated in the proving-ground studies. However, if the exit curb return radius is small (e.g., less than 10 ft), it is reasonable to assume that right-turn exiting traffic would encroach more into the entry portion of the driveway and exit speed may be reduced in some cases.

Study 5

Study 5 was designed to determine whether unequal entry and exit curb return radii at a driveway affect the speed and path of right-turn entry vehicles. Figure 11 shows the single driveway tested in this study.

Vehicle-path data collected at the study 5 driveway are shown in Figure 12. The 25-ft driveway had an entry curb return radius of 20 ft and exit curb return radius of 5 ft. Also shown are the path data for the study 1 driveway (driveway 7), which was identical except that it had equal (20-ft) entry and exit curb return radii. The data in the figure reveal that there was little or no difference in the mean vehicle path at the study 5 driveway compared with the study 1 driveway. Therefore, the use of unequal radii had no apparent effect on vehicle path.

The speed profiles for right-turn entry traffic at the study 5 and study 1 driveways are shown in Figure 13. From the figure, approach speeds at the study 5 driveway (which had unequal curb return radii) were slightly lower than those at the study 1 driveway (which had equal curb return radii). This difference may suggest that right-turn entry traffic, on seeing a sharp exit curb return, slowed down more in anticipation of a difficult entry maneuver.

SUMMARY

Proving-ground studies were conducted at a driveway test track to evaluate the effects of driveway width, curb return radius, and offset taper approach treatments on the speed and path of driveway users. The 59 drivers who participated in the studies collectively performed more than 1400 driveway entry and exit maneuvers in an instrumented study vehicle. Speed and path data were collected for each maneuver, and these data were analyzed to determine the relative performance of 19 driveway design conditions. The results of the proving-ground studies are summarized below:

1. Driveway width and curb return radius had a combined effect on the speed of right-turn entry traffic at the test-track driveways. The relation among width, curb return radius, and speed of right-turn entry traffic is summarized in Figure 14. The figure shows that average entry speed decreased as available width and/or curb return radius decreased.

2. At driveways that had a curb return radius of 20 ft or more, the paths of vehicles turning right into the driveways tended to parallel the entry curbline and drivers tended to remain on the entry side, regardless of driveway width.

3. At driveways that had a curb return radius of 10 ft or less, drivers tended to make a wide turn, using all of the available throat width to compensate for the relatively small curb return radius. Once in these driveways, drivers immediately steered back toward the entry curbline to reposition the test vehicle on the proper (entry) side of the driveway.

4. The presence of an exiting vehicle in a driveway had a greater effect on the speed and path of right-turn entry traffic than could be explained by the reduction in available width that resulted from the position of the exiting vehicle. For example, the added effect of an exiting vehicle on entry speed can be seen by comparing the speed curves shown in Figure 14 for the driveways in studies 1

Figure 12. Average path of right front tire of test vehicle during right-turn entry maneuvers at (top) study 5 driveway and (bottom) driveway 7 (study 1).

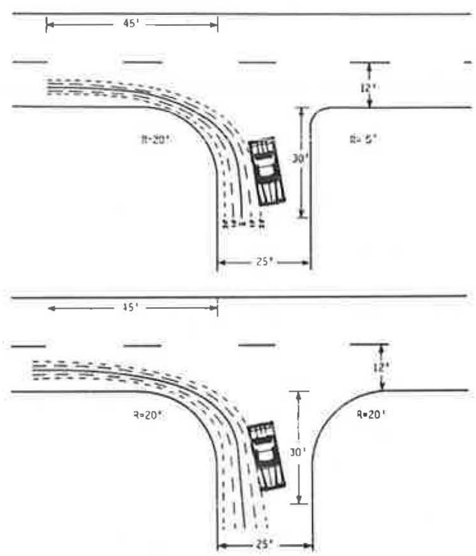


Figure 13. Effects of unequal curb return radii on speed of right-turn entry traffic.

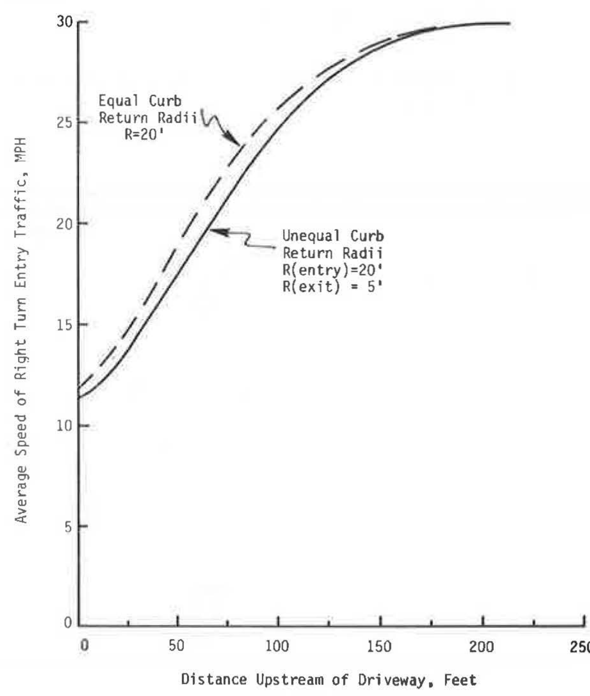
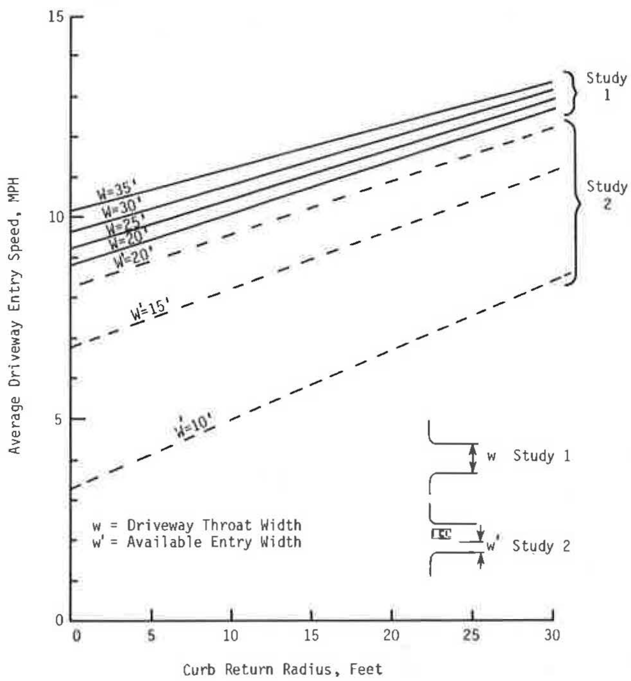


Figure 14. Influence of driveway width and curb return radius on driveway entry speed.



and 2, which both had an available width of 20 ft. Entry speed at the study 2 driveway (where an exiting vehicle was present) was slightly lower than that at the study 1 driveway (where no exiting vehicle was present).

5. The two offset taper approach treatments evaluated in the studies--direct and spiral--offered no advantages in terms of approach or entry speeds. However, in comparison with an identical driveway that had no approach treatment, these treatments did slightly reduce encroachment by right-turn entry traffic into the exit side of the driveways.

6. Under the test-track conditions, exit curb return radius had very little influence on the exit speed and acceleration of right-turn exiting traffic. This finding indicates that, at some driveways, the use of unequal curb return radii (e.g., large entry radius and small exit radius) may be acceptable.

7. The use of a relatively large entry curb return radius (20 ft) in combination with a small exit curb return radius (5 ft) was evaluated with respect to its effect on the speed and path of right-turn entry traffic. Although this use of unequal radii had no significant effect on vehicle path, approach and entry speeds were slightly lower compared with speeds at a driveway that had equal radii. Apparently, many drivers, seeing the small exit curb return radius, slowed down more in anticipation of a difficult entry maneuver.

DISCUSSION AND RECOMMENDATIONS

As mentioned earlier, driving conditions and driver expectancies at the driveway test track were different from those that exist under normal driving conditions. There was no vehicle or pedestrian traffic present, and there were no approach grades or elevation changes at the driveway entrances. Only one type of vehicle was evaluated. For these reasons, the speeds and paths observed at the test-track driveways may be different from those that would be observed at similar operational driveways, and direct application of the speed and path findings may not be appropriate. The findings can be used, however, to compare the relative performance of various driveway designs and, based on the study results, some general recommendations on driveway design can be made:

1. Current standards (5) for driveway width and curb return radius result in driveway designs that may encourage very slow entry speeds (less than 15 miles/h) and, in some cases, undesirable paths. Improved standards are needed, especially for high-volume driveways and driveways on high-speed arterials. In particular, the studies support the need for deceleration lanes at these driveways because the normal curb return radii and widths now used in urban areas severely limit entry speeds.

2. Driveway width and curb return radius work in combination to affect entry speed and path. Standards should be developed that recognize the relation among these features. Current design standards treat these as independent design features.

3. The entry curb return radius (for right-turn entry traffic) at two-way driveways should be at 20 ft to encourage desirable entry paths (for a standard-sized automobile). Smaller entry radii will force drivers to encroach into the exit side of the driveway.

4. Relatively small exit curb return radii (as small as 5 ft) may be used at driveways without significantly affecting the speed or acceleration of exiting traffic. If the radius is too small, however, it will probably negatively affect the path of right-turn exiting traffic.

5. Drivers of standard-sized automobiles should have at least 15 ft of "open" driveway to turn into; otherwise, they must slow down excessively to make the difficult turn maneuver. This suggests that a two-way driveway width of 30 ft would be desirable at high-volume driveways and at driveways on arterial streets (a 15-ft exit lane and a 15-ft entry lane). A narrower driveway may be desirable if the path of exiting vehicles can be controlled by using a centerline or median (1).

6. Offset taper approach treatments, similar to those evaluated, do not significantly increase entry speeds at driveways and have only a minor positive effect on entry path. Their widespread use is not supported by the study findings.

ACKNOWLEDGMENT

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Effects of Paved Shoulders on Accident Rates for Rural Texas Highways

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The shoulder is one of the most extensively studied roadway elements; however, its effectiveness in reducing accidents has been the subject of much debate. A study is described in which accident rates and characteristics were compared for three different types of rural Texas highways: two-lane roadways without paved shoulders, two-lane roadways with full-width paved shoulders, and four-lane undivided roadways without paved shoulders. Approximately 30 roadways of each type were selected for the study. A rigorous screening procedure was developed to ensure that each site was a "typical" Texas roadway. A detailed three-year accident history was obtained for each site. More than 1250 km of highway and 16 000 accidents were included in the study data base. For each roadway type, accident rates increased as traffic volume increased. Two-lane highways without paved shoulders had the highest accident rates and were the most sensitive to changes in traffic volume. Two-lane highways with paved shoulders had the lowest accident rates until the traffic volume reached 7500 vehicles/day. At that point, four-lane undivided highways without paved shoulders were safer. Based on the study findings, it was concluded that full-width paved shoulders are effective in reducing the accident rate on rural highways. It also appears that the presence of full-width paved shoulders may reduce the number of rural intersection accidents.

Today's highway engineers are faced with the dual dilemma of inflationary construction costs and reduced revenues, which necessitates the careful selection of new projects based on the optimum use of existing funds. The Texas State Department of Highways and Public Transportation (TSDHPT) has tried several innovative techniques in order to maximize the use of fiscal resources. One such technique has been to provide additional capacity at minimum expense by converting two-lane roadways with full-width paved shoulders to four-lane roadways without shoulders. This treatment, which has become known as the "poor-boy" highway, entails resurfacing and restriping or simply restriping the existing pavement. Expenses for earthwork, drainage, intersections, and structures are minimized. A poor-boy highway is typically undivided, has no shoulder, and has a paved travel surface from 44 to 48 ft wide.

A poor-boy is certainly an inexpensive alternative to upgrading a two-lane highway to a four-lane divided highway. However, the poor-boy concept is not a standard treatment, and there is currently a limited amount of such mileage in the state. Figure 1 compares the amount of four-lane roadway without shoulders with the amount of two-lane roadways in Texas. As the figure shows, Texas has 69 750 km (43 350 miles) of two-lane highways without shoulders. They are characterized by small traffic volumes. In fact, 95 percent of these roads carry fewer than 2000 vehicles/day. There is also 21 000 km (13 050 miles) of two-lane highways with full-width paved shoulders. Most of these roadways carry 1000-3000 vehicles/day. The state has only 900 km (560 miles) of four-lane roadways without shoulders. These roadways are most heavily concentrated in the range of 1000-5000 vehicles/day. For the remainder of this paper, the terms poor-boy and four-lane highway without shoulders are used interchangeably.

SCOPE OF STUDY

The TSDHPT does not have a documented data base for establishing design policies and practices for the upgrading of two-lane highways without paved shoulders to two-lane highways with paved shoulders or for upgrading two-lane highways with paved shoulders to poor-boy highways. One of the purposes of this research was to establish the accident effects related to the presence or absence of a paved shoulder. The planning division of TSDHPT considers any paved shoulder less than 6 ft wide as "none or inadequate" and codes the state's computerized geometric files in that manner. The same definition for shoulder was adopted for this study. The study was limited to rural Texas highways of the types shown in Figure 2.

BACKGROUND

The shoulder is one of the most extensively studied roadway elements; however, safety findings have not always been consistent. This has caused considerable confusion about the exact relation between shoulder characteristics and accident experience. Previous studies can be placed into three general groups: those that find that wider shoulders have adverse effects, those that indicate that wider shoulders have unclear or null effects, and those that indicate that wider shoulders have favorable effects.

Belmont's studies in California (_1_,_2_) and Blensly and Head's study in Oregon (_3_) found increases in accident rate, property damage, and accident severity for certain types of wide-shoulder conditions. Investigations by Perkins (_4_), Taragin and Eckhardt (_5_), Raff (_6_), and Foody and Long (_7_) indicated that shoulder effects on accidents were marginal or insignificant. Other researchers, including Stohner (_8_), Jorgensen (_9_), and Zegeer and Mayes (_10_), found a reduction in accident rates due to wider shoulders. These studies may be considered a partial list, since there are many other research efforts in the field.

It often seems that different conclusions have been reached in nearly every study on the subject. This diversity of opinion can be explained in part by consideration of the scope of the various studies. Many of the researchers examined data in limited areas of volume, geometry, and operational