Driver Behavior as Related to Shoulder Type And Width on Two-Lane Highways

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● APPROXIMATELY 94 percent of the primary rural roads on a mileage basis are two lanes. In the western states the greatest proportion of these roads are surfaced with bituminous material. In the past, the normal practice has been to construct gravel shoulders adjacent to the traveled lanes. In recent years, however, a number of the western states have adopted the practice of also paving the shoulders with bituminous material. In most cases there has been a definite distinction between the appearance of the traveled lanes and the shoulders, either in color or texture or both. On a small but significant mileage of these rural roads, there is no distinction in color or texture between the lanes and the shoulders. In appearance these roads are two-lane highways with 20-ft lanes without shoulders instead of the normal 12-ft lanes with shoulders.

The change in practice of having no distinction between the pavement and shoulder concerned many engineers since in most cases the shoulder area was not as structurally strong as the traffic lane. Furthermore, it was felt that drivers would attempt to operate on these sections in a manner similar to operation on four-lane undivided highways. This concern resulted in a study to obtain accurate information regarding driver behavior and bearing on safety of operation on two-lane roads when the shoulders are paved with the same material as the traffic lanes and to compare this information with similar information for two-lane roads having shoulders that appear distinctly different from the traffic lane.

This study was a series of cooperative undertakings between the Bureau of Public Roads and the state highway departments of Arizona, California, Colorado, Idaho, New Mexioo, Oregon, Texas, Utah, and Washington. Field work was started in March 1955 and continued for six months. Vehicle speeds and placements were recorded for each of the several sections selected for study. In addition, observations of passing maneuvers were made over a one-half mile length of highway at a limited number of locations. Observers noted the types of vehicles involved in each passing maneuver and the approximate transverse positions of the passed, passing, and oncoming vehicles.

SUMMARY OF MAJOR FINDINGS

The results of this study bring out a number of important findings which apply to rural two-lane highways with 12-ft traffic lanes carrying light to moderate traffic volumes. Included in the study were sections with gravel shoulders, bituminous paved shoulders having an appearance different from the traveled lane and sections where the shoulders were paved to their full width and were not different in appearance from the lanes. Several types of edge striping were also studied.

Following are the more important findings:

1. Although vehicle speeds were not affected by the shoulder width and type, a relation between vehicle speeds and lateral position did exist on sections where the shoulders were paved to their full width. The average position of the slower vehicles, regardless of type, was closer to the shoulder of the highway than that of the faster vehicles.

2. Commercial vehicles encroached on the shoulder to a greater extent than passenger cars. This was more pronounced on sections with paved shoulders when there was no difference in appearance between the shoulder and the traffic lanes. On sections with paved shoulders that appeared different from the traffic lanes, the shoulder encroachment was ½ to ⅓ that on sections where the traffic lanes and shoulders were of uniform color and texture.

3. The concentration of lateral positions of vehicles increased with an increase in the difference in appearance between the traffic lanes and the shoulders. They were somewhat more concentrated on a bituminous road with bituminous shoulders when there was a difference than when there was no difference in appearance between the shoulders and the traffic lanes. On concrete pavements with full-width bituminous shoulders the placements were more concentrated in the lanes than on bituminous pavements with bituminous shoulders. The highest concentration of placements was found on bituminous and concrete roads having grass or gravel shoulders.

TABLE 1

LOCATIONS INCLUDED IN ANALYSIS, CLASSIFIED BY SURFACE AND SHOULDER WIDTHS AND TYPES

Group	Number of Locations Studied	Number of Vehicles Studied	Traffic Lanes		Shoulder Width		Appearance of Bituminous Shoulder Compared with Traffic Lanes
			Width ft	Type	Bituminous ft	Gravel ft	
1	3	4,000	12	Bit.	None	3-5	
2	8	8,900	12	Bit.	None	6-10	
3	6	9,900	12	Bit.	4	4-6	Contrasting
4	15	22,800	12	Bit.	6-10	None	Contrasting
5	16	14,600	12	Bit.	8	None	No contrast
6	3	4,900	12	PCC	8-10	None	
7	3	5,100	12	PCC	None	9	
8	4	7,900	11	Bit.	6-8	None	Contrasting
9	3	2,400	12	Bit.	8	None	No contrast, stripe near outside edge of shoulder
10	2	2,600	12	Bit.	8	None	No contrast, stripe near outside edge of traffic lane
11	3	5,900	12	Bit.	4	6	Contrasting, stripe near outside edge of traffic lane

4. Shoulder edge stripes closer than 1.5 ft from the outside edge of bituminous pavements paved to their full shoulder width had no effect on vehicle speeds or lateral positions.

5. A 2-in. solid white stripe painted 8 ft from the outside edge of the shoulder or 12 ft from the center line of the pavement on roads paved to their full shoulder width was found to be very effective in keeping vehicles in the travel lanes, thus reducing shoulder encroachment by about 50 percent as compared with no edge stripes.

6. On a two-lane 24-ft bituminous pavement with 4-ft bituminous shoulders different in appearance from the traffic lanes and with 6 ft of gravel outside the paved portion of the shoulder, a 4-in. solid yellow stripe 13 ft from the center of the surface was very effective in reducing shoulder use, especially by trucks.

LOCATIONS STUDIED

Level tangent sections having a cross-section design typical of that used in the particular state were always included in the program. The number of locations in each of the several groups of surface and shoulder width and type is shown in Table 1. Speeds and placement data were obtained for over 87,000 vehicles at 66 locations during the daylight hours. Data were also recorded at night at the locations in Groups 9, 10, and 11.

The average speed and placement data obtained for the several groups of locations are typical and representative of driver behavior for the cross-section designs shown. Even though the speeds and placements at some locations with a given cross-section were somewhat different from those at other locations having the same cross-section, the difference was remarkably small and was of an order normally expected between locations.

Of the data shown in Table 1, the information obtained at the locations in Groups 1 through 5 are of primary interest insofar as bituminous surfaces are concerned. These five groups represent five different shoulder widths and types on two-lane highways having 12-ft bituminous lanes. Following is a more detailed description of the types of shoulders included in these groups:

Group 1 - Gravel shoulders 3 to 5 ft in width. The material consisted of gravel or loose stone chips having the same appearance as gravel. The cross slope on the shoulder was considerably greater than on the traffic lanes.

Group 2 - Gravel shoulders 6 to 10 ft in width. The cross-sections, other than the width of the shoulder, were approximately the same as the locations in Group 1. Included also are shoulders that were penetrated with oil, covered with crushed gravel, and had the same appearance as a gravel shoulder.

Group 3 - Four-ft bituminous paved shoulders which appeared distinctly different from the traffic lanes. In each case there was also 4 to 6 ft of gravel outside of the paved shoulder.

Group 4 - Bituminous paved shoulders 6 to 10 ft in width having a distinctly different appearance than the traffic lanes. Beyond the paved shoulder the roadbed sloped sharply to the ditch line. On several of the sections in this group the slope on the paved shoulder was noticeably greater than on the traffic lane.

Group 5 - Full-width paving, or bituminous paved shoulders 8 ft in width having the same appearance, texture, and riding qualities as the traffic lane. To all outward appearances these roads were two-lane highways with 20-ft lanes and no shoulders.

Groups 6 through 11 include cross-sections having other widths or types of surfaces and shoulders. These include some sections which are typical in certain states. Locations where special studies of edge striping and signs were made are also included in these groups. These so-called special studies will be discussed later.

ANALYSIS OF DATA

The data collected consisted primarily of speeds and placements of all vehicles as they passed a selected point of observation. Each vehicle was classified as to whether it was free moving, meeting another vehicle traveling in the opposite direction, trailing a vehicle in the same direction, passing, or being passed. A vehicle not belonging in any of these groups was classified as "other." It has been found that the best measure of the effect on driver behavior of the variables under study is provided by the free-moving and meeting vehicles. Reliable comparisons of speeds and placements were possible between vehicles in these two groups. The remaining groups, with the exception of those passing other vehicles traveling in the same direction, were combined into one group and were identified as "all other vehicles." The number of vehicles involved in passing maneuvers during the periods of study was too few to lend themselves to an analysis which would produce significant results. Because of their position in the left traffic lane (negative placements) the passing vehicles were not included in any of the groups.

Comparative data are, therefore, shown for vehicles in the three following groups:

Free-moving vehicles - Those vehicles which were, for practical purposes, uninfluenced by other traffic on the highway when speed and transverse position were recorded. About 55 percent of the vehicles studied were in this group.

Meeting vehicles - Those vehicles that might have been directly affected by oppos-

TABLE 2

AVERAGE SPEED OF VEHICLES ON TWO-LANE BITUMINOUS RURAL HIGHWAYS WITH TWO 12-FOOT TRAFFIC LANES AND VARIOUS WIDTHS AND TYPES OF SHOULDERS

Vehicle Classification	Shoulder Width and Type				
	3' - 5' Gravel mph	6' - 10' Gravel mph	4' Bituminous Contrasting and 4' - 6' Gravel mph	6' - 10' Bituminous Contrasting with Lane mph	8' Bituminous No Contrast with Lane mph
Passenger cars:					
Free moving	53.4	58.2	55.9	56.3	54.3
Meeting other vehicles	53.2	57.2	55.0	56.0	53.3
All	52.9	57.5	55.0	56.0	53.9
Commercial vehicles:					
Free moving	46.2	49.3	47.2	48.4	47.5
Meeting other vehicles	45.5	50.1	48.7	48.2	49.1
All	46.4	49.2	47.6	48.4	47.2

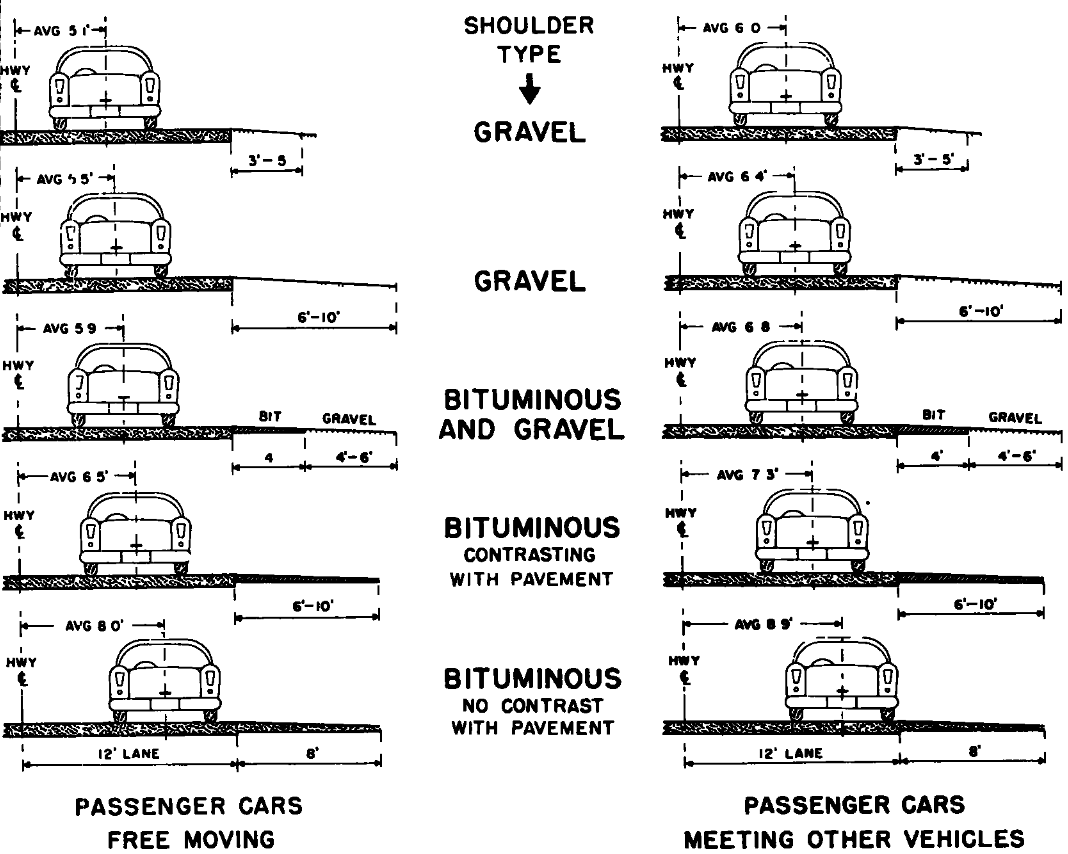

Figure 1. Average lateral position of passenger cars on rural 2-lane bituminous pavements.

ing traffic, but uninfluenced by traffic in the same direction. Clearances between the bodies of these vehicles were calculated from the placement data. About 15 percent of the vehicles were in this group.

All other vehicles - Those vehicles which were not classified as free moving or

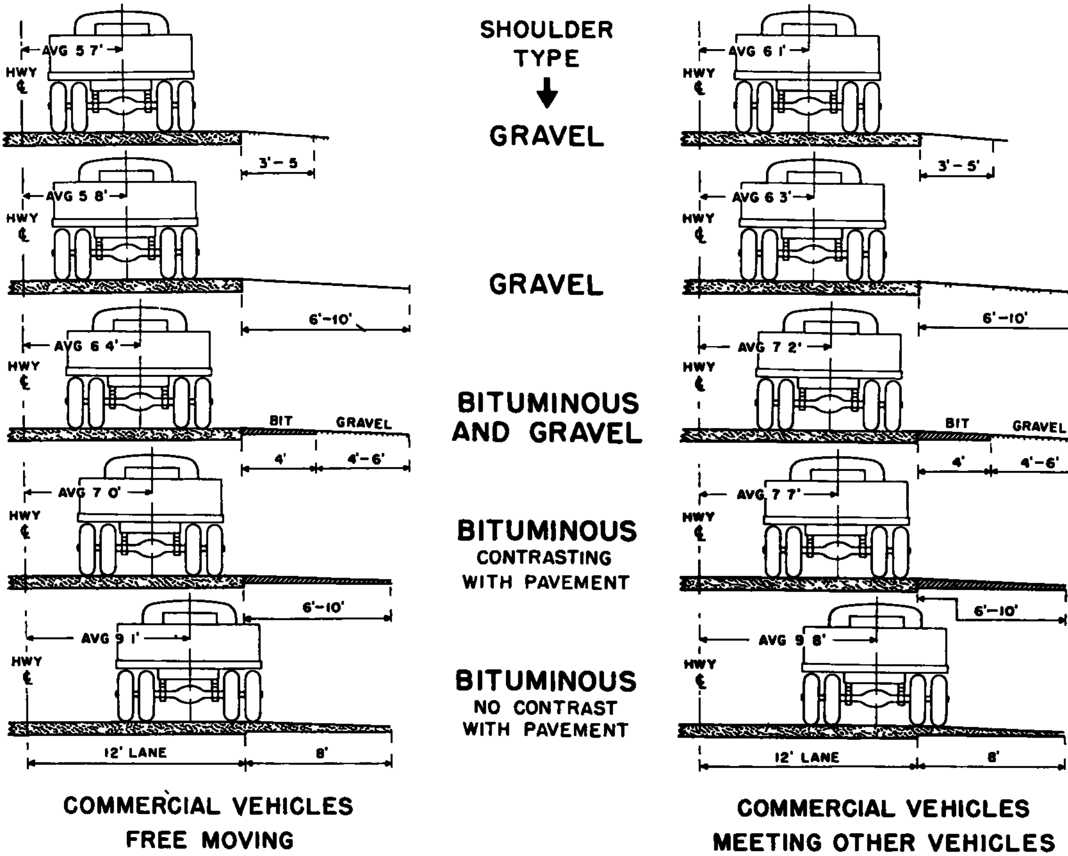

Figure 2. Average lateral position of commercial vehicles on rural 2-lane bituminous pavements.

meeting other vehicles. These vehicles included those which were probably influenced to some degree by other traffic. These constituted 30 percent of all traffic.

Speeds and placements were analyzed separately for passenger cars and for commercial vehicles for each location studied. Data obtained at the several sites having identical highway cross-section geometry were then combined.

OPERATION ON BITUMINOUS PAVEMENTS WITH PAVED SHOULDERS

Vehicle Speeds Typical of Western States

Table 2 shows the average speeds of vehicles obtained for the first five groups of locations studied. There is no great variation between the speeds on sections with narrow shoulders and the speeds on sections with wide shoulders. Within the range of shoulder width and type studied, therefore, the shoulder appears to have no relation to speeds. Passenger car speeds on all the sections studied averaged 55 mph and trucks averaged 48 mph. These are typical of speeds on 2-lane rural roads in the western states.

An examination of the percentages of vehicles traveling below 40 mph and exceed-

TABLE 3

PERCENTAGE OF VEHICLES TRAVELING BELOW 40 MPH AND ABOVE 60 MPH ON TWO-LANE BITUMINOUS RURAL HIGHWAYS WITH TWO 12-FOOT TRAFFIC LANES AND VARIOUS WIDTHS AND TYPES OF SHOULDERS

Vehicle Classification	Shoulder Width and Type				
	3'-5' Gravel	6'-10' Gravel	4' Bituminous Contrasting and 4'-6' Gravel	6'-10' Bituminous Contrasting with Lane	8' Bituminous No Contrast with Lane
Percentage of vehicles traveling below 40 miles per hour					
	Percent	Percent	Percent	Percent	Percent
Passenger cars:					
Free moving	10.4	6.4	6.6	6.7	8.6
Meeting other vehicles	11.6	5.8	7.7	7.2	11.6
All	12.3	6.5	7.7	7.0	8.9
Commercial vehicles:					
Free moving	25.9	14.9	19.3	14.8	20.8
Meeting other vehicles	29.1	10.5	19.1	18.4	16.9
All	25.5	14.8	19.0	15.6	21.2
Percentage of vehicles traveling above 60 miles per hour					
Passenger cars:					
Free moving	29.6	45.7	39.3	42.0	31.6
Meeting other vehicles	27.9	41.3	34.9	40.9	26.3
All	29.3	43.1	35.1	40.7	30.9
Commercial vehicles:					
Free moving	9.0	12.3	9.3	10.5	11.0
Meeting other vehicles	3.5	15.4	13.5	10.9	12.8
All	9.2	11.4	9.7	10.9	10.5

ing 60 mph (Table 3) further verifies the fact that the difference between the shoulder widths and types included in this study did not affect vehicle speeds.

Vehicle Placements

The average lateral positions of the free-moving passenger cars and of the passenger cars meeting other vehicles are shown in Figure 1. Freemoving passenger cars maintained an average lateral position progressively further from the centerline of the highway as the shoulder was increased in width and improved in type. On sections with 6- to 10-ft gravel shoulders the average position was 0.4 ft further to the right than on sections with 3- to 5-ft gravel shoulders. On sections with 4-ft bituminous shoulders different in appearance from the pavement, and with an additional 4 to 6 ft of gravel outside the paved portion, the average position was 0.4 ft farther to the right than on the sections with the 6- to 10-ft gravel shoulders. In this progressive trend the greatest difference in the average lateral position occurred between sections having shoulders and traveled lanes of the same appearance as compared with sections having paved shoulders and traveled lanes distinctly different in appearance. The difference between the lateral positions of free-moving passenger cars for these two groups was 1.5 ft.

Some highway engineers have expressed the thought that an ideal cross-section might be one where the average free-moving vehicle travels in the same path as vehicles which meet oncoming traffic. In other words, traffic would assume a certain lateral position and maintain that position even when meeting oncoming vehicles. It will be noted from Figure 1, however, that the free-moving passenger cars are 0.8 or 0.9 ft nearer the centerline than passenger cars meeting other vehicles for all shoulder widths and types studied.

On sections with gravel shoulders the free-moving commercial vehicles on the average traveled 0.4 to 0.5 ft closer to the centerline than those meeting other vehicles (Fig. 2). On the other sections, the difference was 0.7 to 0.8 ft.

Figure 3 shows the distribution of lateral positions of free-moving passenger cars and of passenger cars meeting other vehicles. This figure is similar to Figure 1. In addition it shows the distributions of the lateral positions. The positions shown are those of the center of the car. A value less than 3 ft from the centerline of the highway indicates that the car was encroaching on the left lane of traffic. Similarly, a value greater than 9 ft indicates that the car was encroaching on the shoulder area. It will be noted from Figure 3 that on 2-lane 24-ft bituminous pavements with gravel shoulders the lateral positions are concentrated mainly within a 3-ft strip in the center of the lane. On the sections with 8-ft shoulders which have the same appearance as the traffic lane (full-width paving), the lateral positions are distributed over a width of about 6 ft.

Let us examine how the pavement and shoulders are being used by vehicles with respect to encroachment on the left lane and on the shoulder. A summary of the percentage of vehicles encroaching on the left lane and on the shoulder is shown by Table 4. This table shows, for each of the five shoulder conditions studied and for the several vehicle classifications, the percentages of vehicles that straddled the centerline (top portion of Table 4) and those which were traveling on the shoulder (lower portion). It will be noted that the type of shoulder does not materially affect the percentages of vehicles straddling the center lane. In general, few vehicles straddle the centerline, and this is particularly true of those vehicles meeting other traffic. This indicates that 12-ft lanes are adequate for 2-lane rural highways and substantiates the results of a previous study.[1]

Shoulder use, on the other hand, is definitely related to the shoulder type (lower portion of Table 4). As might be expected, those vehicles which meet other traffic encroach on the shoulder to a larger extent than vehicles in any of the other groups. Commercial vehicles use the shoulder to a larger extent than passenger cars. The degree of encroachment on the shoulder under various conditions is illustrated in Figure 4.

Encroachment on the shoulder area was the greatest on sections with full-width paving where there was no difference in appearance between the shoulder and the traffic lane. On these sections nearly 80 percent of the trucks meeting other vehicles traveled partly on the shoulder. Full-width paving definitely results in commercial vehicles traveling on that part of the pavement which would normally be considered the shoulder. For this reason it would appear that there is justification for the practice of placing a uniform subgrade and asphalt pavement over the entire width of the roadway where there is no difference between the appearance of shoulder and pavement. Arizona, for example, has followed such a practice for a number of years. The data in Figure 4 indicate, however, that if the traveled lanes are of a color or texture different from that of the shoulder, the structural strength of the entire width of the shoulder need not be as great as that of the traveled lane. Shoulder encroachment on sections where the paved shoulders appear different is ½ to ⅓ that on sections where the traffic lanes

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[1]Effect of Roadway Width on Vehicle Operation, by A. Taragin, Public Roads, October-November-December, 1945.

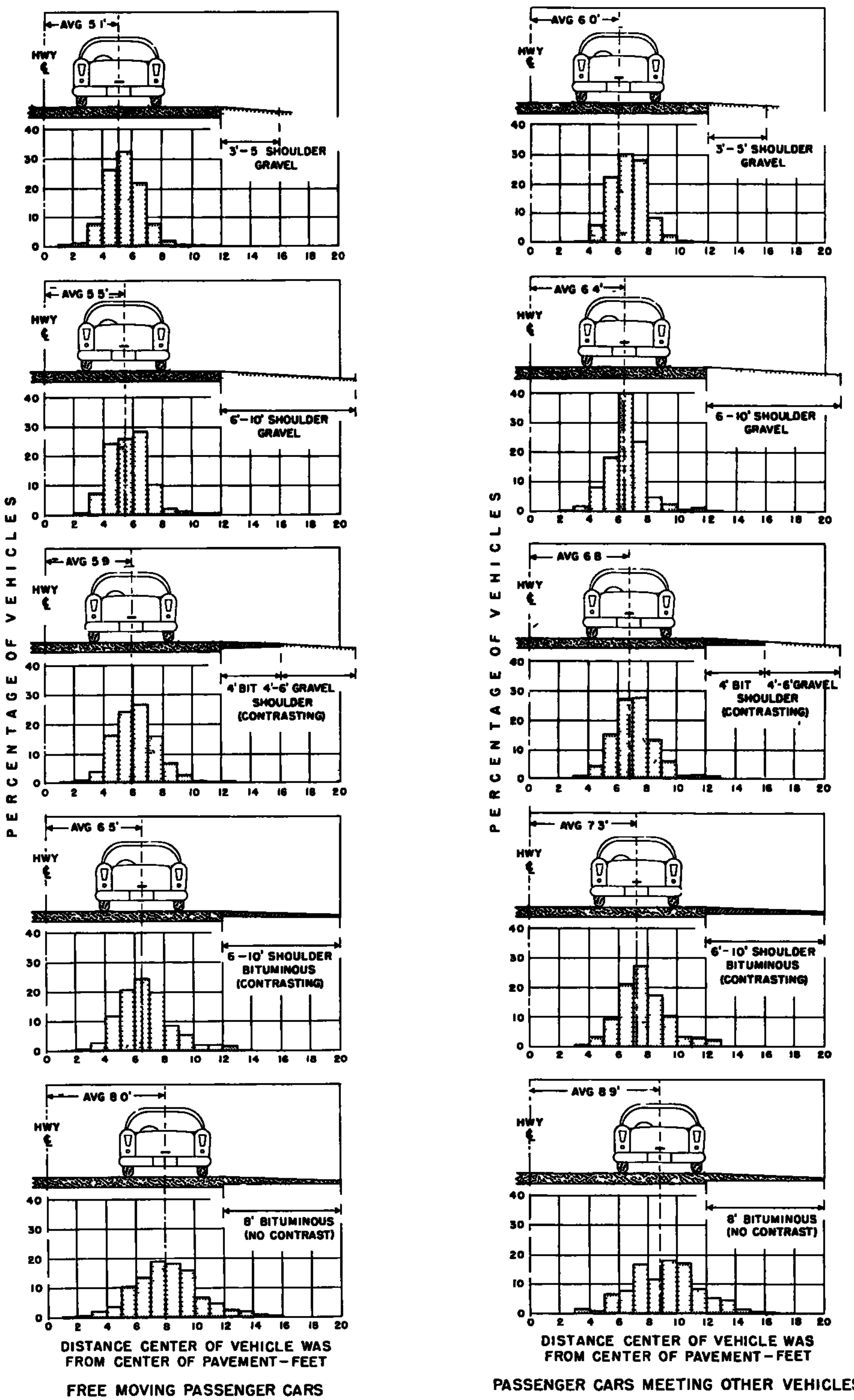

Figure 3. Distribution of lateral positions of passenger cars on rural 2-lane bituminous pavements.

and shoulders are of uniform color and texture (full-width paving).

Let us examine the clearances between the bodies of meeting vehicles and determine the effect that the paved shoulders have on these clearances. Figure 5 shows the distributions and average clearances between the bodies of passenger cars meeting other passenger cars. The percentage of vehicles having clearances of less than 4 ft is very small for all types and widths of shoulder. On sections with narrow gravel shoulders (3 to 5 ft) the average clearance between bodies of passenger cars meeting other passenger cars is 5.8 ft. The average clearances increase with an increase in the shoulder width, and also with the provision of paved shoulders. On sections where there was no difference in appearance between the traveled lane and the shoulder the clearances between the bodies of passenger cars when meeting averaged 11.1 ft, with 94 percent of the meetings having clearances of 6.0 ft or more. It is noteworthy that clearances of 10 ft or more were observed in 63 out of 100 meetings on the full-width paved sections, while on sections having 12-ft bituminous lanes with wide gravel shoulders a clearance of 10 ft or more was observed in 3 out of 100 meetings.

TABLE 4

PERCENTAGE OF VEHICLES STRADDLING CENTERLINE AND TRAVELING ON SHOULDER ON TWO-LANE BITUMINOUS RURAL HIGHWAYS WITH TWO 12-FT TRAFFIC LANES AND VARIOUS WIDTHS AND TYPES OF SHOULDERS

Vehicle Classification	Shoulder Width and Type				
	3'-5' Gravel	6'-10' Gravel	4' Bituminous Contrasting and 4'-6' Gravel	6' - 10' Bituminous Contrasting with Lane	8' Bituminous No Contrast with Lane
Percentage of vehicles straddling centerline					
	Percent	Percent	Percent	Percent	Percent
Passenger cars:					
Free moving	1.3	0.6	1.0	0.4	0.4
Meeting other vehicles	0.2	0.1	0.3	0.2	0
All	1.5	0.8	1.1	0.5	0.5
Commercial vehicles:					
Free moving	2.5	3.9	4.9	0.9	1.3
Meeting other vehicles	0	3.1	1.0	1.5	0.5
All	2.3	2.4	4.9	1.2	1.2
Percentage of vehicles traveling on shoulder					
Passenger cars:					
Free moving	0.7	1.7	3.8	11.6	33.8
Meeting other vehicles	3.4	3.3	10.0	19.8	55.1
All	1.1	1.9	5.9	12.7	36.9
Commercial vehicles:					
Free moving	6.1	3.9	16.4	27.8	67.3
Meeting other vehicles	8.3	10.5	31.6	40.7	78.4
All	5.9	4.6	17.9	30.2	68.7

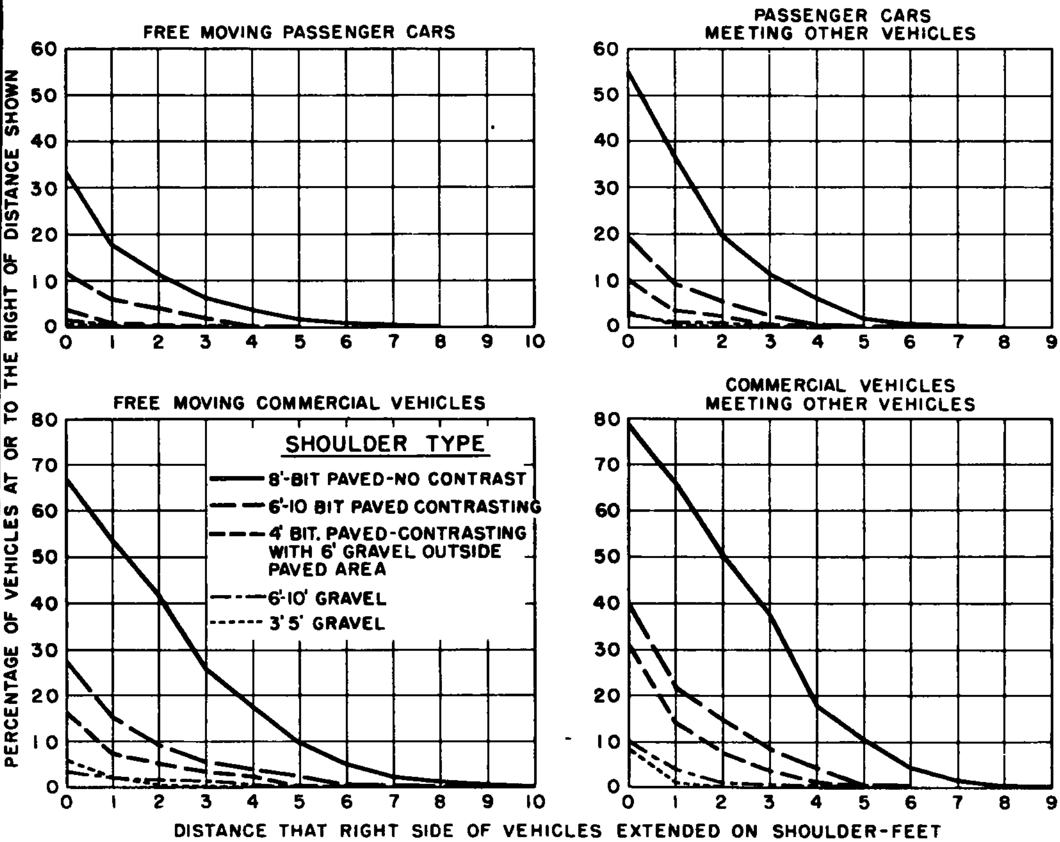

Figure 4. Shoulder encroachment on rural 2-lane bituminous pavements.

TABLE 5

AVERAGE CLEARANCE BETWEEN BODIES OF MEETING VEHICLES ON TWO-LANE BITUMINOUS RURAL HIGHWAYS WITH TWO 12-FOOT TRAFFIC LANES AND VARIOUS WIDTHS AND TYPES OF SHOULDERS

Shoulder Width and Type	Average Clearance Between Bodies for—		
	Passenger Cars Meeting Other Passenger Cars	Passenger Cars and Commercial Vehicles Meeting	Commercial Vehicles Meeting Other Commercial Vehicles
	ft	ft	ft
3-to-5-foot gravel	5.8	5.1	4.6
6-to-10-foot gravel	6.5	5.9	5.2
4-foot bituminous contrasting with lane and 4-to-6-foot gravel outside paved area	7.5	7.4	7.6
6-to-10-foot bituminous contrasting with lane	8.3	8.2	8.1
8-foot bituminous, no contrast with lane	11.1	11.9	10.4

Cumulative distribution of clearances between the bodies as passenger cars meet commercial vehicles are shown in Figure 6. Clearances were lowest on sections with gravel shoulders. On sections with 3- to 5-ft gravel shoulders, 16 percent of the meetings had clearances of 4 ft or less. On sections with 4-ft paved bituminous shoulders and 4- to 6-ft gravel outside the paved portion, however, only 3 percent of the clearances were below 4 ft. On sections where the shoulders were paved with 6 to 10 ft of

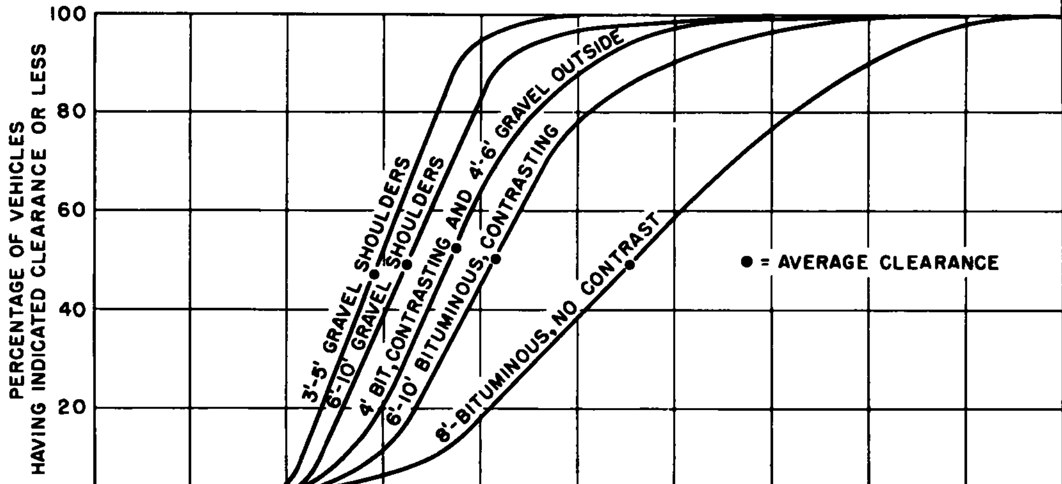

Figure 5. Cumulative distribution of clearances between bodies of meeting passenger cars as related to shoulder width and type on rural 2-lane bituminous pavements.

bituminous material having a different appearance from the traffic lane, the clearances were only slightly greater than on the sections with 4 ft of bituminous material in combination with 4 to 6 ft of gravel. It is obvious that on sections where the 8-ft bituminou shoulders are of the same appearance as the traffic lanes the clearances between passenger cars meeting commercial vehicles are greater than needed for safe operation.

Average clearances between the bodies of commercial vehicles meeting other vehicles were obtained at several typical locations and the results are shown in the last column of Table 5. Although the sample was small, it is interesting to note that only on sections having paved shoulders that were different in appearance with the traffic lanes, were the clearances between the bodies of meeting vehicles about the same for passenger cars as for commercial vehicles.

Sections which had shoulders penetrated with oil and then covered with crushed gravel were included with sections that had gravel shoulders of the same width. Driver behavior on sections with oil shoulders covered with gravel fell well within the range of the data for the untreated gravel shoulders. This was only a reasonable finding sinc both of these shoulder types appeared nearly identical to the driver.

Relation between Speed and Placement

On the normal sections of highways, that is, on sections having 12-ft traffic lanes with grass or gravel shoulders, studies heretofore have shown that there is very little relation between the speeds of vehicles and their lateral position in the traffic lane. Because of the many sections with paved shoulders included in this study, considerable analysis was performed to determine if there was any relation between the speed of a vehicle and its lateral position on the various sections.

A typical illustration of the results is shown by Figure 7. This figure shows the average position of free-moving passenger cars traveling at various speeds on 2-lane rural roads having the five shoulder widths and types. The ordinate shows the speeds at which the cars traveled and the abscissa shows the average position of the centers of the cars with respect to center of the road. It will be noted that on sections with gravel shoulders, there was only a very slight tendency for the slower moving vehicles to travel closer to the shoulder area than the faster moving vehicles. On the sections with the paved shoulders, however, the tendency was appreciably greater. On the sections where the pavement and shoulders were uniform in appearance for the entire width, the lateral position of the slowest group of drivers was more than 2.0 ft closer to the shoulder than the position of the fastest group of drivers. In other words, the slower passenger cars utilized the full width of paving to a greater degree than the

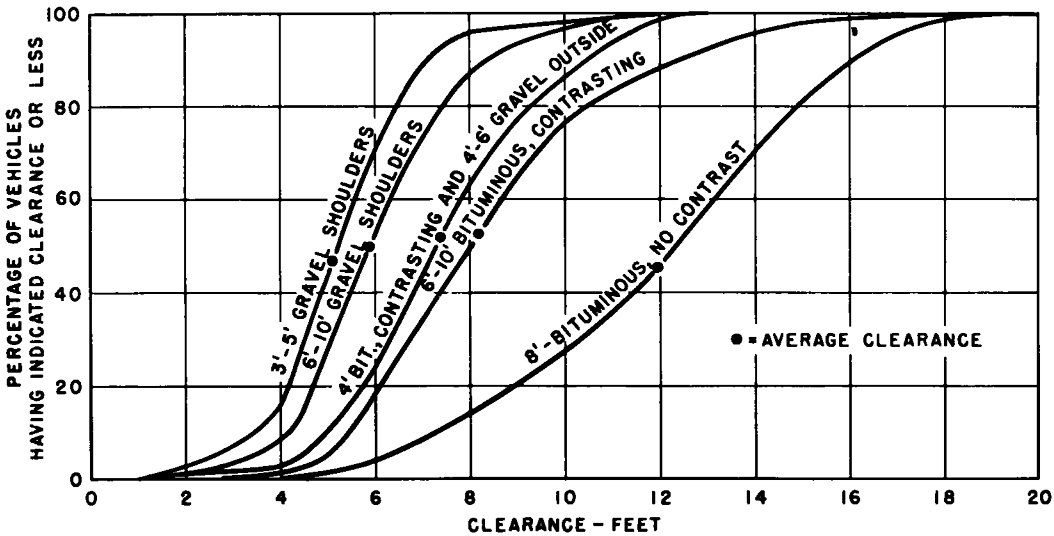

Figure 6. Cumulative distribution of clearances between bodies of passenger cars meeting commercial vehicles as related to shoulder width and type on rural 2-lane bituminous pavements.

faster vehicles. Relations similar to those shown in Figure 7 for free-moving passenger cars were found to exist for other groups of passenger cars and for commercial vehicles.

Passing Practices over Half-Mile Section of Highway

In addition to the speed and placement data which were recorded for each of the sections studied, visual observations were made of passing maneuvers over a one-half mile length of highway at a limited number of locations. The observers classified each passing maneuver by the type of vehicle involved and by the relative transverse and longitudinal position of the passed and passing vehicles. Data were recorded only on sections having the three widths of bituminous paved shoulders shown on Table 6. Results were obtained for 27 locations. It will be noted that the number of passings per mile per hour on sections with the 4-ft bituminous shoulders plus 4- to 6-ft gravel outside the bituminous was the same as on sections with the 6- to 10-ft bituminous shoulders having an appearance different from the traffic lanes. On the full-width paved sections the number of passings performed, reduced to a common traffic volume, was about 30 percent higher than on the other two cross-sections.

It appears, therefore, that the full-width paved sections offer the best opportunity for performing passing maneuvers. Three-lane operation was almost non-existent on

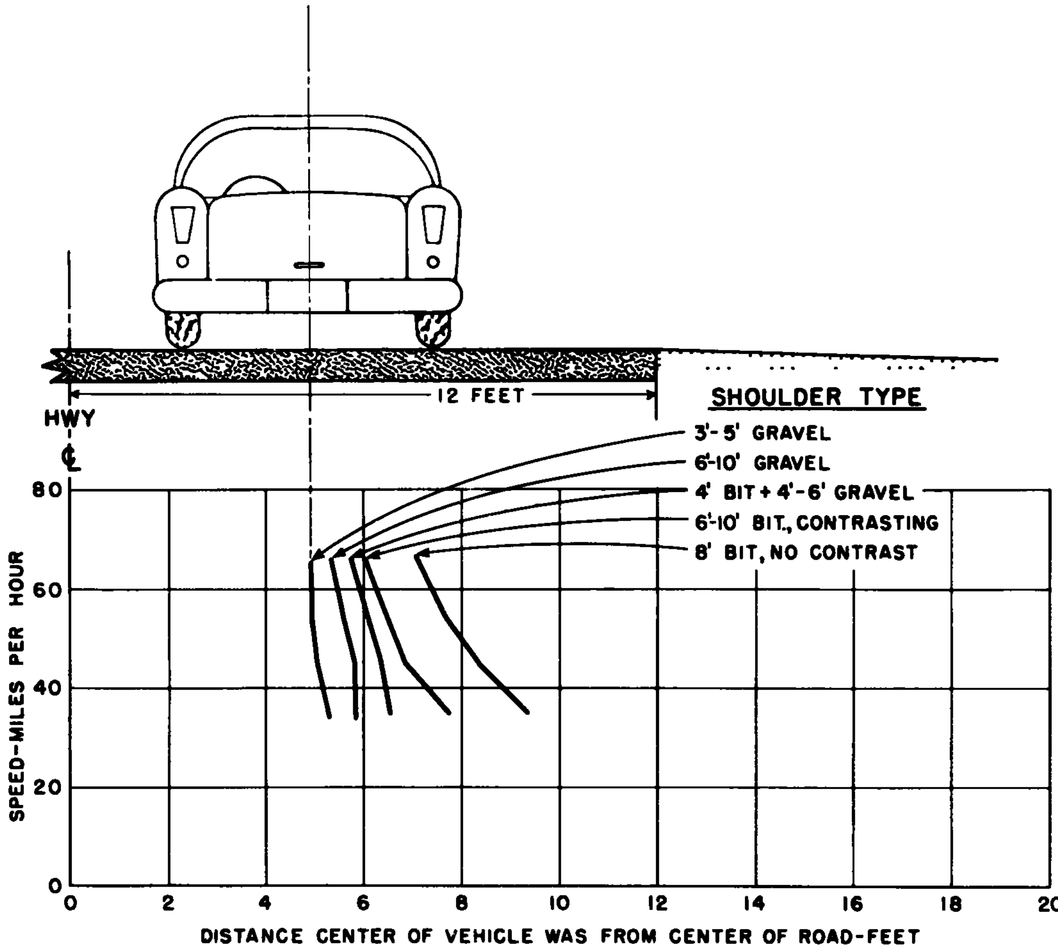

Figure 7. Average position of free moving passenger cars traveling at various speeds on rural 2-lane bituminous pavements.

sections having a 4-ft paved shoulder plus 4- to 6-ft gravel outside the paved portion.

OPERATIONS ON CONCRETE PAVEMENTS WITH PAVED SHOULDERS

As previously stated, shoulder usage was less on bituminous pavements where there was a difference in appearance between the shoulder and the traffic lane than when there was no difference in appearance. The shoulder usage was further reduced on concrete pavements with full-width bituminous shoulders, and still further reduced on sections with grass or gravel shoulders.

Speed and placement data were recorded on 6 level tangent sections of 2-lane, 24-ft concrete pavements. On three of these sections the pavement was flanked by 9-ft bituminous-paved shoulders and on the other three sections the shoulders were grass or gravel and were 8- to 10-ft wide. Table 7 compares the results obtained on the sections with the bituminous shoulders with those obtained on the sections with grass or gravel shoulders. The latter group of sections is identified in Table 7 as gravel shoulders, since results of earlier studies[2] as well as the results of these studies indicate that

[2]See footnote 1.

well-maintained grass shoulders have the same effect on the lateral position of moving vehicles as well-maintained gravel shoulders.

The results (Table 7) show that the speeds were about the same on the sections with the gravel shoulders as on the sections with the bituminous shoulders. Passenger cars traveled about one foot closer to the bituminous shoulders than to the gravel shoulders, while commercial vehicles maintained about the same average lateral position on both shoulder types.

TABLE 6

PASSING MANEUVERS OBSERVED OVER ONE-HALF MILE SECTIONS OF 2-LANE BITUMINOUS RURAL HIGHWAYS WITH TWO 12-FOOT TRAFFIC LANES AND BITUMINOUS PAVED SHOULDERS

Traffic Data and Type of Passing Maneuver	Shoulder Width and Type		
	4-ft Bituminous Contrasting with Lane and 4- to 6-ft Gravel	6- to 10-ft Bituminous Contrasting with Lane	8-ft Bituminous No Contrast with Lane
Number of locations studied	3	11	13
Total hours of study	24	87	95
Average volume - vph	210	210	120
Number of passings per half mile			
Two vehicles abreast:			
Passing vehicles to right of centerline	0	0	4
Passing vehicle straddling centerline	329	1,072	385
Passing vehicle to left of centerline	55	271	252
Three vehicles abreast (2 vehicles in one direction)	2	57	8
Four vehicles abreast	0	2	2
All passings	386	1,402	651
Number of passings per mile per hour	32.2	32.2	13.7
Equivalent number of passings per mile per hour			
for a volume of 210 vph	32.2	32.2	42.0[a]
for a volume of 120 vph	10.5[a]	10.5[a]	13.7

[a]Based on the fact that the number of passings varies as the square of the hourly volume.

Although the percentage of vehicles straddling the centerline was small with either type of shoulder, the percentage of passenger cars that straddled the centerline on the sections with the gravel shoulders was greater than the sections with the bituminous shoulders. More commercial vehicles, on the other hand, straddled the centerline on the sections with the bituminous shoulders than on sections with gravel shoulders, although the difference was slight.

By comparing the results shown in Table 7 for the concrete pavements with similar results for bituminous pavements, shown in Figures 1 and 2, it was found that bituminous shoulders adjacent to the concrete traffic lanes were more effective in confining vehicles to their lane than bituminous pavements with bituminous shoulders of a different appearance from the traffic lane. Vehicle operation, as measured by the lateral position and clearances between vehicles, on 2-lane 24-ft concrete pavements with 9-ft bituminous shoulders was about the same as the operation on 2-lane, 24-ft bituminous pavements with 4-ft bituminous shoulders of different appearance plus 4- to 6-ft gravel outside the paved portion of the shoulder. The greater the difference in appearance between the traffic lane and the paved shoulder, the less was the use of the

TABLE 7

SUMMARY OF SPEEDS AND PLACEMENTS ON 2-LANE PORTLAND CEMENT CONCRETE RURAL HIGHWAYS WITH TWO 12-FOOT TRAFFIC LANES AND 8- TO 10-FOOT BITUMINOUS OR GRAVEL SHOULDERS

Item of Information		Bituminous Shoulders	Gravel Shoulders
Number of locations studied		3	3
Average volume	vph	200	310
Number of vehicles studied		4,928	5,000
Average speed:			
Passenger cars	mph	51.3	50.9
Commercial vehicles	mph	45.1	42.6
Average lateral position:[a]			
Passenger cars:			
Free moving	ft	6.0	5.2
Meeting other vehicles	ft	6.7	5.9
All	ft	6.2	5.4
Commercial vehicles:			
Free moving	ft	6.2	5.9
Meeting other vehicles	ft	6.5	6.6
All	ft	6.3	6.1
Percentage of vehicles straddling centerline:			
Passenger cars:			
Free moving	Percent	0.4	1.6
Meeting other vehicles	Percent	0.1	0.5
All	Percent	0.4	1.2
Commercial vehicles:			
Free moving	Percent	0.6	0
Meeting other vehicles	Percent	0	0
All	Percent	1.8	0.7
Percentage of vehicles encroaching on shoulder:			
Passenger cars:	Percent	3.6	0
Meeting other vehicles	Percent	5.2	0
All	Percent	3.7	b
Commercial vehicles:			
Free moving	Percent	8.5	1.0
Meeting other vehicles	Percent	10.3	5.0
All	Percent	8.5	1.8
Clearance between bodies:	ft	7.1	5.5
Passenger cars meeting other vehicles	ft	6.3	5.7

[a]Distance center of vehicle was from centerline of pavement – feet.

[b]Less than 0.05 percent.

shoulder by moving vehicles, and the better did the moving vehicles position themselves in the traffic lane.

OPERATION ON 2-LANE 22-FT BITUMINOUS PAVEMENTS WITH PAVED SHOULDERS OF DIFFERENT APPEARANCE

Although 11-ft lanes are not now the standard width for primary 2-lane highways, there is a considerable mileage of roads having this width. In conjunction with the studies on sections with 12-ft lanes, 4 locations with 11-ft lanes were studied in three states. These pavements were flanked by 6-to 8-ft bituminous shoulders. One of these locations, which was in Oregon, had red paved shoulders adjacent to the traffic lanes. Another location, also in Oregon, had black shoulders adjacent to a red pavement. The red appearance in the pavement and shoulders was obtained by using red aggregate with an asphaltic binder. On the other two locations, in California and Washington, the shoulders and traffic lanes were bituminous, but the shoulders were distinctly different in appearance from the lanes.

Vehicle speeds on these 22-ft pavements were about the same as for the other sections of 2-lane roads with wider surfaces. Lateral positions with respect to the highway centerline and clearances between meeting vehicles on these sections, however, were nearly the same as they were on 2-lane, 24-ft bituminous pavements with 6- to 10-ft gravel shoulders. It appears, therefore, that paved shoulders adjacent to a 2-lane, 22-ft surface increase the effective surface width about 2 ft.

Vehicle speeds and lateral positions on the section where the shoulders appeared red and the lanes black were very nearly the same as on the sections where the colors were reversed. Furthermore, there was no significant difference between traffic operations on sections where the shoulders and lanes were black and red and sections where the shoulders and lanes were both bituminous but were distinctly different in appearance.

SUMMARY OF RESULTS FOR TWO-LANE PAVEMENTS WITH SHOULDERS PAVED TO THEIR FULL WIDTH

Driver behavior as evidenced by vehicle speed, lateral positions and passing practices was studied on a number of rural 2-lane, 24-ft bituminous pavements grouped in five classes of shoulder width and type. The volumes observed were rather low, usually averaging less than 3,000 vehicles per day and less than 200 vehicles per hour during the periods of study. For these conditions the results may be summarized as follows:

1. Vehicle speeds were about the same on all five groups of sections studied. Passenger cars averaged 55 mph and trucks averaged 48 mph.
2. Vehicles traveled in a lateral position farther from the centerline of the pavement and closer to the shoulder on sections with paved shoulders than on sections with gravel shoulders. The lateral position was farthest from the centerline of the pavement on sections where the paving extended the full width of the shoulder and was of uniform appearance throughout.
3. Encroachment on the left lane of traffic was small on all sections studied, and was not related to the shoulder width or type.
4. Shoulder use was definitely related to shoulder type, and commercial vehicles used the paved shoulders to a larger extent than passenger cars. On the full-width paved sections nearly 80 percent of the trucks meeting other vehicles traveled partly on the shoulder. This compares with about 10 percent of the trucks in this category which encroached on the 6- to 10-ft gravel shoulders.
5. Average clearances between bodies of meeting vehicles was about 6 ft on sections

with wide gravel shoulders, about 7.5 ft on sections having 4 ft bituminous shoulders plus 4- to 6-ft of gravel outside, and over 10 ft on the full-width paved sections.

6. On sections with paved shoulders, and on these sections only, there is a relation between the lateral position of vehicles and their speeds. On these sections the slower vehicles traveled closer to the shoulder than the faster vehicles.

7. Nearly 30 percent more passing maneuvers were performed on sections paved to their full shoulder width than on the other sections.

8. Bituminous shoulders on concrete pavements were used by moving vehicles to a lesser degree than bituminous shoulders adjacent to bituminous pavements.

9. On 2-lane, 22-ft bituminous pavements with 6- to 8-ft bituminous shoulders of an appearance different from the traffic lane, the lateral position of vehicles and clear-

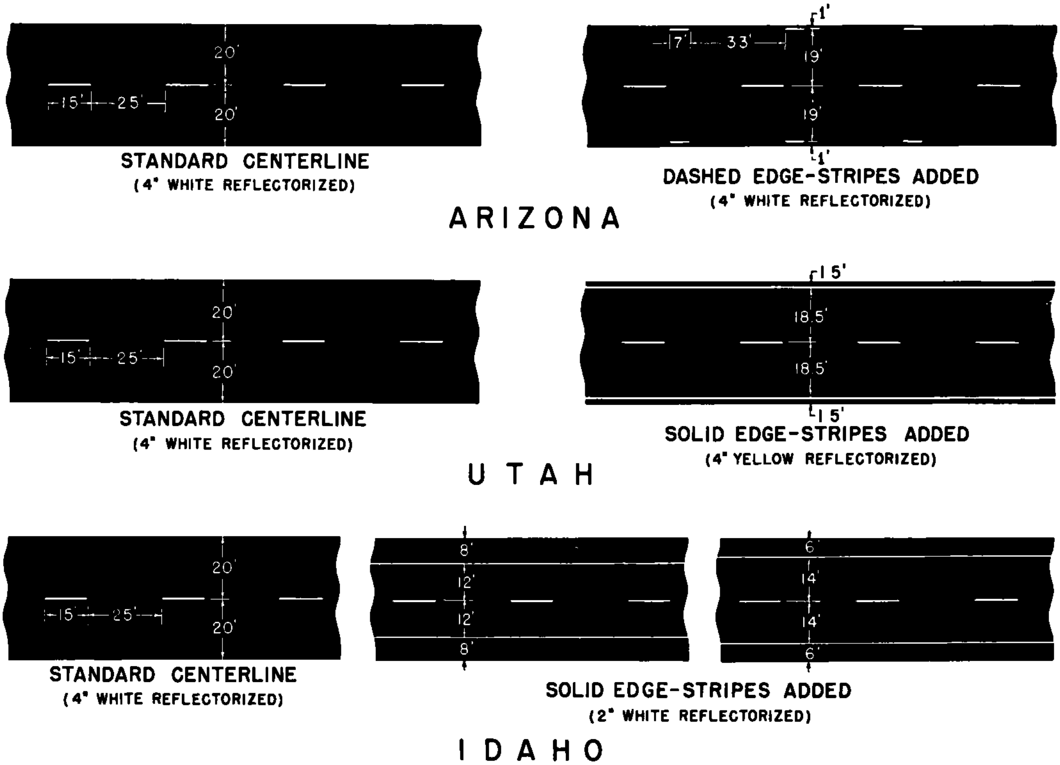

Figure 8. Edge striping on sections paved to their full shoulder width on rural 2-lane bituminous pavements.

ances between vehicles were about the same as on 2-lane, 24-ft bituminous pavements with 6- to 10-ft gravel shoulders.

STUDY OF EDGE STRIPES ON FULL-WIDTH PAVED SECTIONS

Special studies of the effect of edge stripes on vehicle speeds and placements were conducted in conjunction with the studies of full-width paved sections. There was no difference in appearance between the shoulder and traffic lanes on these sections. The pavement consisted, in effect, of two 20-ft lanes without any shoulders. Edge stripes were studied in cooperation with the state highway departments of Arizona, Utah, and Idaho. Standard centerline markings were used in all three states. These consisted of 4-in.-wide white reflectorized dashes, which were 15-ft long, with 25-ft spaces, as illustrated in Figure 8.

In Arizona two sections, both of which were level tangents and on the same highway, were studied simultaneously. One section had no edge stripes. The other section had 4-in.-wide white reflectorized dashes 7-ft long with 33-ft spaces. The dashes were one foot from the pavement edge or 19 ft from the center of the pavement.

In Utah, the studies were conducted at the same location before and after the edge stripes were painted. The edge stripes were 4-in.-wide solid yellow, reflectorized, and were 1.5 ft from the pavement edge or 18.5 ft from the center. Two locations were studied, one on a level tangent and the other near the top of a 3-percent grade about 2,000 ft long.

The speed data (Table 8) indicate that edge stripes caused an increase in speeds in some cases and a decrease in speeds in others. In consideration of the wide disparity in the results, no firm conclusion can be drawn as to the effect of edge stripes on vehicle speeds.

A study of the lateral position of vehicles offers a much more conclusive measure of the effect of edge stripes than a study of speeds. The effect of edge striping on lateral positions is shown by Table 9. The last two columns in this table show for day and night the change in the lateral positions caused by the edge striping.

The edge stripe in Arizona caused passenger cars during the day to travel 0.1 ft closer to the centerline of the pavement than when there was no stripe, and at night the cars traveled 0.4 ft farther from the centerline. The edge stripe in Utah had practically no effect on passenger car placements at night. During the day, however, the average lateral position of passenger cars was 0.6 ft farther from the centerline of the pavement on the level tangent and 0.9 ft farther from the centerline on a 3-per-

TABLE 8

EFFECT OF EDGE STRIPING ON SPEEDS OF VEHICLES ON 2-LANE BITUMINOUS PAVEMENTS WITH FULL-WIDTH PAVED SHOULDERS HAVING THE SAME APPEARANCE AS THE TRAFFIC LANES

State	Alignment	Grade	Edge Stripe				Change in Speed Caused by Edge Striping[b]	
			Color	Type	Width	Distance from Edge[a]	Daytime	Nighttime
All Passenger Cars								
		Percent			in.	ft	mph	mph
Arizona	Tangent	0	White	Dashed	4	1.0	+7.3	+9.5
Utah	Tangent	0	Yellow	Solid	4	1.5	+2.2	-2.5
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	-3.9	+0.9
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	+4.7	+3.8
Idaho	Tangent	0	White	Solid	2	8.0	-9.2	-9.1
Idaho	Tangent	0	White	Solid	2	6.0	-6.9	-4.7
All Commercial Vehicles								
Arizona	Tangent	0	White	Dashed	4	1.0	+6.2	c
Utah	Tangent	0	Yellow	Solid	4	1.5	+2.3	-3.3
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	-2.3	-4.5
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	+5.6	+7.0
Idaho	Tangent	0	White	Solid	2	8.0	-4.6	-4.2
Idaho	Tangent	0	White	Solid	2	6.0	-1.4	0

[a]Distance toward centerline from edge of the full-width paving which was 20 ft from centerline.

[b]Average speed on striped section compared with that on unstriped section.

[c]Insufficient data.

TABLE 9

EFFECT OF EDGE STRIPING ON LATERAL POSITIONS OF VEHICLES ON 2-LANE BITUMINOUS PAVEMENTS WITH FULL-WIDTH PAVED SHOULDERS HAVING THE SAME APPEARANCE AS THE TRAFFIC LANES

State	Alignment	Grade	Edge Stripe				Change in Lateral Position Caused by Edge Stripe[b]	
			Color	Type	Width	Distance from Edge[a]	Daytime	Nighttime
All passenger cars								
		Percent			Inches	Feet	ft	ft
Arizona	Tangent	0	White	Dashed	4	1.0	-0.1	+0.4
Utah	Tangent	0	Yellow	Solid	4	1.5	+0.6	-0.1
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	+0.9	-0.1
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	-1.0	-0.1
Idaho	Tangent	0	White	Solid	2	8.0	-1.9	-2.5
Idaho	Tangent	0	White	Solid	2	6.0	-1.6	-2.3
All commercial vehicles								
Arizona	Tangent	0	White	Dashed	4	1.0	-0.2	+0.1
Utah	Tangent	0	Yellow	Solid	4	1.5	+0.5	+0.2
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	+0.9	+1.3
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	-1.1	-0.1
Idaho	Tangent	0	White	Solid	2	8.0	-1.7	-2.0
Idaho	Tangent	0	White	Solid	2	6.0	-1.7	-2.6

[a]Distance toward centerline from edge of the full-width paving which was 20 ft from centerline.

[b]Average lateral position on striped section compared with that on unstriped section. Minus value indicates that the average position on striped section was closer to the centerline of the highway than on the unstriped section.

cent downgrade. On the 3-percent upgrade passenger cars traveled 1.0 ft closer to the centerline of the pavement with the edge stripe than without it. The change in the average lateral position of commercial vehicles caused by edge stripes in these two states was about the same as the change for passenger cars.

Since the study concerns itself with edge stripes, it is, of course, important to evaluate the effect of these stripes on the extent that vehicles use the shoulder area. Because the pavement consisted, in effect, of two 20-ft lanes, the vehicle was considered to be encroaching on the shoulder area when its right side extended more than 12 ft from the centerline of the pavement. This encroachment is shown by Table 10. This table shows the percentage of vehicles encroaching on the shoulder during the day and at night on sections with and without the edge stripes.

During the daytime in Arizona, passenger cars encroached on the shoulder to about the same extent whether the pavement edge was striped or not. At night, however, the edge stripe caused a considerably larger percentage of cars to travel on the shoulde In Utah, the stripe on the level tangent section had very little effect on the shoulder encroachment of passenger cars either during the day or at night. On the 3-percent downgrade, the stripe caused passenger cars to encroach on the shoulder more during the daytime and less at night. On the upgrade the stripe reduced shoulder encroachmen both during the daytime and at night.

As was brought out earlier nearly 80 percent of the trucks encroached on the shoulder area on the full-width paved sections. The stripes in Arizona did not appreciably affect this encroachment. The stripes in Utah were not effective on the level but had a measurable influence on the 3-percent grade.

The "edge" stripe studies in Idaho were conducted on one level tangent section of highway. The original 4-mile section was divided into two sections of equal length. Two-inch-wide solid reflectorized stripes were painted on one section 8 ft from the pavement edge or 12 ft from the centerline (Fig. 8). On the other section the stripe was painted 6 ft from the edge or 14 ft from the centerline.

No firm conclusion can be drawn as to the effect of these "edge" stripes on vehicle speeds (Table 8). These stripes, however, caused vehicles to travel considerably closer to the centerline of the pavement than when there were no such "edge" stripes (Table 9). The effect was greater at night than during the day and the 8-ft stripe had a greater effect than the 6-ft stripe. These stripes were very effective in reducing the shoulder use, particularly by commercial vehicles (Table 10).

It is interesting to note from the Idaho data that, although fewer vehicles traveled on the shoulder area on the section with 8-ft stripes than on the section with the 6-ft stripes, traffic tried to use the 8 ft to the right of the stripe as a lane. In this case the pavement was used like a 4-lane undivided highway except that the distribution of traffic between lanes was reversed. In other words, the percentage of vehicles that traveled in the 12-ft lane approximated the percentage of vehicles that normally would travel in the right lane of the 4-lane undivided highway with an equal volume of traffic.

SUMMARY OF RESULTS OF EDGE STRIPING STUDY

The results summarized below apply only to 2-lane bituminous roads having full-width paved sections, which in effect present to the motoring public a 2-lane road with two 20-ft lanes and no shoulders. Traffic volumes on the sections studied averaged less than 3,000 vehicles per day. For these conditions the results are as follows:

1. Speeds were higher on some sections after the edge stripes were placed and lower on other sections. It appears that no definite conclusions can be drawn as to the effect of edge stripes on speeds.
2. Four-in.-wide stripes closer than 1.5 ft to the pavement edge (18.5 ft from the centerline) had very little effect on the average lateral position of vehicles and on the percentage of vehicles encroaching on the shoulder area, particularly at night.
3. A 2-in. wide solid white stripe painted 8 ft. from the pavement edge was found to be very effective in keeping vehicles in the 12-ft. travel lane and reduced shoulder encroachment by about 50 percent over that found with no edge stripes. However, those vehicles that did travel to the right of the stripe tried to use the 8 ft. as a lane.

SPECIAL EDGE STRIPES AND SIGNS IN OREGON

A level tangent section of highway in Oregon was selected for study of special edge stripes and signs. The section of highway consisted of two 12-ft bituminous lanes flanked by 10-ft shoulders, 4 ft. of which was of paved bituminous material of an appearance different from the traffic lane, and the outside 6 ft. was of gravel. Speed and placement data were recorded at the same point on the highway under the following different conditions:

1. Normal pavement condition.
2. Signs on the outside of the gravel with the legend, "No Traveling on Paved Shoulders."
3. Signs and edge stripes. The signs were the same as for condition 2 above. The stripes were 4 in. wide, solid yellow reflectorized material and were painted 13 ft. from the center of the pavement.
4. Edge stripes only.
5. Edge stripes only - nighttime.

The signs were covered during conditions 4 and 5, and the first four conditions were

TABLE 10

ENCROACHMENT ON SHOULDER AREA WITH AND WITHOUT EDGE STRIPES ON 2-LANE BITUMINOUS PAVEMENTS WITH FULL-WIDTH PAVED SHOULDERS HAVING THE SAME APPEARANCE AS THE TRAFFIC LANES

State	Alignment	Grade	Color	Edge Stripe			Encroachment on Shoulder Area[b]			
							Daytime		Nighttime	
				Type	Width	Distance from Edge[a]	No Stripe	With Stripe	No Stripe	With Stripe
All passenger cars										
		Percent			in.	ft	Percent	Percent	Percent	Percent
Arizona	Tangent	0	White	Dashed	4	1.0	43.4	45.2	3.7	21.7
Utah	Tangent	0	Yellow	Solid	4	1.5	32.1	34.8	22.3	21.3
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	44.5	57.0	8.1	3.8
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	45.7	30.8	11.4	8.9
Idaho	Tangent	0	White	Solid	2	8.0	60.7	24.9	c	23.7
Idaho	Tangent	0	White	Solid	2	6.0	60.7	31.0	c	25.9
All commercial vehicles										
Arizona	Tangent	0	White	Dashed	4	1.0	97.6	98.5	100.0	66.7
Utah	Tangent	0	Yellow	Solid	4	1.5	56.1	65.0	48.6	53.3
Utah	Tangent	-3.0	Yellow	Solid	4	1.5	46.0	74.2	6.2	35.0
Utah	Tangent	+3.0	Yellow	Solid	4	1.5	86.4	69.1	45.4	43.7
Idaho	Tangent	0	White	Solid	2	8.0	86.8	42.9	c	46.4
Idaho	Tangent	0	White	Solid	2	6.0	86.8	61.0	c	51.3

[a]Distance toward centerline from edge of the full-width paving which was 20 ft from centerline.

[b]Percentage of vehicles with right side extending more than 12 ft from center of pavement.

[c]No data available.

studied during daylight hours only.

Table 11 shows the average speed of passenger cars and of commercial vehicles during the five conditions of study. The percentages of vehicles exceeding 60 mph, and traveling below 40 mph are also shown in this table. It was noted that the speeds on this section of highway were rather high under the normal conditions. Average speeds were 61.3 mph for passenger cars, and 53.2 mph for trucks. The lowest average speed during the daytime was observed when only the edge stripes were present. The lowest percentage of passenger cars traveling over 60 mph during the day, however, was observed when only the signs were present. The percentage of vehicles traveling below 40 mph was lowest when the signs and the edge stripes were present. In general, however, it appears that edge stripes of the type studied in Oregon reduced vehicle speeds more than the special signs. Signs in combination with the edge stripes appear to have had no effect on vehicle speeds.

The primary objective for studying the edge stripes and signs in Oregon was to determine the best type of markings to reduce the use of the shoulders by commercial vehicles. Shown on Table 12 for the several conditions of study are the average lateral positions, the percentage of vehicles encroaching on the shoulder, and the average clearance between the bodies of meeting vehicles. It appears that commercial vehicles used the shoulders less when only the stripes were present than when the stripes were supplemented with signs. During the daytime, more than 40 percent of the trucks encroached on the shoulder during normal operating conditions. When the stripes were present the encroachment was reduced to 13 percent while still maintaining adequate clearances between the bodies of trucks meeting other vehicles. Only 6

TABLE 11

VEHICLE SPEEDS RELATED TO SPECIAL SIGNS AND EDGE STRIPES ON A 2-LANE BITUMINOUS PAVEMENT IN OREGON

(24-ft pavement with 4-ft bituminous shoulders different in appearance from traffic lanes and 6-ft gravel outside paved section)

Condition of Study[a]	Average Speed	Percentage over 60 mph	Percentage under 40 mph
Passenger cars			
	mph	Percent	Percent
Daytime:			
Normal	61.3	60.0	1.8
Signs only	58.3	43.0	3.3
Signs and edge stripes	61.3	60.5	1.4
Edge stripes only	57.9	46.5	3.0
Nighttime:			
Edge stripes only	56.7	41.5	1.8
Commercial vehicles			
Daytime:			
Normal	53.2	18.0	3.2
Signs only	51.3	13.0	5.6
Signs and stripes	52.7	13.2	1.3
Stripes only	49.6	5.4	3.9
Nighttime:			
Stripes only	49.0	6.3	1.4

[a]Legend on signs was "No Traveling on Paved Shoulders". Edge stripes were 4-in. solid yellow reflectorized 13 ft from center of pavement.

TABLE 12

LATERAL POSITIONS OF VEHICLES RELATED TO SPECIAL SIGNS AND EDGE STRIPES ON A 2-LANE BITUMINOUS PAVEMENT IN OREGON

(24-ft pavement with 4-ft bituminous shoulders different in appearance from traffic lanes and 6-ft gravel outside paved section)

Condition of Study[a]	Lateral Position[b]	Percentage Encroaching on Shoulder	Clearance Between Bodies of Meeting Vehicles
	Passenger cars		
	ft	Percent	ft
Daytime:			
Normal	6.6	10.7	8.1
Signs only	6.4	8.4	7.9
Signs and edge stripes	6.1	4.3	7.2
Edge stripes only	6.1	5.4	7.0
Nighttime:			
Edge stripes only	6.0	3.7	7.6
	Commercial vehicles		
Daytime:			
Normal	7.2	41.3	8.4
Signs only	6.6	30.7	7.7
Signs and edge stripes	6.3	18.2	6.2
Edge stripes only	6.2	13.1	7.2
Nighttime:			
Edge stripes only	6.1	6.3	6.3

[a]Legend on signs was "No Traveling on Paved Shoulders". Edge stripes were 4-in. solid yellow reflectorized, 13 ft from center of pavement.

[b]Distance center of vehicle was from center of pavement.

percent of the trucks encroached on the shoulders at night when the edge stripes were present.

In summary it may be stated that a 4-in. -wide solid yellow reflectorized stripe 13 ft. from the center of a 2-lane, 24-ft bituminous pavement or 1 ft on the paved shoulder in Oregon is very effective in reducing the encroachment on the shoulder, especially by trucks. Such an edge stripe reduced vehicle speeds 3 mph. Signs on the extreme edge of the shoulder with the legend "No Traveling on Paved Shoulders" have a minor effect in reducing the shoulder use.