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Bulletin 170

Traffic Behavior As Related to Several Highway Design Features

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Contents

Correlation of Design and Operational Characteristics of Expressways in Texas

CHARLES J. KEESE, Associate Research Engineer, and
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Texas Transportation Institute, A & M College of Texas

Some of the expressways in Texas are now carrying traffic volumes of sufficient magnitude to furnish adequate data for the correlation of the effects of certain design features on operational characteristics.

Because of the lack of sufficient information as to the interrelationships of certain design features and their combined effects on certain operational characteristics, a joint research project was undertaken by the Texas Transportation Institute for the Texas Highway Department to explore the operational characteristics and determine what features warranted specific study and analysis. The City of Houston and the City of Dallas cooperated in the project and close coordination was maintained between the Highway Department, City Traffic Engineering Departments, and the Texas Transportation Institute research personnel through a project advisory committee composed of representatives of each agency.

On the Gulf Freeway in Houston, numerous accidents have resulted from vehicles crossing the median out of control or being forced across into the path of oncoming traffic. To remedy this situation, a steel guard fence was constructed down the center of the 4-ft wide median. This provided an excellent opportunity for a "before and after" study of such factors as the effect of the fence on vehicle placement and lane use. In order for an accurate and comprehensive analysis to be made, approximately 12,000 ft of 16-mm motion picture film were taken at a camera speed of 8 frames per second. The motion pictures were taken from a fixed tower 48 ft above the freeway. Motion pictures were taken for continuous periods of at least 1 hr to record peak and off-peak traffic conditions on several different days.

On the Central Expressway in Dallas, 4,000 ft of film were taken from a tower truck parked on an overpass structure overlooking the expressway.

In each case transverse lines on the pavement were used to divide the study areas into sections 176 ft in length to facilitate time-motion study. A 12-in diameter clock with a sweep second hand was mounted from the towers in such manner as to appear in each frame of the film. The clock was used to identify the time of day and to facilitate calibration of the camera speed.

By using a time-motion study projector, volume, speed, spacing and entering vehicle conditions were obtained to a high degree of accuracy. Placement of the vehicles was determined by viewing the individual frames under magnification, using a special scale for the purpose of measurement.

At a different location on the Gulf Freeway, the Bureau of Public Roads obtained data by the use of tape placement equipment. This was a continuous 11-hr study providing data on volume, speed, and placement. The information was taken from the graphs and recorded and analyzed on punched-card equipment.

During higher traffic volume periods, headways were critical and occassional loses in headway caused by entering or weaving vehicles resulted in stoppages which backlashed for a considerable distance along the lane. Weaving out of the stopped lane generally transferred the stoppage and backlash condition to one or both of the other lanes.

Placement data from some 10,000 observations show the effects of the barrier fence on the placement of the vehicle in the lane adjacent to the median. The film study provides an excellent opportunity for developing and determining the reliability of a sampling process for volume and speed studies.

It was noted early in the studies that entering traffic had sufficient effect on operating conditions to justify a study of regulating traffic volume at the entrances in order to maintain maximum speed-volume relationships. A study of this type has been recorded, but the analysis is not complete.

●THE RECENT rapid development of expressways and freeways has been termed by Thomas H. MacDonald, former Chief of the Bureau of Public Roads, as the beginning of the "second era of modern highway transportation, the express-traffic era." Expressway and freeway type facilities are no longer just designers' dreams. They are rapidly becoming vital parts of our vast highway system. The development of these expressway facilities has been so rapid that relatively little evaluation of the various design features has been possible. Some of the expressways in Texas are now carrying traffic volumes of sufficient magnitude to furnish adequate data for the correlation of the effects of certain design features on the various operational characteristics.

Because of the lack of sufficient information as to the interrelationships of certain design features and their combined effects on certain operational characteristics, a research project was undertaken by the Texas Transportation Institute of Texas A & M College for the Texas Highway Department to explore the operational characteristics and determine what features warranted specific study and analysis. The City of Houston and the City of Dallas cooperated in the project.

Inasmuch as it was desired to study the interrelationships between design features and operational characteristics, a project advisory committee was appointed consisting of representatives of the Texas Highway Department, the agency responsible for design and construction of the freeways, and the directors of the departments of traffic engineering for the two cities, who are directly concerned with the operating characteristics of the facilities.

SITES SELECTED FOR STUDY

Two areas were selected for study: one section of the Gulf Freeway in Houston, and one section of the Central Expressway in Dallas. Aerial views and geometric layouts of the two test sections are shown in Figures 1 and 2. Each facility has three lanes in each direction, diamond type interchanges, continuous one-way service roads through the survey sections, and the same type of pavement. There are several principal differences in the design of the two facilities. The through lanes of the Gulf Freeway go over the intersecting roadways, whereas the through lanes of the Central Expressway go under the intersecting roadways. The median on the Central Expressway is a grassed median 11 ft in width with 6-in. mountable curbs. The median on the Gulf Freeway is a 4-ft paved median with 6-in. barrier-type curbs. The section through the survey site on the Gulf Freeway has full-width acceleration lanes for entering traffic. In the survey section of the Central Expressway, a $7^{\circ}30'$ curve joins the entrance ramp with the freeway lanes.

Because of the frequency of vehicles out of control crossing the Gulf Freeway median or vehicles being forced across the median into the opposing traffic streams, a metal guard fence was constructed as a barrier along the center of the median. The effect of this fence on traffic operation was one of the factors considered in this study. One study was made before construction of the barrier fence and has been designated as Gulf Freeway Study Number 1, or Houston 1. The first study made after construction of the fence has been designated Houston 2.

One study, conducted on a section of the Central Expressway in Dallas, has been designated as Dallas 1.

Observations of the motion pictures taken during the Houston 1 study showed that traffic on the freeway lanes was influenced greatly by vehicles entering the freeway. The variables introduced by entering vehicles were so numerous it was apparent that independent studies of other characteristics would be difficult. For this reason, a

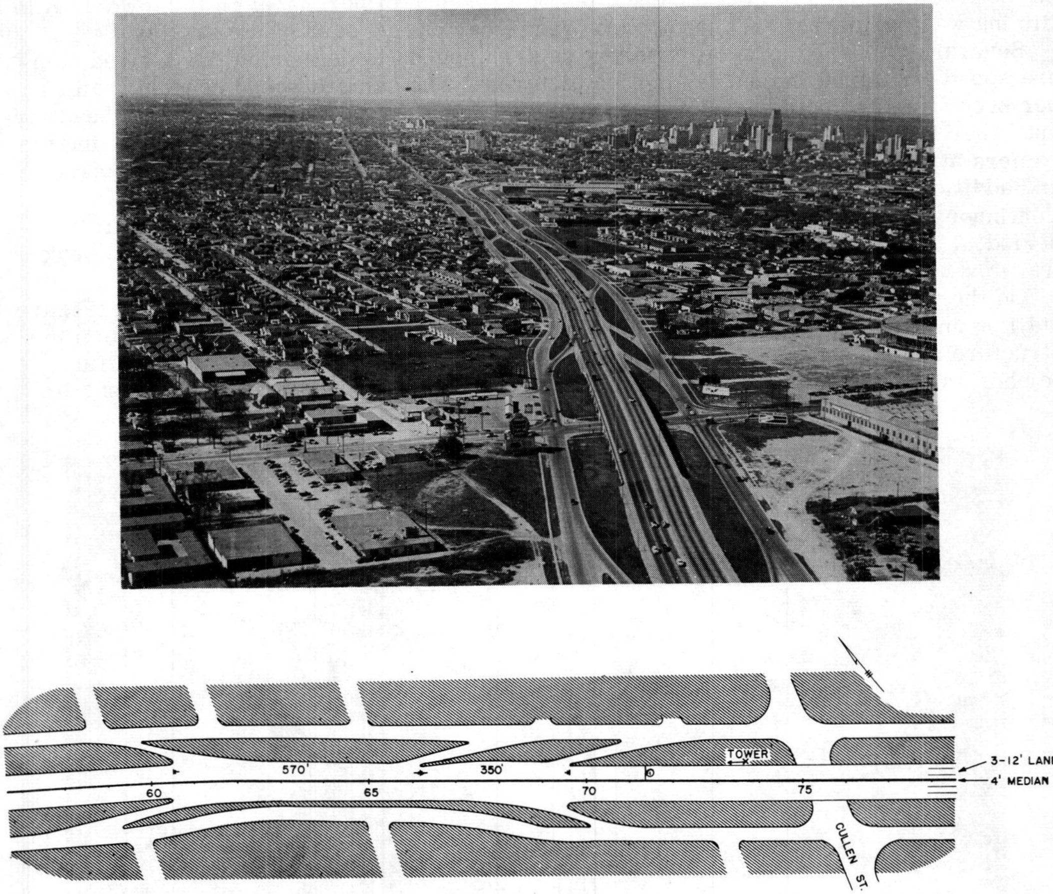


Figure 1. Gulf Freeway, Houston, Texas.

third study, Houston 3, was made with the entrance ramps closed. Barricades were placed across the two entrance ramps by personnel of the City of Houston during the morning peak traffic periods for two weeks before the motion picture study was made in order to allow traffic to become familiar with this condition. Only a small portion of the results of this study are included in this report.

The Bureau of Public Roads and the Highway Planning Survey of the Texas Highway Department cooperatively conducted a placement survey on outbound traffic on the Gulf Freeway in Houston independent of the other studies. This survey is discussed in detail in a later section of this report.

SURVEY METHOD

The motion picture type of study was selected to provide simultaneous evaluation of all operational characteristics. Preliminary tests were made by taking motion pictures from a tower, an overpass structure, an adjacent building, and a helicopter. The tower was selected as being the best of the locations tested.

A 48-ft tower (Figure 3(c)) was constructed adjacent to the freeway overpass structure at one end of the test section on the Gulf Freeway in Houston. The tower was constructed two weeks before the first motion picture study was made and during this period personnel were frequently on the tower for observation and to make tests of survey procedures. On Monday before each survey 100 ft of test film were taken in order to test equipment and to further eliminate the element of surprise to the drivers on the freeway which might be caused by the presence of personnel on the tower. All filming was performed on Tuesday and Wednesday during each of the studies.

Several tests were made at different camera speeds to determine the desired camera speed for taking the survey motion pictures. The camera speed of eight frames per second was selected to provide the desired accuracy in measuring speed, headways, and other factors. It was felt that the additional accuracy possible from operating the camera at a faster speed did not justify the added expense from extra film required and additional time required in taking data from the individual frames of the film. Continuous motion pictures were taken for 1½ hr to include the morning peak traffic period, 1 hr of morning off-peak conditions, and 1½ hr to include the afternoon peak traffic.

On the Central Expressway in Dallas, it was possible to park a tower truck (Figure 3(d)) on an overpass structure overlooking the freeway. The truck was parked on the structure and personnel made observations from the tower during the peak traffic periods each day for one week before the motion picture study was made. Test film

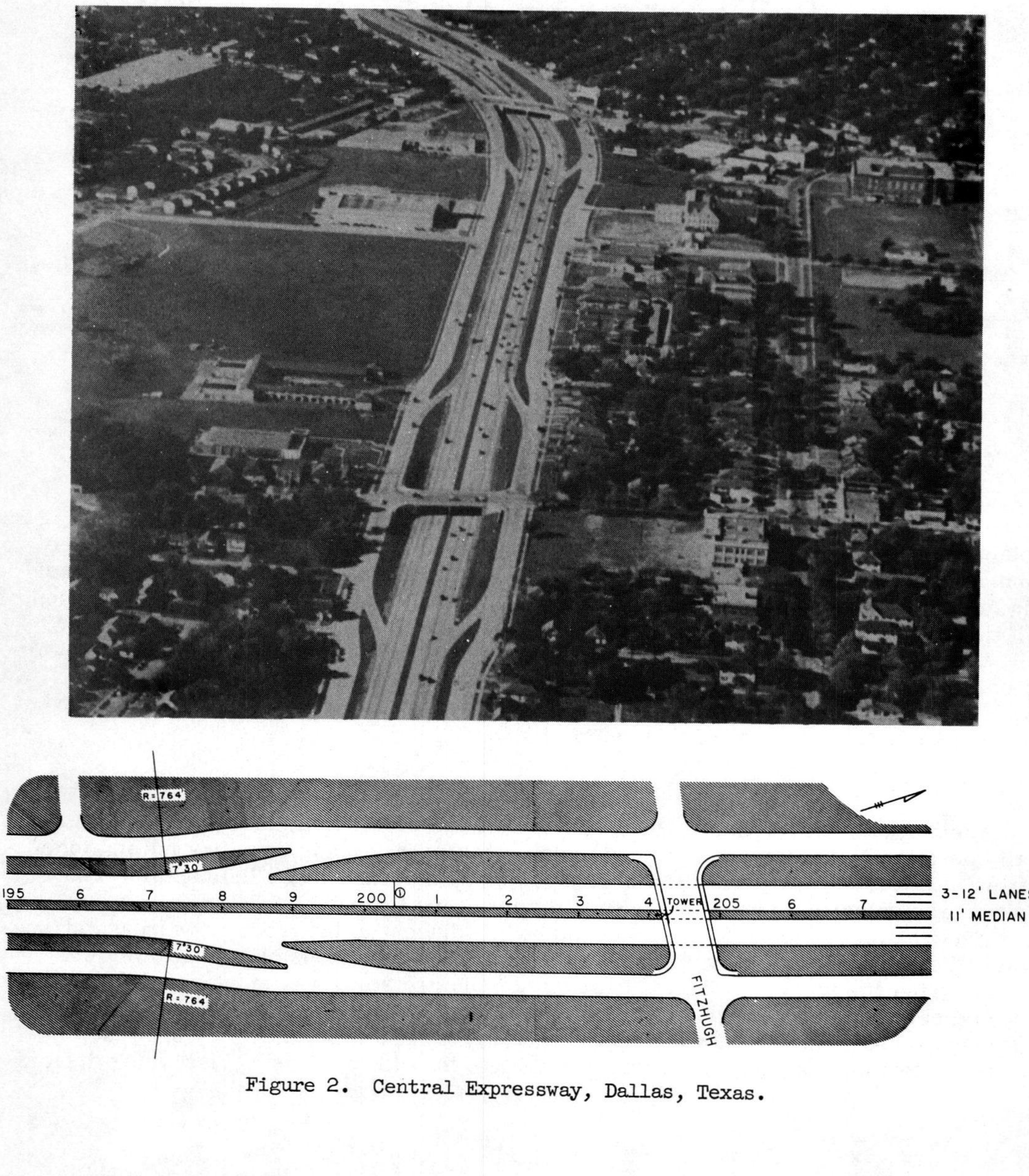
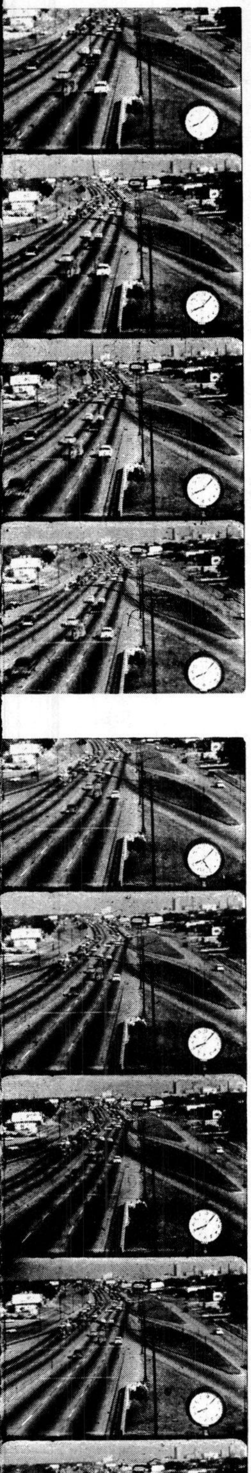
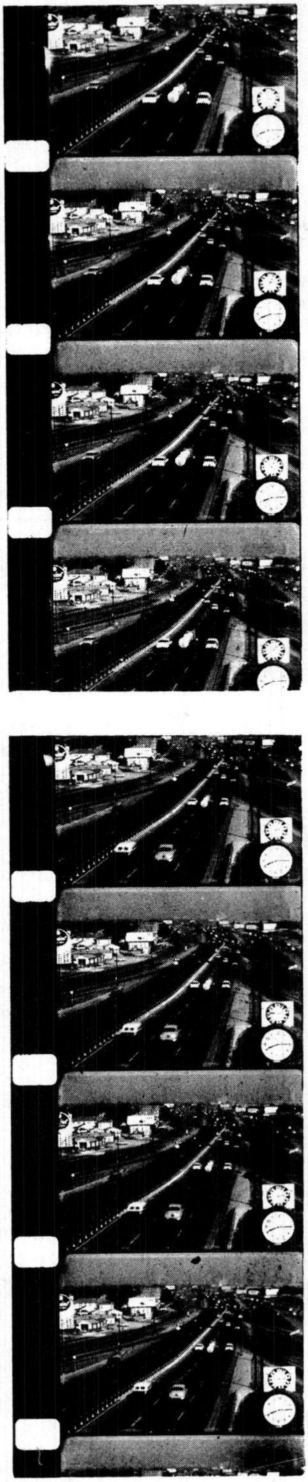


Figure 2. Central Expressway, Dallas, Texas.



(a)



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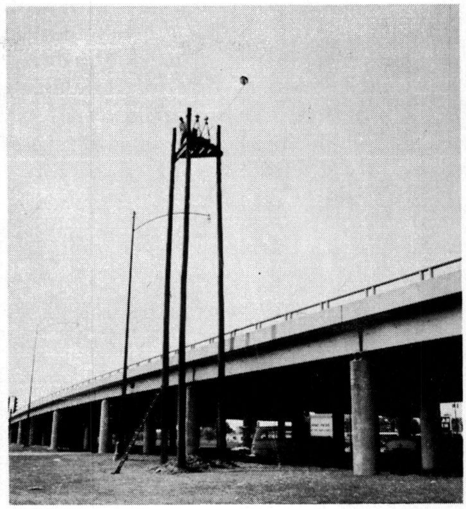
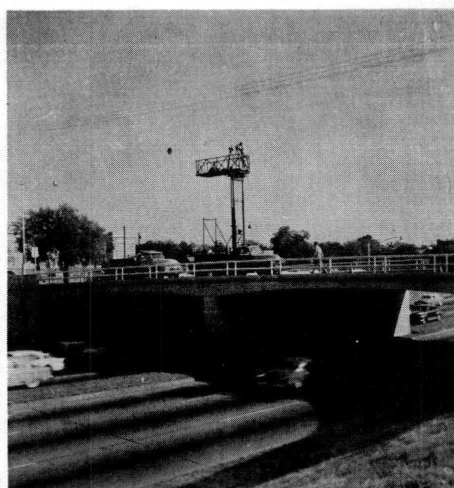


(c)



(d)

Figure 3. Showing: (a and b) Portions of motion picture films taken during study; (c) Tower used during study on Gulf Freeway in Houston; and (d) Tower used during study on Central Expressway in Dallas.

was taken on Monday and the survey motion pictures were taken on Tuesday and Wednesday. The same schedule of filming was followed for the Gulf Freeway studies.

Observations made before and during the various studies indicated there was no apparent influence in driving patterns caused by the tower or by personnel being on the tower.

A 12-in. electric clock with a sweep-second hand was mounted approximately 16 ft from the tower and positioned to appear in an unused portion of each frame of the motion picture film. Although time-distance relationships were determined by frame count, the clock provided a check on camera speed and a record of the time of day.

Portions of film taken during two of the studies are shown in Figure 3 (a) and (b).

Two 16-mm cameras were used to provide continuous filming. Each camera was equipped with a magazine holding 400 ft of film, which provided continuous filming for a period of 30 min. As one camera ran out of film the second camera was started and

TABLE 1

INBOUND ENTRANCE AND EXIT VOLUMES, GULF FREEWAY STUDY NO. 1, MORNING

Time	Entrance Ramp No. 1	Entrance Ramp No. 2	Exit Ramp	Net Total of Entering Traffic
7:00 to 7:05	35	13	15	38
7:05 to 7:10	45	31	19	57
7:10 to 7:15	37	25	12	50
7:15 to 7:20	29	31	14	46
7:20 to 7:25	39	17	14	42
7:25 to 7:30	36	33	8	61
7:30 to 7:45	- - - - - - - - - - Film lost in developing			
7:45 to 7:50	32	30	23	39
7:50 to 7:55	34	26	36	24
7:55 to 8:00	30	23	25	28
8:00 to 8:05	41	17	23	35
8:05 to 8:10	35	31	18	48
8:10 to 8:15	41	23	20	44
8:15 to 8:20	41	27	12	56
8:20 to 8:25	39	20	9	50
8:25 to 8:30	32	20	10	42
8:30 to 8:35	35	21	12	44

the commercial photographer who performed all of the filming had no difficulty changing magazines during the time the alternate camera was in use.

Three transverse white lines were painted on the pavement 176 ft apart to provide reference points from which to measure speed, headways, and other time-distance relationships. These lines are shown in Figure 3 (a) and (b).

DISCUSSION

Volume

Volumes were taken at a point 176 ft in advance of the entrance ramp. Tabulations of volume for each 1-min. period were made by viewing the film and the 1-min. volumes were combined to show 5-min. volumes. Because it is common to think in terms of hourly volume, the equivalent hourly volumes shown in the figures are the 5-min. volumes multiplied by 12 and are shown only for clarification of the 5-min. volume levels.

Gulf Freeway Volumes. The 5-min. volumes by lanes for the time periods studied are shown in Figures 4, 5, and 6. These data show that the middle and inside lanes carry

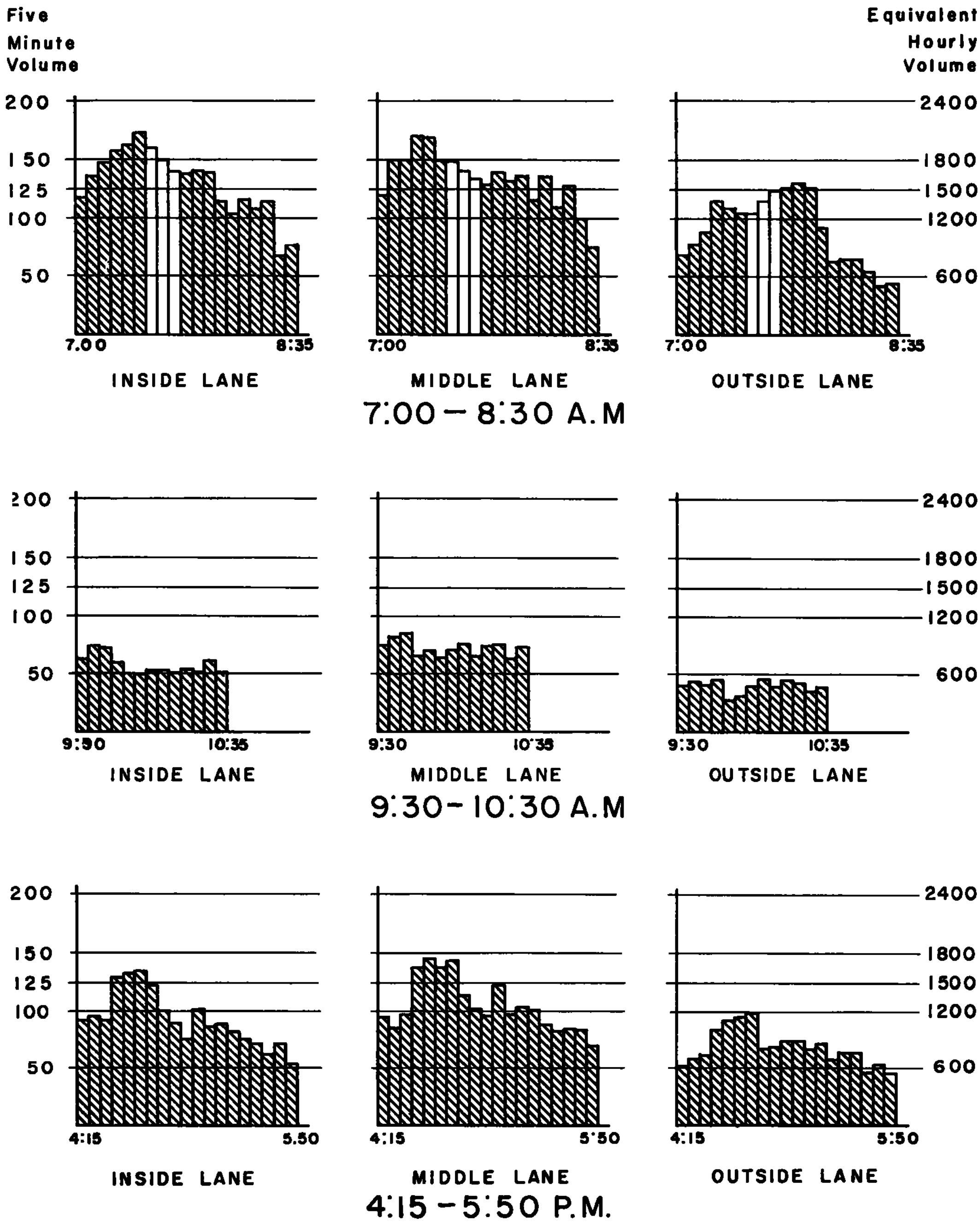


Figure 4. Five-minute volumes by lanes, inbound traffic, Gulf Freeway, Houston, Texas, Study No. 1, May 22, 1956 (volumes recorded in advance of entrance ramp).

approximately the same volume, with the middle lane volume generally slightly higher.

Five-minute volumes in the range of 170 to 178 (equivalent hourly volumes of 2,040 to 2,136) were recorded for at least one 5-min. period during each survey. The outside lane carried volumes considerably below the other two lanes, with the maximum recorded 5-min. volume of 140 (equivalent hourly volume of 1,680). As mentioned previously, these volumes were recorded ahead of the entrance ramp. Entrance ramp volumes are shown in Tables 1, 2, 3 and 4.

This preliminary report covers only the inbound traffic; therefore, the inbound afternoon peak volumes shown could be expected to be somewhat lower than the inbound

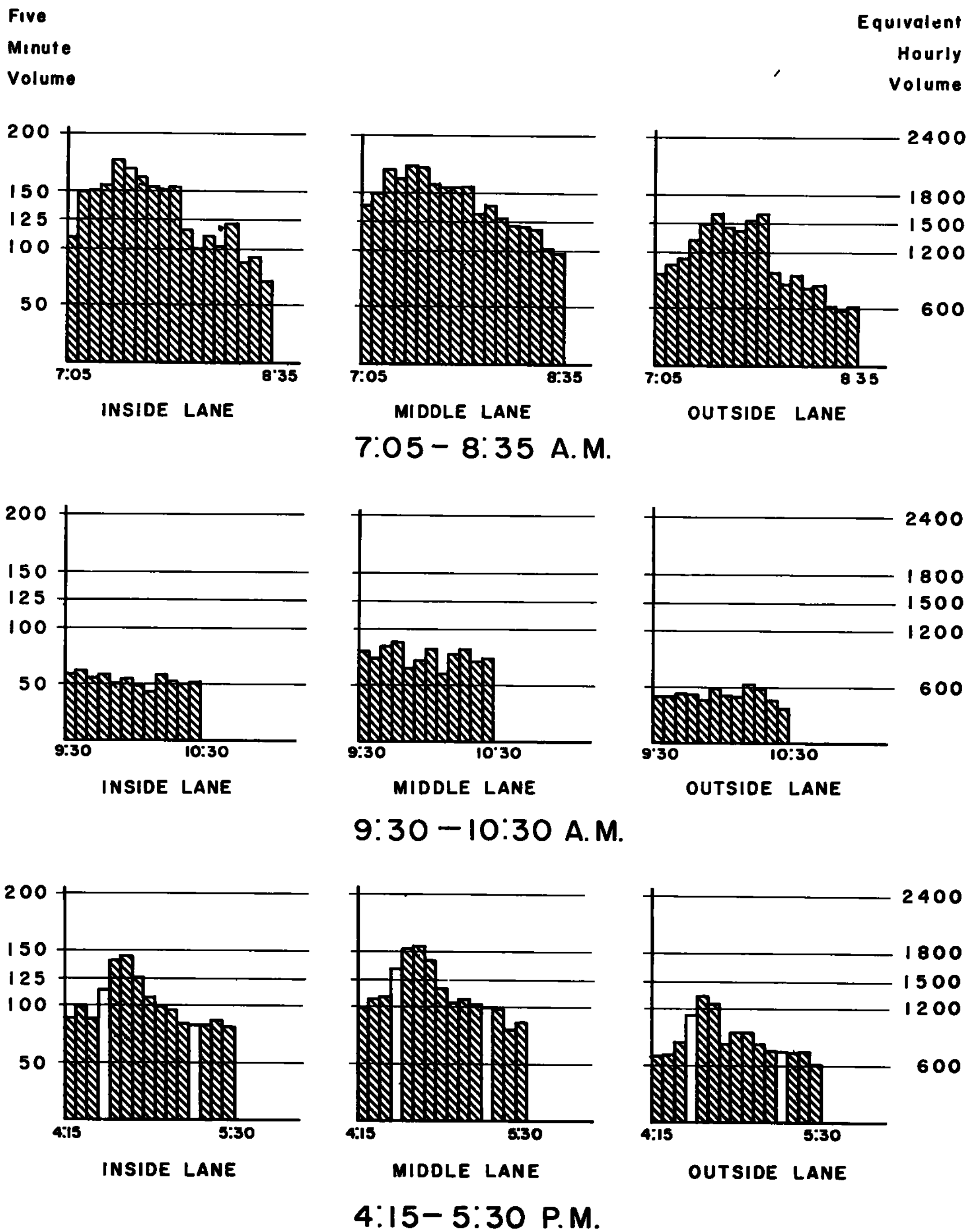


Figure 5. Five-minute volumes by lanes, inbound traffic, Gulf Freeway, Houston, Texas, Study No. 2, September 11, 1956 (volumes recorded in advance of entrance ramp).

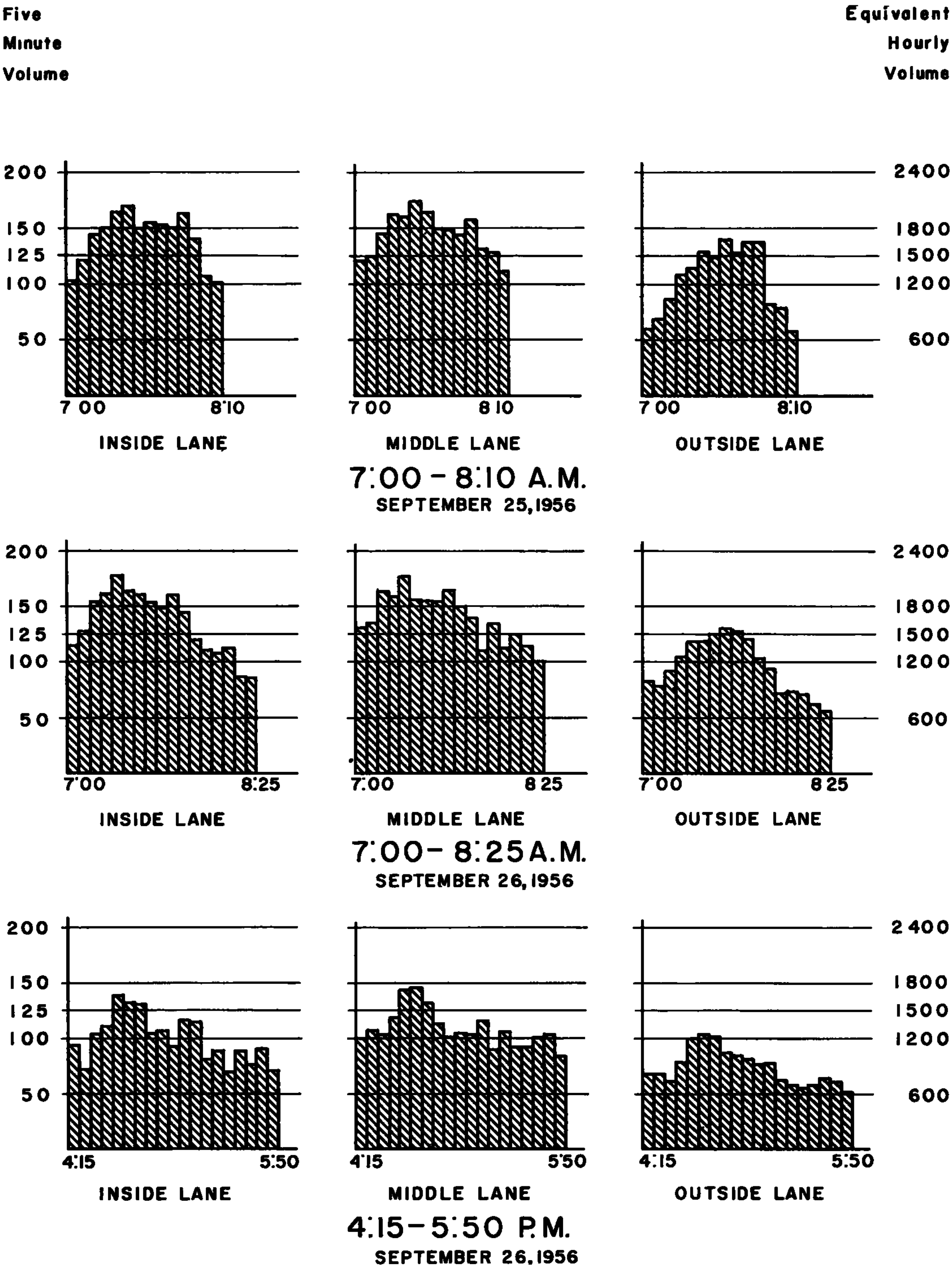


Figure 6. Five-minute volumes by lanes, inbound traffic, Gulf Freeway, Houston, Texas, Study No. 3, September 25 and 26, 1956 (volumes recorded in advance of entrance ramp).

TABLE 2

INBOUND ENTRANCE AND EXIT VOLUMES, GULF FREEWAY STUDY NO. 1, AFTERNOON

Time	Entrance Ramp No. 1	Entrance Ramp No. 2	Exit Ramp	Net Total of Entering Traffic
4:15 to 4:20	31	13	16	28
4:20 to 4:25	22	15	13	24
4:25 to 4:30	28	15	8	35
4:30 to 4:35	32	21	24	29
4:35 to 4:40	32	13	26	19
4:40 to 4:45	33	27	28	32
4:45 to 4:50	35	17	30	22
4:50 to 4:55	32	10	26	16
4:55 to 5:00	34	8	28	14
5:00 to 5:05	36	15	27	24
5:05 to 5:10	31	22	24	29
5:10 to 5:15	34	20	23	31
5:15 to 5:20	30	12	18	24
5:20 to 5:25	20	10	15	15
5:25 to 5:30	34	11	19	26
5:30 to 5:35	30	20	13	37
5:35 to 5:40	22	10	19	13
5:40 to 5:45	23	18	24	17
5:45 to 5:50	23	11	13	21

morning flow. It is noted that 5-min. lane volumes as high as 157 (equivalent hourly volume of 1,884) were recorded for inbound traffic during the afternoon peak period.

Central Expressway Volumes. Figure 7 shows 5-min. volumes recorded on the Central Expressway in Dallas. Here agin only the inbound traffic ahead of the ramp is shown. The daily traffic volume on the Central Expressway is less than that of the Gulf Freeway, but, as can be seen, the critical peak inbound volumes are about the

TABLE 3

INBOUND ENTRANCE AND EXIT VOLUMES, GULF FREEWAY STUDY NO. 2, MORNING

Time	Entrance Ramp No. 1	Entrance Ramp No. 2	Exit Ramp	Net Total of Entering Traffic
7:05 to 7:10	35	31	9	67
7:10 to 7:15	44	33	11	66
7:15 to 7:20	43	21	19	45
7:20 to 7:25	40	27	19	48
7:25 to 7:30	37	39	19	57
7:30 to 7:35	36	32	20	48
7:35 to 7:40	36	34	16	54
7:40 to 7:45	43	32	13	62
7:45 to 7:50	31	41	19	53
7:50 to 7:55	40	35	19	56
7:55 to 8:00	32	18	11	39
8:00 to 8:05	48	27	13	62
8:05 to 8:10	35	28	16	47
8:10 to 8:15	42	40	19	63
8:15 to 8:20	42	26	11	57

TABLE 4

INBOUND ENTRANCE AND EXIT VOLUMES

CENTRAL EXPRESSWAY, MORNING

Time	Entrance Ramp
7:10 to 7:15	24
7:15 to 7:20	22
7:20 to 7:25	38
7:25 to 7:30	33
7:30 to 7:35	14
7:35 to 7:40	38
7:40 to 7:45	23
7:45 to 7:50	37
7:50 to 7:55	27
7:55 to 8:00	34
8:00 to 8:05	32
8:05 to 8:10	35
8:10 to 8:15	24
8:15 to 8:20	44
8:20 to 8:25	21
8:25 to 8:30	24
8:30 to 8:35	25
8:35 to 8:40	23
8:40 to 8:45	23

same, with peak 5-min. lane volumes as high as 174 (equivalent hourly volume of 2,088). The outside lane carried considerably less traffic (measured ahead of the entrance ramp) than the other two lanes. The maximum 5-min. volume recorded in the outside lane was 140 (equivalent hourly volume of 1,680). The inbound flow during the afternoon peak period was quite low.

The maximum inbound lane volume for a full clock hour was 1,862, which occurred in the middle inbound lane of the Gulf Freeway between 7:10 and 3:10 a.m. during the study of Houston 2.

Speed Determinations

The 12-in. electric clock with a sweep-second hand which appeared in each frame was used to determine the exact number of frames per minute. The number of frames per second for each minute of each survey was then determined. Although a constant camera speed was desired, the speed of the cameras used varied slightly as the film was transferred from one reel to the other.

Determination of speed was made by placing the rear of the vehicle at a transverse white line painted on the pavement. By moving the film forward and back a frame at a time, the first frame in which the white line was visible behind the vehicle could be determined. The frame count at this point was recorded and the film moved forward until the vehicle crossed the second white line. The speed in miles per hour was determined from the number of frames required

TABLE 5

TESTS OF SPEED SAMPLING

Time	Average Speed Including Every Vehicle in 5 Min.	Average Speed Including Every 5th Vehicle in 5 Min.	Variation in Mph	Variation in Percent
7:00 to 7:05	41.26	41.94	0.68	1.65
7:05 to 7:10	40.87	40.24	0.63	1.54
7:10 to 7:15	38.80	38.84	0.04	0.10
7:15 to 7:20	36.79	36.74	0.05	0.14
7:20 to 7:25	30.93	30.84	0.09	0.29
7:25 to 7:30	27.23	27.64	0.41	1.51
7:45 to 7:50	27.22	27.17	0.05	0.18
7:50 to 7:55	20.92	20.96	0.04	0.19
7:55 to 8:00	17.32	17.24	0.08	0.46
8:00 to 8:05	31.53	30.55	0.98	3.11
8:05 to 8:10	41.16	42.06	0.90	2.19
8:10 to 8:15	39.88	39.50	0.38	0.95
8:15 to 8:20	42.13	41.76	0.37	0.88
8:20 to 8:25	41.05	40.76	0.29	0.71
8:25 to 8:30	43.29	43.62	0.33	0.76
8:30 to 8:35	42.47	40.63	1.84	4.33
5:45 to 5:50	41.58	42.63	1.05	2.53

for the vehicle to move this distance of 176 ft.

In the early stages of the project, several methods of taking and recording data from the film were tested to determine the best and most economical method. It was decided finally to use punched-card analysis and to obtain the data from the film with a projector more adapted to the problem. While waiting for delivery of this projector, a sampling process was used to determine the average speed for 5-min. increments.

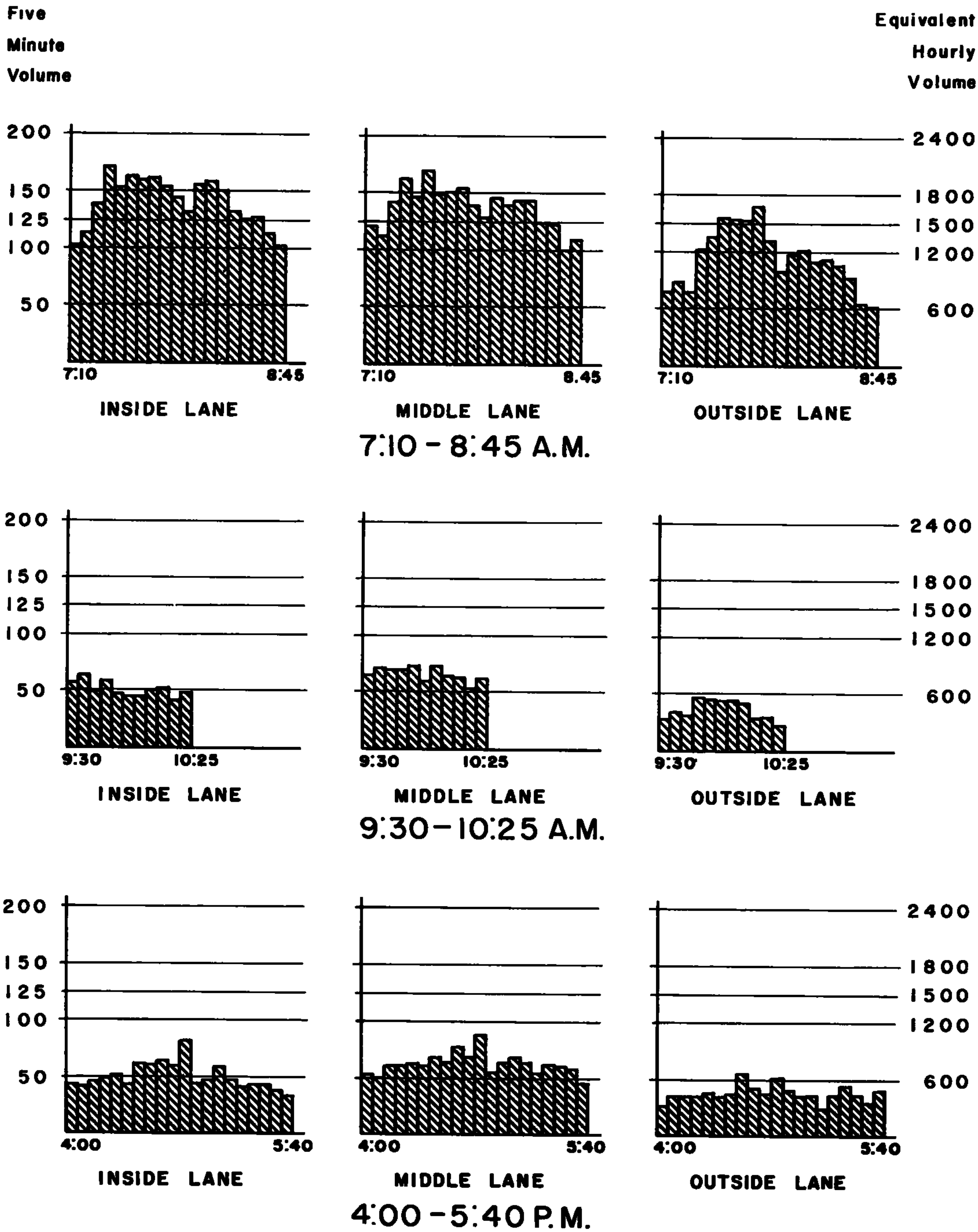


Figure 7. Five-minute volumes by lanes, inbound traffic, Central Expressway, Dallas, Texas, Study No. 1, August 14, 1956 (volumes recorded in advance of entrance ramp).

This sampling technique involved the speed determination of every fifth vehicle for the 5-min. period. The reliability was tested by comparing the 5-min. average speed obtained by sampling every fifth vehicle with the average speed of all vehicles in the 5-min. period. The results of these checks, one of which is shown in Table 5, showed the method to be reliable. Operating the camera at 8 frames per second causes a variation in accuracy with speed. For a difference of one frame, the percentage variation increases as the vehicle speed increases. For 20 mph, the variation is 2.5 percent, or 0.5 mph; for 60 mph the variation is 6.0 percent, or 3.6 mph.

The speeds of the vehicles using the Gulf Freeway and the Central Expressway were influenced by the posted legal speed limits. The minimum speed limit was 40 mph and the maximum speed limit was 50 mph. The average speed of the vehicles using the inside lane was 45 mph during periods when the volume level was less than 1,500 vehicles per hour. The average speeds based on 5-min. periods for the inside lane were within a band width of 5 mph. This held true up to a 5-min. volume of 125, which is equivalent to a level of 1,500 vehicles per hour. When this volume level was exceeded, the average speeds became erratic and varied from 30 mph to 45 mph. It should be emphasized that volume measurements were made in advance of the entrance ramps.

Figure 8 illustrates the decrease in speed with an increase in volume on the Gulf Freeway. The two graphs for the inside lane indicate that the speed was more constant in the study Houston 3 with the entrance ramps closed than in Houston 2 with the entrance ramps open. Figure 9 is presented to show the similarity between the Central Expressway and the Gulf Freeway as to volume and speed. Both experience similar peak volumes and similar decreases in speed. Although the off-peak volume and speed are shown only for the Central Expressway, this is typical of all studies made, with the speed remaining fairly constant as the volume tends to remain constant. During off-peak periods, the speed for this lane was generally 45 mph, halfway between the speed limits.

The average speed for the outside lane was generally 5 mph less than the inside lane for the same time period. A band width of 10 mph would include practically all speeds up to a 5-min. volume of 100, which is equivalent to a volume level of 1,200 vehicles per hour. When this volume was exceeded in the outside lane, the average speed ranged from 16 mph to 40 mph. Referring to Figure 8 and comparing the outside lane graphs for the two entrance ramp conditions, it is readily apparent that smoother operation of the facility results when the entrance ramps were closed. With the entrance ramps open, the average speed decreased from 40 mph at 7:00 a.m. to 22 mph at 7:35 a.m. During this congested period, several complete stoppages of traffic were observed. These stoppages "accordioned" or "backlashed" along the lane until they were absorbed by available gaps in the traffic stream.

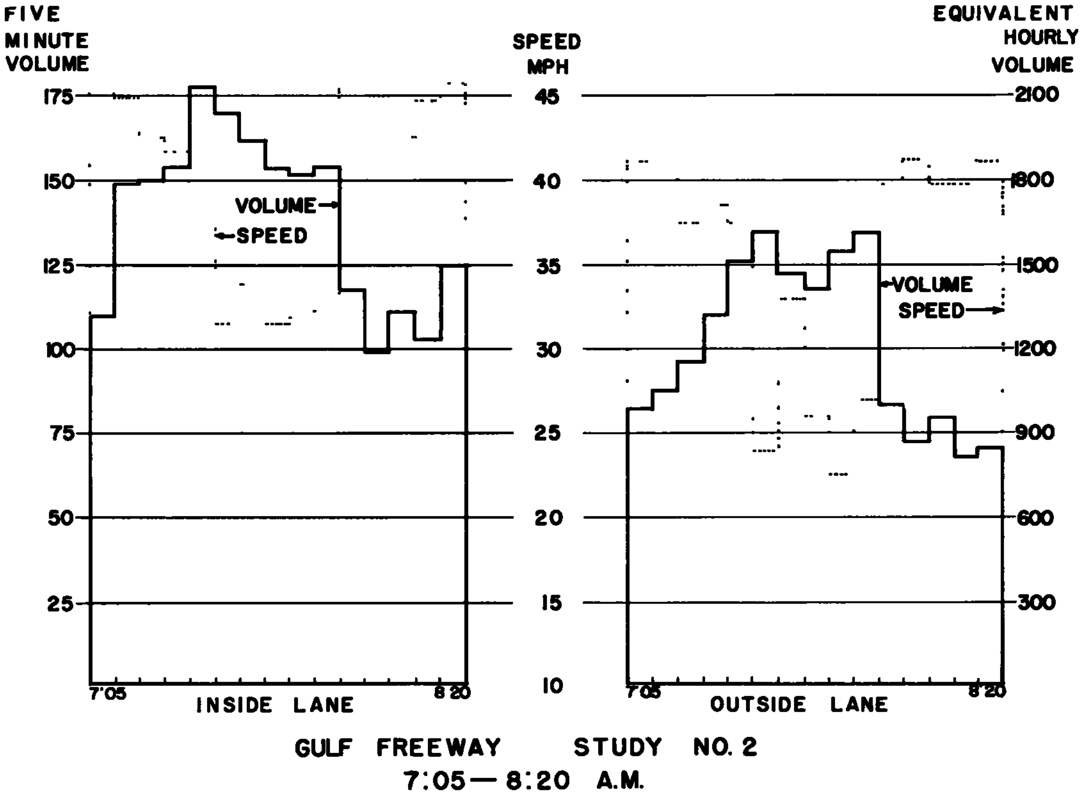
From the tower it could be seen that these backlashes often traveled for considerable distances, depending on the volume conditions. Similar stoppages and backlashing were also observed in the middle and inside lane. These followed stoppage in the outside lane and were probably caused by vehicles weaving out of the outside lane stoppages, thereby reducing headways in the middle and inside lanes, which were already minimum.

The freeway speeds were sharply decreased by these stoppages and often vehicles continued to operate at lower speeds for several minutes. With the ramps closed, the average speed fluctuated only 10 mph, dropping only 5 mph below the speed limit.

From careful observation of the film from all studies, there appears to exist a tendency for all three lanes to operate at approximately the same speed regardless of the volume. Data are insufficient to form any definite conclusions, but there is indication of sympathy in speed between the lanes.

Vehicle Placement

Vehicle placement was measured by viewing the film one frame at a time projected vertically to a table-top screen. The distance from the outside curb to the right rear tire of the vehicle was measured with a special scale with the vehicle tire directly over the transverse line on the pavement 176 ft in advance of the entrance ramp. Checks



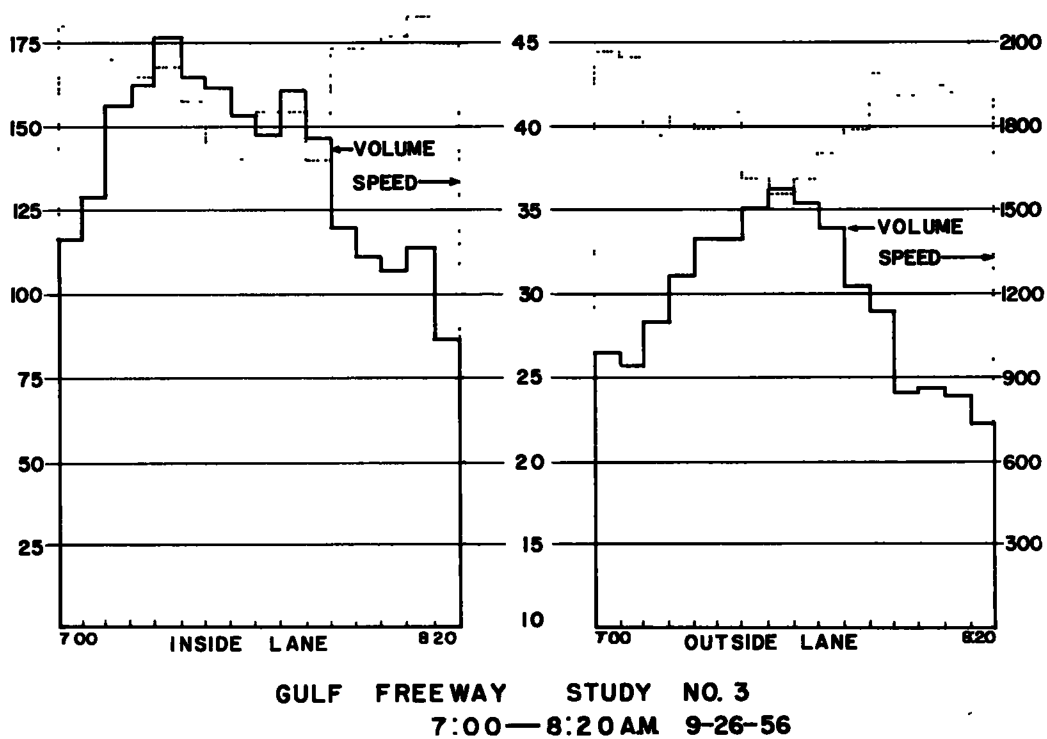


Figure 8. Volume-speed relationship.

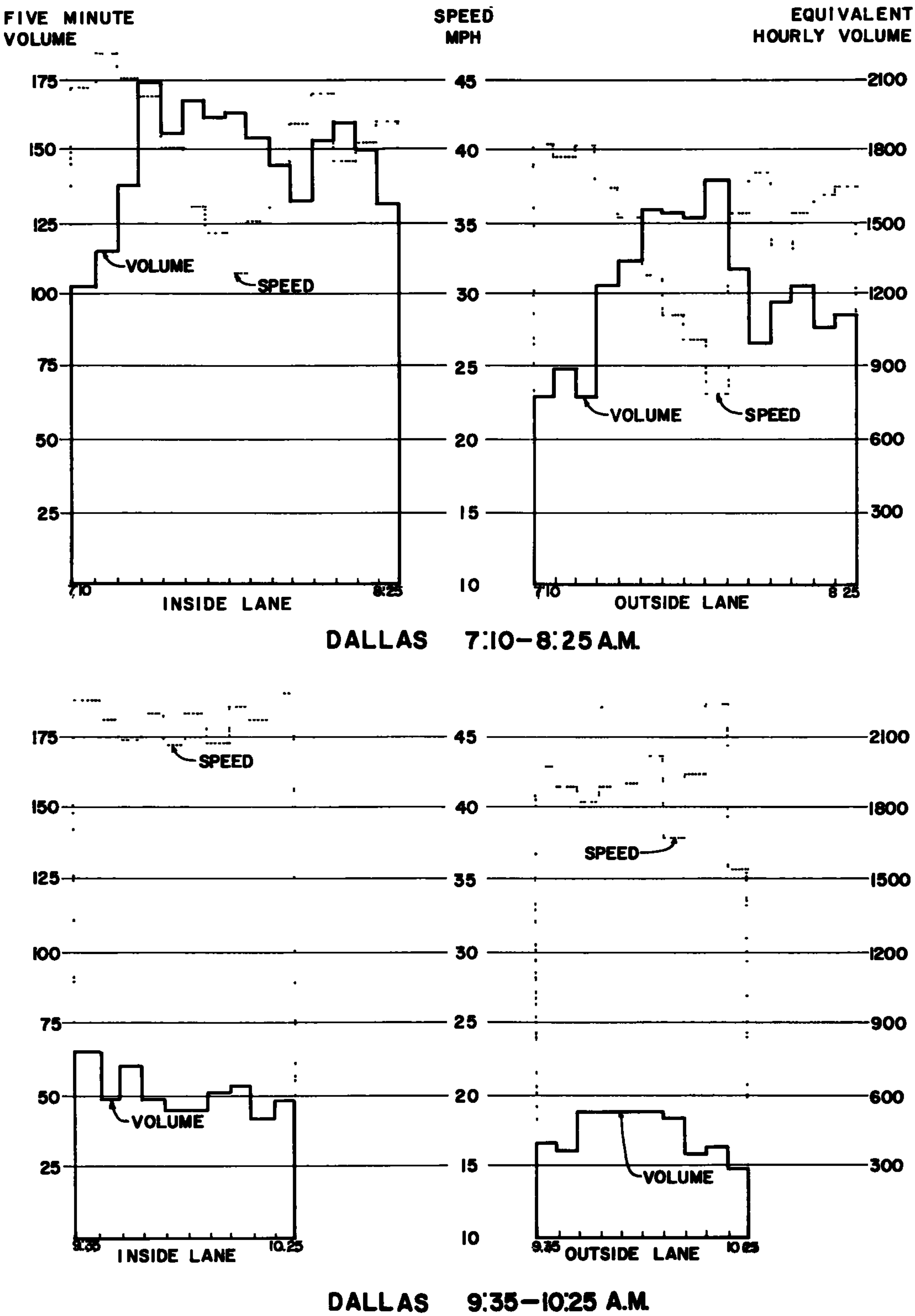


Figure 9. Volume-speed relationship.

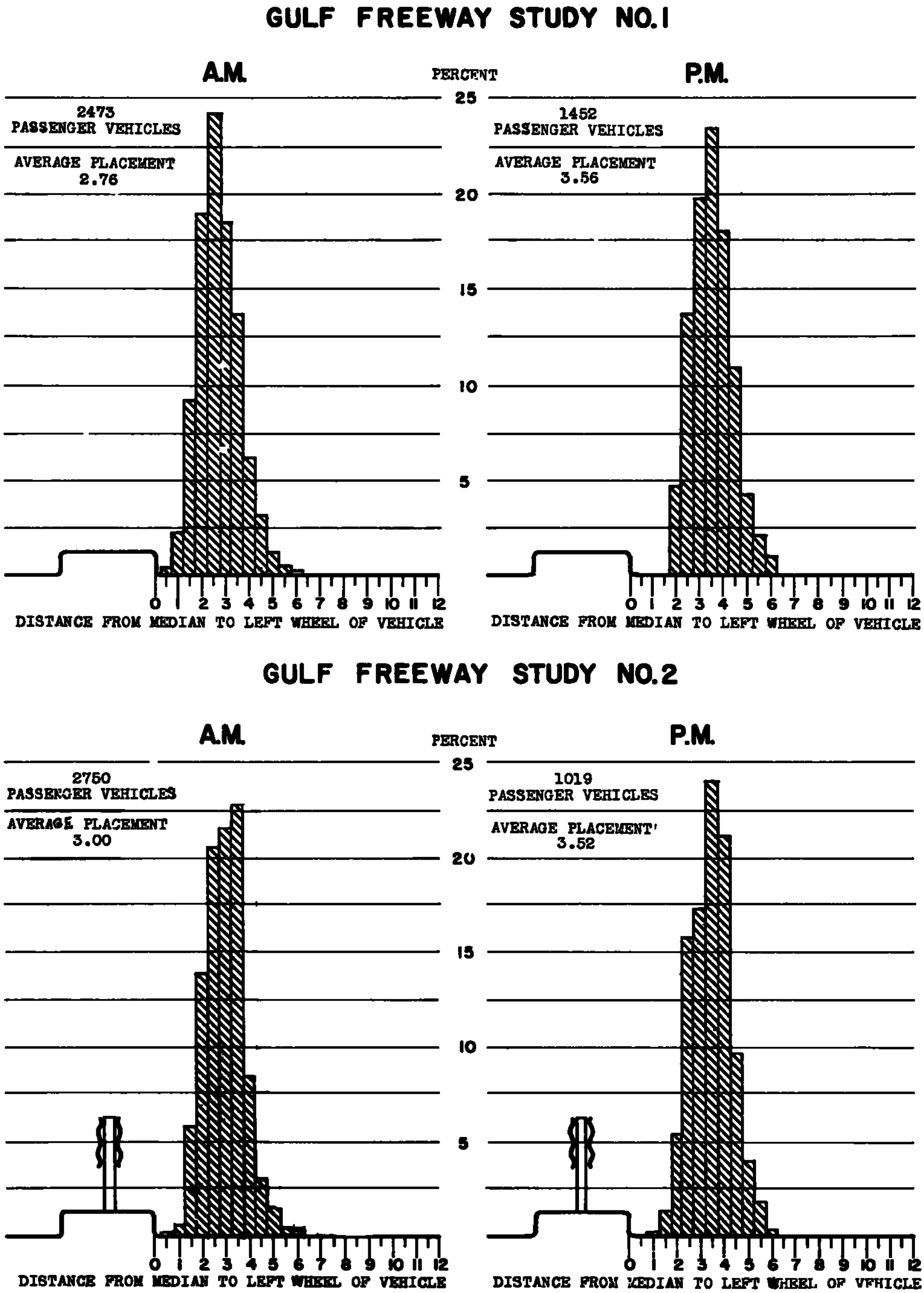


Figure 10. Influence of median barrier fence on inside lane placements.

made by different personnel on some 2,000 vehicles showed that reasonable accuracy could be obtained by reading to the nearest one-half foot. This accuracy possibly was not warranted, but was chosen to encourage more conscientious reading.

The placement measurements were recorded directly on mark-sense cards. The proximity of other vehicles leading, trailing and passing was also recorded. The prox-

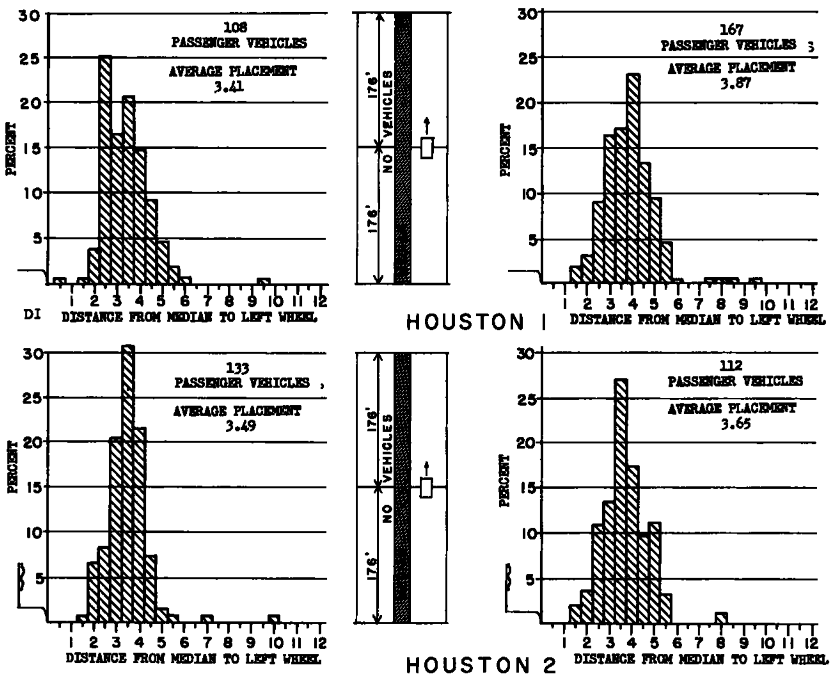


Figure 11. Influence of opposing traffic on inside lane placements, no vehicle in middle lane within 176 feet.

imity of vehicles in the opposing lane was recorded for all vehicles in the inside lane and the proximity of entering vehicles was recorded for all vehicles in the outside lane.

The possible influence of the barrier fence constructed along the center of the median

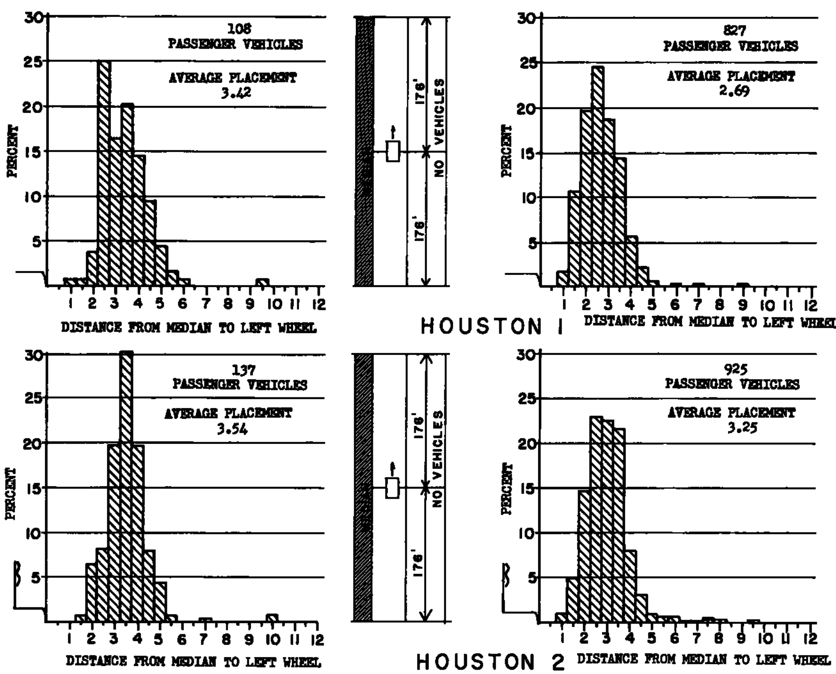
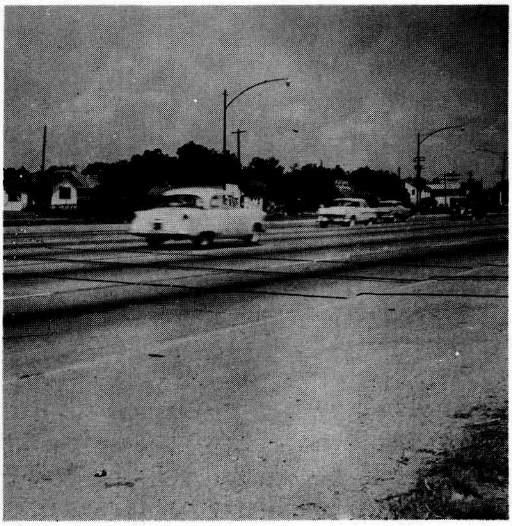
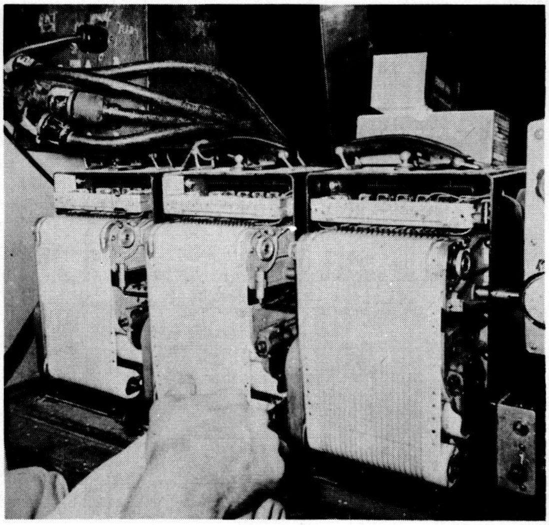


Figure 12. Influence of middle lane traffic on inside lane placements, no vehicle in opposing lane within 176 feet.



(a)



(b)

Figure 13. Speed and placement data were transmitted by roadway tapes: (a) to automatic recording equipment, (b) in a truck concealed from view of freeway traffic.

on the Gulf Freeway was one of the major factors in this study. The influence of the median barrier fence on vehicle placements in the inside lane was determined by comparison of the data taken before and after the construction of the barrier.

For the study prior to the construction of the barrier fence on the Gulf Freeway, analyses were made to determine the influence of opposing traffic and traffic in the middle lane on vehicle placements in the inside lane.

Effect of Median Barrier Fence on Inside Lane Placements

Placements for passenger vehicles in the inside lane adjacent to the median are shown in Figure 10 for conditions before and after construction of the median barrier fence. Placements are shown separately for the morning and afternoon periods. The average placement of the left wheels with respect to the median during the morning was 2.76 ft before and 3.00 ft after construction of the barrier. This positioned the centers of the vehicles virtually in the center of the lane, with most of the traffic within 1 ft of the center of the lane. There was a slight shift away from the median during the afternoon peak periods, when the opposing outbound flow was heaviest. The average placement of the left wheels with respect to the median during the afternoon peaks was 3.56 ft before and 3.52 ft after construction of the barrier.

These data are not sufficiently complete to justify any positive conclusions, but from the data taken thus far it appears that the barrier fence had little influence on placement of passenger vehicles in the inside lane.

It may be noted at this point that in the only reported accident involving the fence in the first four months after completion, the fence prevented a truck from being forced across the median. Observations indicate that the fence probably provides a much better reference point for driving in the inside lane than did the low median.

Influence of Opposing Traffic on Inside Lane Placements

To determine the influence of opposing traffic on placement of inbound vehicles in the inside lane on the Gulf Freeway, placements were tabulated for two conditions of opposing traffic, as follows:

1. No vehicle in opposing inside lane within 176 ft.
2. A vehicle within 88 ft in the opposing inside lane.

These data were taken for the condition of no vehicle in the middle inbound lane within 176 ft of the vehicle being studied. The results of the Houston 1 study, made before construction of the median barrier, and the results of the Houston 2 study, made after construction of the barrier, are shown in Figure 11.

For the study made before construction of the barrier, the average placement moves to the right 0.46 ft away from vehicles in the opposing lane. For the Houston 2 study, made after construction of the barrier, the average placement moves only 0.16 ft to the right for the condition of vehicles immediately to the left in the opposing lane.

Influence of Middle Lane Traffic on Inside Lane Placements

To determine the influence of inbound middle lane traffic on placements of inbound vehicles in the inside lane on the Gulf Freeway, placements were tabulated first for the

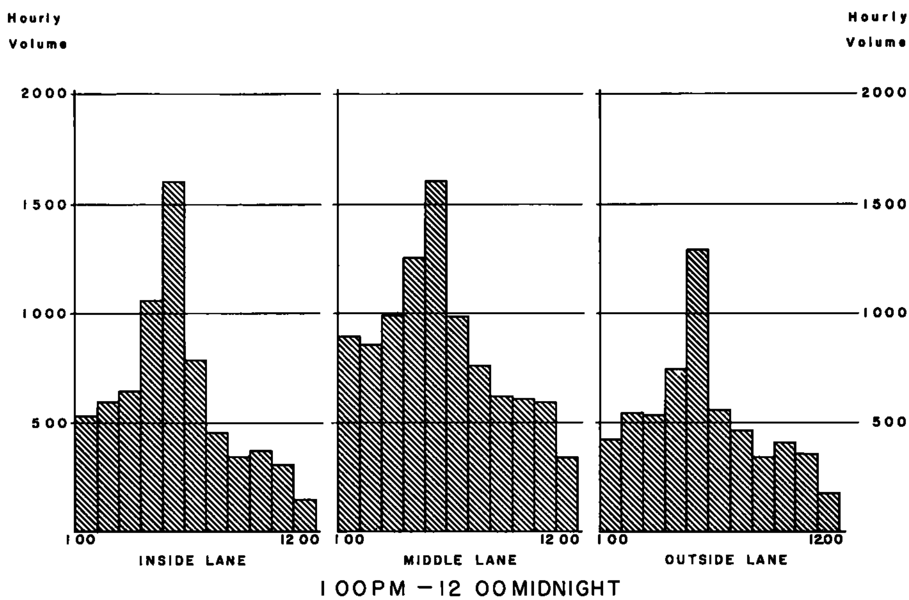


Figure 14. Hourly volumes by lanes, outbound traffic, Gulf Freeway, Houston, Texas (Bureau of Public Roads Survey, May 23, 1956).

condition of no vehicle in the middle lane within 176 ft and secondly for the condition of a vehicle in the middle lane within 88 ft of the vehicle being studied. These data were taken for the condition of no traffic in the opposing inside lane within 176 ft. The results of the Houston 1 study and the results of the Houston 2 study are shown in Figure 12.

The results of the Houston 1 study indicate that vehicles drove closer to the median when there were vehicles immediately to the right in the middle lane. The average placement of the left wheels with respect to the median moves from 3.42 ft with no middle lane traffic to 2.69 ft when there were vehicles in the middle lane within 88 ft of the vehicle being studied.

The results of the Houston 2 study show a change in average placement of only 0.29 ft toward the median for the same conditions.

TAPE-PLACEMENT SURVEY

A comprehensive 11-hr placement survey was made on the Gulf Freeway in Houston on May 23, 1956, using placement equipment supplied and supervised by representatives of the Bureau of Public Roads. Personnel of the Texas Highway Department assisted with with the operation of the equipment.

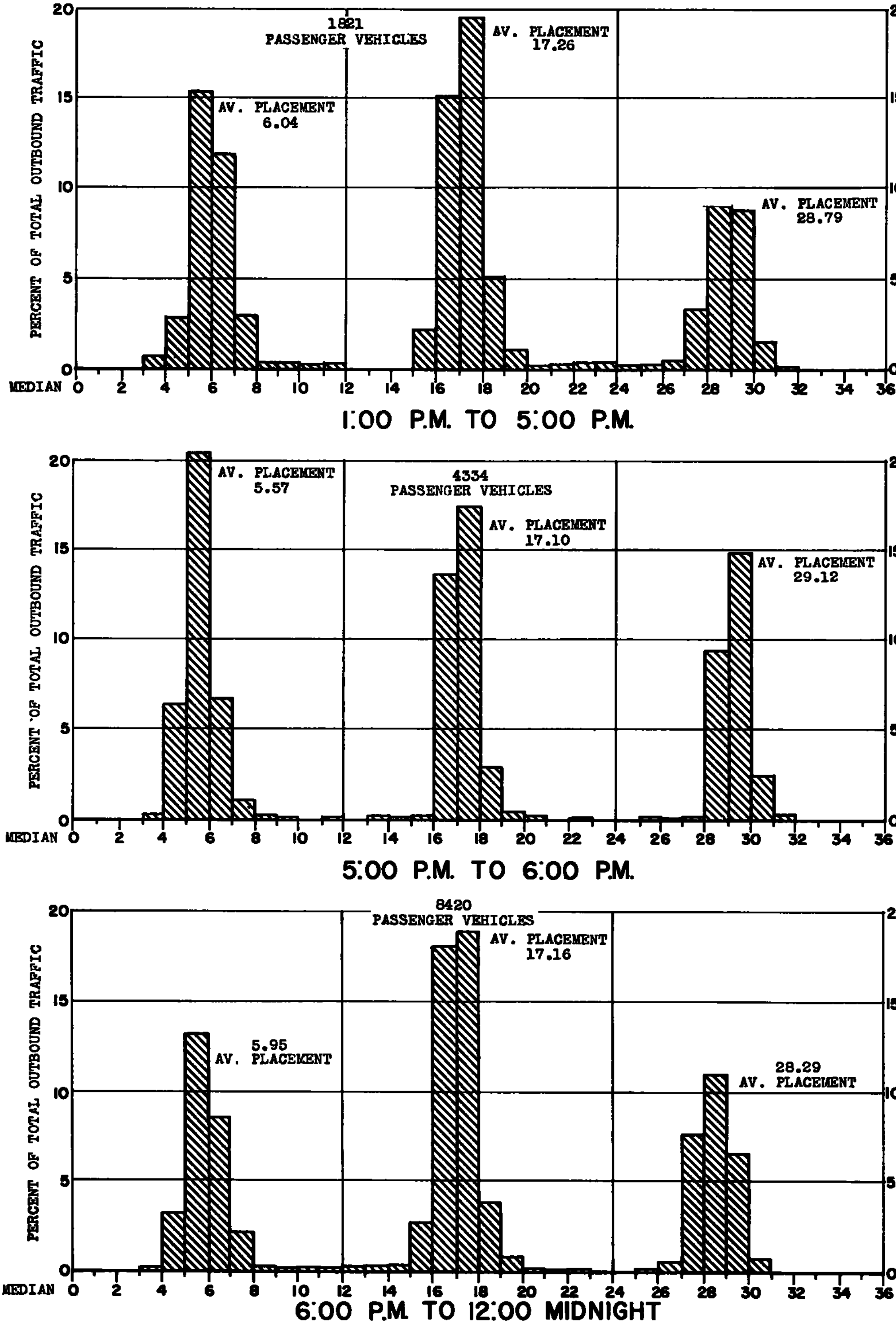


Figure 15. Vehicle placements and lane use, Gulf Freeway, Houston, Texas, May 23, 1956, outbound traffic, Bureau of Public Roads Survey (placements of centers of vehicles).

This survey was conducted on the outbound traffic lanes on a straight section of the freeway. The site was located 600 ft beyond an exit ramp and 1,000 ft before an entrance ramp. The site was selected to provide as little direct influence from entrance and exit ramps as possible.

The tapes were placed on the pavement as shown in Figure 13 to provide placement

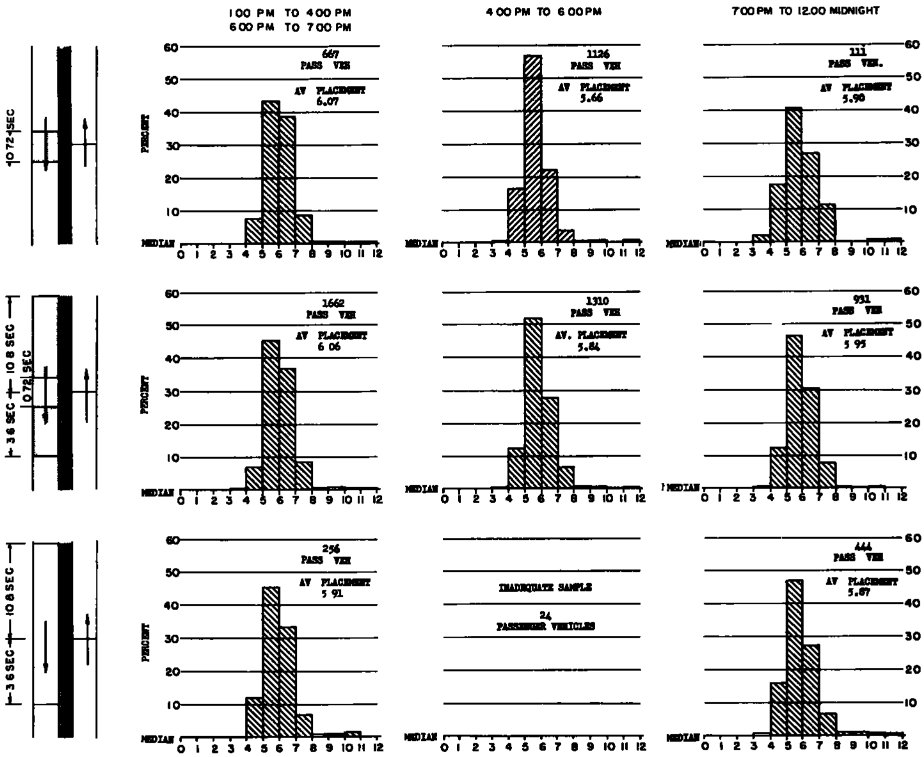


Figure 16. Influence of opposing traffic on inside lane placements, Gulf Freeway, Houston, Texas, Bureau of Public Roads Survey, May 23, 1956 (placements of centers of vehicles).

and speed of each vehicle. These data were recorded graphically on moving paper tapes by three 20-pen recorders. The recording equipment (Figure 13(b)) was mounted in a truck concealed from the view of the freeway traffic. Placements were recorded for all three lanes of outbound traffic on moving paper tape graduated to show the time each vehicle crossed the tube. This provided measurement of headway between vehicles and relative positioning in the traffic streams to the nearest 0.36 sec. A tube was placed across the opposing inside lane to record only the time each vehicle in that lane crossed the tube. These data were taken to determine the influence of opposing traffic. Speeds were recorded for only the inside and outside lanes of outbound traffic.

The information from the tapes was transferred to punch cards and the tabulations made on punch card equipment. Only a portion of these data are presented in this report.

Volume

The volumes by lanes obtained from the tape-placement survey are shown in Figure 14, which shows that the volume in the outside lane is less than that of the other two lanes except during extremely low volume conditions. A maximum hourly lane volume of 1,651 was recorded in the inside lane. A maximum volume of 192 was recorded in the inside lane during a 6-min. period, which represents an equivalent hourly volume of 1,920 vph.

Vehicle Placement

The tape installed across the pavement to record vehicle placement was wired so that each 2-ft section provided an impulse to actuate a pen of the 20-pen recorder. Each pair of wheels passing over the tube actuated two pens. The various combinations of pens were coded to provide the placement of the center of each vehicle. The placements for passenger vehicles are shown in Figure 15 for all three lanes, with distances measured from the median. The percentages are based on the total traffic for all three lanes and indicate relative lane use. The placements are shown only to the nearest foot to permit easier reading of the graphs.

These data show that the average placement in the inside lane adjacent to the median was basically in the center of the 12-ft lane for conditions of both daylight and darkness. There was a slight shift toward the median during the afternoon peak traffic period.

The average middle lane placement was very nearly 17 ft for all conditions, which is 1 ft to the left (or toward the median) from the center of the middle lane.

The average placement in the outside lane was approximately 29 ft, which is 1 ft to the left (or away from the outside curb) from the center of the outside lane. During conditions of darkness the outside lane placements shifted slightly to the left. The average placement during this period was 28.29 ft, which is 1.71 ft to the left of the center of the outside lane.

Influence of Opposing Traffic on Inside Lane Placements

The placements for passenger vehicles in the inside lane are shown in Figure 16 for three conditions of traffic in the adjacent opposing lane across the median. These data are shown for afternoon, afternoon peak, and nighttime traffic conditions. Inside lane placements are shown for a vehicle or vehicles in the adjacent opposing lane within 0.72 sec. of the vehicle being studied. The second condition shown is for vehicles in approaching or passed positions in the opposing lane with no vehicle within 0.72 sec. The third condition shown is for no approaching vehicle in the opposing lane within 10.8 sec. and no passed vehicle within 3.6 sec.

These data do not indicate that placements in the inside lane are influenced by vehicles in the opposing inside lane.

SUMMARY

The collection and analysis of the data from the studies reported in this paper are not sufficiently complete to justify positive conclusions. The following comments are subject to revision when the collection and analysis of data from these and other studies are completed:

1. The motion picture type of survey provides an accurate method of obtaining all necessary data for studying traffic operational characteristics. Closeness in agreement of data from the various studies made at different times verifies the accuracy of the survey method.
2. During extremely heavy traffic peaks, on the two freeways studied, 5-min. volumes are more indicative of traffic flow conditions than are hourly volumes.
3. Average speeds of 40 to 50 mph are maintained in the outside lane when the volume level for any 5-min. period is less than 125 or an equivalent hourly volume level of 1,500 vph. Five minute average speeds of 40 to 50 mph are maintained in the middle and inside lanes when the 5-min. lane volumes are below 150 or an equivalent hourly volume level of 1,800 vph (see Fig. 8, Study 3).
4. On the two freeways studied, the vehicles in each lane tend to adjust to the speed of the slower parallel lane. This sympathy of speed between lanes appears to exist regardless of volume.
5. Comparison of the studies made with the entrance ramps open and those made with the entrance ramps closed indicates that smoothness of operation and uniform speeds can be maintained by controlling the freeway volumes.
6. The barrier fence constructed along the center of the 4-ft median on the Gulf

Freeway did not materially influence placements of vehicles in the inside lane.

7. Before construction of the median barrier, middle lane traffic appeared to have more influence on placements of vehicles in the inside lane than did vehicles in the opposing lane. After construction of the fence, no great influence by either opposing or middle lane traffic was indicated. The shift in placement away from the median during heavy peak opposing traffic flow indicates an influence of density of opposing flow rather than individual opposing vehicles.

8. Placements in the three outbound lanes of the Gulf Freeway obtained by the Bureau of Public Roads equipment show that in the outside and middle lanes the average vehicle placements are to the left of the center of the lane. Inasmuch as these data were taken on a straight tangent section free from entrance or exit interference, an inadequate reference point by which to drive in the outside lane is indicated.

9. The data obtained by the tape-placement survey do not indicate any influence on inside lane placements by vehicles in the inside opposing lane.

ACKNOWLEDGMENTS

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Grateful acknowledgment is also made for the cooperation and direction given by the members of the Project Advisory Committee, M.D. Shelby, Supervising Research Engineer, Texas Highway Department, Austin; Reed Baker, Traffic Manager, Texas Highway Department, Austin; J.M. Battle, Assistant Urban Manager, Texas Highway Department, Austin; W.E. Carmichael, District Engineer, Texas Highway Department, Houston; W.H. Carsten, Director, Department of Traffic Control, Dallas; F.W. Cawthon, District Engineer, Texas Highway Department, Dallas; A.C. Kyser, Engineer-Manager, Houston Urban Project, Texas Highway Department, Houston; Eugene Maier, Director, Department of Traffic and Transportation, Houston; Oliver Raynor, Expressway Engineer, Texas Highway Department, Dallas; Paul R. Tutt, Senior Designing Engineer, Texas Highway Department, Austin; and W.R. Welty, Traffic Designing Engineer, Texas Highway Department, Austin.

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Vehicle Speed and Placement Survey

M.D. SHELBY and P.R. TUTT, Road Design Division, Texas Highway Department

The paper reports data obtained from three separate surveys, as follows:

1. Speed and placement by vehicle type, maneuver, and light condition on two-lane rural highways at twelve observations sites. The sites included lane widths from a minimum of 11 to a maximum of 19 ft. Shoulder conditions included asphalt sealed, gravel, and grass. The purpose of the study was to obtain data to support a possible change in recommended lane width.

2. Relative placements by vehicle type, maneuver, and light condition on six different width roadways of rural bridges from a minimum of 24 to a maximum of 44 ft were obtained. These data, plus vehicle speeds, were obtained on the approach roadway to each of these six structures. All approach pavements were 24 ft wide with sealed shoulders with fair to good color contrast. The purpose of this study was to obtain data to support a possible change in recommended width of restricted roadway bridges.

3. Relative effect on traffic operation of a parked vehicle on a 6-ft wide shoulder on a one-way 2-lane urban grade separation structure. This study was very limited in scope, but was made in an effort to gain a partial answer as to the effectiveness of this narrow shoulder. Speed and placement by vehicle type, maneuver, and light condition were obtained on each of two consecutive days. The first day was without a vehicle parked on the shoulder, the second day with a passenger vehicle parked on the shoulder. Although the presence of the parked vehicle had a marked effect on the traffic flow, the two lanes of traffic could move over the structure at reasonable speeds.

Copies of the complete published reports may be obtained from the authors or on loan from the library of the Highway Research Board.

Part 1: Two-Lane Rural Highways

●THIS STUDY was conducted primarily to obtain facts about vehicle behavior under various conditions on 2-lane roads as a guide to formulating future design standards. In general the study was limited to traffic volumes that can reasonably be accommodated on 2 lanes. The results and findings should, therefore, be applicable only to those roads which are not overloaded.

The principal variables which can be studied on a 2-lane road are somewhat limited, being primarily lane width, shoulder width and shoulder type. Obtaining data in sufficient quantities to hold all but one feature constant while that one was studied was found to be somewhat difficult but a fair sample was possible in each case.

By studying the speed and lateral placement of vehicles, it was hoped to obtain basic data which could be applied in the design of future roads and to the maintenance and redesign of existing roads.

Correlation of some of these data with the results of the Western Association of State Highway Officials, Idaho Road Test makes possible certain structural design criteria while correlation with known accident data allows the development of safety standards. The application of placement in the development of safety standards is in lieu of adequate accident records, but since these are not now available, and since it is possible to associate placement data with the available accident records, it is felt that a reasonable standard can be achieved.

METHODS

The equipment used in obtaining the field data consisted of combination speed-meters and transverse placement detectors. (1) This equipment was furnished and operated by the U.S. Bureau of Public Roads (Fig. 1).

The speed-meters were operated by use of pneumatic detectors that actuated a timing device which in turn recorded the speed of the vehicle on a moving paper tape. The speed was recorded by groups and for this survey there were twenty-five groups with the upper and lower limits being open classifications.

An electro-mechanical tape which actuated a recording device was used to record the transverse placement. This tape was separated so that most vehicles actuated only two pins on the recorder thus giving an accurate location of the vehicle.

Figure 1. View of lateral placement and speed tapes with recording truck in the background.

The moving paper tapes used for recording were timed so that they moved past the pins at a constant rate. This made possible the classification of maneuvers by time spacing and also the matching of speed and placement for each vehicle. Manual notes were made on the paper tape for vehicles other than passenger cars and for the passing maneuver.

The truck containing the recording equipment was located well away from the road site and was hidden from view to as great an extent as was possible to avoid influencing driver behavior. The data were hand coded and transferred to punched cards for machine tabulation.

LOCATION AND DESCRIPTION OF SITES

The study was conducted primarily in the Austin area. Some data from a study which dealt primarily with bridges were also included (Sites 50-A and 52-A). The locations of the study sites are shown in Figures 2 and 3. The locations were selected on the basis of providing data which would be uninfluenced by any but the factors under study. The sites were located on long tangents and at spots where no outside influence which might affect traffic behavior would be present. The ideal was not always achieved but in the majority of cases, the external influence was slight. Table 1 gives pertinent data for each site. Traffic volumes, except for Site 2, are within the normal range for 2-lane roads. The number of examples for each condition was smaller than desirable

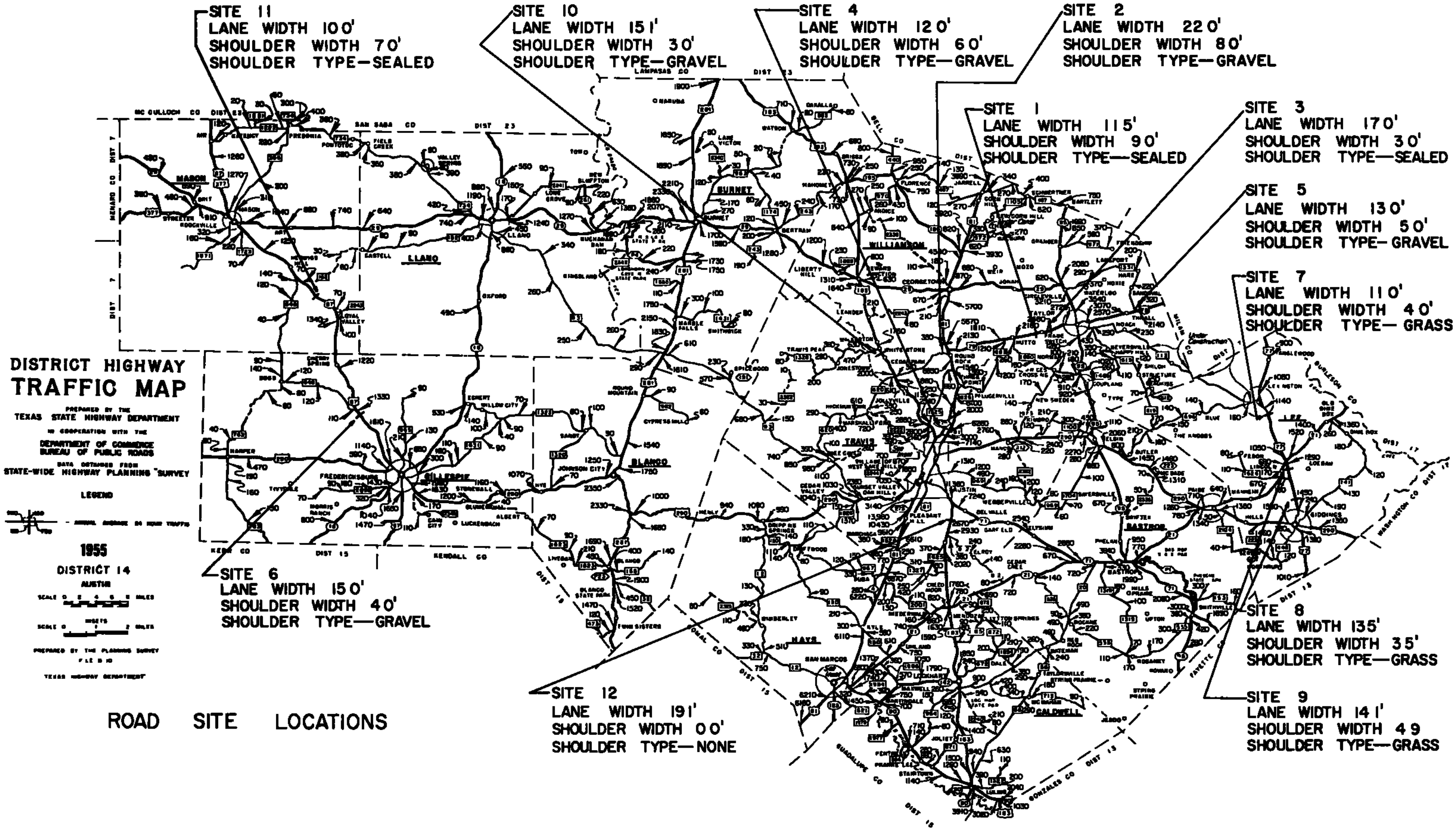
SITE 11
LANE WIDTH 10.0'
SHOULDER WIDTH 7.0'
SHOULDER TYPE—SEALED
SITE 10
LANE WIDTH 15.1'
SHOULDER WIDTH 3.0'
SHOULDER TYPE—GRAVEL
SITE 4
LANE WIDTH 12.0'
SHOULDER WIDTH 6.0'
SHOULDER TYPE—GRAVEL
SITE 2
LANE WIDTH 22.0'
SHOULDER WIDTH 8.0'
SHOULDER TYPE—GRAVEL
SITE 1
LANE WIDTH 11.5'
SHOULDER WIDTH 9.0'
SHOULDER TYPE—SEALED
SITE 3
LANE WIDTH 17.0'
SHOULDER WIDTH 3.0'
SHOULDER TYPE—SEALED
SITE 5
LANE WIDTH 13.0'
SHOULDER WIDTH 5.0'
SHOULDER TYPE—GRAVEL
SITE 7
LANE WIDTH 11.0'
SHOULDER WIDTH 4.0'
SHOULDER TYPE—GRASS
DISTRICT HIGHWAY
TRAFFIC MAP
1955
DISTRICT 14
SITE 6
LANE WIDTH 15.0'
SHOULDER WIDTH 4.0'
SHOULDER TYPE—GRAVEL
SITE 8
LANE WIDTH 13.5'
SHOULDER WIDTH 3.5'
SHOULDER TYPE—GRASS
SITE 12
LANE WIDTH 19.1'
SHOULDER WIDTH 0.0'
SHOULDER TYPE—NONE
SITE 9
LANE WIDTH 14.1'
SHOULDER WIDTH 4.9
SHOULDER TYPE—GRASS
ROAD SITE LOCATIONS
MASON
LLANO
BURNET
WILLIAMSON
TRAVIS
BLANCO
GILLESPIE
HAYS
BASTROP
CALDWELL
LEE

Figure 2.

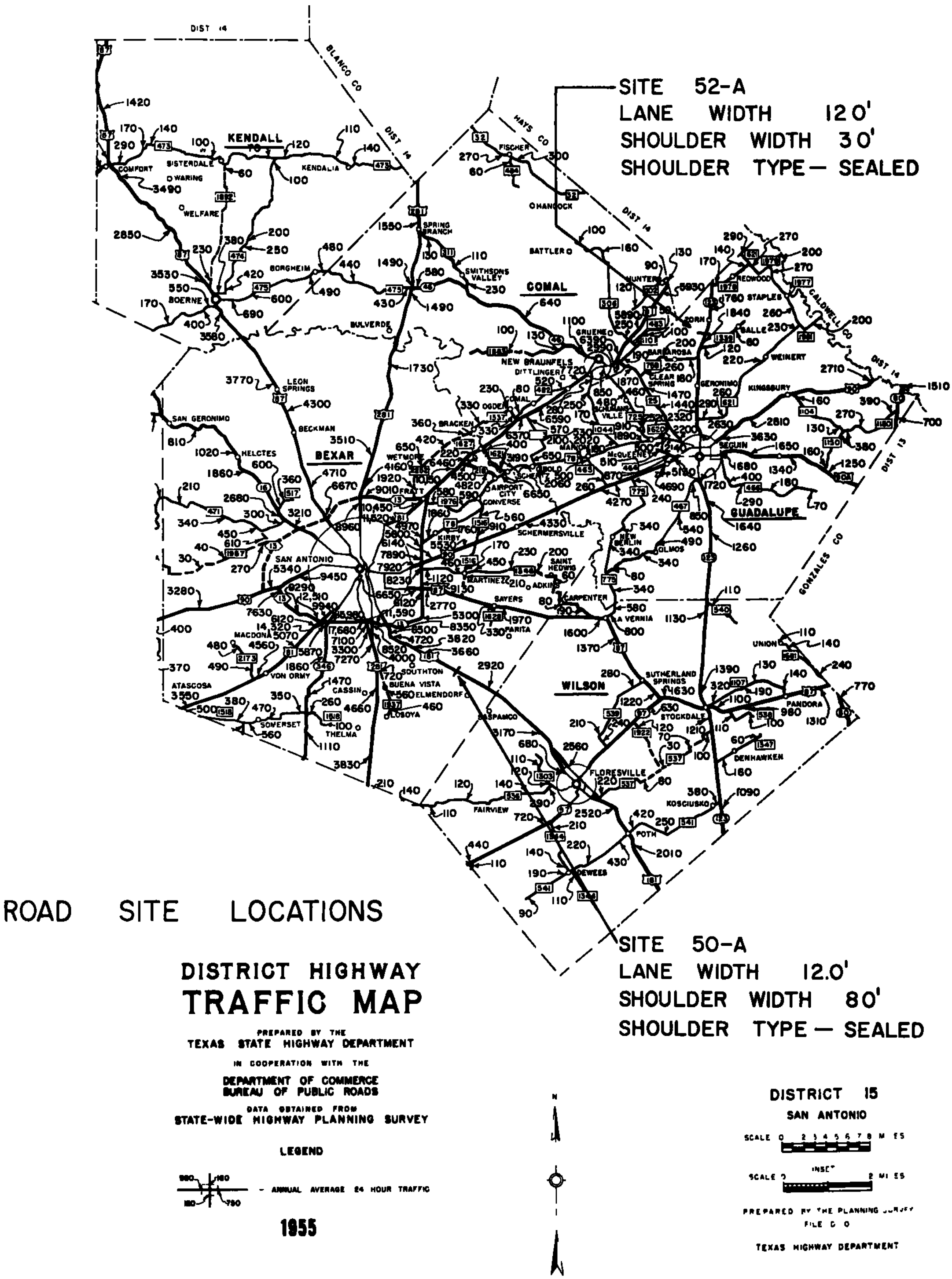
SITE 52-A
LANE WIDTH 12.0'
SHOULDER WIDTH 3.0'
SHOULDER TYPE — SEALED
KENDALL
COMAL
BEXAR
GUADALUPE
WILSON
SAN ANTONIO
NEW BRAUNFELS
SEGUIN
FLORESVILLE
BOERNE
COMFORT
ROAD SITE LOCATIONS
SITE 50-A
LANE WIDTH 12.0'
SHOULDER WIDTH 8.0'
SHOULDER TYPE — SEALED
DISTRICT HIGHWAY
TRAFFIC MAP
PREPARED BY THE
TEXAS STATE HIGHWAY DEPARTMENT
IN COOPERATION WITH THE
DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
DATA OBTAINED FROM
STATE-WIDE HIGHWAY PLANNING SURVEY
LEGEND
- ANNUAL AVERAGE 24 HOUR TRAFFIC
1955
DISTRICT 15
SAN ANTONIO
TEXAS HIGHWAY DEPARTMENT

Figure 3.

TABLE 1

CHARACTERISTICS OF ROADWAY AND TRAFFIC AT OBSERVATION STATIONS 1-12, 50-A AND 52-A

Observation Station No	1	2	3	4	5	6	7	8	9	10	11	12	50-A	52-A
Lane Width (ft)	11.5	22.0	17.0	12.0	13.0	15.0	11.0	13.5	14.1	15.1	10.0	19.1	12.0	12.0
Shoulder Width (ft)	9.0	8.0	3.0	6.0	5.0	4.0	4.0	3.5	4.9	3.0	7.0	0.0	8.0	3.0
Type of Shoulder	Sealed	Gravel	Sealed	Gravel	Gravel	Gravel	Grass	Grass	Grass	Gravel	Sealed	-	Sealed	Sealed
Color-Shoulder and Traffic Lane	Contrasting	Contrasting	Same	Contrasting	Contrasting	Contrasting	Contrasting	Contrasting	Contrasting	Contrasting	Same	-	Contrasting	Contrasting
Total Vehicles Counted	2,270	4,298	2,630	2,593	2,006	667	957	1,329	1,076	2,219	621	2,421	2,031	1,148
Percent Passenger Cars	88.7	77.0	89.1	89.8	83.1	68.1	82.0	80.7	78.3	85.6	76.8	85.1	82.2	78.3
Percent Trucks	8.4	20.1	8.4	8.8	14.3	24.4	15.8	14.8	18.4	11.2	19.5	12.3	15.7	17.4
Percent Buses	0.5	0.8	0.7	0.6	0.8	2.4	0.6	1.2	1.2	0.8	1.1	0.6	0.7	2.2
Percent Others	2.4	2.1	1.8	0.8	1.8	5.1	1.6	3.3	2.1	2.4	2.6	2.0	1.4	2.1
Night Vehicles Counted	455	1,141	585	426	340	119	119	178	181	402	117	475	224	195
Percent Passinger Cars	87.7	64.7	88.5	95.8	85.3	65.5	81.5	80.9	70.2	88.8	64.1	85.9	78.6	76.9
Percent Trucks	10.5	32.9	9.4	3.5	12.3	29.4	18.5	16.3	26.0	9.2	30.8	13.1	19.6	20.0
Percent Buses	0.9	1.0	1.4	0.7	1.8	1.7	0.0	0.6	1.1	0.8	1.7	0.4	0.9	1.0
Percent Others	0.9	1.4	0.7	0.0	0.6	3.4	0.0	2.2	2.7	1.2	3.4	0.6	0.9	2.1
1955 Average Daily Traffic	2,320	5,670	2,720	2,680	2,140	1,330	1,140	1,450	1,290	2,000	1,295	2,930	3,290	1,800
County	Williamson	Williamson	Williamson	Travis	Williamson	Gillispie	Lee	Lee	Lee	Williamson	Mason	Travis	Bexar	Guadalupe
Highway No	U S 79	U S 81	U S 79	U S 81	U S 79	U S 87	U S 77	U S 77	U S 77	U S 183	U S 87	U S 183	U S 181	S H 123
Control and Section	204-2	15-9	204-3	Business 15-11	204-4	71-6	211-3	211-4	211-4	151-5	71-5	152-1	100-2	366-2
Location	5.3 mi W of S H 95	1.1 mi N of U S 79	3.2 mi W of S H 95	2.2 mi N of U S 183	1.0 mi E of F M 1331	1.6 mi S of F M 648	6.2 mi N of S H 21	3.0 mi N of U S 290	1.1 mi N of F M 1624	0.7 mi S of F M 1328	8.6 mi N of Gillespie C L	1.7 mi S of S H 71	0.5 mi N W of Wilson C L	1.8 mi S of Hays C L

but the correlation of the data worked out well for the major factors studied. Complete data for each site condition have been published by the Road Design Division, Texas Highway Department (2).

STUDIES MADE

Speed

Speed studies were made at each of the sites and the data were plotted as a cumulative speed curve, showing the 85 percentile speed for passenger cars and trucks. All speeds fell within the normal range for the conditions studied. The 85 percentile speed for passenger cars ranged from 59 to 69 mph and from 45 to 59 mph for trucks. There does not appear to be a significant correlation between speed and the factors studied.

Lateral Placement

Bar charts showing vehicle placements for free-moving and meeting passenger cars and trucks were prepared for both day and night conditions. These charts showed the average placement for each condition and the percent of vehicles encroaching on the shoulder and across the centerline of the road and provided most of the basic data which were used in developing the average placement relationships and from which the conclusions were drawn (2).

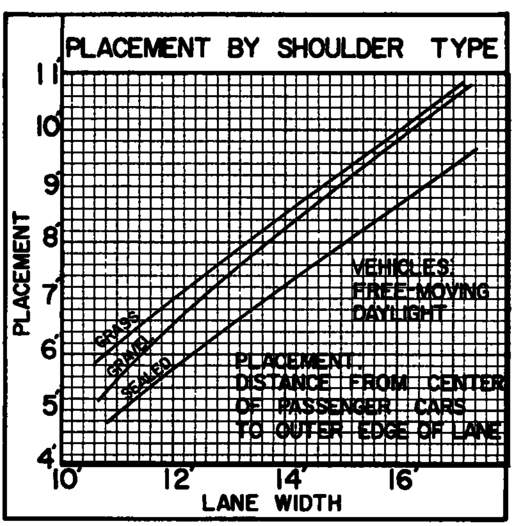

Figure 4.

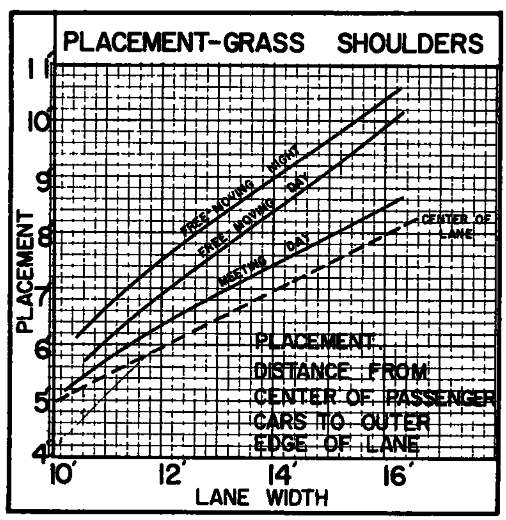

Figure 5.

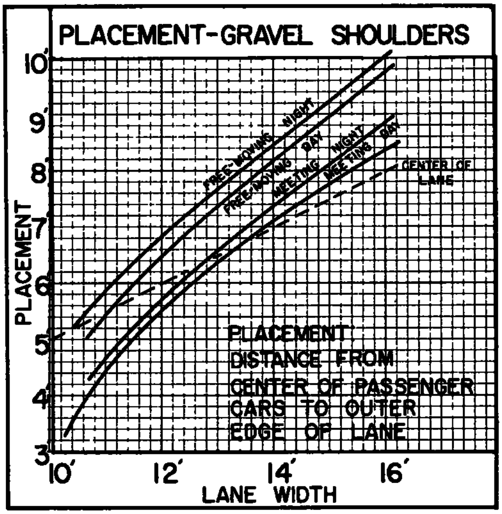

Figure 6.

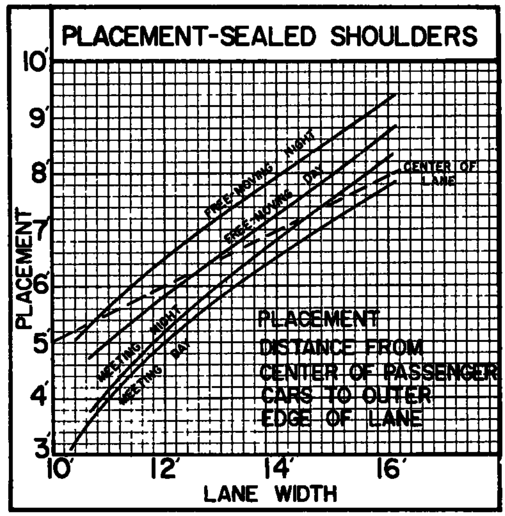

Figure 7.

In plotting the average placement against various width factors such as centerline of road, edge of lane, and edge of shoulder, it was found that the best correlation resulted when the distance from the center of the vehicle to the outer edge of the lane was plotted against lane width. This was somewhat contrary to expectations, and it is concluded that the driver is influenced more in selecting his lateral position by the edge of the lane than he is by the centerline of the road.

Shoulder Width and Type

Several attempts were made to correlate placement to shoulder width without success. Since this study did not include any shoulders less than 3 ft in width, shoulders 3 ft wide or wider do not affect placement. There is undoubtedly some width of shoulders, less than 3 ft, that would have a definite effect on vehicle placement, but it was not within the scope of this study to determine that exact width. The type of shoulder has a very definite effect on the lateral placement of vehicles. This is illustrated in Figure 4 which is a series of curves averaged from the data. The relationship between vehicle placements for free-moving-daylight conditions, which

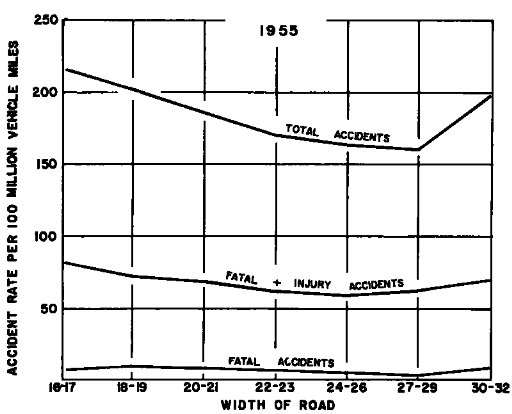

Figure 8. Rural accident rates by width of two-lane roads.

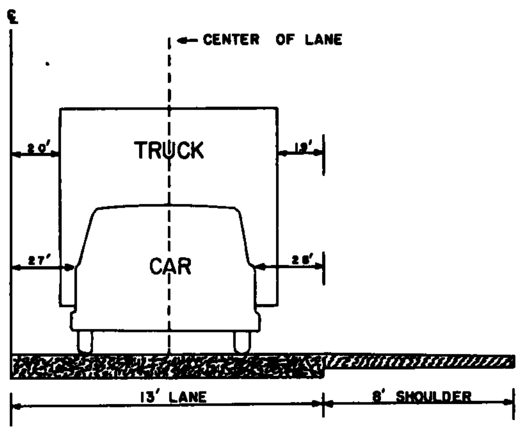

Figure 9. Typical placement range for a 13-ft lane with an 8-ft sealed shoulder for passenger cars and trucks.

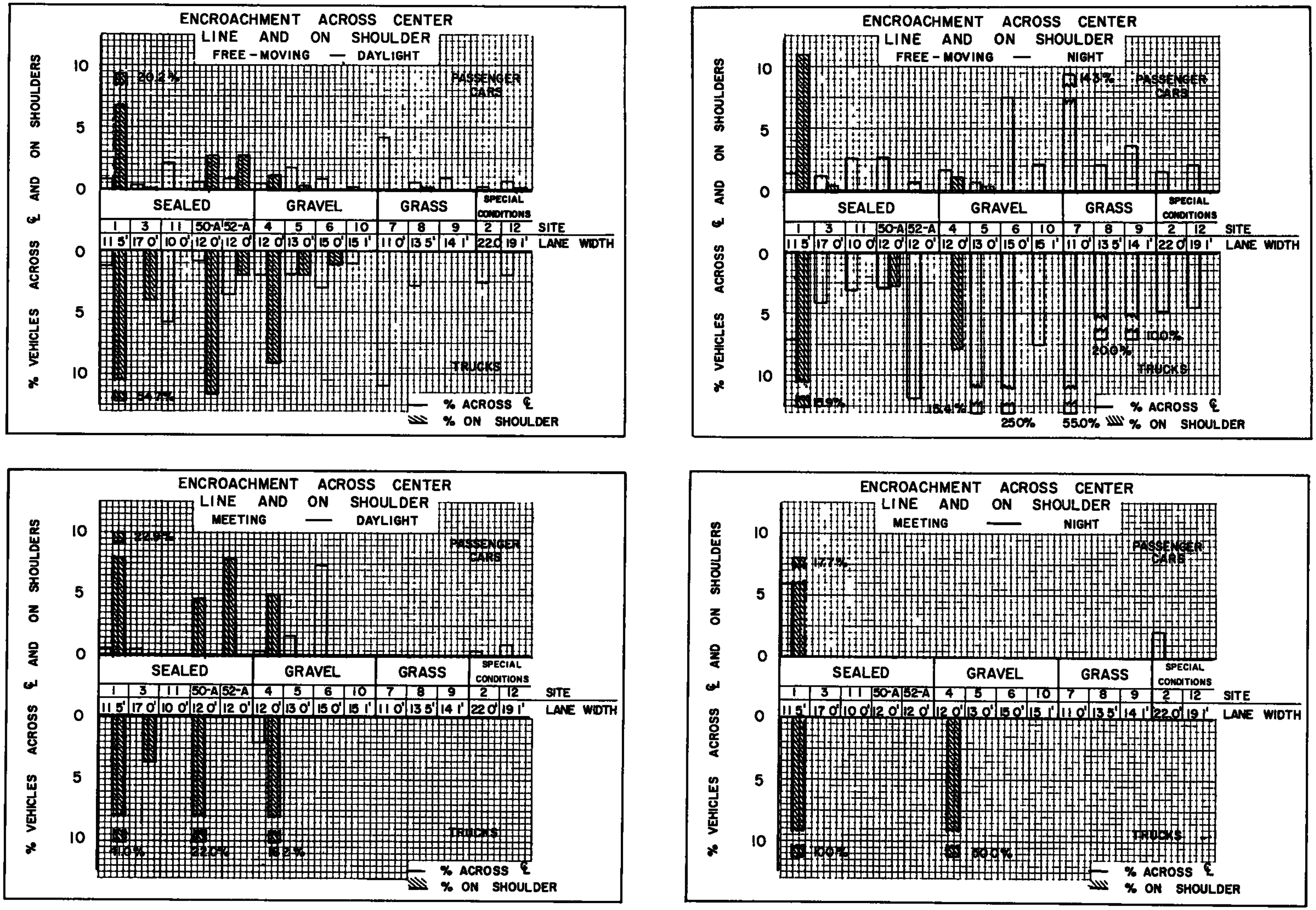
ENCROACHMENT ACROSS CENTER LINE AND ON SHOULDER
FREE-MOVING — DAYLIGHT
FREE-MOVING — NIGHT
MEETING — DAYLIGHT
MEETING — NIGHT
% VEHICLES ACROSS ℄ AND ON SHOULDERS
PASSENGER CARS
TRUCKS
SEALED
GRAVEL
GRASS
SPECIAL CONDITIONS
SITE
LANE WIDTH
1 3 11 50-A 52-A 4 5 6 10 7 8 9 2 12
11 5' 17 0' 10 0' 12 0' 12 0' 12 0' 13 0' 15 0' 15 1' 11 0' 13 5' 14 1' 22 0' 19 1'
% ACROSS ℄
% ON SHOULDER

Figure 10.

are the most representative, for the various types of shoulder, is shown. As the type of shoulder is improved, traffic drives closer to it. Gravel shoulders encourage traffic to travel closer to the edge than do grass, and surfaced shoulders have an even greater effect. All placements for grass shoulders lie closer to the centerline of the road than to the edge. A vehicle is centered in an 11-ft lane with gravel shoulders and is centered in a 13-ft lane with a surfaced shoulder.

Lane Width

The relationship between lane width and vehicle placement is shown in Figures 5, 6, and 7. These are average curves taken from the original plottings (2). The figures

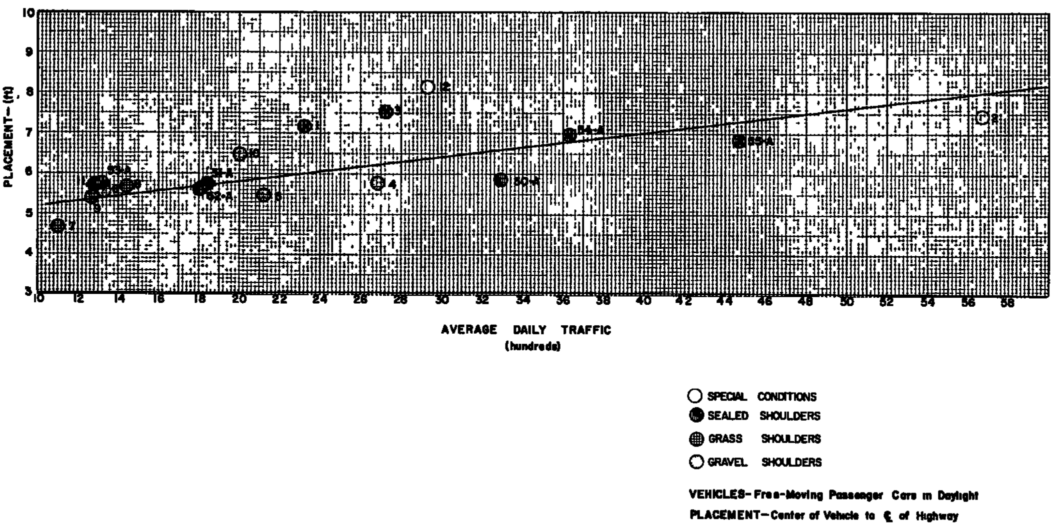

Figure 11.

show, by the shape of the data lines, that as the pavement is widened the vehicles move out, but for each foot added to the lane, vehicles move an average of 3 in. from the centerline and 9 in. from the edge of the pavement or in a ratio of about 1 to 3. All indications are that no matter how much the pavement is widened, the vehicles would continue to move out, staying somewhere near the center of the lane. This can undoubtedly be carried too far both economically and from a safety standpoint. Figure 8 shows the accident rates[1] for 2-lane pavements of various widths. The rates indicate a definite decrease up to a 23-ft pavement. Between 23 and 29 ft, they are somewhat erratic and start back up for pavement wider than 29 ft. This would indicate that the safest lane width is somewhere between 11.5 and 14.5 ft. None of these factors is conclusive in itself, but together they make a rather strong case for a 13-ft lane with 8-ft surfaced shoulders. Figure 9 shows the typical placement range for this type pavement. Adequate clearance between meeting vehicles is provided for both passenger cars and trucks;

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[1]Rates were compiled by the Traffic Engineering Section of the Division of Maintenance Operations and included all 2-lane roads in Texas for 1955.

the lane width falls in that range found to have the lowest accident rate and the vehicles tend to center themselves in the lane, thereby making full use of the available facility.

If surfaced shoulders are to function as a shoulder and are not to be considered by the motorist as a part of a very wide lane, a good contrast of color and width should be maintained between the shoulder and the lane. The surfaced shoulder should also have sufficient slope to render it uncomfortable to use as a driving lane but still safe for emergency use. It is believed that a slope of $^3/_4$ in. per ft would accomplish this result.

Encroachment Across Centerline and on Shoulder

Considerable encroachment on both the shoulder and across the centerline was found. The percentage at the various sites is shown in Figure 10. Several attempts were made to correlate this data, but no consistent relationship was found. Several things are evident from the figures. Encroachment by meeting vehicles on both the shoulder and across the centerline is less than that for free-moving vehicles and is less at night than in the daylight. This could probably be taken to indicate that drivers are more alert when meeting and are consciously placing their vehicle in the lane. Figures 5, 6, and 7 show that meeting vehicles drive on an average 1 ft closer to the edge than do non-meeting vehicles.

The percentage of encroachment on the shoulder was considerably higher where shoulders were surfaced. This is to be expected, especially since some of the surfaced shoulders studied did not contrast greatly with the pavement on the travel lane, and drivers could see little reason for not driving on them when it suited their purpose. Figure 11 shows the average placement for free-moving passenger cars for each of the sites studied plotted against traffic volume. It indicates a definite trend to a placement nearer the edge of the pavement as volume increases. This was true regardless of lane width, shoulder width, and shoulder type.

Encroachment can undoubtedly be reduced by making the shoulder less attractive to drive on by providing distinct contrast in both color and texture; however, from Figure 11, it seems probable that an overloaded condition on the road will result in encroachment regardless of the contrast and that 4-lane operation will nearly always result where the shoulder is surfaced and traffic volumes are great enough that they cannot be efficiently accommodated on a 2-lane road.

Trucks

A considerable number of trucks were included in the study (Table 1). These data were somewhat more erratic than for passenger cars, but the general trend was very similar to that for passenger cars. Trucks appeared to drive a little closer to the edge of the pavement, especially on extra wide pavements, probably because they try to stay out of the way of faster moving vehicles.

SUMMARY

1. Speed was apparently not a factor in the elements studied.

2. Drivers are apparently influenced in their lateral placement more by the edge of the pavement than they are by the centerline of the road.

3. Should width of 3 ft or more did not appear to affect the lateral placement of vehicles.

4. The type of shoulder had a definite effect on the lateral placement of vehicles. The higher the quality of construction, the closer to the shoulder traffic will drive.

5. Lateral placement appears to be a function of lane width. As lane width increases traffic moves farther from the centerline but in a ratio of about 3 to 1. For every foot of widening, the average placement moved 3 in. from the centerline and 9 in. from the edge of the lane.

6. Vehicle encroachment across the centerline and on the shoulder is a definite problem. Encroachment on surfaced shoulders can be reduced considerably by providing good contrast between the pavement and the shoulder, but even this will not prevent encroachment if the road is overloaded.

7. Trucks behaved about the same as passenger cars. Their over-all average placement was a little closer to the edge of the pavement but with their greater width there was slightly less clearance to the centerline.

8. Encroachment on surfaced shoulders by trucks was very evident. This is probably brought about by a desire on the part of truckers to not obstruct traffic. They seem to drive on the shoulder so that faster passenger cars can get by them. This might be combatted by an informational campaign and by designing the shoulder so it does not appear to be a traffic lane.

9. There was not enough data on passing maneuvers to arrive at any definite conclusions in this study. Speed curves are therefore not included in this report.

Part 2: Two-Lane Rural Bridges

The general objective of this study was to determine the effect of the width of 2-lane roadway bridges on the lateral placement of vehicles as compared with the lateral placement on a 2-lane road. The lateral placement near the end and near the middle of a long bridge was also measured to determine whether or not the vehicles moved laterally while driving across a long bridge.

It was hoped through this study of traffic behavior to find some indication as to what the proper width for 2-lane roadway bridges should be.

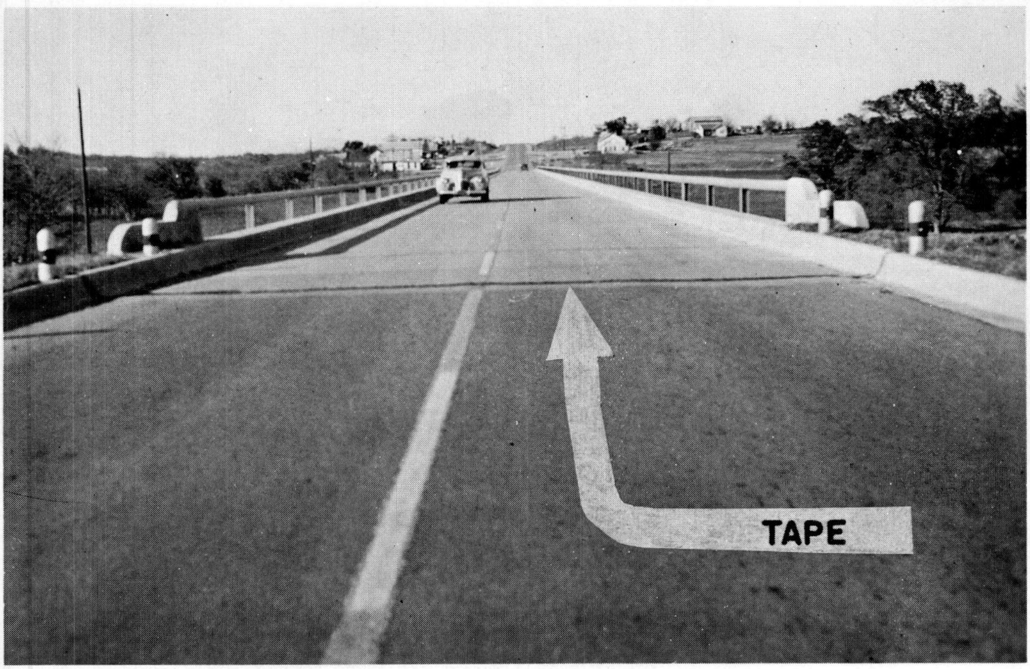


Figure 12. View of bridge showing tape for measuring lateral placement.

METHOD OF STUDY

The method of study was the same as that described previously, but with some additions.

Vehicles were classified into 10 types but samples in some types were small and operating characteristics were similar. For analysis only two classifications were

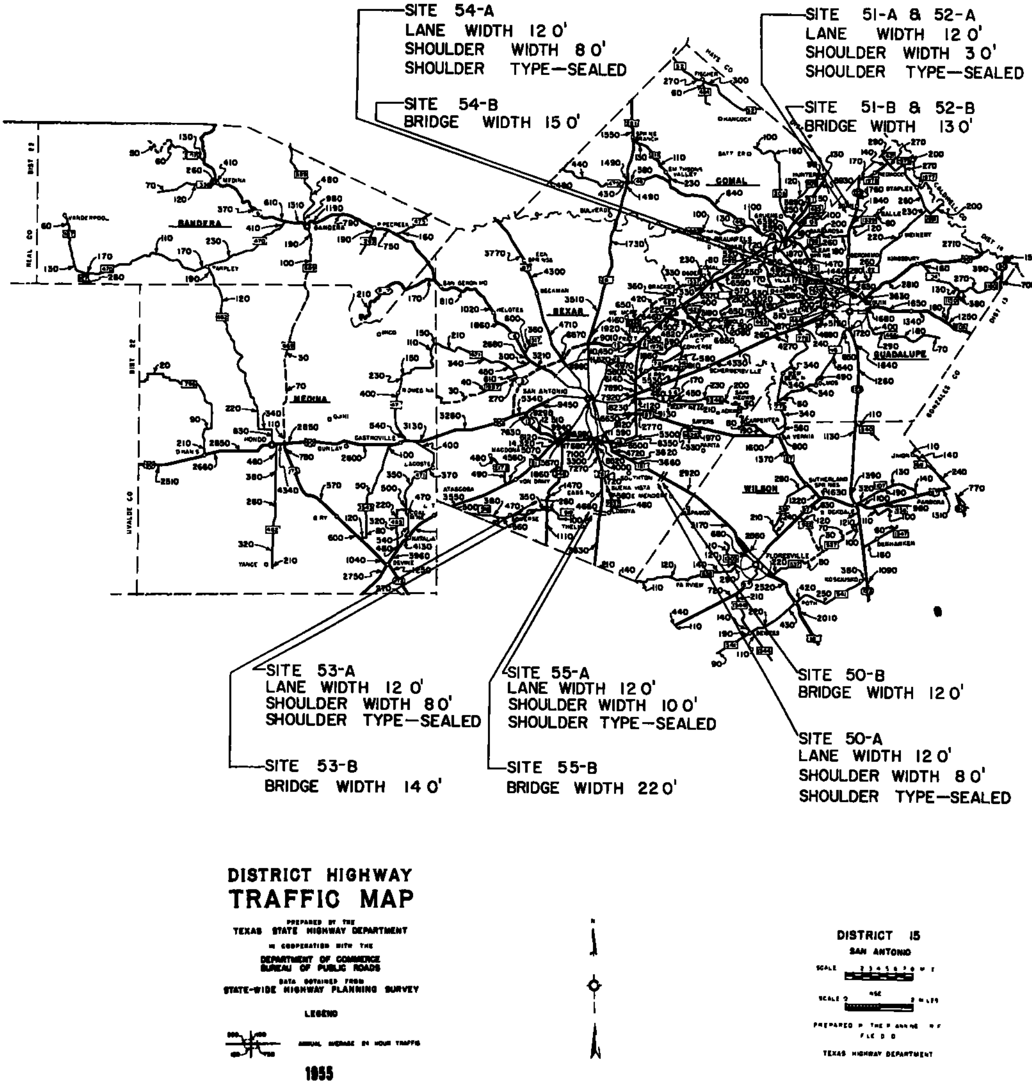


Figure 13. Road and bridge site locations.

used. One included passenger cars and pick-ups, and the other included buses and all trucks.

In addition to the meeting and free-moving maneuvers, the data were recorded for passing and trailing and all combinations thereof, but samples in these categories were small for analysis.

The following classifications of vehicle maneuvers were made:

Free-moving	- Over 7.2 sec to nearest vehicle both directions.
Trailing	- Less than 3.6 sec to next vehicle ahead traveling same direction, and over 7.2 sec to next vehicle ahead traveling opposite direction.
Meeting	- Less than 3.6 sec to next vehicle ahead traveling opposite directio
Passing	- 1.8 sec or less behind or ahead of car being passed.
Being Passed	- 1.8 sec or less behind or ahead of car passing.
All others.	

TABLE 2

CHARACTERISTICS OF ROADWAY AND BRIDGES AT SITES 50-A THROUGH 55-B

Site No	50-A	50-B Bridge	51-A	51-B Bridge	52-A	52-B Bridge	53-A	53-B Bridge	54-A	54-B Bridge	55-A	55-B Bridge
Bridge Width (ft)		12 0		13 0		13 0		14 0		15 0		22 0
Bridge Length (ft)		360 0		960 0		960 0		201 5		200 0		156 0
Lane Width (ft)	12 0		12 0		12 0		12 0		12 0		12 0	
Shoulder Width (ft)	8 0		3 0		3 0		8 0		8 0		10 0	
Shoulder Contrast (All Sealed)	Good		Fair		Fair		Good		Fair		Good	
Total Vehicles Counted	2,031	1,774	1,071	1,103	1,148	1,144	1,067	1,318	3,556	2,873	2,630	2,161
Percent Passenger Cars	82 2	83 7	79 3	79 2	78 3	79 1	80 6	83 4	84 1	85 7	77 1	80 3
Percent Trucks	15 7	14 7	16 1	16 5	17 4	16 7	18 6	15 7	14 2	12 5	20 8	18 2
Percent Buses	0 7	0 6	1 3	1 4	2 2	2 2	0 5	0 4	0 4	0 4	0 8	0 6
Percent Others	1 4	1 0	3 3	2 9	2 1	2 0	0 3	0 5	1 3	1 4	1 3	0 9
Night Vehicles Counted	224	222	153	170	195	201	140	194	776	601	414	430
Percent Passenger Cars	78 6	78 8	69 9	71 8	76 9	77 1	90 7	93 8	88 7	85 7	67 6	70 2
Percent Trucks	19 6	19 8	24 8	23 5	20 0	19 9	8 6	6 2	10 6	13 5	30 7	28 6
Percent Buses	0 9	0 5	2 0	2 4	1 0	1 0	0 0	0 0	0 2	0 3	0 7	0 5
Percent Others	0 9	0 9	3 3	2 3	2 1	2 0	0 7	0 0	0 5	0 5	1 0	0 7
1955 Average Daily Traffic	3,290	3,290	1,840	1,840	1,840	1,840	1,350	1,350	3,630	3,630	4,500	4,500
County	Bexar	Bexar	Guadalupe	Guadalupe	Guadalupe	Guadalupe	Bexar	Bexar	Guadalupe	Guadalupe	Bexar	Bexar
Highway No	US 181	US 181	SH 123	SH 123	SH 123	SH 123	SH 346	SH 346	US 90	US 90	US 281	US 281
Control and Section	100-2	100-2	366-2	366-2	366-2	366-2	613-1	613-1	29-2	29-2	73-2	73-2
Location	Approx 850' NW of Bridge 50-B	4 mi NW of Wilson C L	1 4 mi S of Bridge 51-B	4 0 mi S of Hays C L	1 4 mi S of Bridge 52-B	4 0 mi S of Hays C L	Approx 1 mi S of Bridge 53-B	4 8 mi N of Atascosa C L	8 mi W of Bridge 54-B	2 0 mi E of S H 123	3 mi S of Bridge 55-B	7 8 mi S of Loop 13

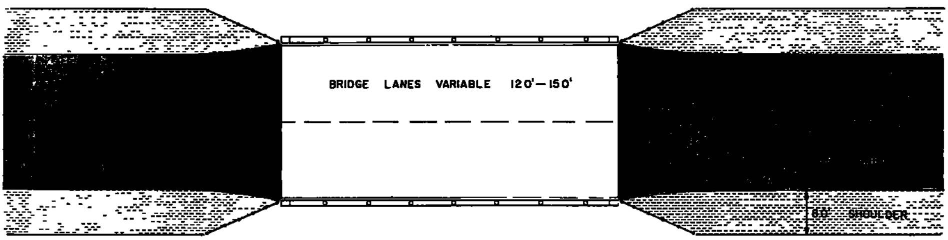


Figure 14. Typical bridge showing fixed and variable conditions.

DESCRIPTION OF SITES

The study was conducted on bridges in Highway Department District 15 with headquarters at San Antonio. The locations of the study sites are shown in Figure 13 and a tabulation of data for each of the sites is shown in Table 2. In each case, the location on the bridge is designated with a B, and the road site near the bridge is designated with an A. Complete data for each site have been published previously (7).

As far as possible, all of the bridges studied were similar in appearance as far as the driver was concerned. Rail and curb designs were substantially the same. The bridges varied in length from 156 ft to 360 ft plus the 960 ft bridge.

To make the bridge placement measurements valid, it was felt that the design of the roadway on either side of the bridges should be held constant (Fig. 14). The roadway in each case consisted of two 12-ft lanes with surfaced shoulders. At three of the six sites studied, the road shoulders were 8 ft wide, at sites 51 and 52 the shoulders were 3 ft wide, and at site 55 they were 10 ft wide. It was determined previously that shoulders 3 ft wide and wider did not affect the lateral placement of vehicles; therefore, it was felt that the inclusion of these sites was valid. Sites 51 and 55 were, however, eliminated from the final analysis for other reasons. The roadway locations at sites 51 and 52, because they were actually at the same place, could not be considered as two locations in a statistical analysis. These were made in conjunction with the bridge sites near the middle and near the end of this 960-ft bridge. Site 51 was therefore omitted.

Site 55 was located on a highway carrying 4,500 vehicles per day, which would require a 4-lane facility by highway department standards and it was felt that vehicle placement measurements under these conditions would not be comparable to those at the other sites, particularly since there is a farily definite relationship between volume and lateral placement. Rain during a part of the study at this site probably also had some influence on the data. Another factor at site 55 making the data here somewhat doubtful was the fact that the pavement was flared to the width of the bridge for about 200 ft on either side of the bridge.

Four sites were included in the actual analysis, each having comparable characteristics. Bridge lane widths measured from the centerline of the bridge to the edge of the traveled surface were 12 ft, 13 ft, 14 ft, and 15 ft. The analysis is then actually based on the following sites:

Site 50 bridge lane width 12 ft;
Site 52 bridge lane width 13 ft;
Site 53 bridge lane width 14 ft;
Site 54 bridge lane width 15 ft.

Sites 51 and 52 which were on the same bridge were to determine whether or not a consistent placement existed over the length of a long bridge. This bridge was 960 ft long. Site 51 was near the middle of the bridge and Site 52 was near the end. No significant difference in the placement was found.

DISCUSSION AND ANALYSIS

Speed

Speed studies were made at each of the road sites. Speeds were not measured on the bridges. Cumulative speed curves showing the 85 percentile speed at each of the road sites were plotted (7). There does not appear to be a significant correlation between speed and the factors studied.

Lateral Placement

Lateral placement of vehicles was measured at each of the sites, both on the road and on the bridges. The studies on the road were made far enough from the bridges so

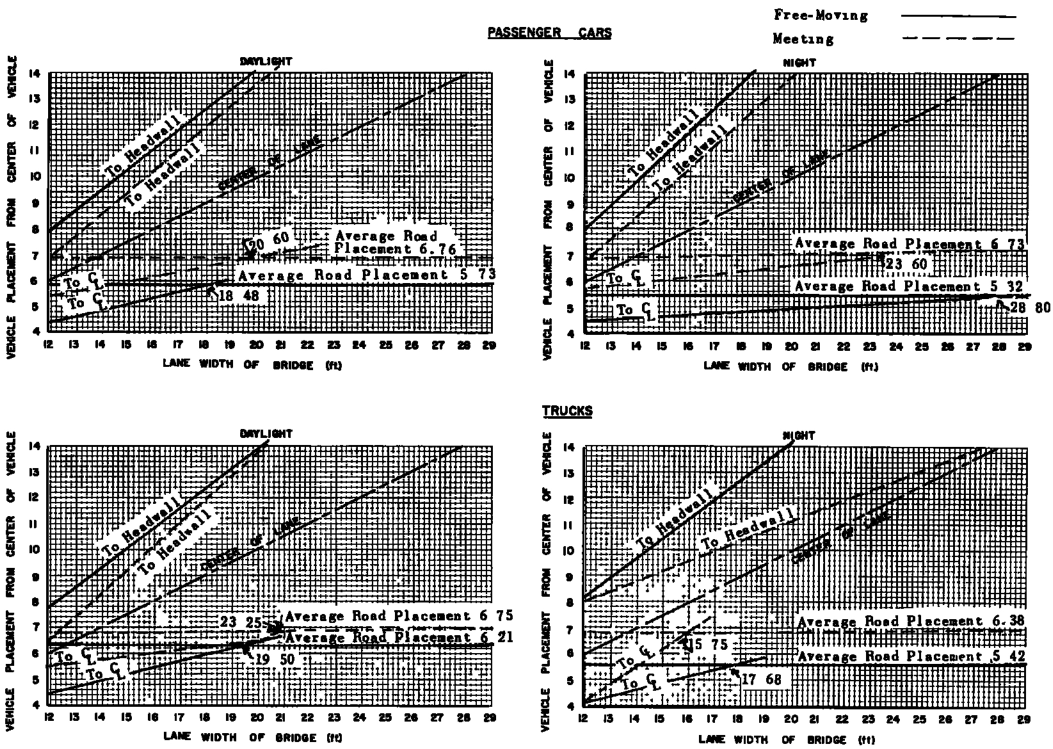


Figure 15. Placement of vehicles on bridges vs. bridge lane width.

that the bridge did not influence placement. The minimum distance from the road site to the bridge was 850 ft.

The basic data from which the conclusions were extracted were a series of bar charts representing the vehicle placements at the sites (7).

In attempting to relate placement data to a basis for the determination of a bridge width several approaches were tried. Walker (8) developed a formula by which he computed a bridge width. It consisted of the sum of the following three items:

TABLE 3

BRIDGE LANE WIDTHS FOR VARIOUS CONDITIONS

	Passenger Cars	Trucks
Free-Moving - Daylight	18.48	19.50
Free-Moving - Night	28.80	17.68
Meeting - Daylight	20.60	23.25
Meeting - Night	23.60	15.75
Average Daylight	20.45	
Average Night	21.46	
Average Meeting	20.40	
Average Total	20.95	

1. "The distance of the left wheel to the right of the centerline for vehicles meeting on the tangent section, which is equivalent to one-half the clearance between the left wheels of vehicles when meeting."
2. "The distance freely moving vehicles preferred to allow between their right wheels and the curb or parapet of the bridge."
3. "The tread width of the average car, or approximately 5 feet."

In attempting to apply this formula, it was found that item 2 was not a consistent figure but varied with the width of bridge. For this reason, this approach did not seem applicable.

It was thought, however, that a bridge width which would encourage a vehicle to maintain the same lateral position on the bridge that it occupied on the road would result in the safest operation — that least likely to result in accidents. This would mean that the driver would be only slightly aware of the presence of a bridge and would not feel that it was necessary to take any action because of the bridge.

In order to establish what this bridge width would be, it was first necessary to establish the average position of vehicles on the road for the various light conditions and maneuvers which could not be kept constant. These averages are represented by the horizontal lines in Figure 15. They were derived by averaging the placement figures for the road sites near the bridges. They do not agree exactly with the results of Part 1, but are within reasonable range. These placement figures were measured to the centerline of the road or bridge.

Vehicle placement figures for the various bridges were also plotted on Figure 15. The plotting of these data with reference to the centerline of the bridge produces a line which when extended intersects the horizontal or average road placement line. This point of intersection then represents the width of bridge lane necessary for the average vehicle to pass over it without altering its lateral placement with respect to the centerline. These intersection points vary for the different conditions. Based on this approach to bridge width determination, Table 3 shows the widths required for the various conditions. However, these widths were derived from data on 12- to 15-ft bridge lanes. It is possible that rather than a straight line, as assumed in Figure 15, the bridge placement data would curve up and intersect the road placement line at some lesser bridge width. Absence of data on bridge lane widths wider than 15 ft places some doubt on how the bridge placement data would behave in this area. Studies on wider bridges would tie the placement down more accurately but in the absence of this information, it was thought that the straight line expansion of the known data was reasonable.

The required widths vary from a low of 15.75 ft for trucks meeting at night to a high of 28.80 ft for free-moving cars at night. The average bridge lane width for all of the conditions was 20.95 ft.

It might be considered proper in a situation of this kind to design for the extreme condition which would mean a bridge lane width of 28.80 ft or a total bridge width of 57.60 ft. However, the 28.80 lane is for free-moving cars at night. Free-moving trucks at night require a width of only 17.68 ft indicating that the passenger car drivers are probably allowing an unnecessarily large clearance to the bridge headwall.

Meeting vehicles probably represent the most realistic condition on which to base a conclusion. It is somewhat surprising that this does not call for the widest bridge. It does seem significant, however, that all of the various averages shown in Table 3 are in the vicinity of 20 ft.

Figure 15 also shows the placement of vehicles to the bridge headwall and how it varies with the width of the bridge. The lines representing the placement distance to the bridge headwall are much steeper than those representing the placement to the centerline, with the ratio between the two being as great as 19 to 1 for free-moving passenger cars at night. The least ratio is 1 to 1 for meeting trucks at night, and the average is approximately 6 to 1.

The use of placement data as a basis for determining bridge widths is at best a substitute for adequate accident data. It can be considered indicative of desirable conditions, however, and in the absence of a sufficiently long and detailed accident survey, it appears to be the most reasonable basis available for studying bridge widths.

CONCLUSIONS

The conclusions are somewhat general and lend themselves to discussion rather than numerical listing. The purpose of the study was to determine the effect of bridge width on traffic behavior. It was established that the bridge width has a definite influence on lateral placement of vehicles. It was not possible to arrive at a definite recommendation for widths of 2-lane highway bridges but the data do indicate that a bridge lane width 2 ft wider than the road lane adjacent to the bridge causes the average driver to deviate considerably from the lateral position he assumes on the roadway.

It appears that the average driver needs a bridge lane width of about 20 ft in order to cross the bridge with little or no deviation in lateral position from that assumed on the approach roadway. Negligible difference was found in the lateral placement measured near the middle of a 960-ft bridge and near the end of the same bridge.

Part 3: Freeway Bridge

The purpose of this study was to determine the effect on traffic behavior of a vehicle stopped on the 6-ft shoulder of a 2-lane one-way freeway overpass. In the course of the study, however, it became evident that the data being collected were adaptable to further analysis dealing with the general operating characteristics of traffic. The speed and lateral placement of vehicles under various traffic volume conditions are indicative of the adequacy of the design with respect to horizontal clearances, lane width, and shoulder width.

The conditions without and with vehicle on 6-ft emergency shoulder are shown in Figures 16 and 17.

CLASSIFICATIONS

The following classifications of vehicle maneuvers were made:

Passing - 1.8 sec or less behind or ahead of car being passed. Passing vehicles are always in the left lane.

Being Passed - 1.8 sec or less behind or ahead of car passing. Being-passed vehicles are always in the right lane.

Non-Passing - Includes all vehicles in either lane not included in the two classifications above.

LOCATION AND DESCRIPTION OF SITE

The study was conducted on the westbound lanes of State Highway 550 Freeway Bridge crossing over Camp Bowie Boulevard in Fort Worth. The over-all site is shown in Figure 18. The location of the study is shown in Figure 19.

The freeway bridge roadway is 24 ft wide with standard guardrail, plus a 6-ft emer-

Figure 16. Site 25 — shoulder clear.

gency shoulder on the right and a $3\frac{1}{2}$-ft shoulder on the left (Fig. 20). The roadway at the point of the study is on a 2 deg curve to the right.

The freeway at this point carries a considerable amount of traffic bound for the Convair Aircraft Plant and Carswell Air Force Base, which causes a high peak interval for a relatively short duration. The average daily traffic at this point for the one-way 2-lane bridge is 15,760 vehicles, while the highest hour studied was 1,414 vehicles. A 5-min volume counted during the peak interval, which lasted about 20 min, resulted in an hourly volume of 2,484 vehicles when expanded.

DISCUSSION

The study was conducted from 7:00 a.m. to 12:00 midnight on March 19, 1956 and March 20, 1956. On the first day the 6-ft shoulder was clear (Fig. 16). On the second

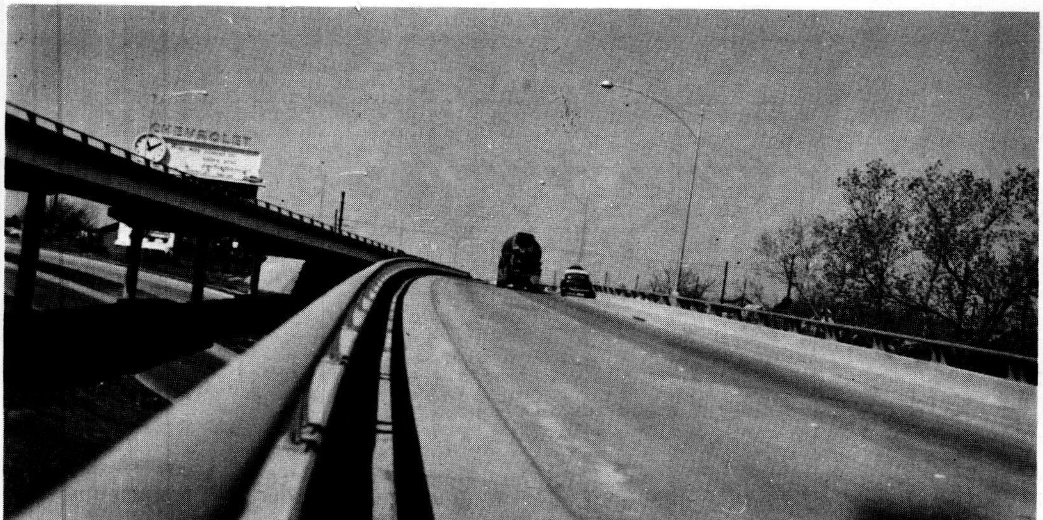


Figure 17. Site 26 — Passenger car parked on partial shoulder with hood raised, simulating disabled vehicle.

Figure 18.

TABLE 4

AVERAGE HOURLY TRAFFIC VOLUMES

TIME	VOLUME CONDITION	SITE NO.	PASSENGER VEHICLES LANE 1	PASSENGER VEHICLES LANE 2	COMMERCIAL VEHICLES LANE 1	COMMERCIAL VEHICLES LANE 2	TOTAL VEHICLES LANE 1	TOTAL VEHICLES LANE 2	AVERAGE HOURLY TRAFFIC VOLUME
7:45 A.M.	PEAK EXPANDED FROM 5 MINUTE PEAK INTERVALS	25	1440	1032	—	—	1440	1032	2472
		26	1308	1176	—	—	1308	1176	2484
		AVERAGE	1374	1104	—	—	1374	1104	2478
7 to 8 A.M.	PEAK HOUR	25	892	501	21	—	913	501	1414
		26	827	494	19	1	846	495	1341
		AVERAGE	860	497	20	1	880	498	1378
2 to 6 P.M.	MID-PEAK	25	418	120	6	—	424	120	544
		26	363	158	8	1	371	159	530
		AVERAGE	390	139	7	1	397	140	537
8 A.M. to 2 P.M. 6 to 7 P.M.	NORMAL	25	188	19	10	—	198	19	217
		26	153	41	10	—	163	41	204
		AVERAGE	170	30	10	—	180	30	210
7 to 11:59 P.M.	NIGHT	25	152	16	—	—	152	16	168
		26	118	39	—	—	118	39	157
		AVERAGE	135	28	—	—	135	28	163

ALL FIGURES ARE HOURLY AVERAGES FOR THE TIMES INDICATED.

LANE 1 - RIGHT LANE OR SHOULDER LANE
LANE 2 - LEFT LANE OR MEDIAN LANE

SITES 25 & 26 ARE THE SAME LOCATION
SITE 25 - SHOULDER CLEAR
SITE 26 - VEHICLE ON SHOULDER

day a car, supposedly a disabled vehicle, was stopped on the shoulder with the hood raised (Fig. 17). There was no one visible around the parked car. Speed and lateral placement were studied under both of these conditions.

Because of the similarity of volumes during parts of the time period studied, certain

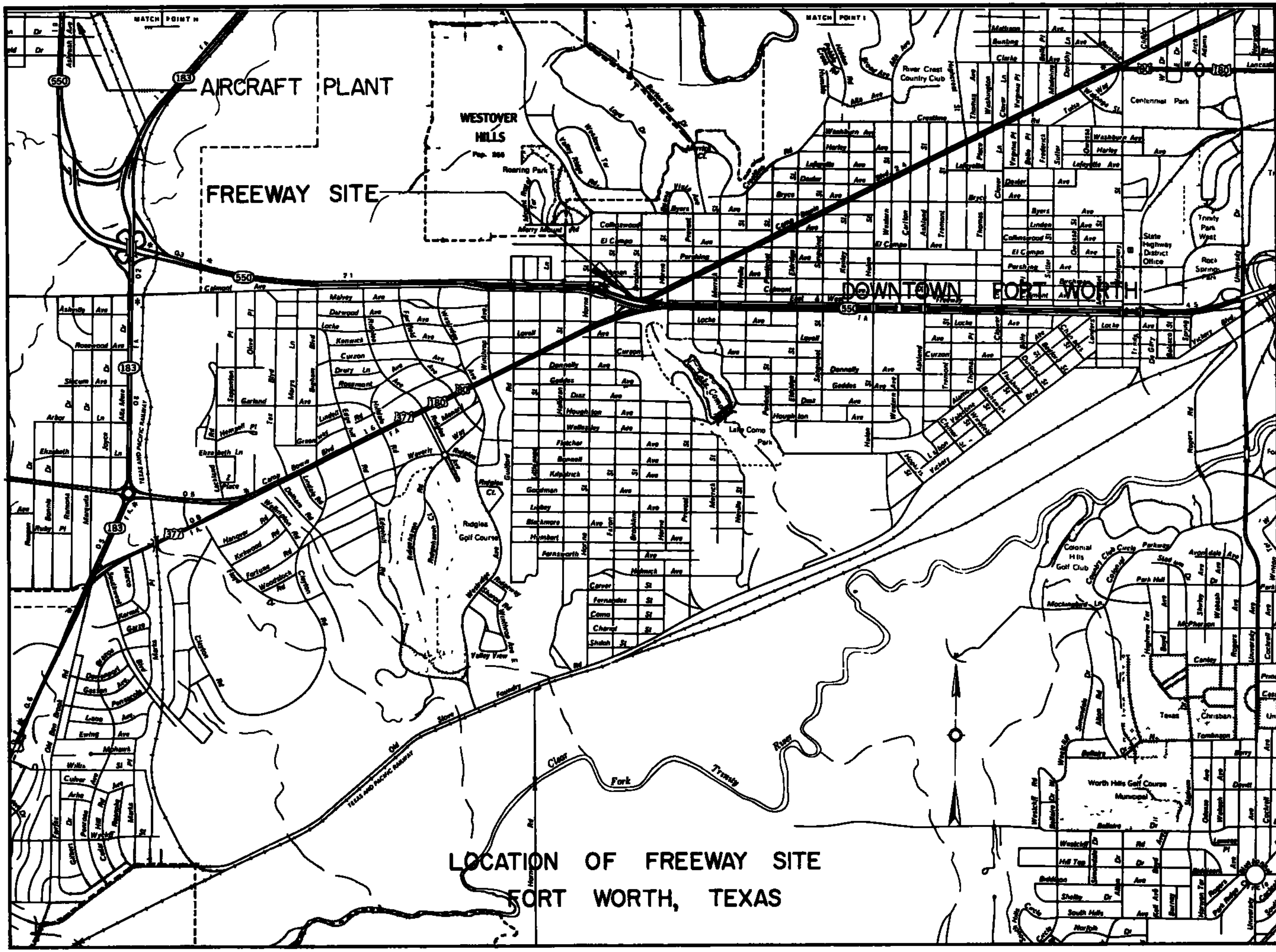

AIRCRAFT PLANT
FREEWAY SITE
WESTOVER HILLS
DOWNTOWN FORT WORTH
River Crest Country Club
Centennial Park
Lake Como Park
Ridglea Golf Course
Colonial Hills Golf Club
Worth Hills Golf Course
Clear Fork Trinity River
TEXAS AND PACIFIC RAILWAY
LOCATION OF FREEWAY SITE
FORT WORTH, TEXAS

Figure 19.

of the hours were grouped together for analysis. This grouping and the averages resulting from the combination of hours are shown in Table 4. For certain figures the data for the peak 5-min period were extracted but the majority include one or more full hours. This 5-min extraction was made to show the operation at near capacity conditio

The number of commercial vehicles observed in this study was too small for accura analysis, and so it has been omitted from all computations except Table 4.

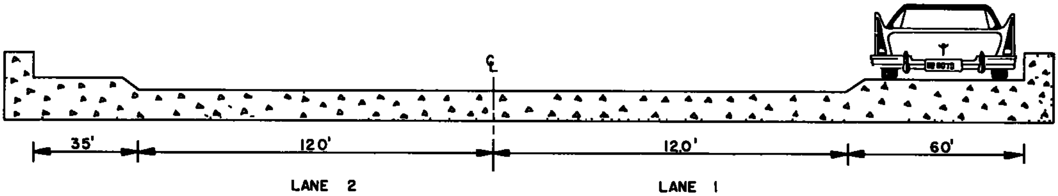


Figure 20. Cross-section of freeway bridge.

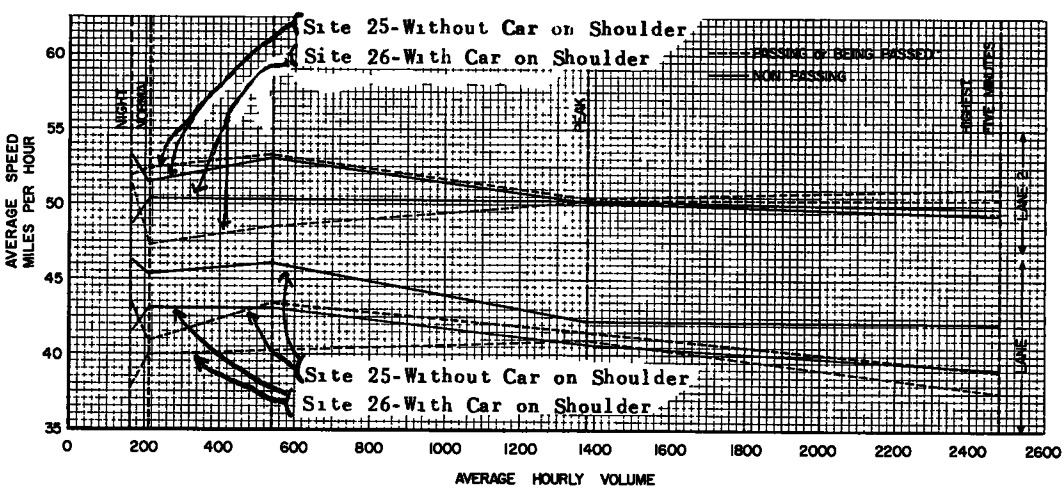
Speed

Cumulative speed curves and the 85 percentile speeds for the various volume conditions and vehicle maneuvers were arranged so that comparisons could be made between the two shoulder conditions. The general effect of the parked car seems to have been to reduce speeds. It was also evident that speeds were lower in the right lane than they were in the left lane (9).

Speed Volume

Figure 21 shows the average speed plotted in relation to the hourly traffic volumes for the two shoulder conditions. Speeds in Lane 1, the right lane, are less than they are in Lane 2. This difference seems to be increased by the presence of the vehicle on the shoulder, as volumes increase. This increased influence is more pronounced for passing and being passed vehicles than for non-passing vehicles, which indicates that a car in the right lane decreases its speed when it is "sandwiched" between a car on the shoulder and a car in the left lane. The effect on speeds by the vehicle on the shoulder is somewhat similar for both lanes for lower volumes, but as volumes increase, the effect on the left lane decreases.

There is a general convering of the speeds at the peak hour, with vehicles in the left lane traveling at a speed of about 50 mph and those in the right lane at about 41 mph. Speeds in the left lane continue to be fairly constant through the peak 5-min volume;



speeds in the right lane tend to decrease and show a wider variation between passing and non-passing vehicles.

Lateral Placement

The lateral placement of the vehicles is shown in Figures 23A and 23B. The distribution of vehicles within the lanes and the percentage are shown by the height of the bars. Each lane is plotted separately so that the percentages in each lane will add up to 100 percent. Volumes are not the same in each lane. Figure 22 shows the lane volume distribution for the various volumes studied. The percentage of the traffic in the right lane decreases steadily as the total volume increases. The effect of the car on the shoulder was to increase the percentage of vehicles in the left lane at all volume conditions, indicating that regardless of the volume some vehicles moved from the right lane to the left lane because of the vehicle on the shoulder.

This movement became less pronounced as volumes increased, partly because it became more difficult to find a gap in the left lane to move into, and partly because vehicles traveling in a more dense stream of traffic did not become aware of the vehicle on the shoulder until after it was too late to take any action.

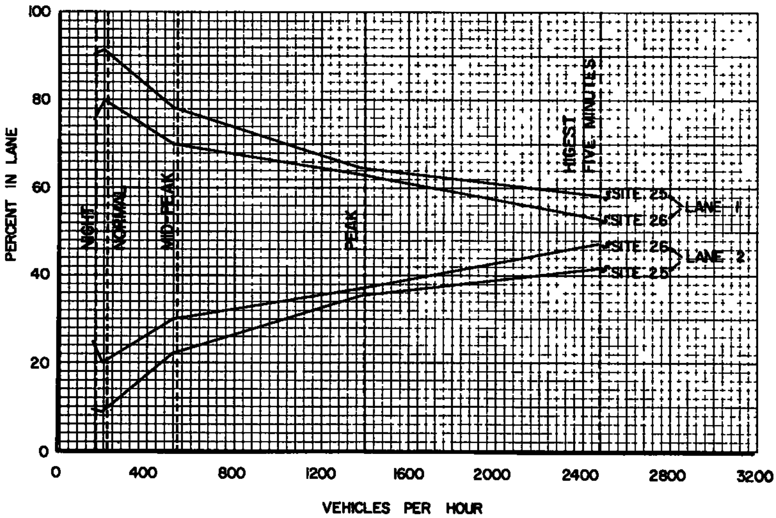


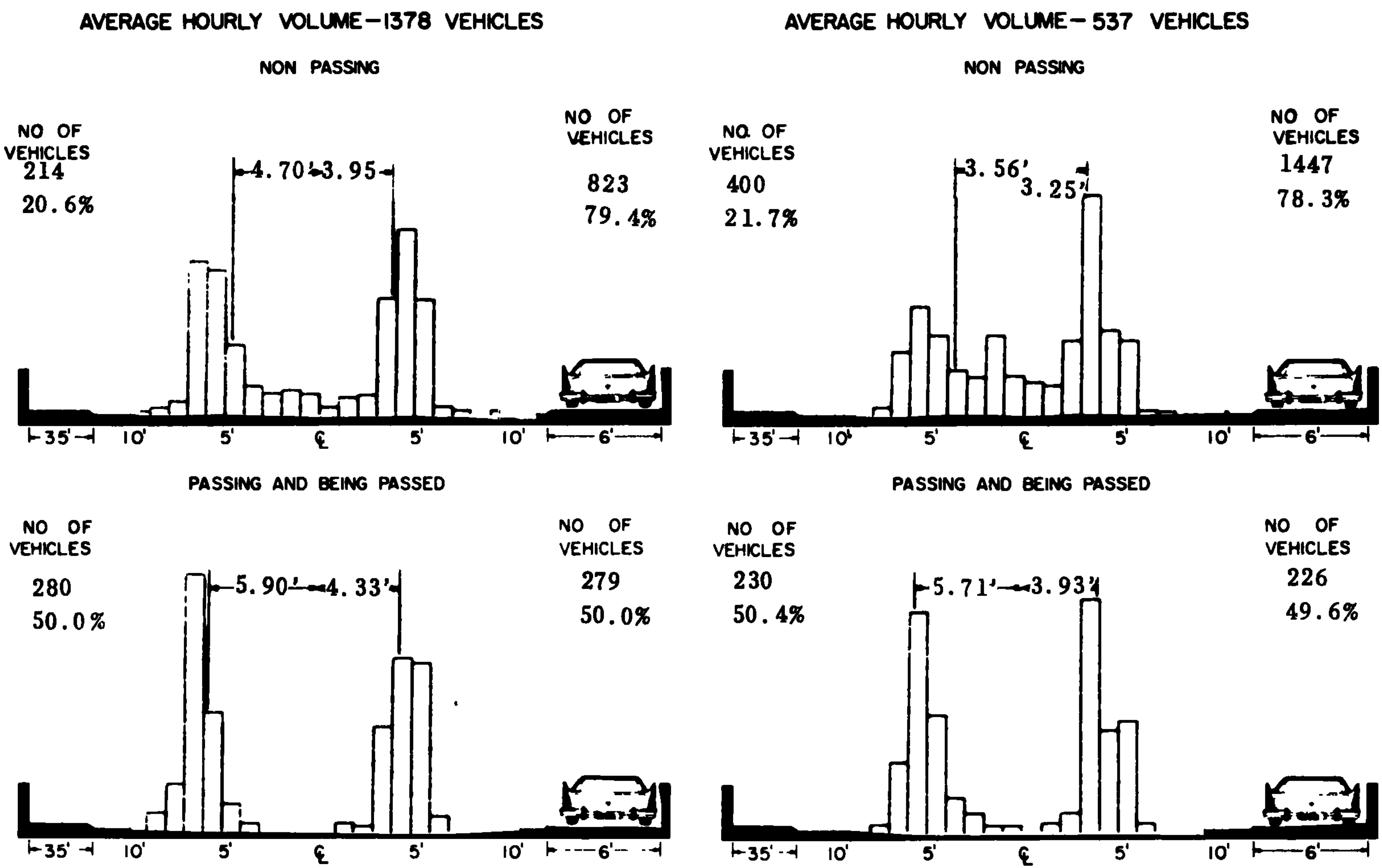
Figure 22. Percent of vehicles in lanes 1 & 2 vs. volume.

Figures 24A and 24B show vehicle placement plotted against traffic volumes and indicate the most conclusive effect of the car on the shoulder. The effect of the vehicle is particularly pronounced in the right lane and at lower volumes. As volumes increase, the effect of the stopped vehicle decreases. For all conditions as volumes increase the vehicle placement moves closer to the center of the lane, and also, for all conditions, the average placement for both the left and right lane lies closer to the center of the lane than to the outer edge of the pavement.

The shape of the curve for the non-passing vehicles in the left lane with the car on the shoulder indicates that, at lower volumes, vehicles were moving from the right lane to the left lane to allow a greater lateral distance to the stopped vehicle. This substantiates Figure 22, which shows a greater percentage of vehicles in the left lane when the car was stopped on the shoulder.

CONCLUSIONS

The vehicle stopped on the 6-ft shoulder did have an effect on traffic, but as traffic volumes increased the effect decreased. Differences in behavior in both speed and lateral placement were detected, with the lateral placement being most noticeably affected.


AVERAGE HOURLY VOLUME—1378 VEHICLES
NON PASSING
NO OF VEHICLES 214 20.6%
4.70' 3.95'
NO OF VEHICLES 823 79.4%
35' 10' 5' ℄ 5' 10' 6'
PASSING AND BEING PASSED
NO OF VEHICLES 280 50.0%
5.90' 4.33'
NO OF VEHICLES 279 50.0%
35' 10' 5' ℄ 5' 10' 6'
AVERAGE HOURLY VOLUME—537 VEHICLES
NON PASSING
NO. OF VEHICLES 400 21.7%
3.56' 3.25'
NO OF VEHICLES 1447 78.3%
35' 10' 5' ℄ 5' 10' 6'
PASSING AND BEING PASSED
NO OF VEHICLES 230 50.4%
5.71' 3.93'
NO OF VEHICLES 226 49.6%
35' 10' 5' ℄ 5' 10' 6'

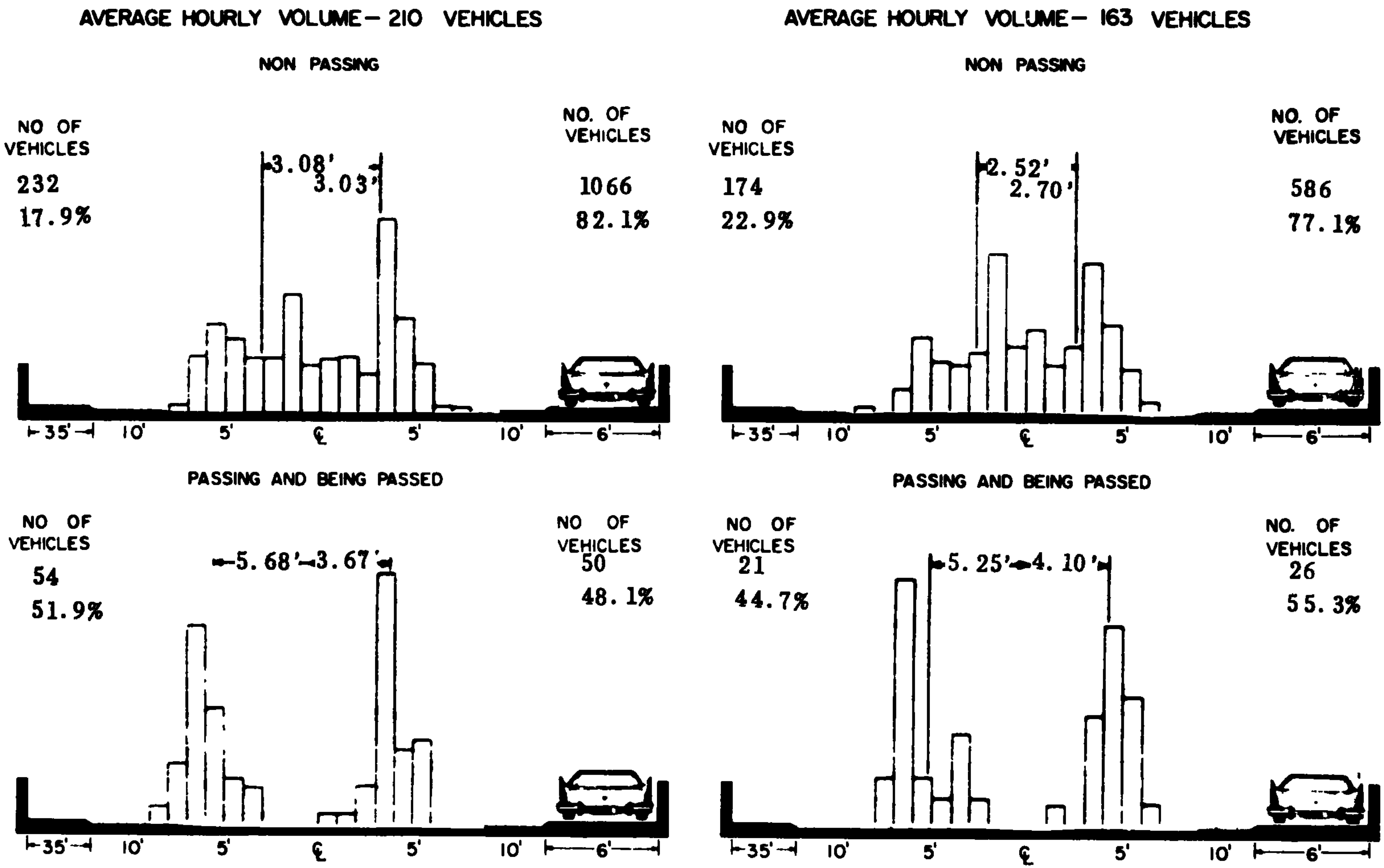
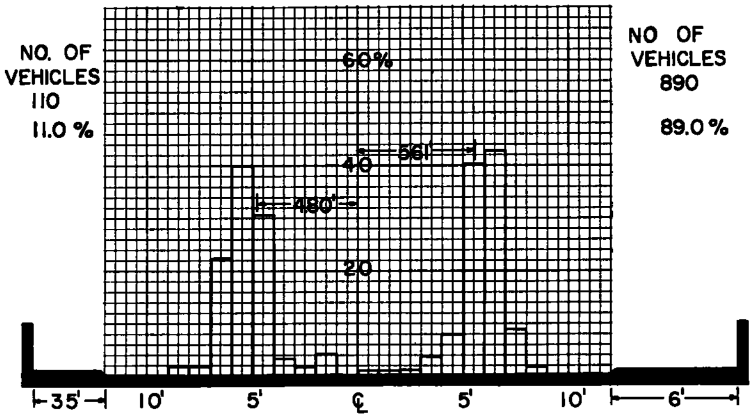


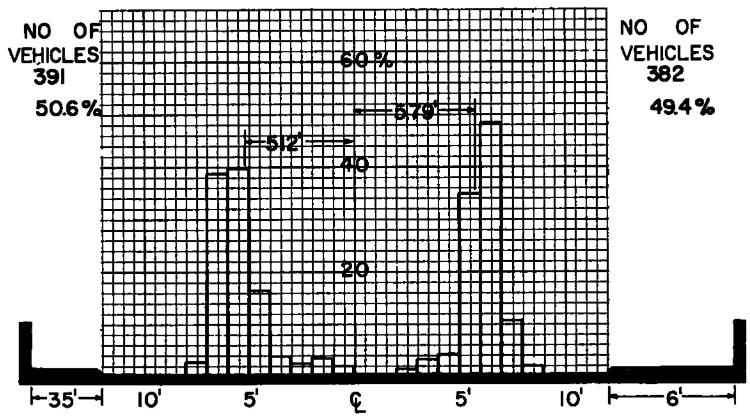
Figure 23A. Lateral placement of vehicles by lane - Site 26 (with vehicle).

AVERAGE HOURLY VOLUME—1378 VEHICLES

NON PASSING

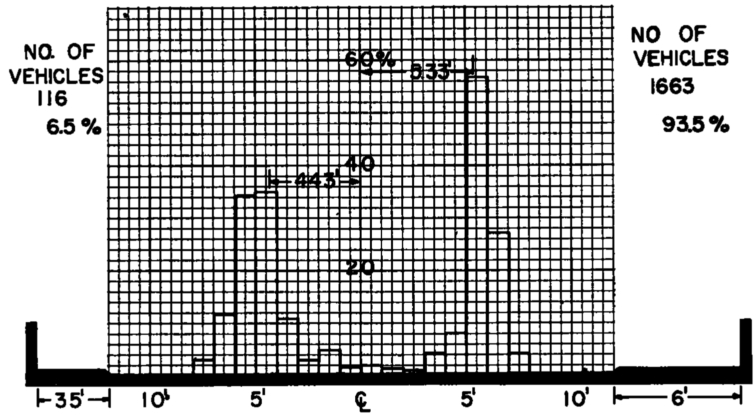


PASSING AND BEING PASSED

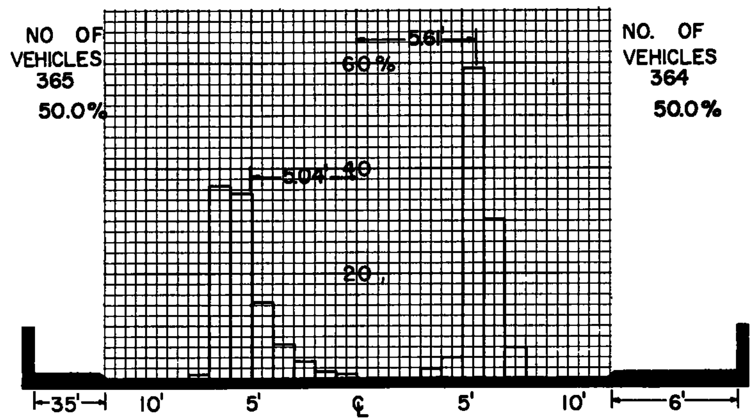


AVERAGE HOURLY VOLUME— 537 VEHICLES

NON PASSING



PASSING AND BEING PASSED



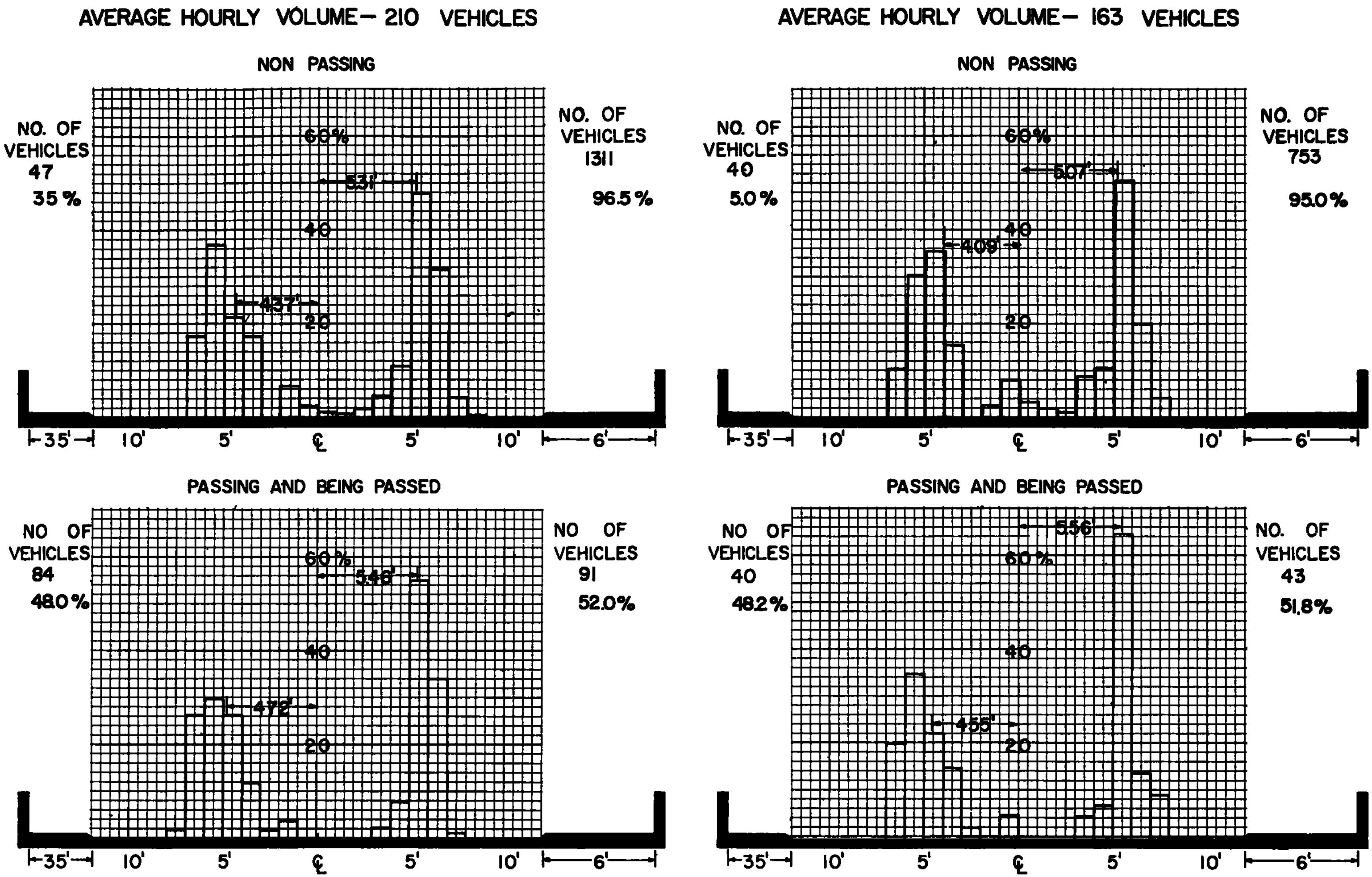


Figure 23B. Lateral placement of vehicles by lane - Site 25 (without vehicle).

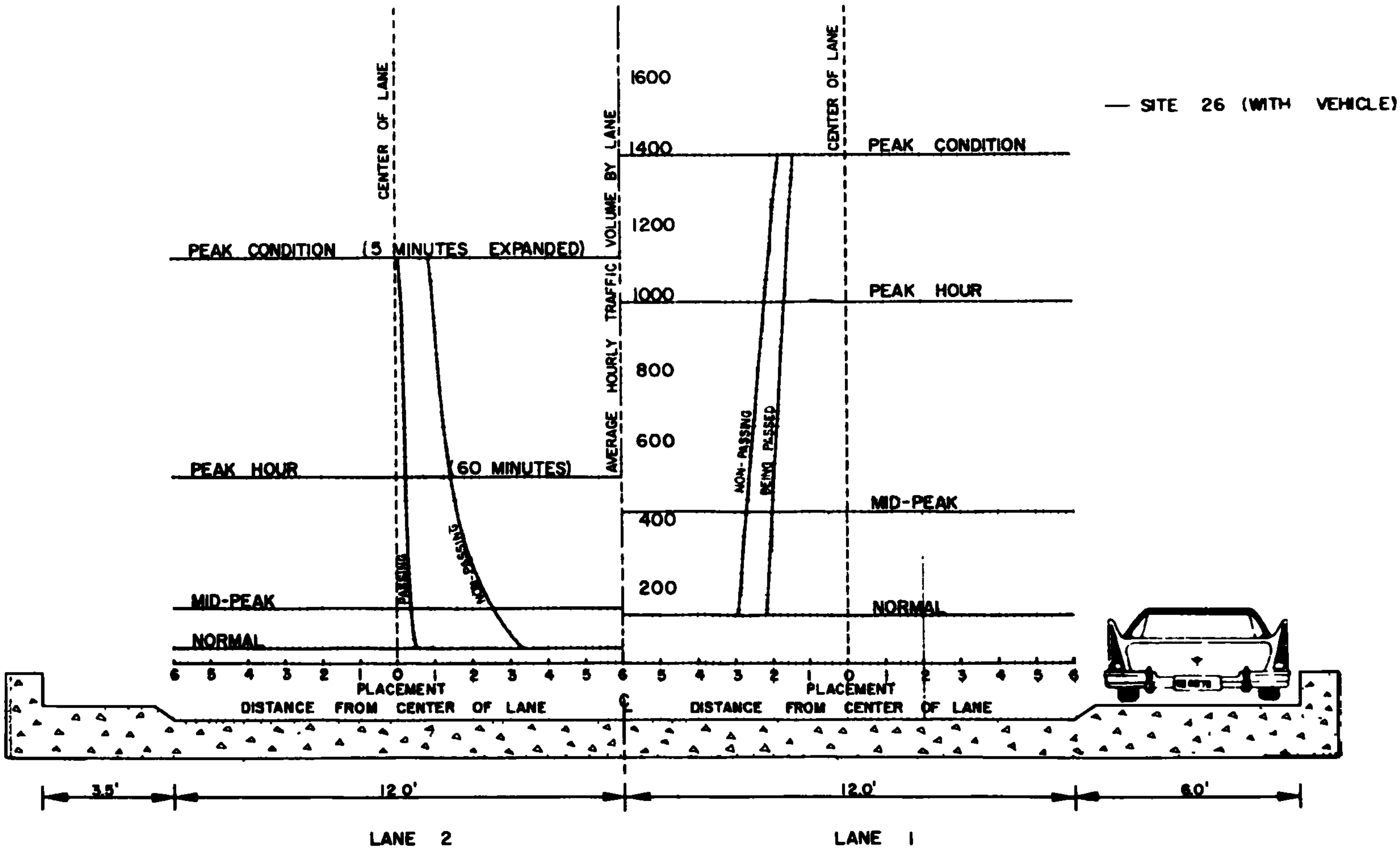


Figure 24A. Placement of vehicles on two-lane freeway bridge in relation to traffic volume with disabled vehicle on six-ft emergency shoulder.

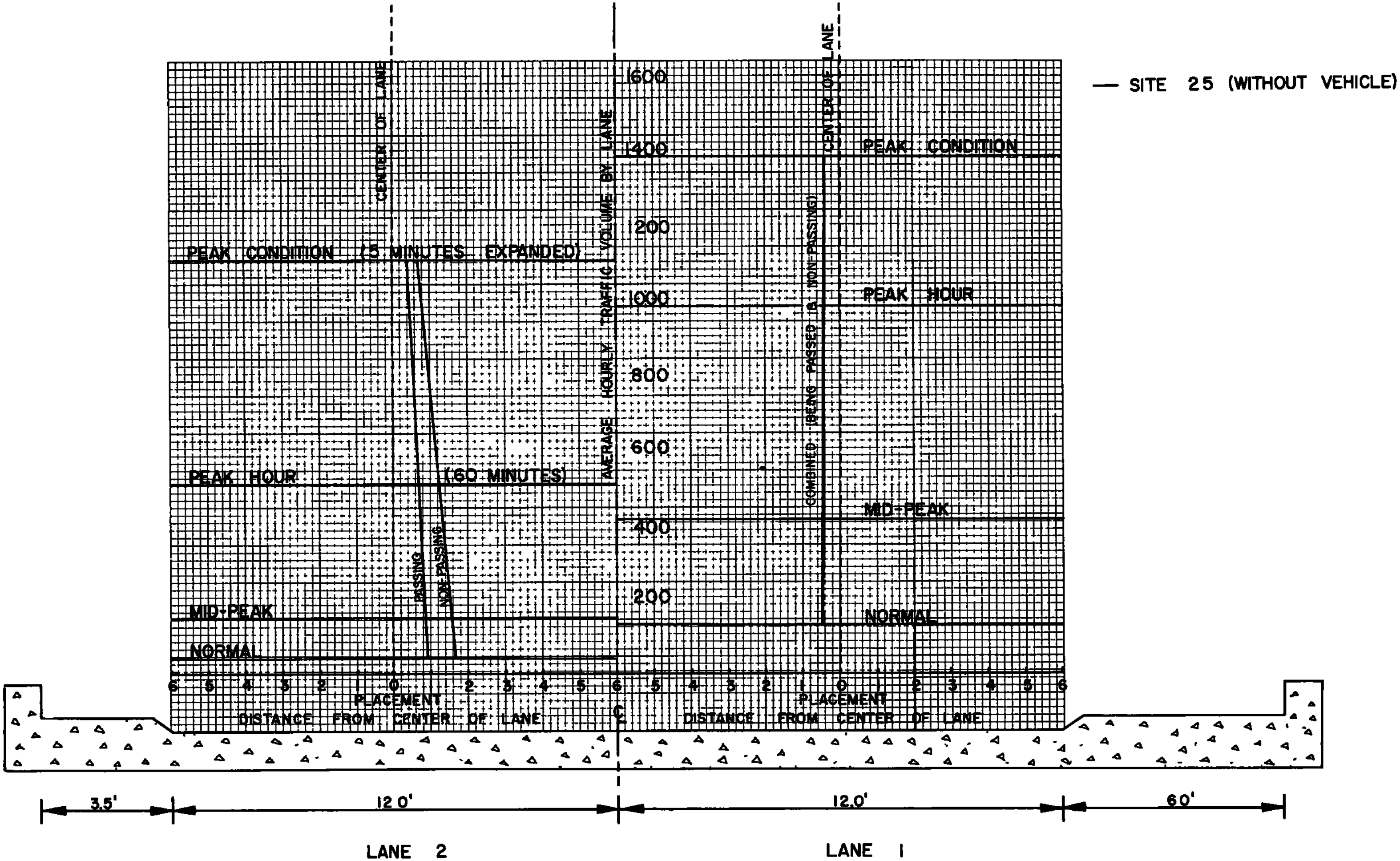


Figure 24B. Placement of vehicles on two-lane freeway bridge in relation to traffic volume without disabled vehicle on six-ft emergency shoulder.

The presence of the vehicle, although it had an influence on traffic, did not seriousl decrease the capacity or noticeably impair the safety of the facility which would indicate that a 6-ft emergency shoulder can accommodate a single stalled vehicle without seriously affecting traffic operation.

The application of the data collected in this study to general freeway operating characteristics is necessarily tied in with the association of these data with those collected at other locations. For this reason, no conclusions have been drawn on this phase of the study. However, the data have been presented in full.

Conditions existing during this study which should be considered in the application of these results are as follows:

1. There was no one visible around the disabled vehicle during the time of the study
2. The disabled vehicle was stopped so close to the bridge rail that it was impossible to open the right door; and
3. The percentage of trucks at this particular location was small, amounting to less than one percent of the vehicles during the peak hour.

ACKNOWLEDGMENTS

This research was performed under the general direction of the Road Design Divisic Texas Highway Department, and was made possible by the cooperation of the U.S. Bureau of Public Roads, which furnished the measuring equipment used and also much expert advice and assistance through representatives from its headquarters, regional and district offices. The project was a coordinated effort of the Road Design Division, the Planning Survey Division, and the Austin, San Antonio, and Fort Worth Districts.

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Shoulder Use

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New Jersey State Highway Department, Trenton

● THE NEW JERSEY State Highway Department has conducted a study to determine the frequency of use of shoulders along state highways. The purpose was to determine the frequency of use for leisure stops and for emergency stops.

Points of observation were selected where other reasons for stopping, such as those attracted by business establishments or residences, were at a minimum. The points of observation were also selected where one mile of highway could be observed and where the observer would have a minimum of influence on driver behavior.

Data recorded included:

- Type of vehicle - truck or passenger car
- State of registration
- Time of stopping
- Time of resuming trip
- Lateral distance from edge of pavement
- Number of occupants
- Purpose of stop
- Direction of travel
- Distance from other vehicles on shoulder
- Location of stop longitudinally
- Special remarks

A summary of the data is given in Table 1.

Also shown on the summary sheet are the emergency stops on the Skyway, Route U.S. 1 in Newark, Kearny and Jersey City. This is an elevated structure with no shoulders on which leisure stops are not made. It is 3.25 miles long, carrying about 55,000 vehicles per average day during the year of study. Trucks are not allowed on the Skyway. The State Highway Department maintained a jeep service free of charge for about a year and a half in 1948 and 1949. Police patrolling the Skyway notified the jeep service and reports were kept for each incident. The service was maintained 16 hr per day from 6:00 a.m. to 10:00 p.m. The records of this service are used for part of this study.

From the Skyway study, there was one emergency stop for each 13,450 vehicle miles; whereas the summary of six locations shows one emergency stop per 11,800 vehicle miles of travel. This difference is accountable by the fact that trucks are not allowed on the Skyway. At the six locations, there were three emergency truck stops and five emergency passenger car stops. The trucks accounted for 37.5 percent of the emergency stops; whereas, the truck mileage is 20 percent of the total mileage.

Of the 197 leisure stops, the reasons for stopping were as follows:

Rest, including sleeping	135
Check vehicle (tires, motor, load)	31
Refer to road map	4
Slight pause	4
Change drivers	3
Writing reports	1
Eating in car	1
Inspect shrubbery	1
Empty car (cleaning inside)	1
Not determinable	16
	197

Trucks	120
Passenger Cars	77
TOTAL	197

Although there are many other items of interest that can be summarized from these data, the items pertinent to highway safety, highway capacity and service to the driving public are:

TABLE 1

SUMMARY OF OBSERVED DATA ON SHOULDER USE

Route and Time	Number of Vehicles					Vehicle Miles	Vehicle Miles per Stop				
	Leisure	Emergency	Business	Other	Total		Leisure	Emergency	Business	Other	Total
Rt. U.S. 1 - Middlesex Co.											
Tues. 8/4/53 8:00 a.m. -4:00 p.m.	8	2	2		12	5,280	660	2,640	2,640		440
Wed. 8/5/53 8:00 a.m. -4:00 p.m.	50	2	2	4	58	28,150	563	14,075	14,075	7,037	485
Thur. 9/16/54 12:00 noon -1:00 p.m.	4				4	690	172				172
Tues. 10/5/54 11:00 a.m. -3:00 p.m.	6				6	2,920	487				487
Rt. U.S. 9 - Middlesex Co.											
Thur. 7/26/56 10:00 a.m.-3:30 p.m.	8		2	1	11	4,700	690		2,350	4,700	427
Fri. 7/27/56 9:15 a.m.-3:15 p.m.	9		5	12	26	4,800	540		960	400	185
Rt. U.S. 22 - Hunterdon Co.											
Fri. 4/27/56 1:45 p.m. -3:45 p.m.	2		1		3	2,210	1,105		2,210		737
Mon. 4/30/56 9:15 a.m. -4:30 p.m.	14		2	3	19	6,330	450		3,165	2,110	333
Tues. 5/1/56 9:15 a.m. -4:30 p.m.	19		1		20	5,400	284		5,400		270
Rt. U.S. 22 - Somerset Co.											
Wed. 7/11/56 9:30 a.m. -3:30 p.m.	16			4	20	4,600	288			1,150	230
Thur. 7/12/56 8:50 a.m. -5:00 p.m.	23	2		2	27	6,500	282	3,250		3,250	240
Wed. 7/18/56 9:00 a.m. -4:00 p.m.	8		31	1	40	5,620	703		181	5,620	140
Thur. 7/19/56 9:15 a.m. -3:30 p.m.	21	1		2	24	10,600	505	10,600		5,300	442
Rt. U.S. 130 - Mercer Co.											
Tues. 3/29/55 10:30 a.m.-2:00 p.m.	6	1	13		20	1,940	323	1,940	149		97
Rt. U.S. 206 - Somerset Co.											
Wed. 5/23/56 3:15 a.m.-4:30 p.m.				2	2	860				430	430
Tues. 7/3/56 10:30 a.m.-4:00 p.m.	3			2	5	3,670	1,235			1,835	734
Total	197	8	59	33	297	94,270	480	11,800	1,600	2,860	318
Rt. U.S. 1 - Skyway 1 year 7/1/48 to 6/30/49 6:00 a.m. -10:00 p.m.		Emergency 4,049[a]				Vehicle Miles 54,500,000	Vehicle Miles per Stop 13,450				

Emergency passenger car stops occur once for every 13,450 passenger car miles.

Emergency truck stops occur once for every 5,200 truck miles.

Emergency stops occur once for every 11,800 vehicle miles with 20 percent trucks.

Leisure passenger car stops occur once for every 980 passenger car miles.

Leisure truck stops occur once for every 154 truck miles.

Leisure stops occur once for every 480 vehicle miles with traffic 20 percent trucks.

Passenger cars make leisure stops 13.7 times as frequently as they make emergency stops.

Trucks make leisure stops 33.8 times as frequently as they make emergency stops.

With 20 percent trucks there are 24.6 times as many leisure stops as there are emergency stops.

The following discussion is based on the above observations, supplemented with logical reasoning and a knowledge of relative highway problems:

Stopping on shoulders reduces the capacity of a highway and increases the accident hazard potential.

In order to stop on a shoulder a vehicle will slow down on the pavement to speeds far below the normal speed of the highway, therefore, affecting the smooth flow of traffic within the influence area. When resuming the trip after stopping, the vehicle will enter the pavement far below the normal speed of the highway, and, consequently interrupt the smooth flow of traffic. For each stop, therefore, there are two interferences with normal traffic flow, each of which reduces capacity and sets up an accident hazard potential.

Emergency stops cannot be avoided but leisure stops can be avoided. Business stops, considered parking, is not a problem of this discussion. Of the stops listed as "others" some can be avoided and others, such as police enforcement, probably cannot be avoided.

Shoulders are needed for emergency stops but, when provided, they encourage leisure stops. If shoulders are not provided, there would be no leisure stops.

A possible solution would be to provide shoulders but regulate them for emergency stops only. This has proven successful along the New Jersey Turnpike. In such case, it would be desirable to provide areas for leisure stops well off the roadway with deceleration and acceleration lanes designed to avoid slow speed movements on the roadway.

This study is not presented as conclusive evidence. It can only be accepted as an indication for the specific locations and times. No nighttime or weekend observations were recorded. It is desirable to supplement these findings with findings in other states.

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

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Division of Highway Transport Research
Bureau of Public Roads

● 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

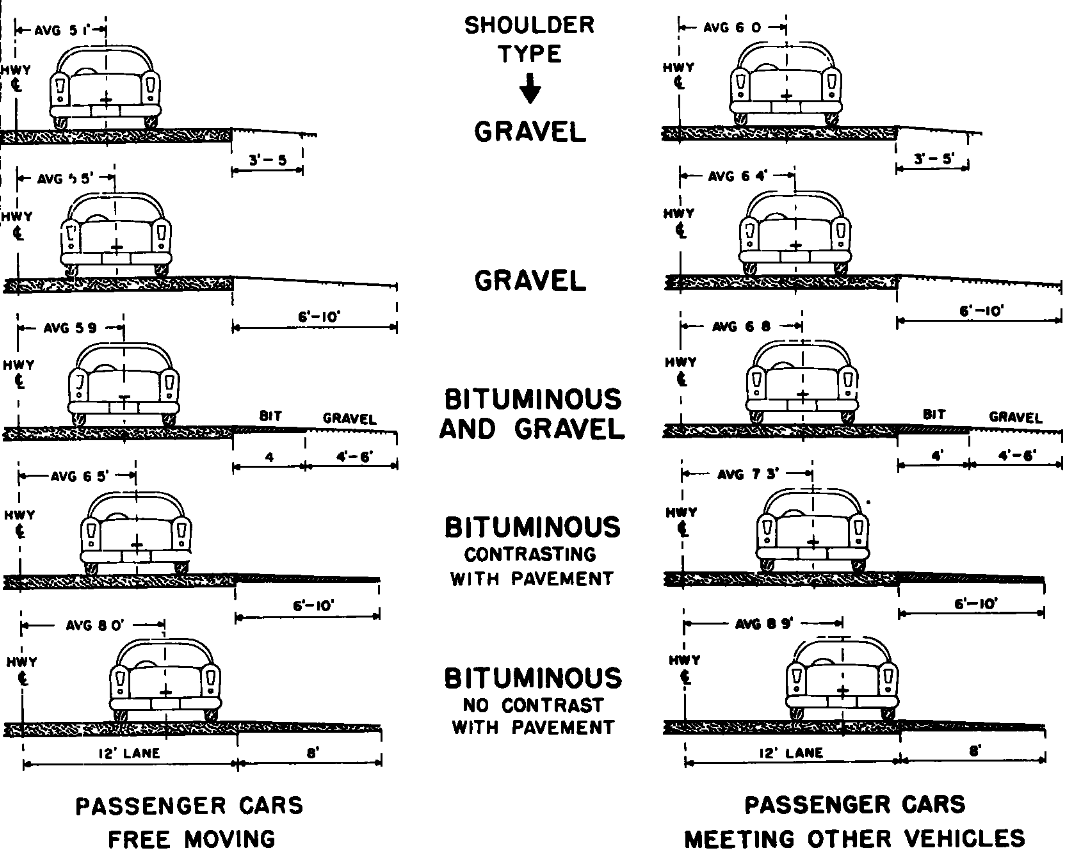

Figure 1. Average lateral position of passenger cars on rural 2-lane bituminous pavements.

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

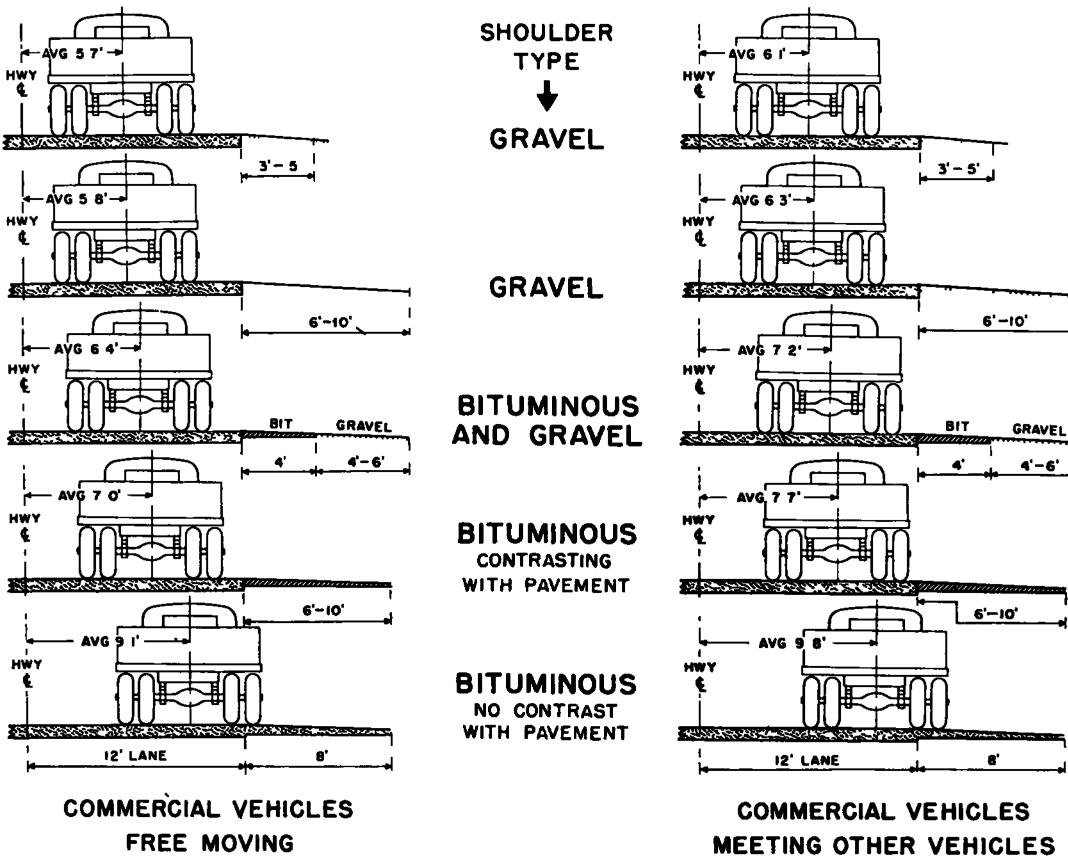

Figure 2. Average lateral position of commercial vehicles on rural 2-lane bituminous pavements.

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

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

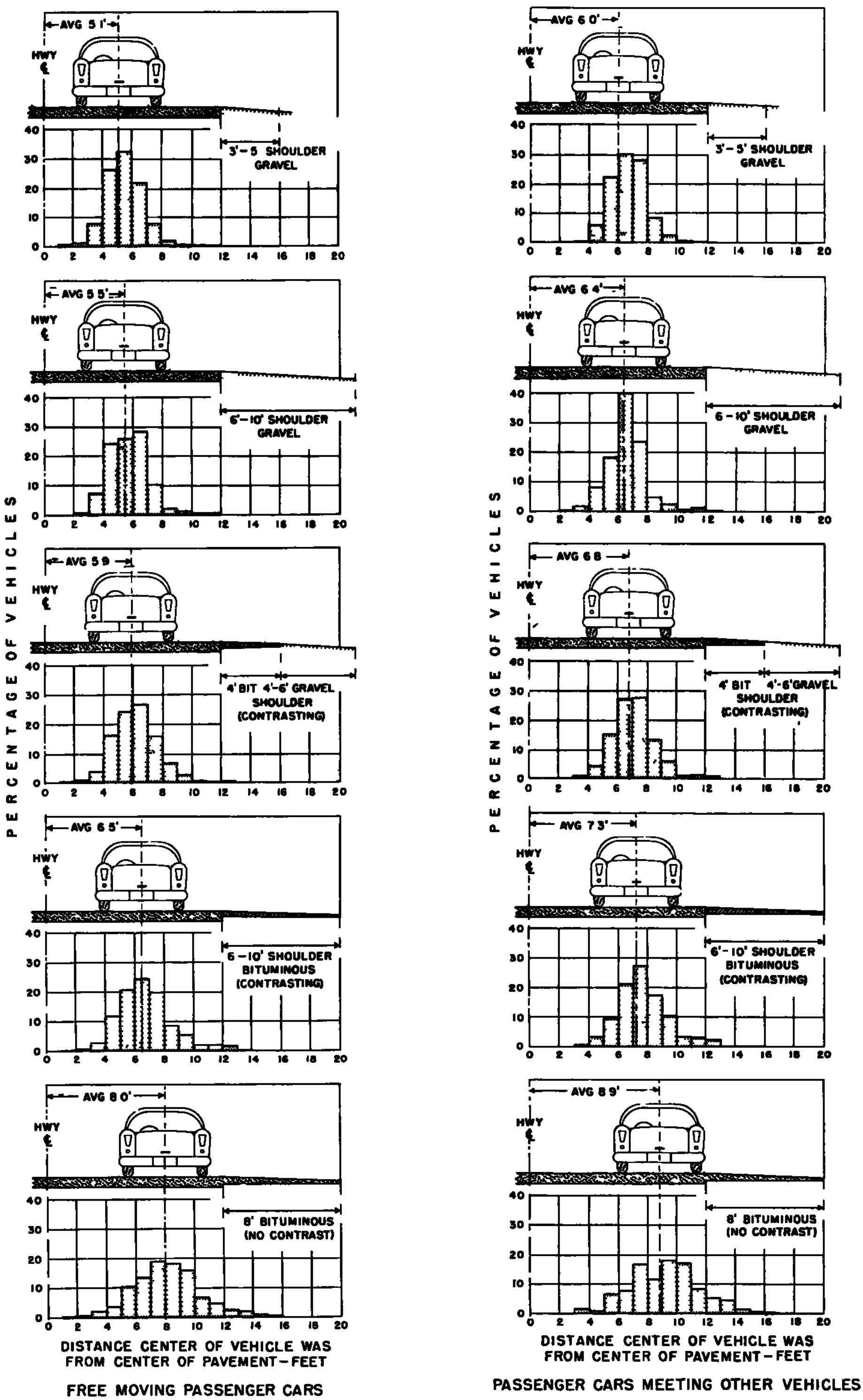

Figure 3. Distribution of lateral positions of passenger cars on rural 2-lane bituminous pavements.

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

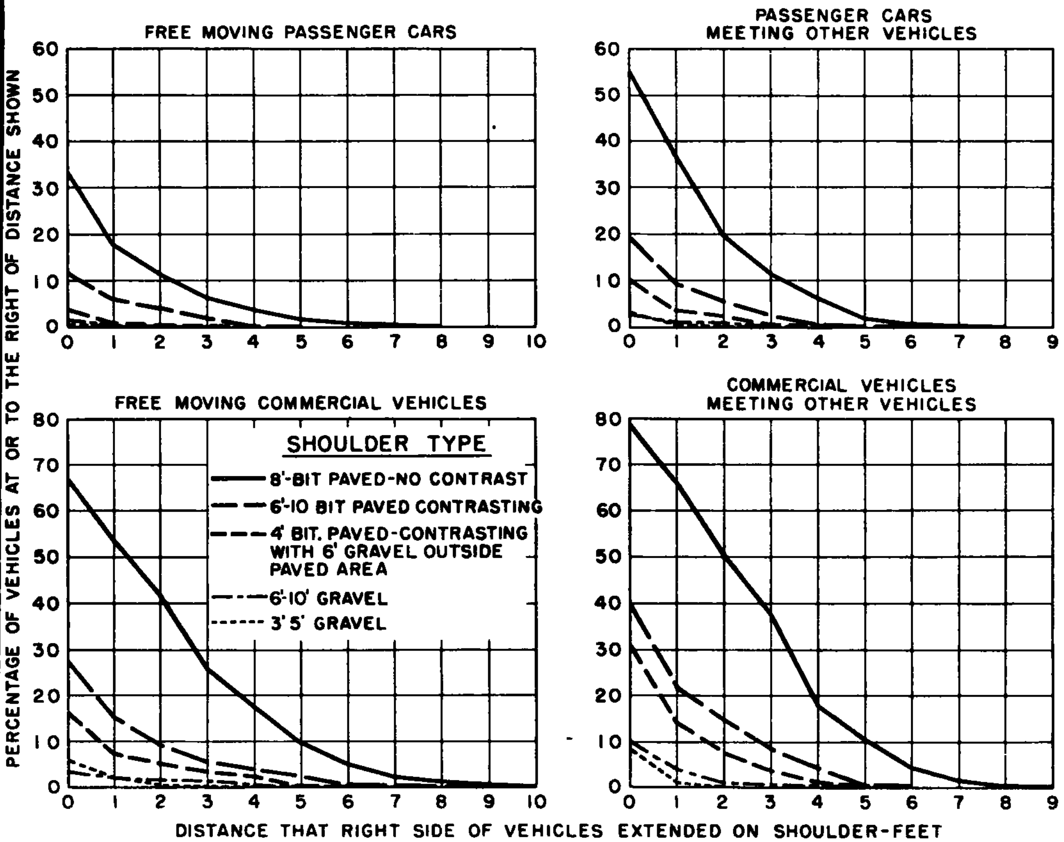

Figure 4. Shoulder encroachment on rural 2-lane bituminous pavements.

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

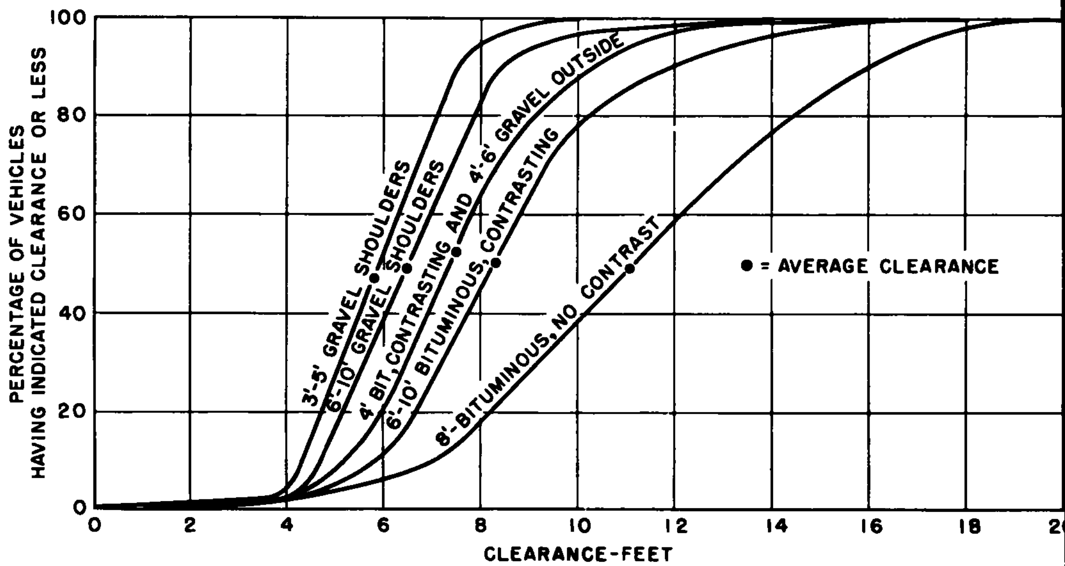

Figure 5. Cumulative distribution of clearances between bodies of meeting passenger cars as related to shoulder width and type on rural 2-lane bituminous pavements.

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 bituminous 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 since 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

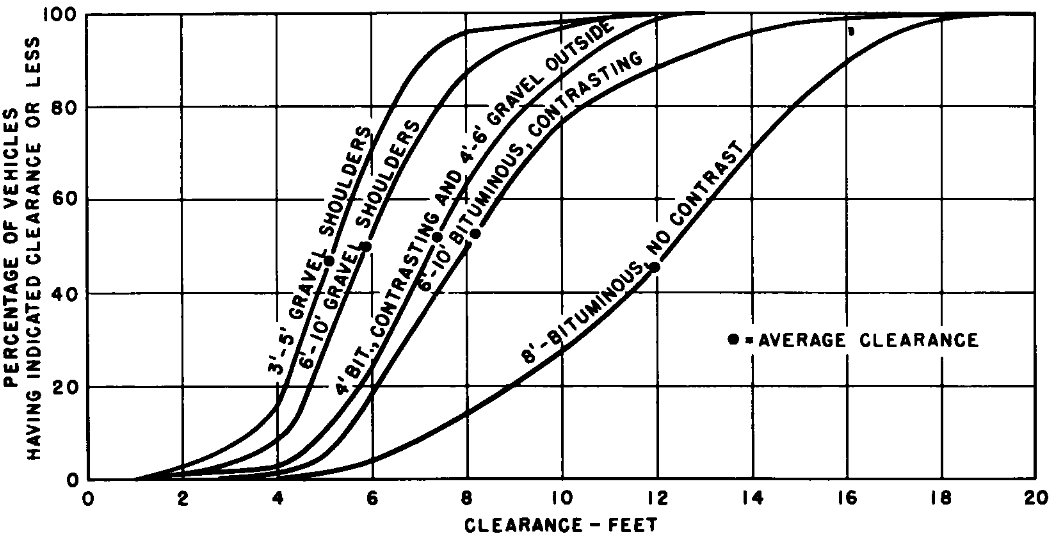

Figure 6. Cumulative distribution of clearances between bodies of passenger cars meeting commercial vehicles as related to shoulder width and type on rural 2-lane bituminous pavements.

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

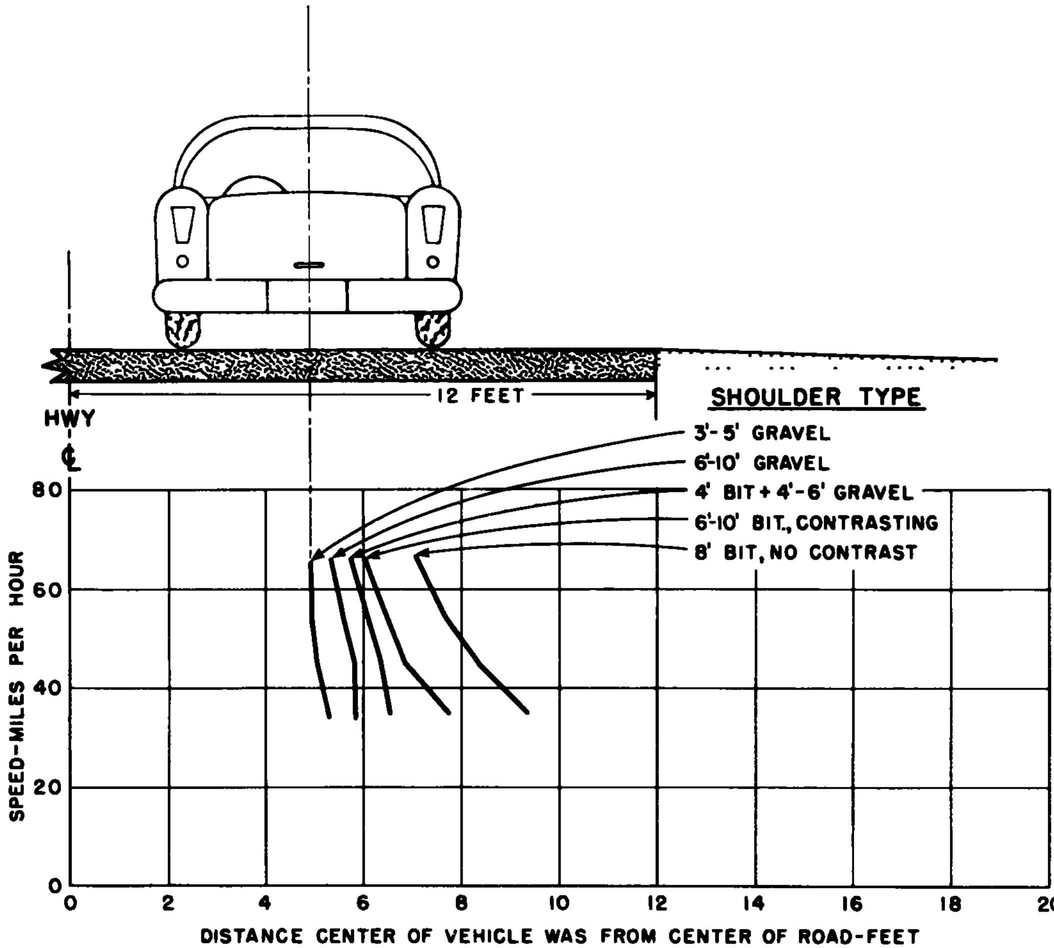

Figure 7. Average position of free moving passenger cars traveling at various speeds on rural 2-lane bituminous pavements.

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-

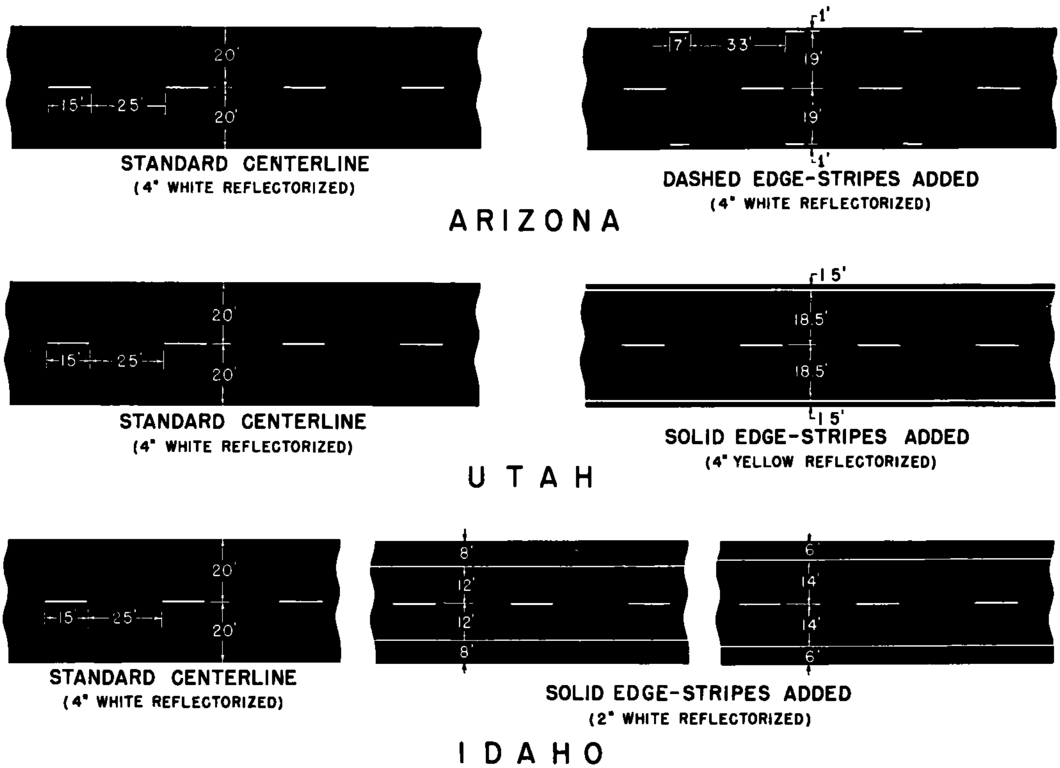

Figure 8. Edge striping on sections paved to their full shoulder width on rural 2-lane bituminous pavements.

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]			
				Type	Width	Distance from Edge[a]	Daytime		Nighttime	
							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.

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