HIGHWAY RESEARCH BOARD

Bulletin 266

Pavement Edge Markings, Shoulders and Medians

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Pavement Edge Markings, Shoulders and Medians

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Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio

JAMES V. MUSICK, Engineer of Traffic
Ohio Department of Highways, Columbus

● IN 1957, the Ohio Department of Highways initiated a program of pavement edge marking on all 2-lane rural state highways which were at least 20 ft wide. No prior research on pavement edge marking in Ohio was available, hence 12 pairs of sections of the programmed edge marking were selected as test samples for a controlled "before-and-after" study on the effects of these markings on the accident patterns. Subsequently, construction changes were made on two pairs of sections and it was discovered that a third pair was a 4-lane highway. These sections were excluded from the study. This resulted in nine pairs of 2-lane sections available for the study.

Each pair of sections consisted of a test section (pavement edge marked) and a control section (pavement not edge marked). These test and control sections were located as nearly as possible adjacent to each other and were selected so that the geometric design characteristics and culture surrounding each of the sections were similar in nature. The volume and character of traffic on each of the sections within a pair was comparable. The section chosen for edge marking within each pair was selected at random—literally by "tossing a coin." This procedure eliminated any bias due to section selection.

One pair of sections was located in each of 9 of the 12 highway department divisions within the state as shown in Figure 1. A total of 116 mi of highway were selected for study including 61 mi of test sections (edge marked) and 55 mi of control sections (not edge marked).

Six pairs of sections were 24 ft wide and the remainder were 20 to 22 ft wide. Pavements less than 20 ft wide were not included in the pavement edge-marking program. Shoulders varied from a curb to 14 ft wide but were generally between 4 and 8 ft wide. Both asphalt and concrete pavements were studied and shoulders were generally cinders or gravel with some grass shoulders and a smaller proportion of bituminous concrete and earth shoulders.

ACCIDENT STUDIES

Analyses were made of all reported accidents on each of the test and control sections both before and after edge marking. In each case, the "before" period was the year 1956. The "after" period was the first full 12-month period following the application of the edge marking. The "after" period began immediately after the placement of the edge marking.

The reported accidents were summarized by location, type of collision, light condition and pavement condition. The number of fatalities and injuries was also recorded.

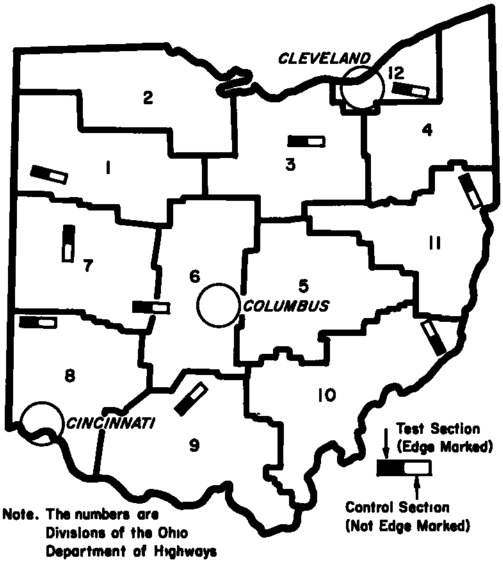
The accident studies showed that there was a net reduction of 19 percent (Fig. 2) in accidents after the pavement edge marking on the 2-lane rural state highways. This net change was computed as given in Table 1.

TABLE 1

TOTAL NUMBER OF ACCIDENTS BEFORE AND AFTER EDGE MARKING OF 2-LANE RURAL HIGHWAYS IN OHIO

Section	Total Accidents			
	Before Edge Marking	After Edge Marking	Anticipated After	Net Change
	No.	No.	No.	Percent
Test (edge marked)	123	126	156	-19
Control (not edge marked)	132	167		

The control sections (not edge marked) showed an increase of 26.5 percent in the number of accidents between the before-and-after periods: $\frac{167-132}{132} \times 100$. If the test sections (edge marked) had not been treated with edge markings, it may have been expected that the edge-marked sections, also, would have shown an increase of 26.5 percent to 156 accidents: 123 + (123 x 0.265). The difference between the expected number of accidents (156) and the actual number (126) is 30 accidents or a net reduction of nineteen percent: $\frac{30}{156} \times 100$.



Note. The numbers are Divisions of the Ohio Department of Highways

Figure 1. Location of test and control sections for pavement edge marking study on 2-lane rural state highways in Ohio.

Statistical analysis of the data indicates that the significance level of the 19 percent accident reduction is 0.22 if the 2 x 2 chi-square test is employed, and 0.16 if the "t" test is used. In other words, the probability is about 1 in 5 or 6 that a net accident reduction of 19 percent or more could have occurred merely by chance. The "t" test is a slightly more sensitive test than the chi-square test but the difference between it and the chi-square test in this case is very small. There is some question as to whether the "t" test can be applied to these data and therefore it was thought desirable to confine the tests of statistical significance to the chi-square test.

SEVERITY OF ACCIDENTS REDUCED

Figure 2 shows a computed net reduction of 37 percent in fatalities and injuries after edge mark-

TABLE 2

FATALITIES AND INJURIES BEFORE AND AFTER EDGE MARKING OF 2-LANE RURAL HIGHWAYS IN OHIO

Section	Fatalities and Injuries: Before Edge Marking	After Edge Marking	Anticipated After	Net Change
	No.	No.	No.	Percent
Test (edge marked)				
Killed	3	5		
Injured	93	85		
Total	96	90	143	-37
Control (not edge marked)				
Killed	6	8		
Injured	86	129		
Total	92	137		

ing. The computation of this net reduction is given in Table 2.

The before-and-after comparison on the edge-marked sections shows a decrease in the total number of injuries and fatalities in the "after" period. The control sections showed a marked increase in the number of fatalities and injuries in the "after" period, actually, a 49 percent increase. If the control sections are used as the base, then the net reduction appears to be approximately 37 percent.

The results showed that the net reduction of 37 percent in the number of persons killed and injured after pavement edge marking was significant at the 0.02 level employing the 2 x 2 chi-square test. In other words, there was only a remote possibility that this reduction occurred by chance.

A comparison of the injury and fatality frequency (that is, the number of injuries and fatalities per accident) shows that the edge-marked sections decreased from 0.78 to 0.71 while the control sections increased from 0.70 to 0.82 during the corresponding period.

ACCIDENTS REDUCED AT ACCESS POINTS

Accidents occurring at access points such as intersections, alleys, and driveways, decreased 24 percent in the period after the edge marking was applied. In the corresponding period, accidents at these locations on the "control" sections showed an increase of 106 percent. Assuming that the control establishes the normal pattern of increase for all sections, then the apparent effect of the edge marking

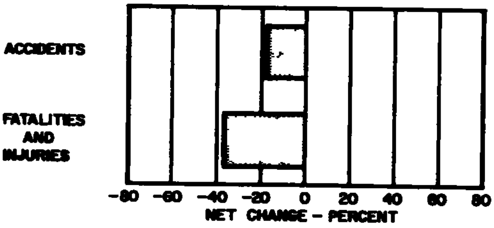


Figure 2. Net change in accidents and fatalities and injuries after edge marking of 2-lane rural state highways in Ohio.

would be a reduction of approximately 63 percent as shown in Figure 3.

No specific reason could be established to relate edge marking to the reduction in accidents at intersections, alleys, and driveways. A theory has been advanced that edge marking may encourage drivers to watch the pavement edge further in advance of the vehicle and, consequently, to be more aware of vehicles entering the roadway from side roads and driveways. With this "increased vision ahead," the driver has more time to react to intersectional friction.

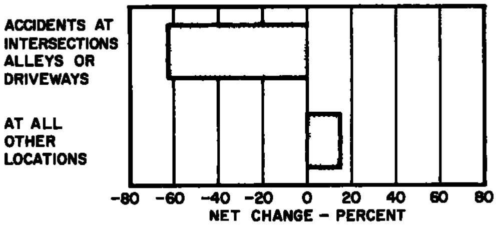


Figure 3. Net change in accidents by location after edge marking of 2-lane state highways in Ohio.

Accidents at locations other than intersections, alleys, and driveways showed an 18 percent increase after edge marking as compared to the before period. Because accidents increased only 3 percent on the comparable control sections, the net increase in accidents was approximately 15 percent (Fig 3). Further analysis showed that there was a significant net accident reduction in accidents at access points during both day and night conditions although the net reduction was greater at night. There was no significant change in accidents between access points during either day or night conditions.

NIGHT ACCIDENTS REDUCED

Figure 4 shows a comparison of accidents according to the time of day. During the before period, the edge-marked sections showed 56 percent of the accidents occurring in daylight hours and 44 percent in darkness hours. The control sections showed 53 percent of the accidents during daylight hours and 47 percent in darkness hours. The sections were assumed to be comparable in the percentage distribution of day and night accidents.

After the edge marking was applied to the test sections, these sections showed a 19 percent increase in the number of day accidents whereas the control sections showed a 29 percent increase. This would seem to indicate that edge marking has a favorable effect on daylight vehicle operation. The difference was not statistically significant, however.

When the edge marking was applied to the test sections, the night accidents on these sections showed a 19 percent decrease whereas the control sections recorded an increase of 25 percent. The net decrease in night accidents is then approximately 35 percent and is significant at the 0.11 level.

In addition, the ratio of night-to-day accidents on the marked sections showed a significant change. Before the edge markings were applied to the test sections, 44 percent of the accidents occurred during darkness, whereas after the edge markings were applied, only 34 percent of the accidents occurred during these hours. For the same period, the control sections showed no significant change in the percentage of accidents taking place at night.

ADVANTAGE OF EMPLOYING CONTROL SECTIONS

One other point might well be highlighted for the benefit of future "before-and-after studies" of this type. If a simple noncontrolled "before-and-after" study had been made, employing test sections only, the results would have indicated that accidents increased 2 percent as a result of edge marking, and injuries and fatalities decreased 6 percent. However, by the use of control sections the net effect was shown to be a reduction of 19 percent in the number of accidents and 37 percent in the number of fatalities and injuries after edge marking had been installed. This comparison points up the value of using control sections in studies of this type wherever possible.

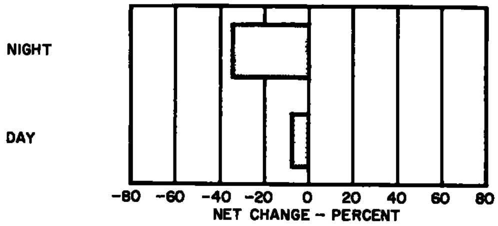


Figure 4. Net change in accidents during daylight and darkness hours after edge marking of 2-lane rural state highways in Ohio.

ADDITIONAL STUDIES

Although the idea of pavement edge marking is not new, the early adoption of this principle and rapid acceptance by the motorists in Ohio has foreclosed the possibility of much research on the subject and the continuance of any extensive "controlled before-and-after studies" in Ohio. However, it is anticipated that the department of highways will continue to study the use of edge marking on narrower highways and the effects of these lines on driver behavior and accident patterns.

SUMMARY

Table 3 summarizes the principal findings of this study. Items 1 and 2 were calculated as given in Tables 1 and 2, respectively. The remaining items were computed in a similar fashion. Table 3 gives:

1. The net reduction of 37 percent in fatalities and injuries due to the edge marking was significant at the 0.02 level employing the 2 x 2 chi-square test.
2. The reduction of night accidents of 35 percent was significant at the 0.11 level using the chi-square test.
3. At intersections, alleys, and driveways there was a significant reduction in accidents, and the angle-type collisions which are associated with intersections, alleys, and driveways were also reduced significantly.

All other comparisons were not significant at the 0.10 level by employing the 2 x 2 chi-square test. The "net changes" in accidents for these comparisons are not considered reliable because they could easily have occurred by mere chance. A reduction in accidents which has a significance level of 0.10 indicates that there is only one chance in ten that a "net change" as great or greater than that shown could have occurred merely by chance. This level of significance was considered the minimum acceptable for this study. It may be noted that the significance level for night accidents was 0.11—a marginal value.

TABLE 3

NET CHANGE IN ACCIDENTS AFTER EDGE MARKING OF 2-LANE RURAL HIGHWAYS IN OHIO SUBDIVIDED BY LOCATION, TYPE OF COLLISION, LIGHT CONDITION AND WEATHER

Item	Net Change (%)	No. of Accidents 1/	Significance Level 2/
1. Total accidents	-19	548	0.22
2. Persons killed and injured	-37	415 3/	0.02
3. Location:			
At intersections, alleys, driveways	-63	177	0.01
Between intersections, alleys, driveways	+15	371	0.25+
4. Type of collision:			
Pedestrian	4/	5	0.25+
Turn	4/	10	0.25+
Angle	-83	51	0.01
Rear-end	-21	210	0.25+
Head-on	4/	14	0.25+
Sideswipe	- 6	42	0.25+
Other collision	+ 8	57	0.25+
Non-collision	+ 6	159	0.25+
5. Light condition:			
Day	- 8	311	0.25+
Night	-35	233	0.11
6. Pavement condition:			
Dry	-24	285	0.25+
Wet	-12	119	0.25+
Ice	- 1	75	0.25+
Not stated	-33	69	0.25+

1/ The number of accidents refers to the total sample and includes both edge-marked and control sections for the year before and the year after edge marking.

2/ The significance level indicates the probability that the net change could have occurred merely by chance. A significance level of 0.01, for example, indicates that there is only one chance in 100 that a "net change" as great or greater than that shown could have occurred merely by chance.

3/ The number 415 refers to the number of persons killed and injured.

4/ Total sample is too small to warrant computing net change.

CONCLUSIONS

The significant conclusions from this study are:

1. On 2-lane rural highways in Ohio, the use of pavement edge mark-

ings resulted in a significant reduction in fatality and injury-causing accidents.

2. Accidents at intersections, alleys, and driveways were significantly reduced but accidents between access points showed no significant change.

3. The only type of collision to show a significant change (a substantial reduction) was the angle collision which is associated with access points.

4. There was no significant change in day accidents; night accidents were reduced but the change was marginal as far as statistical significance is concerned.

Effect of Pavement Edge Markings on Operator Behavior

ROBERT M. WILLISTON, Engineer of Traffic
Connecticut State Highway Department, Wethersfield

● TWENTY YEARS AGO the Connecticut State Highway Department applied paint markings along the outer edges of the travel portion of roadway to delineate the separation point between paved roadway and paved shoulder. This application was made on a 2-lane highway which carried substantially heavy traffic volumes and was used by many pedestrians. The pedestrians were mostly residents from a Veterans Home who walked along this highway frequently between the home and a village located some 3 mi distant. (Numerous accidents had occurred during hours of darkness, many of them fatal, involving vehicles and pedestrian.) The placing of a continuous white stripe along the outer edge of pavement provided an area for these pedestrians to walk and at the same time delineated the limits of the traveled roadway for operators of motor vehicles. These lines were termed shoulder lines and their effectiveness was measured by the elimination of pedestrian accidents at night and significant favorable public response to "shoulder striping."

The intent of the foregoing statement is to present the background for Connecticut's edge-marking policy which during the past years has expanded from 3 mi of shoulder striping to a program which now involves painted edge markings on nearly 1,500 mi of roadway. Subsequent to the favorable public response following the initial installation of edge markings or "shoulder lines," several selected locations were marked similarly. These later markings were still termed "shoulder lines" and intended to provide a refuge area for children walking to and from school in rural areas, along roads carrying comparatively large traffic volumes at relatively high speeds. There is no accident experience to accurately measure statistical benefits at these locations but it can be demonstrated through vehicle placement and speed measurements at specific study points that vehicular traffic was influenced by the presence of a painted edge line and that the roadway appeared to be safer particularly for the pedestrians required to use the shoulder.

Following the application of edge lines on several miles of 2-lane roads it was suggested to the Department that the outer edge or curb of the Merritt Parkway be painted to provide a safer nighttime travel condition; it was the opinion that painted curbings would furnish drivers with improved pavement delineation during inclement weather or fog conditions. The 38 mi of Merritt Parkway was edge striped in 1954 but not until a study was completed at a test section to determine what, if any, influence a paint stripe along the outer edge of the parkway would have on operator behavior. The results of this study are explained as part of this paper.

The Connecticut Highway Department now stripes the outer edges of all

4- or 6-lane divided roadways and a high percentage of the 2-lane road system. Since 1956 the Department has used yellow paint for the edge striping on these 2-lane and multilane facilities. Yellow was selected as it is in contrast to the continuous white centerline used in a barrier system to denote "No Passing Zones" on 2-lane roads, and on the inside edges of the median divider where continuous white line is applied. No studies have been made to measure what possible differences in operator performance may occur with the use of yellow edge lines as compared with white.

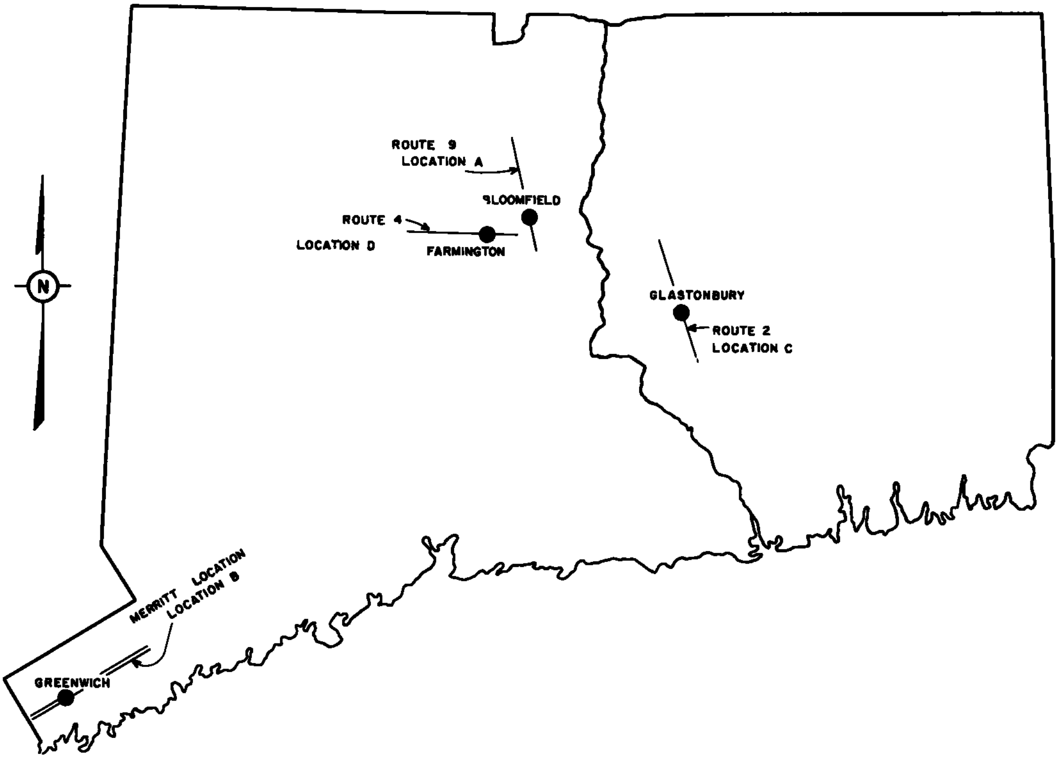


Figure 1. Study location sites.

The expansion of Connecticut's edge marking from its initial shoulder line application to its present 1,500 mi of edge striping has not been based upon favorable public reaction alone. It is also supported by the results of studies conducted at several locations on state highways where changes in operator behavior and vehicle operation and performance have been observed after edge lines were applied. The purpose of this paper is to describe the methods used in these studies together with the observations and conclusions derived therefrom.

LOCATIONS FOR STUDY

The locations where studies have been performed are described as follows: Figure 1—Bloomfield, Route 9; Meritt Parkway, Greenwich; Glastonbury, Route 2; Farmington, Route 4.

Location A—Figure 2

Route 9 in Bloomfield was studied before and after edge marking were placed as the result of requests to provide protection for school children. These observations were made in 1950 and again in 1951. This is a section of highway carrying ADT of 3,400 vehicles. The road originally constructed as an 18-ft bituminous penetration with 5-ft shoulders was later surface treated the full width of 28 ft with no discernible shoulder areas. Sparsely placed homes along the route make it residential and a generator of light pedestrian volumes, where during certain times of the day concentrations of children walking to and from school may be observed. To provide some sort of refuge area for this movement, continuous white lines were painted along the outer edges of a 20-ft traveled portion of roadway.

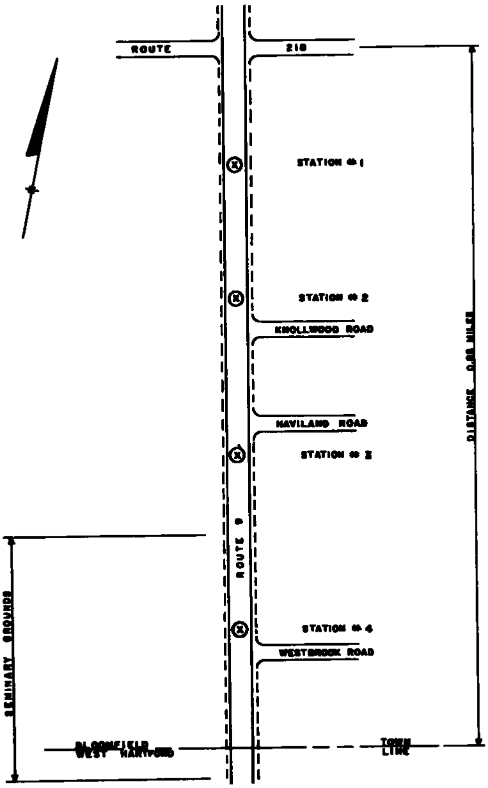


Figure 2. Location A.

Location B—Figure 3

The Merritt Parkway was a limited study to determine any influence on driver behavior after edge lines were placed on a 4-lane divided highway. This is a tangent and curve on the eastbound lanes of the Merritt Parkway. The study site chosen was on a bituminous concrete section of the Merritt Parkway located in the town of Greenwich. It is a tangent curve area and measures 2,000 ft in length, it encompasses a 40-deg 30-min left-hand curve which, in itself is 1,554 ft long. Other physical features which enhanced the particular location as a study site were the descending grade through the test area, the presence of a wire rope railing in the first section of the area, planting in the esplanade, and a tangent area leading to the curve, of sufficient length to establish base speed and transverse placement values. The bituminous concrete pavement measures 26 ft wide and the outer shoulder area adjoining, constructed of a like surface, averages 8 ft wide. Gradient for eastbound vehicles varies from -5 percent at Station No. 1 to -1.6 percent at Station No. 2, to -3.8 percent at Station No. 3. Sight distances are to be considered unlimited (more than 500 ft) except in the region of Station No. 2 where this distance falls only slightly, to 450± ft.

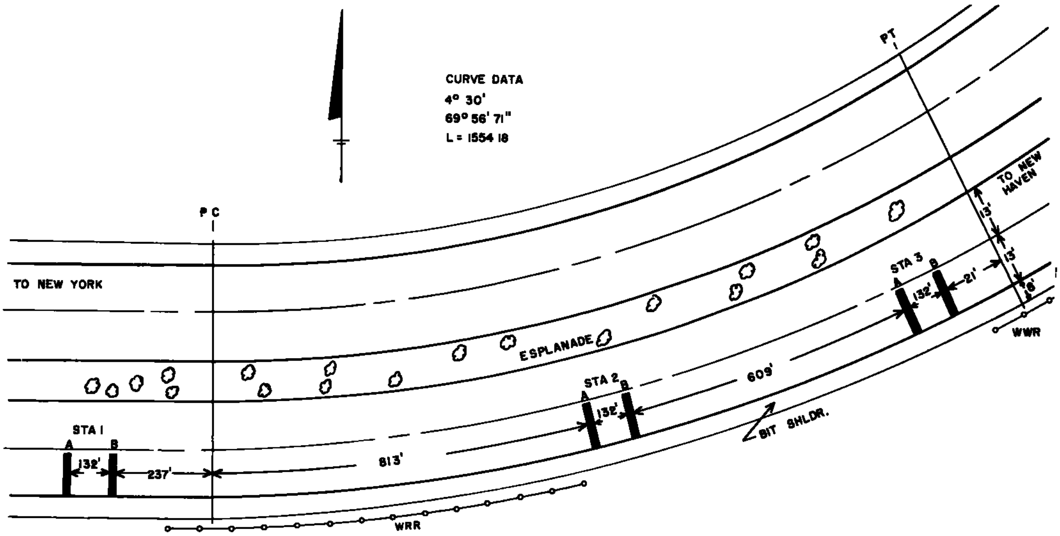


Figure 3. Test area—Town of Greenwich, Route 15, Location B.

Location C—Figure 4

The Glastonbury, Route 2 study was made on a newly constructed section of 2-lane roadway with black top surface and paved black shoulders. The study was done in cooperation with a student at the Yale Traffic Bureau, an employee of the highway department, as a thesis project. Route 2 in the study area is a 2-lane rural highway running in a general northeast-southwesterly direction and carrying an annual ADT volume of 5,300 vehicles (1953). The roadway was reconstructed on new alignment and grade in 1949 with a 24-ft armor-type surface and 8-ft bituminous surfaced shoulders providing a total paved width of 40 ft. The pavement is divided into two 12-ft lanes by a painted white dashed centerline (reflectorized). Both pavement and shoulders were in excellent condition and were discerni-

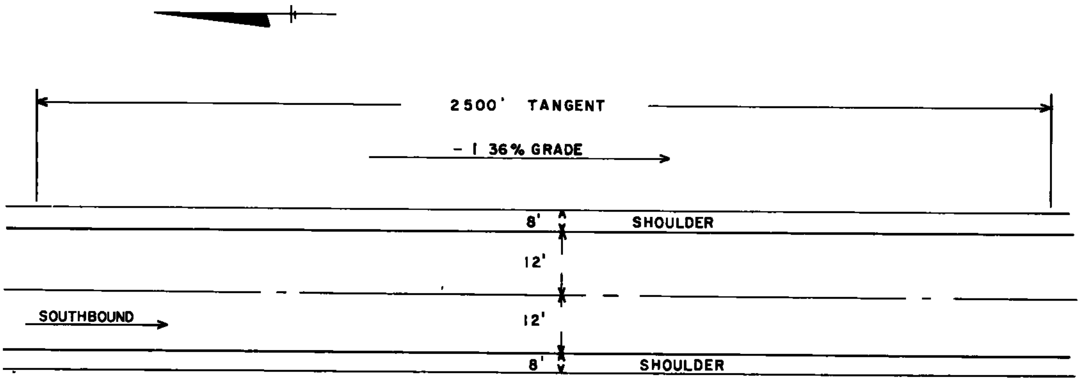


Figure 4. Test area—Town of Glastonbury, Route 2, Location C.

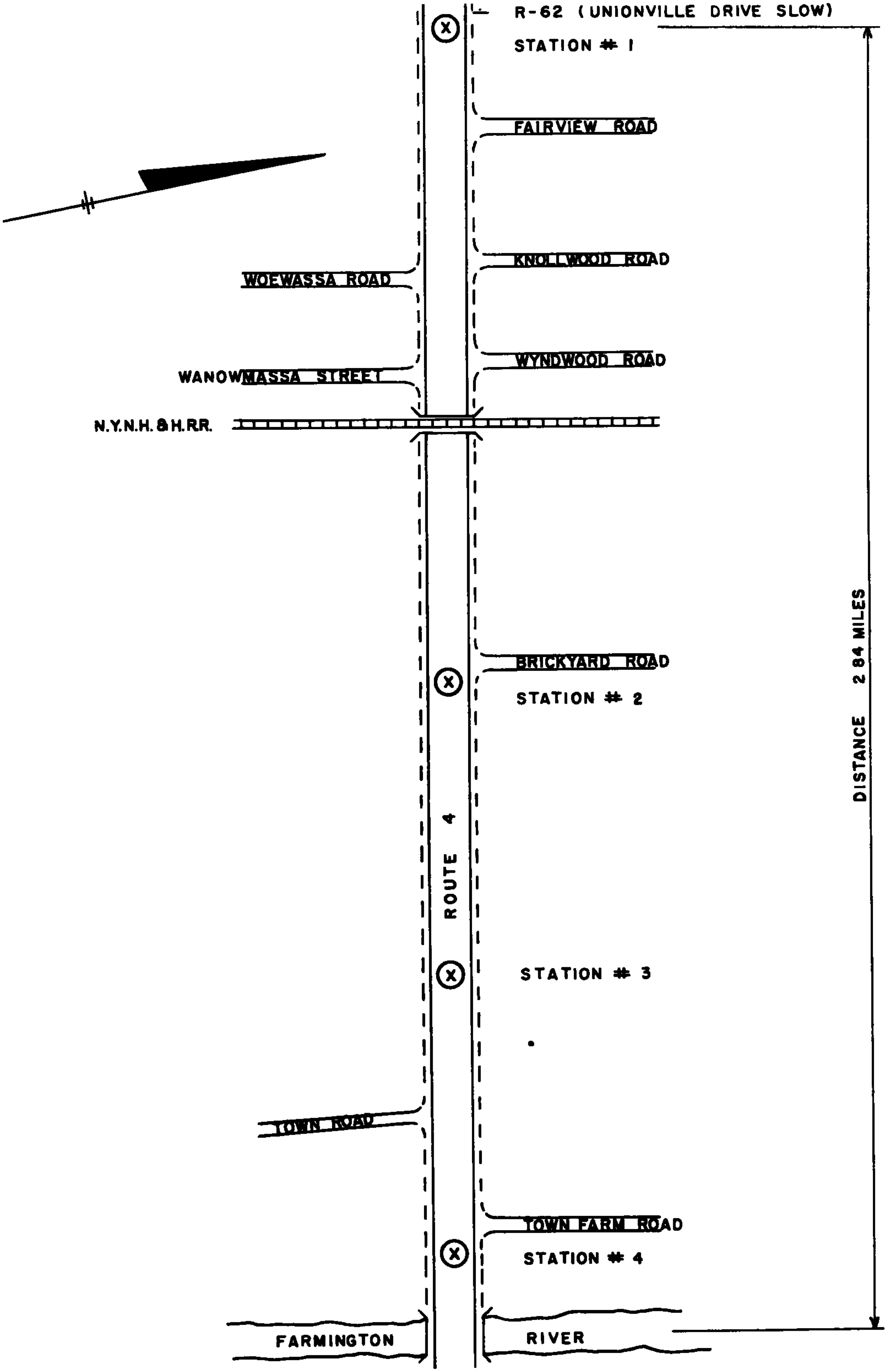


Figure 5. Location D.

ble, one from the other, during daylight hours. The study site was confined to the southbound lane only. The site lies roughly in the center of a 2,500-ft tangent with a minus 1.36 percent gradient (southbound) extending at least 700 ft either side of the site.

Location D—Figure 5

The Farmington, Route 4 studies were made at 4 locations in this area. Observations of traffic performance were made before any pavement markings were placed, with centerline striping and with both centerline and edge markings. This is a rural area sparsely developed as residential and business. Some pedestrian traffic is present on the shoulder areas with many being children walking to and from school. Vehicular traffic averages 5,000 vehicles per day. Route 4 is a black top pavement with bituminous surfaced shoulders matching the paved surface to give an appearance of the wide roadway with no shoulders. The test areas selected are not all similar in cross-section, thus offering an opportunity to augment the effectiveness of pavement markings on a highway with variances in roadway width and cross slope. A physical description of each of the 4 study areas is as follows:

Station #1.—24 ft . . . bituminous-treated travelway; 1.5 ft . . . bituminous-treated shoulders; 12 ft . . . distance between center stripe and shoulder stripe; and 1/8 in. per ft . . . cross slope.

Station #2.—28 ft . . . bituminous-treated travelway; 3 ft . . . bituminous-treated shoulders; 13 ft . . . distance between center stripe and shoulder stripe; and 1/4 in. per ft . . . cross slope.

Station #3.—30 ft . . . bituminous-treated travelway; 4 ft . . . bituminous-treated shoulders; 13 ft . . . distance between center stripe and shoulder stripe; and 1 in. per ft . . . cross slope.

Station #4.—24 ft . . . bituminous-macadam travelway; 8 ft . . . bituminous-treated shoulders; 14 ft . . . distance between center stripe and shoulder stripe; and 1/8 in. per ft . . . cross slope.

TABLE 1

AVERAGE SPEEDS (MPH)

Speed Observations	Sta. 1	Sta. 2	Sta. 3
Day			
1. Before shoulder line installed	55.7	56.5	54.3
2. After line—18 in. off edge of pavement	54.9	54.2	51.2
3. After line—at edge of pavement	52.9	50.8	53.1
Night			
1. Before shoulder line installed	52.1	47.8	48.5
2. After line—18 in. off edge of pavement	53.8	51.6	53.8
3. After line—at edge of pavement	51.6	51.0	53.0

METHODS USED IN STUDIES

Location A involved the measurement of transverse placement alone and was accomplished by placing chalk lines transversely on the travel lanes and positions coded at 1-ft intervals starting at the painted centerline and measuring outward. The left wheels of vehicles were observed and their positions recorded so that a distribution of vehicle lateral placement was obtained.

Location B involved the measurement of transverse placement and speed. Equipment used was an Easterline-Angus battery-operated 20 pen recorder with rubber coated pressure-sensitive detector tapes placed on the pavement and connected with the recorder by means of multi-wire transmitting cable. Observations were recorded at three locations:

Station #1—237 ft west of the P.C.
Station #2—813 ft east of the P.C. (52 percent around curve)
Station #3— 21 ft west of the P.T.

The detectors consist of 10 ea. 12-in. long segments with 2-2½-in. terminal area at either end. Approximately the center 8 in. of each segment is sensitive to pressure and on actuation transmits an impulse to the corresponding pen of the recorder. Placement of the detectors on the outer lane at right angles to the centerline and with the zero end of tape at the outer edge of pavement permits accurate transverse placement recordings. By spacing two tapes 132 ft apart at each station and adjusting the recording paper to turn at 10 graduations per second it was possible to obtain the placement and speed of a vehicle at each station. Because the speed tape placed in advance of the placement tape was, in effect, a duplicate piece of equipment, the total recordings for one vehicle through each station consisted of two transverse placements and one speed rating.

ANALYSIS OF DATA

At Location A transverse placement of vehicles was observed in November 1950 with a painted white centerline and no edge markings. Measurements were again taken in October 1951 after the edge markings had been added and were in place approximately 10 months. Between 600-700 vehicles were observed prior to the edge striping and approximately the same number afterwards. Vehicles observed here were all free-moving and not influenced by opposing traffic. Nonuniformity in the pavement cross-section and slight variance in the over-all width of paved surface apparently influenced vehicle placement so that no distinct pattern is discernible. However, the comparison before-and-after studies reveal a change in the vehicle performance from the original observations (Figs. 6, 7, 8 and 9).

At Location B the lateral placement and speed observations totalling 11,289 were obtained at six locations. Observations were limited to free-moving vehicles in the outer lane first, because speed and placement of the vehicle in question might be affected by the presence of a second vehicle in the proximity and, second, because it was presumed there would be no effect of a right-hand shoulder line on traffic moving in the second lane (Table 1).

Figure 10 shows that in the daytime vehicles are positioned closer to the center of lane when the 4-in. white line was painted 18 in. away from the edge of shoulder. At night, vehicles traveled nearer to the lane line with the line painted at the edge of pavement.

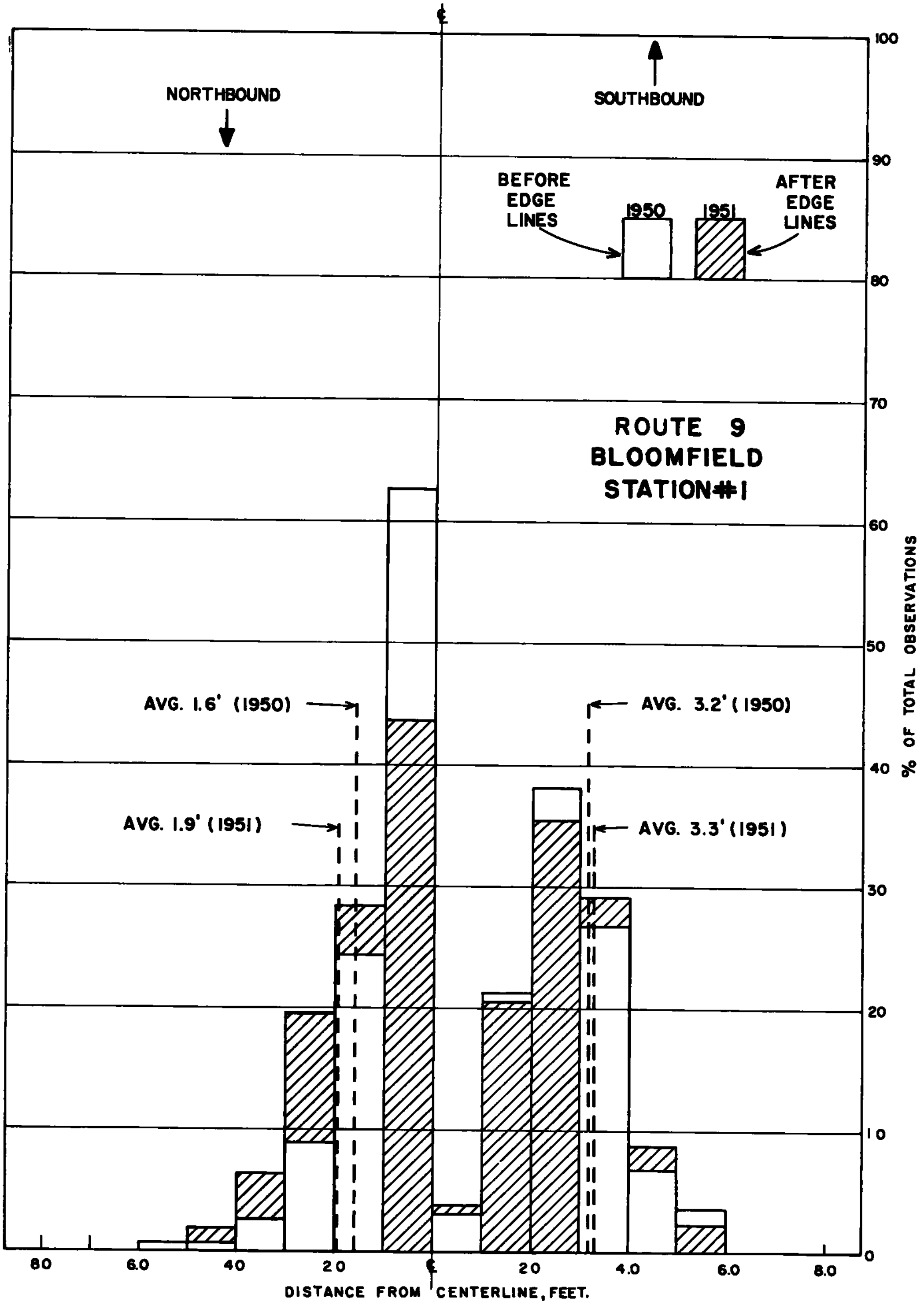

NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION #1
AVG. 1.6' (1950)
AVG. 1.9' (1951)
AVG. 3.2' (1950)
AVG. 3.3' (1951)
% OF TOTAL OBSERVATIONS
100
90
80
70
60
50
40
30
20
10
0
8.0
6.0
4.0
2.0
℄
2.0
4.0
6.0
8.0
DISTANCE FROM CENTERLINE, FEET.

Figure 6.

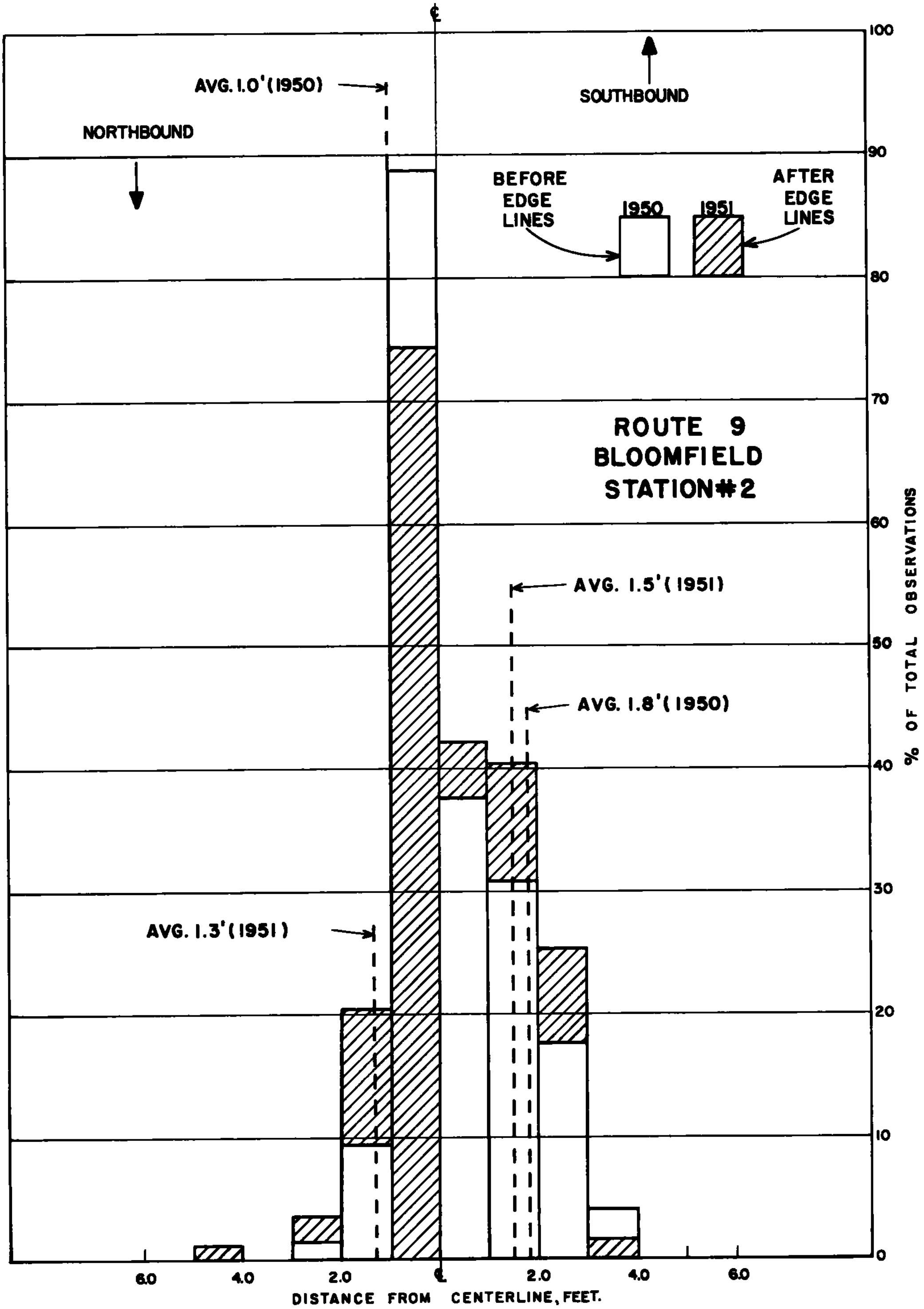

℄
AVG. 1.0'(1950)
NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION #2
AVG. 1.5'(1951)
AVG. 1.8'(1950)
AVG. 1.3'(1951)
% OF TOTAL OBSERVATIONS
100
90
80
70
60
50
40
30
20
10
0
6.0
4.0
2.0
℄
2.0
4.0
6.0
DISTANCE FROM CENTERLINE, FEET.

Figure 7.

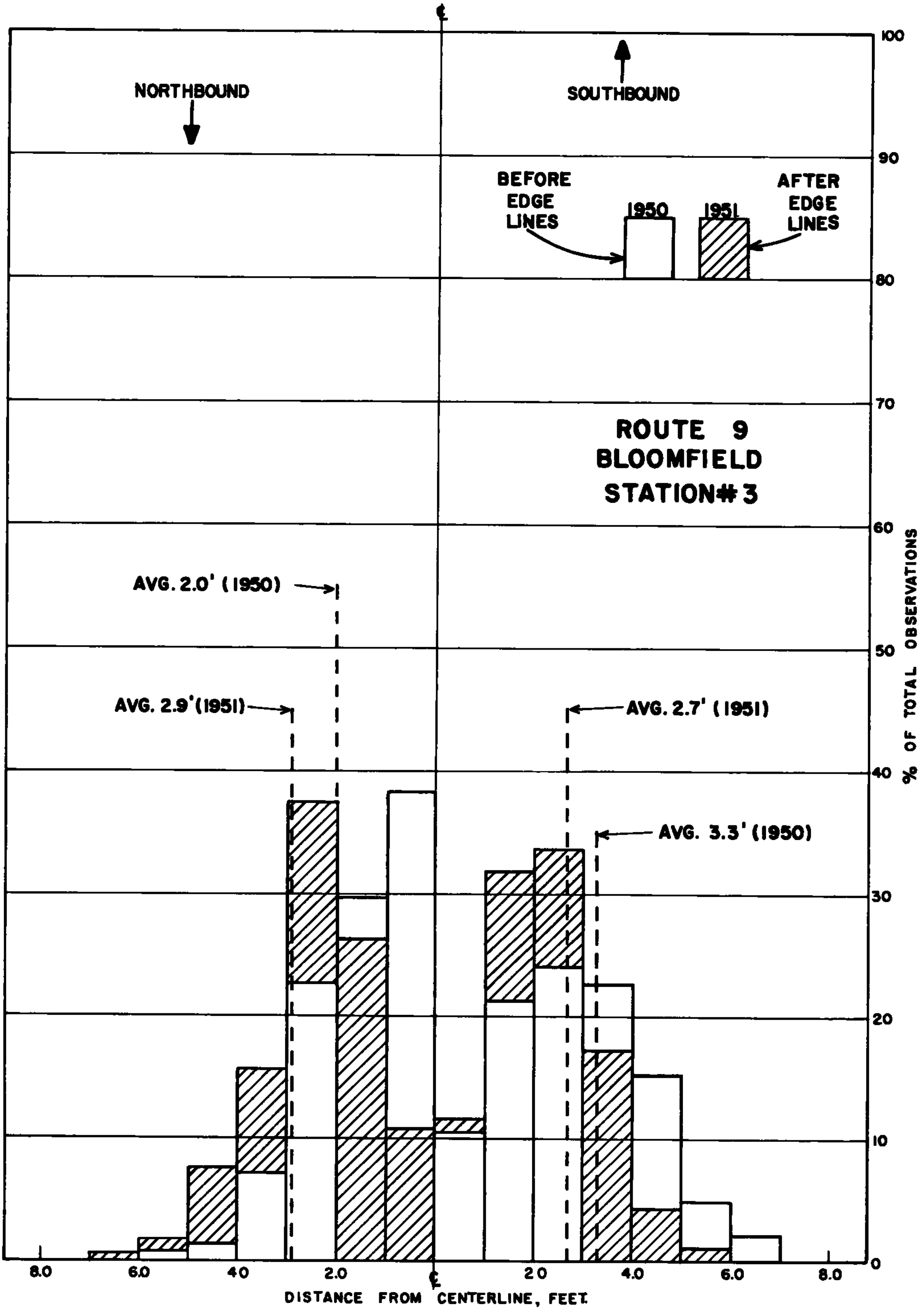

NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION # 3
AVG. 2.0' (1950)
AVG. 2.9' (1951)
AVG. 2.7' (1951)
AVG. 3.3' (1950)
100
90
80
70
60
50
40
30
20
10
0
% OF TOTAL OBSERVATIONS
8.0
6.0
4.0
2.0
℄
2.0
4.0
6.0
8.0
DISTANCE FROM CENTERLINE, FEET

Figure 8.

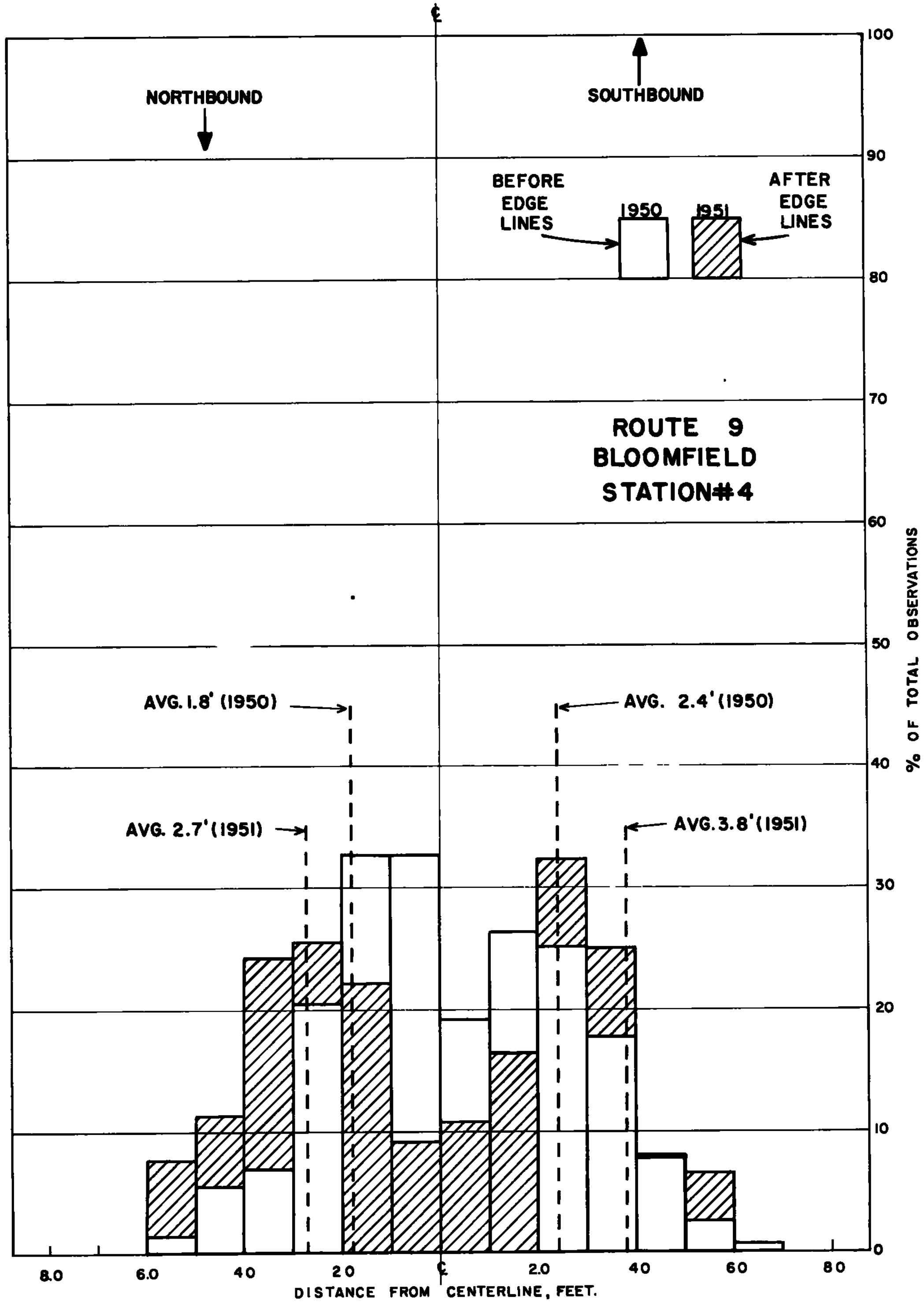

NORTHBOUND
SOUTHBOUND
BEFORE EDGE LINES
1950
1951
AFTER EDGE LINES
ROUTE 9
BLOOMFIELD
STATION#4
AVG. 1.8' (1950)
AVG. 2.4' (1950)
AVG. 2.7' (1951)
AVG. 3.8' (1951)
100
90
80
70
60
50
40
30
20
10
0
% OF TOTAL OBSERVATIONS
8.0
6.0
40
20
℄
2.0
40
60
80
DISTANCE FROM CENTERLINE, FEET.

Figure 9.

TABLE 2

SUMMARY—AVERAGE LATERAL POSITIONS[a]

Time	Condition	Number Samples Obtained	Mean Position (ft)
Day	Before	297	3.73
Day	After	231	3.85
Night	Before	172	2.28
Night	After	162	2.69

[a] Distance in feet from centerline of road to left wheel of vehicle.

Figure 11 shows that during the daytime, with no edge stripe, vehicle speeds rose slightly between the beginning and middle of curve and then dropped sharply on reaching the end of curve.

At night the speeds dropped 4 mph between the beginning of curve to middle of curve and rose slightly from this point to end of curve.

With a 4-in. line 18 in. outside of the pavement edge in the daytime vehicle speeds dropped slightly between beginning and middle of curve and

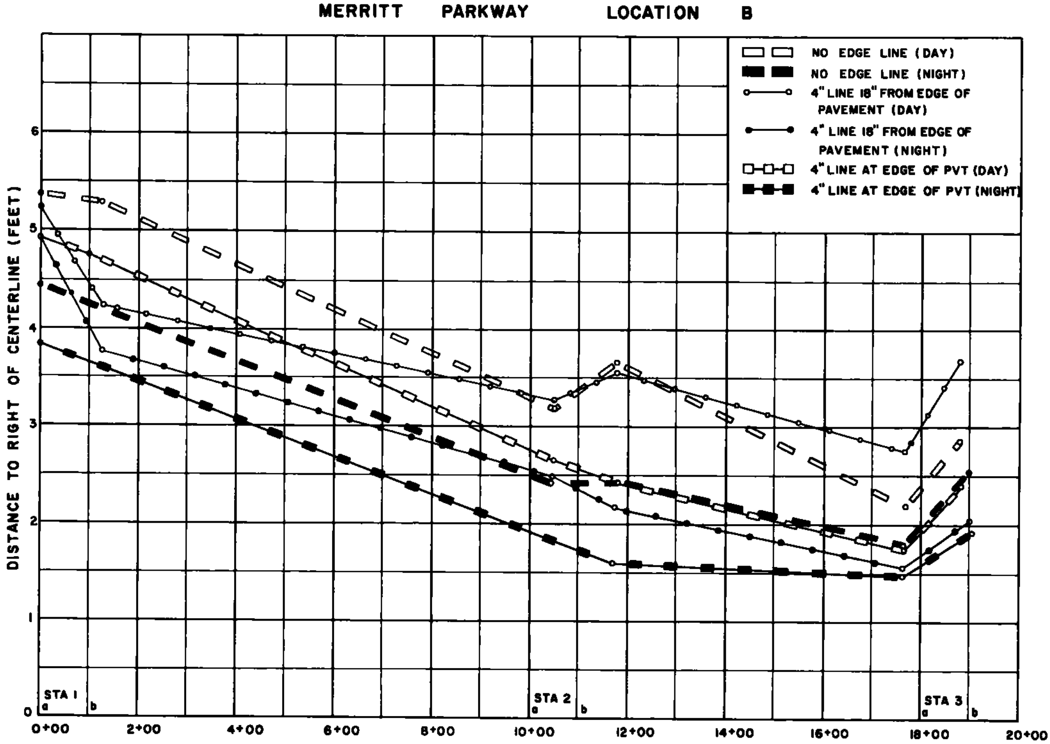


Figure 10.

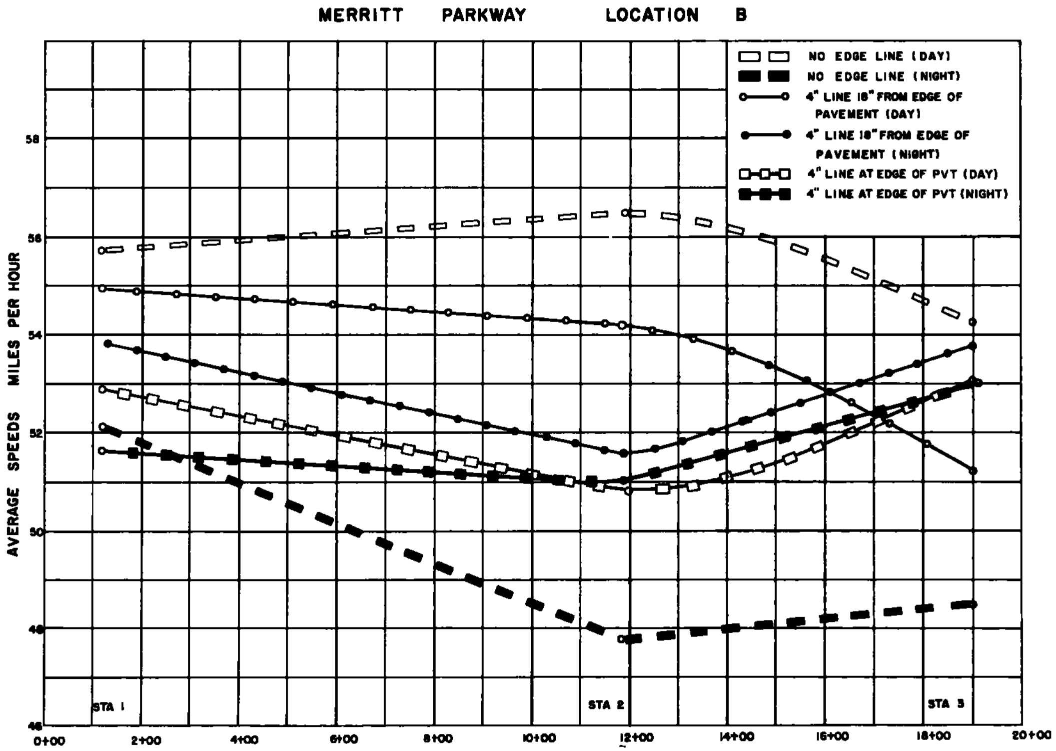


Figure 11.

then lowered abruptly to the end of curve. At night the speeds dropped sharply from beginning to middle of curve and then rose towards the end of curve.

With the edge line at edge of pavement during both day and night operation speeds lowered slightly from beginning of curve to the mid-point and then rose slightly to the end of curve.

It appears that a more uniform movement occurred when a 4-in. line was painted on the pavement's edge.

TABLE 3

SUMMARY—SPOT SPEEDS

Time	Condition	Number Samples Obtained	Mean Speed (mph)	85% Speed (mph)
Day	Before	277	47.7	51.8
Day	After	230	51.8	55.2
Night	Before	172	43.6	48.5
Night	After	161	50.1	54.7

A comparison of average lateral positions under the various conditions of the study at Location C are given in Table 2. After installation of the pavement edge line, the changes in the average lateral position of vehicles are noted as follows:

Daytime—a shift of 0.12 ft to the right, away from the centerline or, toward the edge of line.
At night—a shift of 0.41 ft to the right, away from the centerline toward the edge line.

A comparison of daytime with nighttime average lateral positions reveals the following:

Before edge line—night positions are 1.45 ft nearer to the road centerline than day positions.
After edge line—night positions are 1.16 ft nearer to the road centerline than day positions.

Spot Speed—Analysis

A tabular comparison of spot speeds irrespective of lateral position is given in Table 3.

From Table 3, it is apparent that after the installation of the pavement edge lines, the daytime average speed increased 4.1 mph and the nighttime average speed increased 6.5 mph.

Average speeds at night were consistently less than daytime average speeds; however, after painting of the pavement edge line, the speed differential between night and day speeds was reduced from 4.1 to 1.7 mph.

When the after studies were started, edge markings had been placed using yellow reflectorized paint.

At Location D where 4 separate conditions were studied, vehicle placement was first observed with no pavement markings. Vehicle placement was again observed after the application of a white reflectorized centerline. A third observation was made after the addition of a continuous 4-in. yellow reflectorized shoulder line.

The study was undertaken on weekdays from October 28, 1957, through December 31, 1957, from 12: Noon to 8:00 P.M. Vehicle placement was observed for one direction only, with no differentiation between vehicle types. The only two vehicle maneuvers considered were free-moving and meeting opposing traffic. Average values of the transverse placement are shown in Figures 10, 11, 12 and 13.

These Figures indicate the following trends:

1. With or without pavement markings, both free-moving vehicles and vehicles meeting opposing traffic tend to travel closer to the known centerline at night than during daylight hours.
2. The transverse placement of vehicles on a road with centerline and edge marking varies with the positioning of the shoulder line.
3. The vehicle placement of a centerline marked highway is closer to the known centerline than on a similar unmarked highway.
4. The addition of an edge line to the centerline has little effect during the day; however, at night this additional edge marking tends to position free-moving vehicles more centrally in the marked lane.
5. The positioning of vehicles with opposing traffic showed little change except on the widest section of roadway where the position away from the centerline at night indicated the greatest variance.

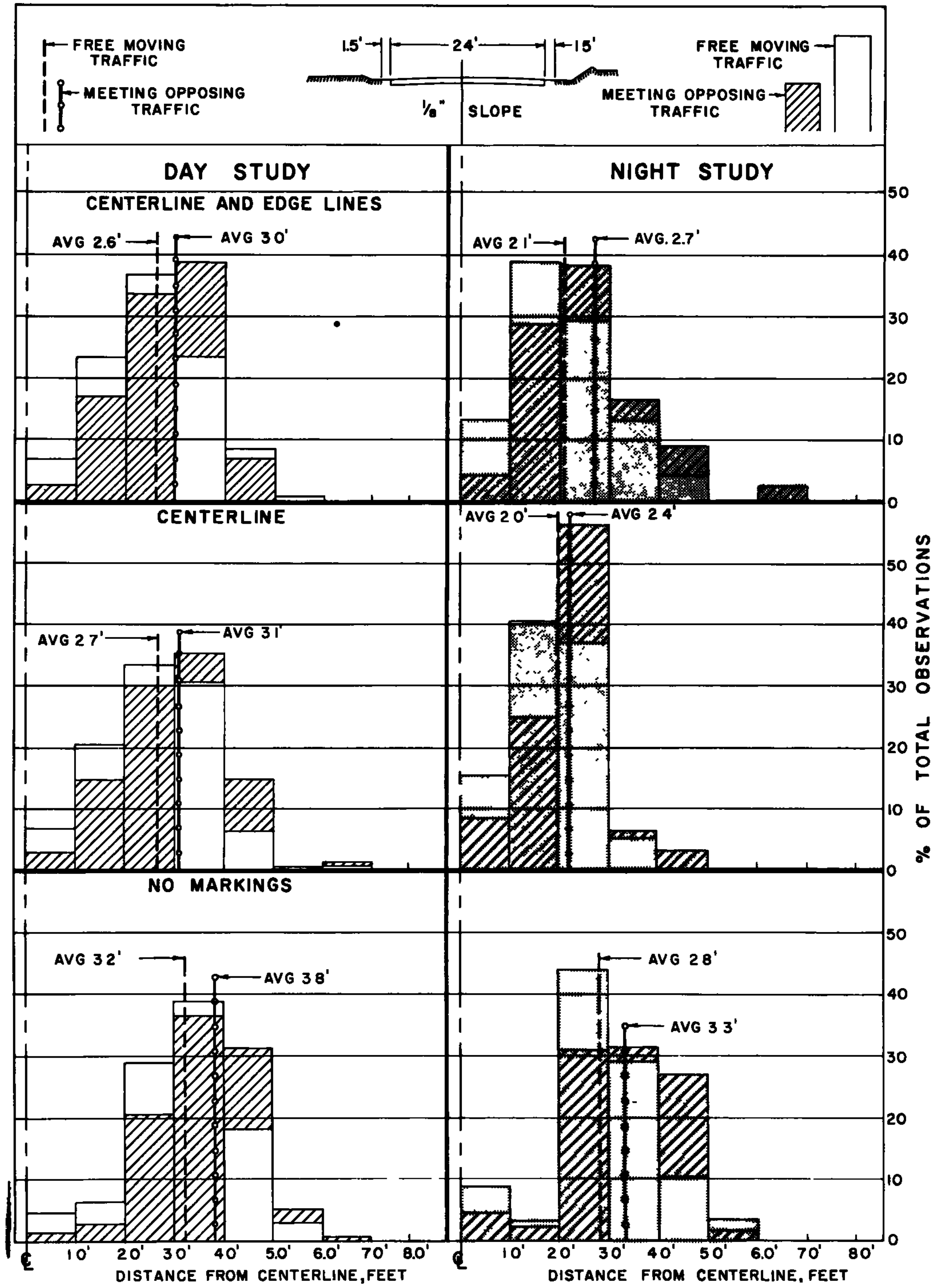


Figure 12. Farmington Station #1.

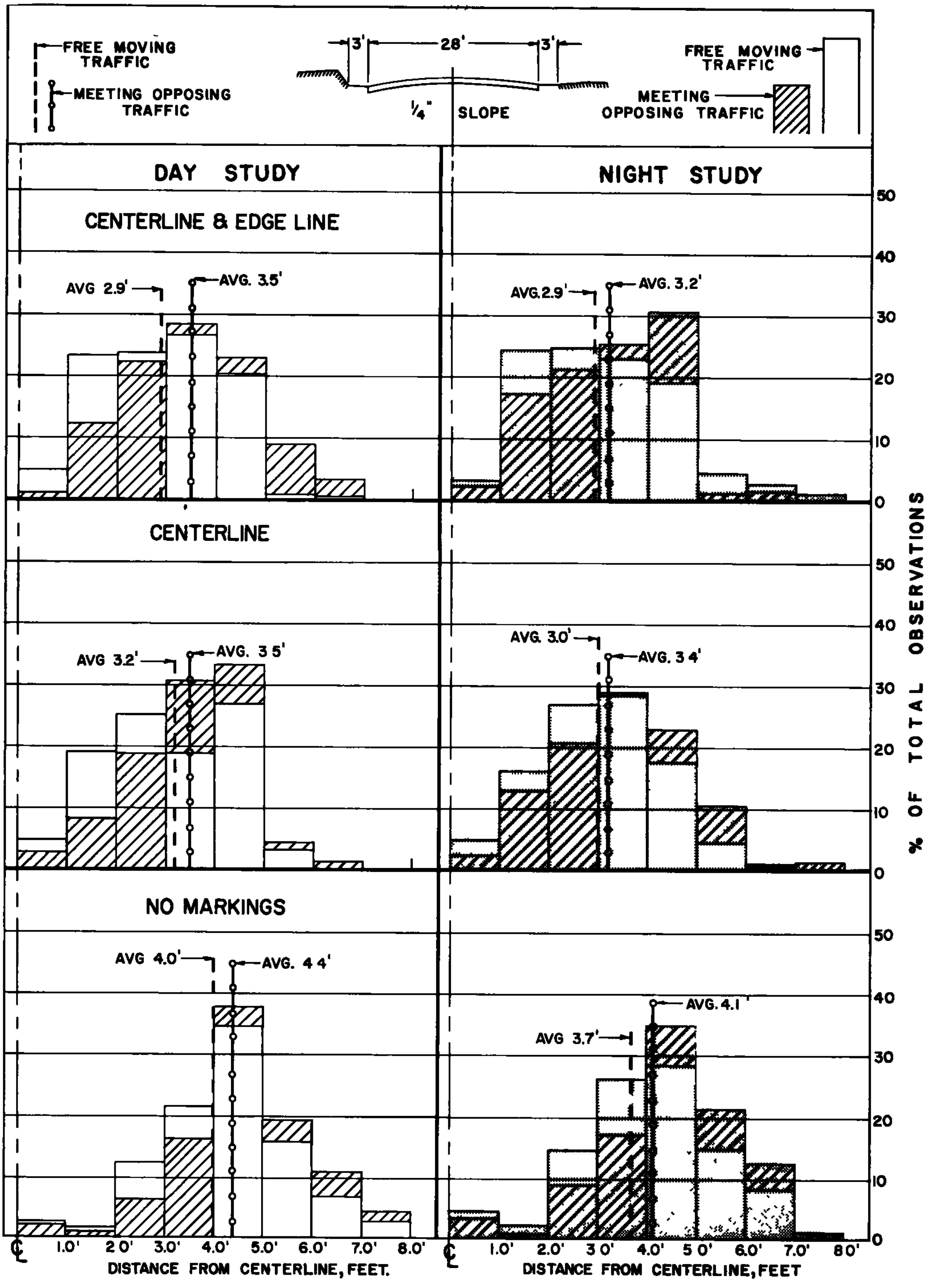


Figure 13. Farmington Station #2.

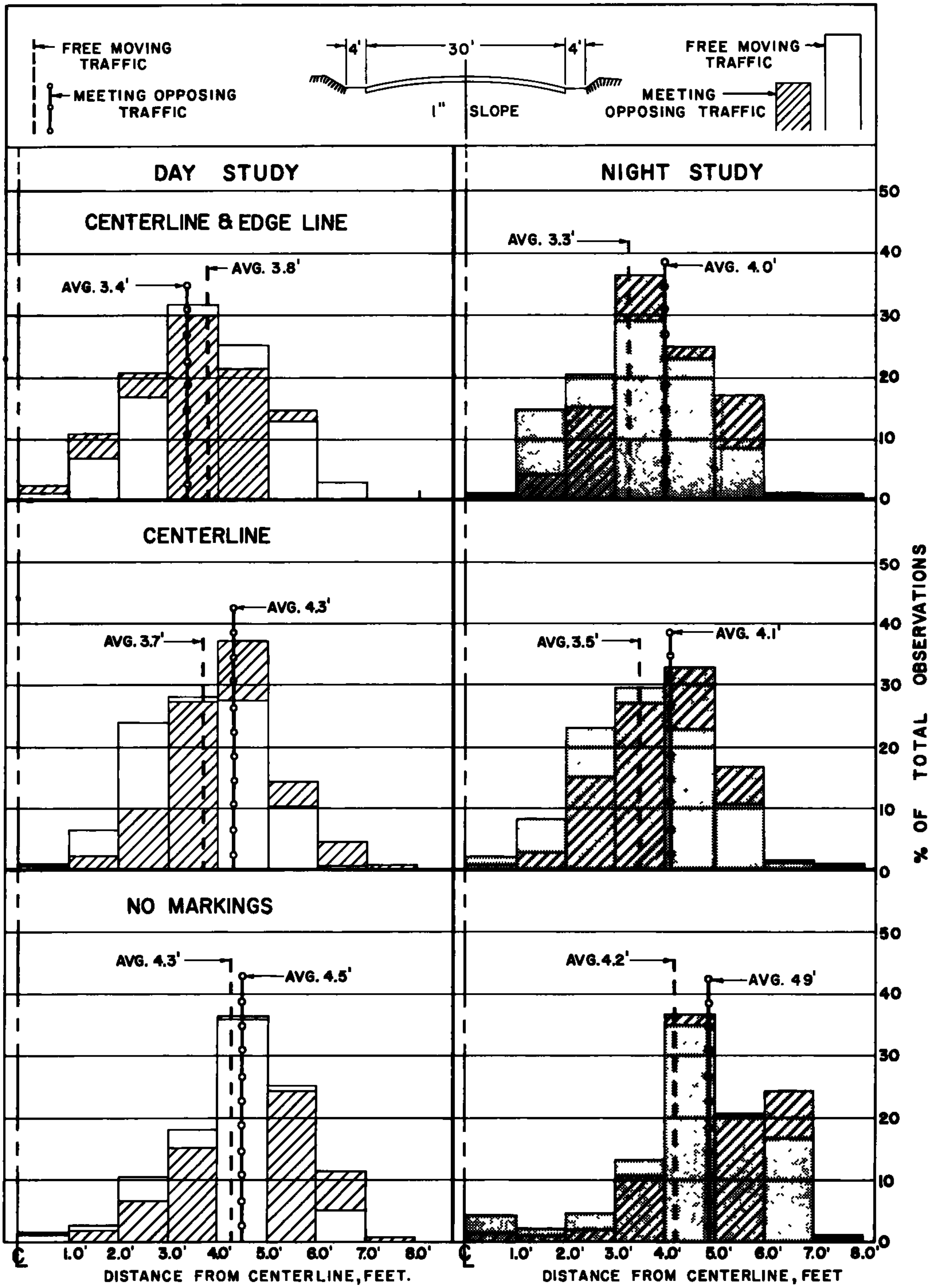


Figure 14. Farmington Station #3.

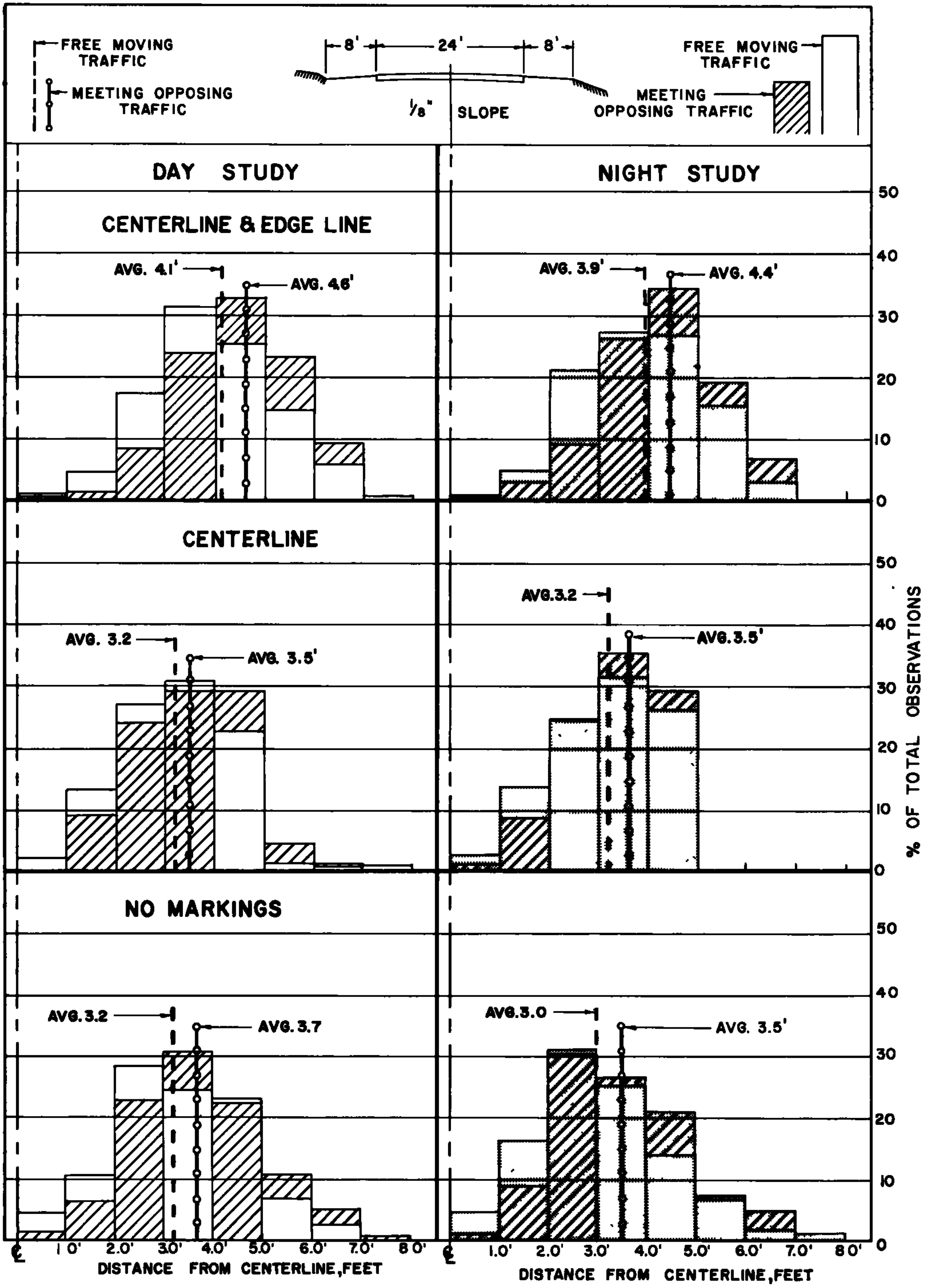


Figure 15. Farmington Station #4.

TABLE 4

MERRITT PARKWAY—SUMMARY OF ACCIDENTS TO RIGHT OF TRAVELWAY

Contributing Factors

	1953		1955		1957	
	Lt.	Dk.	Lt.	Dk.	Lt.	Dk.
Driver inattentive	28	22	19	10	10	16
Surface condition	18	10	37	25	19	18
Driver asleep or incapacitated	10	13	2	12	13	17
Tire failure	4	7	5	2	9	3
Other mechanical failure	4	2	3	2	1	0
Passing maneuver	8	3	3	7	4	3
All others	3	2	7	0	3	4
Totals	75	59	76	58	59	61

ACCIDENT EXPERIENCE

At the four locations studied there appears to be no reliable data which might indicate possible accident reduction which might be related to the presence of a shoulder line.

Although no figures are presently available, it is generally accepted as factual within the Department that the pedestrian accidents, many of them fatal, at the first mentioned location where "shoulder lines" were placed were essentially eliminated.

The Merritt Parkway accident experience does reveal certain data which might indicate a reduction in accidents after the edge markings were placed (Table 4).

Table 4 is a summary of accidents in 1953, 1955, 1957 which involved vehicles leaving the roadway on the right-hand side. The inattentive classification is perhaps the only grouping that may indicate the influence of an edge line.

In 1953 when there were no edge markings there were 50 of this type accident (28 day—22 night). In 1955 one complete year with a white edge line shows 29 of this type accident (19 day—10 night). In 1957 one complete year with yellow edge lines there were 26 accidents of this type (10 day and 16 night).

CONCLUSIONS

1. On 2-lane and 4-lane divided highways the presence of a painted line along the outer edge of pavement affects the lateral position of vehicles. The most significant change in position occurs during darkness.
2. Some reduction in accidents involving vehicles leaving the roadway on the right is apparent on the 4-lane divided highway after an edge marking is placed.
3. The presence of an edge line along roadways where pedestrians

must use shoulders because of the absence of sidewalks offers additional security to both pedestrians and drivers.

4. It appears that an outer edge line provides pavement delineation and a point for a driver to focus his eyes when faced with oncoming headlights.

5. Edge markings appear to have some influence on operating speeds, a factor which might permit a deduction that the added delineation of the pavement edge increases driver confidence with a resulting safer operation.

Shoulders and Accident Experience on Two-Lane Rural Highways: A Summary

R. C. BLENSLY, Planning Survey Engineer, and
J. A. HEAD, Assistant Traffic Engineer,
Oregon State Highway Department, Salem

Several studies have been made attempting to determine the relationship between the frequency of accidents and the width of shoulders on 2-lane rural highway sections. This report brings together the information available from these past studies and correlates them with Oregon's concluding research on this phase.

The studies of gravel shoulders on 2-lane rural highways have indicated a tendency for total accidents and property-damage accidents to decrease as the shoulder width increased for the intermediate traffic volume ranges. No relationship was indicated for the low and high traffic volume ranges, nor was any relationship found for personal-injury accidents.

In contrast to the gravel shoulder studies, the studies of paved shoulders on 2-lane rural highways have indicated a tendency for total accidents and property-damage accidents to increase as the paved shoulder width increased. For personal-injury accidents the same relationship has been indicated in one study, but was not found in another study.

In summary, it appears rather certain that higher average accident frequency occurs on sections having wide paved shoulders. The findings of the studies could be stated to the effect that "it cannot be shown that increasing the width of paved shoulders is actually helpful in reducing accident frequency on 2-lane rural highways." Although there appears to be an adverse relationship between shoulder width and accidents, it must be kept in mind that this is only one element of many governing the selection of proper shoulder width.

● THE STEADY INCREASE in the weight and size of trucks and the growth of traffic volumes has resulted in considerable damage to highways in the area of the shoulder immediately adjacent to the traveled portion of the roadway. During recent years, it has become standard practice on highways with heavy volumes and/or heavily loaded vehicles to pave an additional distance of the shoulder beyond the normal travel lane. This additional paving has been added to reduce maintenance costs by increasing the strength of the pavement. Among the by-products received from this paving of the shoulder was believed to be increased safety by the provision of an emergency area which would allow disabled vehicles to pull off the roadway. It was also felt that the increased width of pavement would change the lateral placement of the vehicles. Several studies have now been conducted to study the relationship between paved shoulders and changes in the safety features as a result of shoulder improvement.

In 1953 one of the first comprehensive analysis of accidents and relationship to various roadway elements was reported by Morton S. Raff (1). This study, however, did not deal with paved shoulders, rather it is believed that most of the data analyzed were for graveled shoulders. The New York Studies in 1956 and 1957 (3, 4) also reported on the relationship between accidents and graveled shoulders. In 1956 one of the authors (J. A. Head) reported on the relationship between accident data and the width of graveled shoulders in Oregon (2). The Oregon study was an actuality prompted by two earlier studies by Belmont (5, 6), studies on paved shoulders in California. A study in Oregon on the relationship between the frequency of traffic accidents and the width of paved shoulders was reported in 1959 by the authors (7), and subsequent to that time research has been continued in Oregon which is contained in an unpublished report in the files of the Oregon State Highway Department.

Considerable research has been completed, and as is often the case, some contradictory results have been presented. In the main, however, the various studies have tended to compensate each other, and much valuable information is available for actual application. It is the intent of this report to pull together all data, so that it will be readily available in summary form for use by those parties desiring information on the relationship between paved shoulders and accident experience.

GRAVEL SHOULDERS

In Raff's report (1) it was the intent to determine, if possible, how accident rates on main rural highways are affected by design features and use characteristics. To supply the necessary data, 15 states supplied information covering a year's accident experience on about 5,000 mi of highway. The basic technique involved divided the study routes into a large number of short homogeneous sections which could then be combined so as to group these sections according to any factor whose effects were of interest. An accident rate was computed for each group. Regression coefficients were computed where it appeared that there was a steady trend or relation between accident rate and the roadway characteristic. The study indicated that on 2-lane tangent highways there was no significant relationship between shoulder width and accident experience. However, on 2-lane curves there was a definite tendency for a reduction in the accident rate with increased shoulder width.

The Oregon report of gravel shoulders (2) was confined to a study of shoulders on tangent and level sections of rural highway. This provided for a physical control of terrain, curvature, sight distance, accesses, etc. Those sections which had 30 percent or more sight distance restrictions were excluded from this study. In Raff's report (1), considerable difficulty was experienced in comparing the data obtained from the different states, because of the difference in accident reporting from one state to the next. In the analysis of the data in his study three analyses were made so that accident data could be grouped based on different assumptions. In the Oregon study, however, it was felt that accident reporting was very good and generally represented 80 to 90 percent of all accidents. It was, therefore, possible to compute the relationship not only for total accidents, but for property damage and personal-injury accidents. In the Oregon study no significant relationship was found between shoulder width and accident experience for those sections with an ADT less than 3,600 vehicles per day. In the higher ADT ranges (in excess of 3,600 vehicles per day) the frequency of all types of accidents appeared to decrease as shoulder widths increased. Statistically, the only reliable trends were that total accidents and property damage accidents decreased as shoulder widths increased in the 3,600 to 5,500 ADT range. No statistical or significant relationship was found between accidents and shoulder widths for those sections with an ADT of 5,600 to 7,500 vehicles per day. No significant relationships were found between shoulder width and personal-injury accidents.

The New York Report (4) was fairly evenly divided between earth and/or grass, and graveled and/or macadam shoulders. The study was confined to accidents reported on Highway Form HA-48, and covered a period from October 1947 through July 1955. The accidents included in this report were fatal and serious-injury accidents, and those accidents occurring on the highway system which involved state-owned motor equipment. For the study, only sections on 2-lane rural highways were studied.

The New York Study indicated that medium wide shoulders had lower accident indices than narrow shoulders under all conditions of horizontal and vertical alignment. Wide shoulders had lower accident indices than narrow and medium wide shoulders on poor alignment.

PAVED SHOULDERS

The initial study of paved shoulders was conducted by Belmont (5) based on personal-injury accidents reported for 2-lane rural highways of the California Interstate Highway System for the year 1948. The sample was further limited to rural areas with a 55 mph speed limit, no extensive roadside culture and predominately straight and level. All sections included in the study had paved or treated shoulders with some being concrete, but the large majority bituminous. Regression equations were computed using the square root of the number of accidents as a dependent variable. The erratic nature of data required that the analysis be based on three shoulder widths; that is, less than 6 ft, 6 ft, and more than 6 ft. The study indicated that shoulders 6 ft wide were safer than the narrow shoulders, and further they were also safer than the wider shoulders for those sections with a traffic volume in excess of 5,000 vehicles per day.

Because of limitations of the original data, Belmont followed with a study (6) based on California data for the years 1951 and 1952. The sample in the study included only the sections with paved shoulders bordered by not more than 1 ft of untreated or soft shoulders. Roads were excluded if they adjoined long stretches of firm ground which could readily be used as shoulders by a motorist. The roads were all in rural areas with a 55 mph speed limit and no extensive roadside developments. They were generally straight and level and no curves to restrict speed or visibility.

Because of the method of accident reporting, it was desirable to confine the study to an analysis of personal-injury accidents only. Regression equations were computed using the square root of the number of accidents as the dependent variable for ungrouped data and the number of accidents as the dependent variable for grouped data.

The general results of the study indicated a tendency for injury accidents to increase with increases in shoulder width, except for sections with traffic volumes less than 2,000 vehicles per day for which no relationship was found. This report contradicts to some extent the earlier investigation; however, they do agree that 6-ft shoulders appear to be safer than the wider shoulders at high traffic volumes.

This pioneer effort on paved shoulders raised many an eyebrow, inasmuch as the results were quite contrary to what most students in the field would expect. Therefore, additional studies were undertaken in Oregon to determine if the relationships were chance relationships with respect to personal-injury accidents only, or whether the same relationships might be found for all accidents.

The accident reporting in Oregon as contrasted to California requires a report for any accident occurring on a public way, regardless of the extent of property damage. Although it is a known fact that not all accidents are reported, it is generally assumed that 80 to 90 percent of the total accidents are reported, and that those not reported normally involve only minor property damage.

The authors reported in 1959 on the Oregon Study (7) on the relationship between paved shoulders on level and tangent rural 2-lane highways and accident frequency. Because of the limited number of sections with paved shoulders, it was necessary to use sample elements in the analysis. The sample elements were obtained by multiplying each 1-mi section of highway meeting the minimum criteria for the study by the number of years for which accident data were available after the paved shoulders were constructed. This then provided a sufficient sample for the analysis.

Two methods were utilized in Oregon's procedures—the partial correlation technique and the analysis of co-variance. The partial correlation technique was utilized to determine if there were any relationship between accident frequency and paved shoulder width. With the exception of the 2,000-2,999 ADT range where property damage and total accidents showed a significant tendency to increase as the width of the paved shoulders increased, no relationship between accident frequency and paved shoulder width was found. The analysis of co-variance, on the other hand, indicated that the wide paved shoulders had a significantly higher mean number of property damage and total accidents than did the narrow paved shoulders. In the analysis of co-variance, shoulder widths were grouped; those over 8 ft and those under 4 ft. There were insufficient samples of paved shoulders in the widths from 4 to 8 ft, therefore they were not included in this analysis. No significant relationships were found for personal-injury accidents by either method of analysis.

The final study in Oregon, an unpublished report, varies from the original in that it considered all sections which had horizontal and vertical alignment restrictions. It was again confined to rural 2-lane highways. It was felt that this additional study, along with the original, would encompass all possible rural 2-lane sections without regard to alignment characteristics.

Although there were large differences in alignment for the sections included in the two studies, the relationships as found in the first study were identical to the relationships found in the second study. This would indicate then that in Oregon there is a tendency for the accident frequency to increase on sections with wide paved shoulders as contrasted to sections with narrow paved shoulders, further that there is a real causal relationship between accidents and paved shoulder width for highways in the traffic volume group of 2,000-2,999 vehicles per day.

DISCUSSION OF FINDINGS

Although definite relationships have been found between shoulder widths and accident experience, there is still some question as to exactly how these two are related. Figure 1 shows graphically the relationship as generally found in the studies. This figure is a symbolic presentation only, and indicates that in general gravel shoulders tend to have a decreasing accident experience with an increase in shoulder width. On the other hand, paved shoulders tend to have an increase in accident experience with increasing shoulder width. These general tendencies have been found in all studies reported to date. It must be remembered, however, that in some of these studies the relationships were found only for property-damage accidents, and in others only for personal-injury accidents, and in most instances the relationships were statistically significant only for certain traffic volume ranges. It is quite possible that a negative result is indicated from the studies; namely, "that it cannot be shown that increasing the width of paved shoulders is actually helpful in reducing accident frequency on rural 2-lane highways."

The analysis of data does not tell us why wide gravel shoulders should be safer than narrow gravel shoulders and on the other hand why wide paved shoulders are more hazardous than narrow paved shoulders. It is possible that items such as the greater off-the-road parking space, or the greater emergency maneuverability provided by this off-the-road parking space received different type of use for highways with different types of shoulders; that is, graveled or paved. In the gravel shoulder study an attempt was made to relate the speed to ADT and accident experience. It was found in intermediate volume ranges from 3,600 to 5,500 vehicles per day that there was no significant relationship between shoulder width and speed, whereas, in the volume range of 5,600 to 7,500 vehicles per day vehicles were found to move faster on those sections with the wider shoulders. It appears that the detracting influence of increased speed on the benefits of the wider shoulders may have been partially responsible for the insignificant tendency for a reduction in accident frequency on wider shoulders in the higher ADT ranges. It is entirely conceivable that this relationship between ADT and speed becomes much stronger for sections with paved shoulders and may even reach the point where the reduced accidents resulting from increased shoulder width are offset and the trend is reversed by the increase in accidents due to increased speeds. To date, however, no factual study has been made to check this theory.

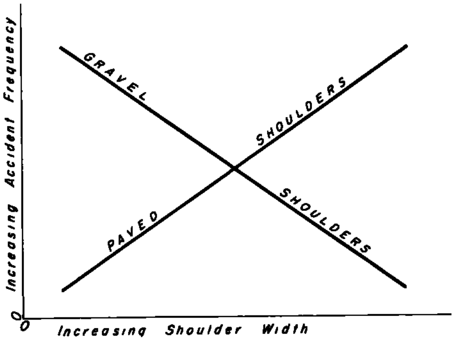


Figure 1. Accident frequency and shoulder width.

An analysis was made to help explain why accidents increased with the increase in the paved shoulder width. For this analysis the total shoulder width, paved plus gravel, was considered. It was thought that possibly those sections with a high number of accidents on wide paved shoulders had narrower over-all shoulder width. A preliminary analysis, however, indicated that those sections with high accidents and wide paved shoulders normally had the widest over-all shoulder width. It appears that one of the original conclusions made by Belmont (6)—"As shoulder width increases, drivers may gain an unjustified feeling of security. Speed may increase, with an attendant rise in accident rate"—has as much meaning today as it did when it was first made.

It must be remembered that the paving of shoulders was initially a design function to help increase the structural strength of the pavement and was not done primarily to increase the safety to the motoring public. It does appear from the data available that no additional safety can be gained by adding extra width to the paved shoulders, and that, therefore, the width of the paved shoulders should probably be controlled by the width required to obtain the structural strength necessary to avoid raveling and deterioration of the pavement by heavy traffic volumes or heavily loaded vehicles coupled with emergency stops.

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California Median Study: 1958

K. MOSKOWITZ, and
W. E. SCHAEFER, Assistant Traffic Engineers
California Division of Highways, Sacramento

This study concerns the relative safety of the various types of median design, including the positive barrier median, on divided highways carrying traffic volumes in excess of 15,000 vehicles per day, and the development of tentative criteria for the installation of positive median barriers. A report covering a previous median study of divided highways which carried volumes up to 25,000 vehicles per day was presented at the HRB Thirty-Second Annual Meeting.

An analysis was made of the approximately 8,000 accidents which occurred in 1956 and 1957 on some 265 mi of divided highway with deterring and non-traversable median designs. Operating conditions, as measured by the average daily traffic (ADT) volume, apparently influenced the relative safety of the deterring and non-traversable medians. In the volume range of up to 130,000 vehicles per day, the deterring-type median had the lower accident and injury rate. In the volume range of 130,000 or more vehicles per day, the advantage shifted to the non-traversable medians which had the lower accident and injury rate.

To emphasize the cross-median fatal head-on-type accident, the 407 fatal accidents which occurred on freeways in 1956, 1957 and 1958 were then analyzed.

During this period, the cross-median collisions accounted for 19 percent of the fatalities on freeways. Freeways carrying more than 60,000 vehicles per day accounted for one-fifth the mileage and two-thirds of the fatal cross-median collisions. Therefore, in order to make a significant attack on the cross-median fatal accident problem, it would be necessary to reach down to the 60,000 ADT level with the installation of median barriers. Past experience indicates that barriers may convert cross-median accidents to other types. However, newly-developed barrier designs may reduce the severity of collisions with the barriers and result in fewer casualties even though the accident rate may rise.

● DIVIDED HIGHWAYS have demonstrated their ability to carry large volumes of traffic efficiently and safely. However, the most modern highway does not prevent all accidents. This results in a continuing demand to improve design and increase safety.

One of the major questions with respect to safety is the type and design of medians for the various conditions under which they must be constructed. Varying terrain in rural areas and high cost of right-of-way in urban areas has led to a variety of median designs.

ACCIDENT RATES AND TYPE AND WIDTH OF MEDIAN

In an effort to evaluate the safety of the various types and designs of medians, a comprehensive study of medians was made in 1952. This study was based on 12,836 reported accidents on 563 mi of 4-lane divided highways with traffic volumes up to 25,000 vehicles per day.

The 1952 study indicated that the type of median influenced the accident rate, and, with respect to those highways within this range of traffic volumes, the traversable and deterring-type medians were superior to the non-traversable group. However, there appeared to be an indication that at higher traffic volumes the non-traversable median might be superior. At that time, there was not much experience with high traffic volumes, and firm conclusions could not be drawn regarding highways in that class.

Since the previous report was made, there has been a tremendous increase, both in traffic volumes and in the mileage of divided highways. For example, a portion of the Hollywood Freeway in Los Angeles carries a traffic volume of 200,000 vehicles per day.

The purpose of the present study is to investigate the effect of median design on accident rates for divided highways carrying traffic volumes in excess of 15,000 vehicles per day and to develop criteria for the use of the various types of median.

DESCRIPTION

A field investigation was made of all divided highways with a 1955 volume of 15,000 or more vehicles per day to establish the location and types of median and to log all features which might affect the accident rate.

To reduce the influence of factors other than median design, only freeways (no intersections), expressways (access rights to adjacent property are severely restricted, but there are intersections), and highways without roadside development were investigated. The study, then, is essentially a comparison of median types as applied to limited-access facilities.

From approximately 530 mi of highway logged in the field, 265.76 mi were selected for detailed study. The remaining mileage was eliminated because of factors other than median design which possibly would influence the accident rate or because of the inability to obtain adequate accident records. All intersection accidents were eliminated.

The median designs were classified in two general categories that were used in the 1952 study, as follows:

1. The deterring type, which, by a physical obstruction, discourages deliberate entrance or crossing of the median. The raised bar or low dike, the mountable double curb, and most of the earth-type medians with flat cross-slopes are in this group.

2. The non-traversable type, which, by a physical obstruction, would presumably prevent crossing from one roadway to another without a reportable accident. Separate roadways; barrier-type medians, including the non-mountable curbs; and earth medians with a continuous obstruction are included in this group. Also included in this group are earth medians with a steep cross-slope. Additionally, all medians greater than 100 ft in width were classified as non-traversable.

The mileage of traversable type medians, such as a paved median or an earth median with a flat, smooth, hard surface, which was available

TABLE 1

Type	Mileage		Accidents	
	1956	1957	1956	1957
Deterring:				
1. Earth median; soft or loose surface, slopes 4 to 1 or flatter	134.80	132.67	1107	1222
2. Double-curbed median with standard curbs less than 6 in. in height	45.34	63.14	1311	1777
3. Miscellaneous features: median with ditch, dike or high raised bars	13.34	14.25	131	175
Sub-total deterring type	193.48	210.06	2549	3174
Non-traversable:				
1. Barrier-type median with guardrailing or concrete wall to prevent crossing	13.78	12.52	367	388
2. Barrier-type median with concrete posts to prevent crossing	18.71	17.78	130	101
3. Barrier-type median with fence to prevent crossing	5.73	3.82	78	57
4. Two separate roadways with slope in median steeper than 4 to 1 or median width greater than 100 ft	13.82	14.66	474	404
5. Miscellaneous features: earth or paved median not crossable because of ditch high curb, or other similar feature	8.87	6.92	140	132
Sub-total non-traversable type	60.91	55.70	1189	1082
Grand total	254.39	265.76	3738	4256

for study was considered too small to draw any conclusions from, because it comprised only two or three short sections of highway.

A summary of the mileage and number of accidents studied in each category is given in Table 1. Examples of the various median types are shown in Figure 1.

Many variables other than median type and design influence the frequency of accidents. Among these are the exposure as measured in vehicle-miles of travel, the design standards and features of a particular facility, traffic density, climatic conditions, speed differentials and many others. Obviously, not all of these variables may be controlled in this kind of study. However, it should be noted that no one section of highway was large enough to bias the over-all results, and in general it was considered fair to assume that variables other than volume were distributed randomly among the median classifications studied, because changes in median type and design occurred frequently along almost all lengths of highway. The 266 mi of highways studied is made up of segments averaging 0.61 mi in length with a maximum length of segment of 5.92 mi.

INFLUENCE OF MEDIAN WIDTH

The accident rates by median width groups are plotted in Figure 2 for the two basic median types. An attempt was made to investigate the effect of the median width for the various median types within each basic group. Whereas the various sub-groups followed the same general pattern as the basic types, the individual samples were too small to correlate the degree of traversability with the accident rates for the various median widths.

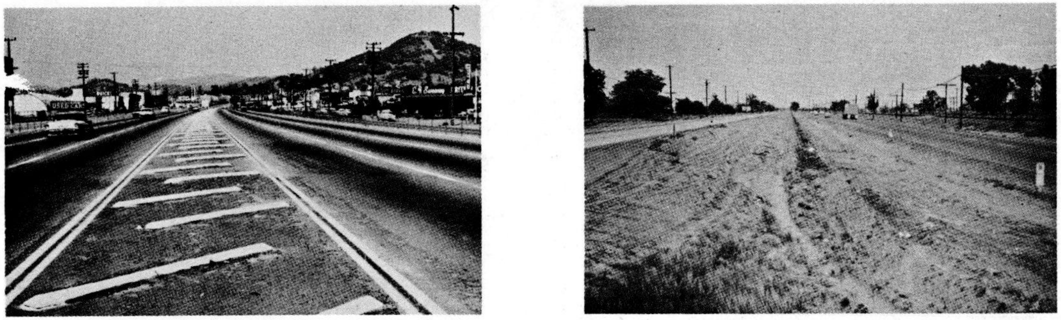
As may be seen in Figure 2, there appears to be no correlation between the accident rates and the width of median for the basic median types. This was also the case in the previous median study (1) and in a study of the accident experience with traversable medians by Hurd (2).

This seems to contradict the hypothesis that, for the same general conditions, the greater the lateral separation, the safer the facility. One explanation for this contradiction is that the median width used in this study (and as generally defined) is the width between the edges of opposing roadways, not the width available for maneuvering or for emergency parking. When a vehicle leaves the roadway, there is a good chance of avoiding a reportable accident if maneuvering room is available. The "width" of median between opposing lanes of traffic is not a direct function of this maneuvering room.

If effective width instead of "median" width were used in constructing Figure 2, a somewhat different picture might have resulted. On the other hand, wide medians (more than 16 ft) of the deterring type are generally earth medians with a slope of 4:1 or flatter. In this case, the effective width would be essentially the same as the actual width. However, this type median shows the same general pattern as the non-traversable median.

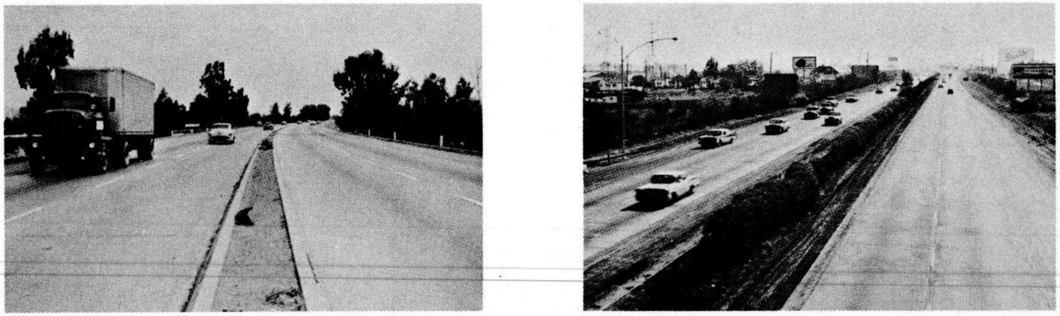
INFLUENCE OF TRAFFIC VOLUME

With respect to the over-all safety of a highway, the median types should be investigated for all operating conditions. It is recognized that hourly traffic volumes are a more accurate indication of the oper-



DETERRING-RAISED BARS

DETERRING-EARTH

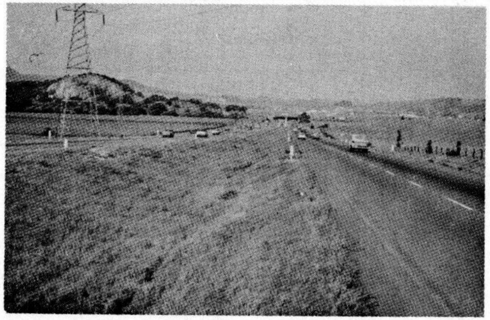


DETERRING-CURBED

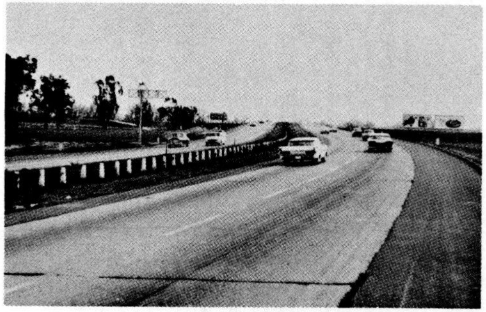
NON TRAVERSABLE-FENCE

Figure 1A.

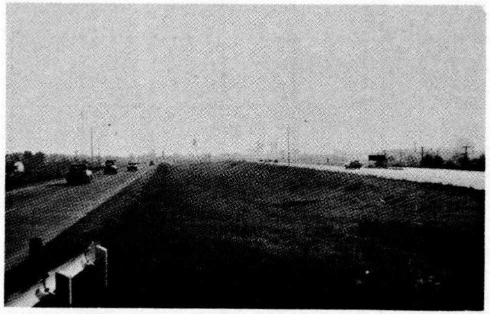
NON TRAVERSABLE-CONCRETE WALL



NON TRAVERSABLE-EARTH



NON TRAVERSABLE-BARRIER POST



NON TRAVERSABLE-SEPARATE ROADWAY

Figure 1B.

ating conditions and degree of congestion than the average daily traffic flow. However, because of obvious difficulties in relating accident rates to hourly flow, the rates were compared by volume groups, using the average daily traffic volume. It is believed that in a large sample such

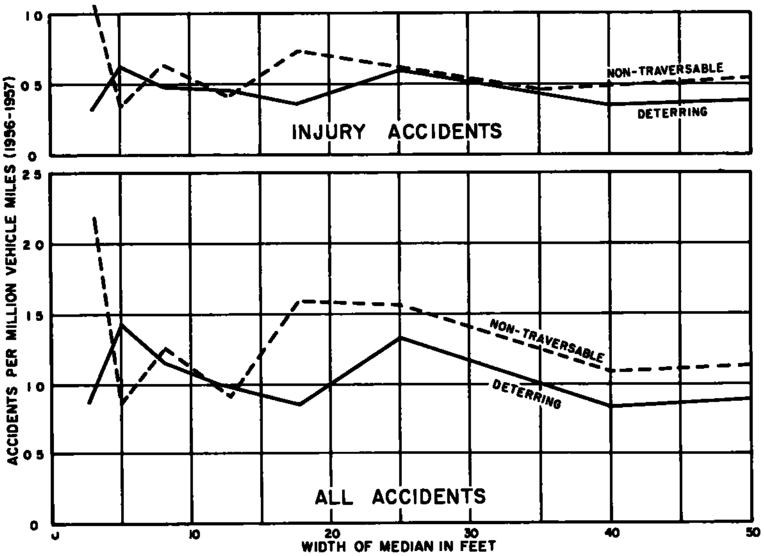


Figure 2. Accidents per million vehicle miles by width of median.

as this, facilities within the same daily volume groups will have similar hourly flow patterns except for the very low volume groups which include facilities in the more rural areas.

The effect of lane volume was also investigated, but no significant difference could be established between the accident rates for facilities carrying the same traffic volumes on different numbers of traffic lanes. However, it should be noted that in this study, there was not enough overlapping of volumes for different widths to form a real basis of comparison. That is to say, in the lower volume groups, almost all the roads were 4-lane, and in the upper volume range there were really not enough mileage of 6- and 8-lane highways carrying equal volume to compare one with the other for the same volume.

Figure 3 shows the accident rates for the two basic types of medians for various daily traffic volumes. The deterring-type median appears to be superior to the non-traversable type until very high volumes are reached. At an average traffic volume of 130,000 vehicles per day, the advantage appears to shift to the non-traversable type. This is illustrated by both the injury and all-accident rates, which follow similar patterns.

The study sections included in volume groups of 130,000 and more vehicles per day are all located in two facilities, the Hollywood and Harbor Freeways in Los Angeles. On these two freeways during the two-year study

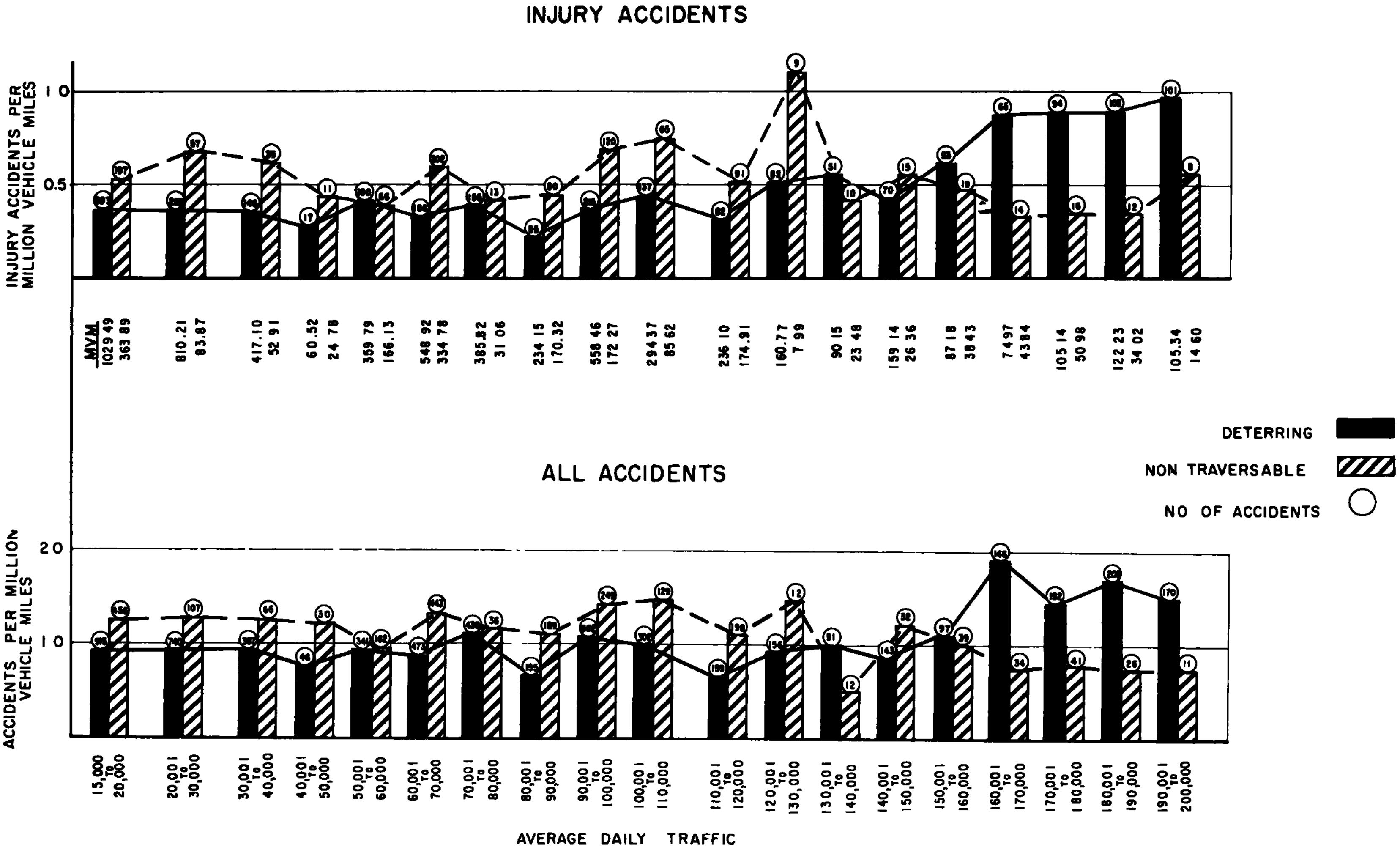


Figure 3. Accidents per million vehicle-miles by 10,000 vehicle per day volume groups.

period, there were 12.48 mile-years of double-curbed deterring type and 3.86 mile-years of non-traversable (separate roadway, guardrail or concrete wall) type. The width of the deterring type varies from 6 to 100 ft, but is typically 12 ft. It is possible that the accident rates in the very high volume groups may reflect accident conditions peculiar to these two freeways, including the fact that reporting is extraordinarily complete. Keeping this in mind, there is nevertheless an indication that at traffic volumes of 130,000 or more vehicles per day, the non-traversable type median is superior. No attempt has been made to derive a statistical measurement of reliability, but the number of accidents and number of vehicle-miles for each plotted point (bar) on the graph are given.

TABLE 1A

Type of Median	Mileage				Million Vehicle-Miles		Accidents			
	1956		1957				1956		1957	
	Volume Group I (15,000 - 130,000 ADT)									
All	247.25		256.22		6764.23		3155		3636	
Deterring:	188.36		202.41		5095.70		2079		2636	
Earth		134.80		132.67		2663.72		1107		1222
Curbed		40.22		55.49		2085.37		841		1239
Misc. features		13.34		14.25		346.61		131		175
Non-Traversable:	58.89		53.81		1668.53		1076		1000	
Guardrail or concrete wall		13.28		12.52		534.53		339		388
Barrier post		18.71		17.78		256.55		130		101
Fence		5.73		3.82		110.69		78		57
Two separate roads		12.30		12.77		511.77		389		322
Misc. features		8.87		6.92		254.99		140		132
	Volume Group II (Above 130,000 ADT)									
All	7.14		9.54		975.86		583		620	
Deterring:	5.12		7.65		744.15		470		538	
Curbed		5.12		7.65		744.15		470		538
Non-Traversable:	2.02		1.89		231.71		113		82	
Guardrail or concrete wall		0.50		0.00		26.17		28		0
Two separate roads		1.52		1.89		205.54		85		82

INFLUENCE OF MEDIAN ON TYPE OF ACCIDENT

To investigate the influence of median types on the safety of a facility in more detail, the study mileage was divided into two traffic volume ranges (Table 1A) on the basis of the preceding analysis. Volume Range 1 includes all mileage with traffic volume between 15,000 and 130,000 vehicles per day. Volume Range 2 includes the mileage with a traffic volume of 130,000 or more vehicles per day.

Tables 2A and B give the accident rates per million vehicle-miles by type of accident for the two ranges. Table 2A lists the "all-accident" rates and Table 2B lists the injury-accident rates. In both volume ranges, the overtaking-type accident accounted for the majority of the total accidents. In Volume Range 2, the approach and single-vehicle-type accidents were relatively insignificant.

In the lower volume range, the deterring-type median has the lowest total accident rate. As expected, the approach-type accident rate increases with the degree of traversability. However, in this range of volumes, it is seen that the approach-type accident (head-on) only accounts for 1/25 of all accidents and 1/21 of the injury accidents. Although the non-traversable median has the lowest rate for the approach-type accident, this advantage is more than offset by the higher rate of overtaking and single-vehicle-type accidents.

In the higher volume group, the non-traversable median had lower accident rates for all types of accidents with no approach-type accidents.

INFLUENCE OF MEDIAN ON SEVERITY OF ACCIDENTS

The severity of accidents for the several types of median is given in Table 3 for the two volume groups.

Using the number of injuries per vehicle-mile as an index of severity, it is seen that when the volume was less than 130,000 vehicles per day, the deterring type (whether curbed or earth) had the most favorable record. In fact, the number of injuries per vehicle-mile was 44 percent higher for the non-traversable type than for the deterring type.

On highways having a traffic volume in excess of 130,000 vehicles per day, the injury rate of the deterring type was twice that of the non-traversable type. This may be compared with the fact that the all-accident rate of the deterring type was 1.6 times that of the non-traversable.

MEDIAN ACCIDENTS

A breakdown of median accidents is given in Table 4 for the various median types. As expected, the deterring-type medians had the greater cross-median accident rate per 100 million vehicle-miles in both volume ranges.

On roads carrying between 15,000 and 130,000 vehicles per day, the deterring-type median has the lowest total median-accident rate per million vehicle-miles. On roads with more than 130,000 vehicles per day, the non-traversable median has the lower median-accident rate. However, the percentage of accidents involving the median was higher for the non-traversable type in both volume ranges. This might be expected, because it is known that many vehicles enter the median and recover without having an accident, unless there is something non-traversable to hit.

The severity of the median accidents is given in Table 5. On roads with traffic volumes between 15,000 and 130,000 per day, the deterring-type median had a lower accident severity as measured by the number of injury accidents, injuries, and fatalities per million vehicle-miles than the non-traversable median group. On roads with more than 130,000 vehicles per day, the advantage switched to the non-traversable.

SUMMARY

Operating conditions as measured by the average daily traffic volume apparently influence the relative safety of the deterring and non-traversable medians.

In the volume range between 15,000 and 130,000 vehicles per day, the deterring type median had the lower accident and injury rate. While the non-traversable median had fewer approach-type accidents, the higher rates of overtaking and single-vehicle accidents more than offset this advantage.

In the volume range of 130,000 vehicles or more per day, the advantage shifted to the non-traversable median, which had the lower accident and injury rate.

FATAL ACCIDENTS, FULL FREEWAYS, AND MEDIAN BARRIERS

In the foregoing, it was found that the barrier-type median does not seem to be as good as the curbed or earth type from the standpoint of overall traffic safety or severity of accidents, except on highways carrying extremely high volumes of traffic. However, that analysis did not emphasize the cross-median-, head-on-type accident at the exclusion of fatal or severe accidents of other kinds.

Full freeways (that is, divided highways with no cross traffic and no roadside access) have always had a good record in number of fatal accidents per vehicle-mile, especially when compared with other types of highways or streets. However, even freeways do have fatal accidents, and as the mileage and travel on them has increased, the number of fatal accidents has increased. Perhaps because of their rarity, each of these accidents attracts considerable public attention, especially when it is of the spectacular head-on variety, which frequently (but not always) means that one of the drivers crossed the median.

Ten times as many fatal head-on accidents occur annually on conventional roads and streets in California as occur on freeways. Almost all of these, on both kinds of highway, involve driver error and many of them involve "innocent" victims; that is, the victim was on his own side of

TABLE 2A

ACCIDENT PATTERN AND RATES* BY TYPE OF MEDIAN

Type of Median	Million Vehicle-Miles	Approach	Over-taking	Single Vehicle	All Accidents Including Pedestrian
Volume Group I (15,000 - 130,000 ADT)					
All	6764.23	4	69	23	100
Deterring:	5095.70	5	65	19	92
Earth	2663.72	4	58	22	87
Curbed	2085.37	6	74	16	100
Misc. features	346.61	3	64	16	88
Non-Traversable:	1668.53	3	83	34	124
Guardrail or concrete wall	534.53	4	96	31	136
Barrier post	256.55	3	52	29	90
Fence	110.69	2	77	39	122
Two separate roads	511.77	4	89	42	139
Misc. features	254.99	2	76	25	107
Volume Group II (Above 130,000 ADT)					
All	975.86	4	107	9	123
Deterring:	744.15	6	118	9	135
Curbed	744.15	6	118	9	135
Non-Traversable:	231.71	—	74	8	84
Guardrail or concrete wall	26.17	—	103	4	107
Two separate roads	205.54	—	70	9	81

*Per 100 million vehicle-miles.

the road. While the public attributes the ten-elevenths that happen on ordinary roads to speed, drinking, immaturity, and many other driver factors, the one-eleventh that happen on freeways are attributed to highway design. This is presumably because it looks so simple to erect an unbreakable wall in the middle of a freeway and thus "prevent" the accident from happening. The fact that when a car hits a wall there is an accident, possibly fatal and often involving an "innocent victim"; the fact that this same car would stand a good chance of not becoming involved in any accident at all if there were no curb or wall to throw it out of control; and the fact that the cost of the unbreakable wall must be deducted from money available to correct other highway deficiencies, are all overlooked.

TABLE 2B

INJURY*-ACCIDENT PATTERN AND RATES** BY TYPE OF MEDIAN

Type of Median	Approach		Over-taking		Single Vehicle		All Injury Accs. Including Pedestrian	
Volume Group I (15,000 - 130,000 ADT)								
All	2		27		10		42	
Deterring:	3		25		8		38	
Earth		2		23		9		36
Curbed		4		28		7		41
Misc. features		2		20		6		30
Non-Traversable:	2		36		16		56	
Guardrail or concrete wall		2		45		14		64
Barrier post		2		23		13		40
Fence		1		31		9		43
Two separate roads		3		37		22		64
Misc. features		1		29		15		48
Volume Group II (Above 130,000 ADT)								
All	3		56		4		65	
Deterring:	4		61		4		73	
Curbed		4		61		4		73
Non-Traversable:	—		37		3		41	
Guardrail or concrete wall		—		42		—		42
Two separate roads		—		36		4		41

*Includes fatal and non-fatal.
**Per 100 million vehicle-miles.

ANALYSIS OF FATAL ACCIDENTS ON FREEWAYS

A separate analysis was made of the 407 fatal accidents that happened on freeways in 1956, 1957 and 1958. The purpose of this analysis which follows, is to provide some guidance for determining how far to go in providing median barriers on freeways.

The first thing to look at is the distribution of fatal freeway accidents by type of accident. A breakdown of accidents and fatalities by type for the three years is given in Table 6 and shown in Figure 4.

Figure 5 shows the types of fatal accidents on freeways by hour of occurrence. It may be noted that the majority of all types of fatal accidents occurred in the hours of lighter travel from 7 P. M. to 7 A. M. This part of the day, while accounting for only 28 percent of the travel, accounted for 270 or 66 percent of all fatal freeway accidents.

Single Vehicles

As given in Table 6, the largest percentage of fatalities and fatal accidents involve only one vehicle. Single vehicles accounted for 43 percent of the fatal accidents and 42 percent of the fatalities. In 15 of these accidents, the vehicle crossed the median.

TABLE 3

FATAL AND NON-FATAL ACCIDENTS AND INJURIES

Type of Median	Injury* Accs. Per 100 Million Vehicle-Miles		Injuries* Per 100 Million Vehicle-Miles		Fatalities Per 100 Million Vehicle-Miles	
	Volume Group I (15,000 - 130,000 ADT)					
All	42		71		2.99	
Deterring:	38		64		2.82	
Earth		36		61		2.48
Curbed		41		68		3.12
Misc. features		30		63		3.75
Non-Traversable:	56		92		3.48	
Guardrail or concrete wall		64		105		2.62
Barrier post		40		65		6.24
Fence		43		73		1.81
Two separate roads		64		101		3.91
Misc. features		48		80		2.35
	Volume Group II (Above 130,000 ADT)					
All	65		116		1.33	
Deterring:	73		132		1.48	
Curbed		73		132		1.48
Non-Traversable:	41		65		0.86	
Guardrail or concrete wall		42		92		—
Two separate roads		41		61		0.97

*Includes fatal and non-fatal.

Pedestrians

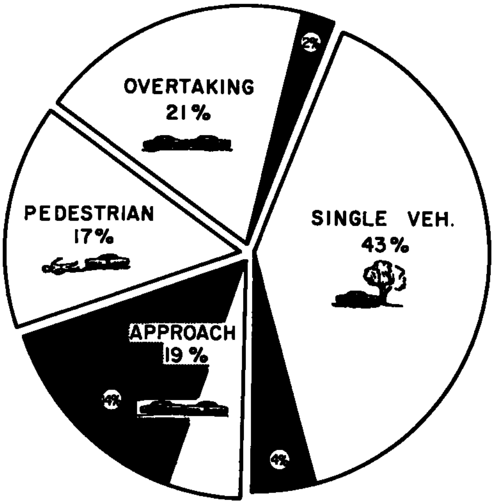


Figure 4. Types of full freeway fatal accidents 1956, 1957, 1958.

Seventy-one (14 percent of the fatalities involved pedestrians. The number of pedestrian fatalities is unduly high, considering that most freeways are fenced and pedestrians are prohibited. Fifty-five (78 percent) of these fatalities involved pedestrians who were walking or hitchhiking on the freeway.

Prevention of this type of accident poses interesting questions: First, how shall the transient be informed of this provision of the law? Second, should the law authorize the patrolling officer to arrest a hitchhiker (for example, a young sailor)? If so, what does the officer do with him? Give him a citation, put him in jail, or carry him off the freeway and release him? How does he make the pedestrian stay off? Third, what about the motorist in distress? Should he be encouraged to walk along the freeway by placing telephones for emergency use at intervals along the shoulder?

Overtaking

Overtaking-type fatal accidents account for 101 (20 percent) of the total fatalities. The overtaking-type fatal accidents, with a description of the accident and the location of the victim with respect to the overtaking or overtaken vehicle, are listed in Appendix A. It is often argued that a driver may adequately protect himself from vehicles traveling in the same direction while it is not possible to protect himself from vehicles traveling in the opposite direction. There is no doubt that, in general, a driver may better avoid vehicles proceeding in the same direction; however, a review of these accidents illustrates the fact that there are many "innocent" victims of overtaking accidents who were unable to avoid the accident. For example, in 22 of these accidents, the victims were struck from the rear by another vehicle.

Approach

Approach, or head-on-type accidents, are the most severe type accident. Fifty-five head-ons were attributable to vehicles crossing the median. The other 22, or 29 percent, involved vehicles driving in the wrong lane opposing traffic for other reasons. Generally, it was impossible to determine where or how the vehicle got into the opposing traffic lanes, either because the accident was a fatal one or the driver condition was such that he was unable or unwilling to give this information. With this information unavailable, it is difficult to propose an engineering solution to the problem. As yet, there is no positive solution to the problem of wrong-way movements at off-ramps. It might not be inappropriate to point out that a median barrier would make it more difficult for a car headed the wrong way either to get off the road or to get on the right side of the freeway.

TABLE 4

ACCIDENTS INVOLVING THE MEDIAN

Type of Median	All Cross-Median Accs. Per 100 Million Vehicle-Miles	All Median Accs. Per 100 Million Vehicle-Miles	All Median Accs. as a Percent of All Accs.	Cross-Median Accs. as a Percent of All Accs.
Volume Group I (15,000 - 130,000 ADT)				
All	7	28	28.0	7.2
Deterring:	8	24	25.7	8.4
Earth	6	27	31.2	6.4
Curbed	10	20	19.7	10.2
Misc. features	10	22	25.2	11.1
Non-Traversable:	6	41	33.0	4.6
Guardrail or concrete wall	6	44	32.6	4.8
Barrier post	6	38	42.8	6.9
Fence	6	44	36.3	5.2
Two separate roads	7	49	35.4	5.1
Misc. features	1	19	17.6	0.7
Volume Group II (Above 130,000 ADT)				
All	6	17	14.1	5.1
Deterring:	8	19	13.9	6.0
Curbed	8	19	13.9	6.0
Non-Traversable:	—	13	15.4	—
Guardrail or concrete wall	—	19	17.8	—
Two separate roads	—	12	15.0	—

Cross-Median Accidents

Cross-median accidents accounted for 55 of the approach-type fatal accidents, 7 of the overtaking-type accidents, and 15 of the single-vehicle fatal accidents. It should be explained that the accident classification is determined by the first event. Thus, the cross-median-overtaking accidents involved an overtaking-type collision before the vehicle crossed the median.

The cross-median fatal accidents are listed in Appendix B with a description of the accident. This list illustrates the wide variety of factors associated with cross-median fatal accidents. It may be noted that it is not always a "guilty" party that crosses the median. In 8 fatal-cross-median-approach accidents, the driver of the vehicle crossing the median was not careless or negligent, hence would not be considered "guilty." In 5 of these accidents, the vehicle crossing the median was struck by another vehicle and forced across the median. In an additional 18 accidents, the sequence of events preceding the accident was unknown.

The outstanding statistic here is that cross-median collisions of two or more vehicles accounted for 95, or 19 percent, of all fatalities on freeways in California during 1956, 1957 and 1958. (During the same years there were 11,005 traffic fatalities in the state.)

EXPERIENCE WITH MEDIAN BARRIERS

Grapevine Grade

When the Grapevine Grade on US 99 was converted from a 3-lane to a 4-lane-divided highway, a median barrier was placed on 3.6 mi of it. By 1949, the entire grade, 5.0 mi long, was equipped with a concrete barrier. While it was not possible to make before-and-after comparisons on the whole grade, because of the changes in width and character of the road and influence of the war years, such a comparison was made for the last 1.4 mi that were finished in 1949.

This road is on a 6 percent grade and there were many accidents resulting from cars and trucks losing control going downhill. The accident rate and fatality rate were bad before erection of the barrier, but after erection of the barrier they became worse. On the 1.4-mi section where the before-and-after study was made, the accident rate increased 88 percent and the injury rate increased 53 percent. There was one fatal accident in the "before" period and there were two in the "after" period.

On the entire 5.0 mi of the Grapevine Grade, fatal accidents have continued to be numerous during the succeeding 10 years. The fatality rate is 33 per 100 million vehicle-miles, which is about 4 times the statewide average for rural highways and 10 times the statewide average for freeways. During the years 1951 to 1958, inclusive, 57 people were killed on this 5.0-mi stretch.

San Bernardino Freeway

In 1956, a median guardrail-type barrier was installed on a 1 3/4-mi section of the San Bernardino Freeway in Los Angeles. The results were disappointing. A comparison of the records for 22 months before and 22 months after the installation showed that the all-accident rate increased three-fourths and the injury accident rate increased by 116 percent (more than double). While cross-median accidents were almost eliminated, the median accident rates increased by two-thirds and the number of persons injured per accident increased 30 percent. This comparison is based on a total of 167 accidents before and 338 accidents after.

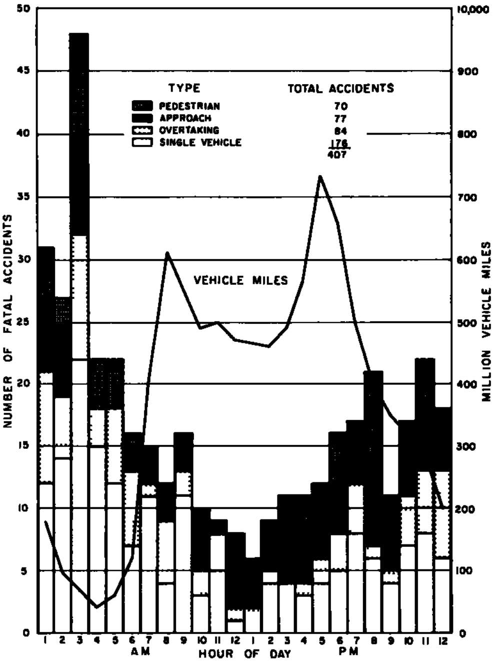


Figure 5. Freeway fatal accident summary by type for hour of day 1956, 1957, 1958.

Bayshore Freeway

In 1957, a median guardrail was installed on a 1.07-mi section of the Bayshore Freeway in San Francisco. In contrast to the Grapevine and San Bernardino Freeway experience, the results here are favorable, to date.

A comparison of accidents 12 months before and after the installation revealed that the total accident rate and the injury accident rate decreased approximately 40 percent after the barrier was installed. Cross-median accidents were eliminated and the median injury accident rate decreased 45 percent after the installation. The number of persons injured per accident decreased 16 percent. These observations are based on a total of 141 accidents before and 88 accidents after.

In evaluating the results of these studies, it must be noted that there has been considerable variation in the rates for segments of these freeways from year to year, presumably by chance.

TABLE 5

FATAL AND NON-FATAL MEDIAN ACCIDENTS AND INJURIES

Type of Median	Injury* Accs. Per 100 Million Vehicle-Miles		Injuries* Per 100 Million Vehicle-Miles		Fatalities Rate Per 100 Million Vehicle-Miles	
Volume Group I (15,000 - 130,000 ADT)						
All	14		25		1.27	
Deterring:	12		23		1.18	
Earth		14		25		1.28
Curbed		10		19		1.00
Misc. features		12		28		1.73
Non-Traversable:	20		31		1.56	
Guardrail or concrete wall		19		26		1.68
Barrier post		17		31		2.73
Fence		20		33		0.90
Two separate roads		24		38		1.37
Misc. features		16		26		0.78
Volume Group II (Above 130,000 ADT)						
All	10		19		0.82	
Deterring:	11		23		0.94	
Curbed		11		23		0.94
Non-Traversable:	5		6		0.43	
Guardrail or concrete wall		—		—		—
Two separate roads		6		7		0.49

*Includes fatal and non-fatal.

POSSIBLE REASONS FOR UNFAVORABLE RECORD OF BARRIERS

In view of the unfavorable record of barriers in two of the before-and-after studies and in the 265-mi study, it would be in order to discuss what factors are associated with barriers that might affect accident rates unfavorably. A Texas study (3) indicated that barriers in narrow medians have little influence on the placement of vehicles in the median lane. Opposing traffic appeared to have exerted a similar influence on vehicle placement. This study did note that the barrier appeared to provide a better reference point for driving in the median lane than a low curb.

On the other hand, the introduction of a physical barrier in a traversable or deterring median reduces the usable width of the median. If this usable width of the median is a factor in the over-all safety of a freeway, it would be a rational explanation of the noted increase in the accident rates with the installation of a barrier. A driver's freedom to maneuver to avoid collision with other vehicles is reduced by a median barrier. There are undoubtedly vehicles which enter and in some cases cross the median and recover without a reportable accident when no barrier is present. More important, perhaps, is the fact that stalled vehicles are observed daily in median areas.

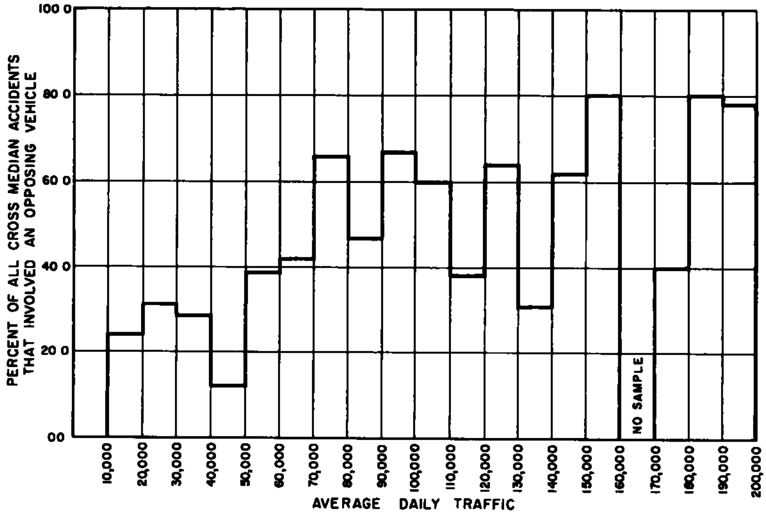


Figure 6. Proportion of all cross-median accidents that involved opposing vehicles, as a function of traffic volume.

It is frequently taken for granted that if a car crosses the median of a heavily-traveled freeway, it is bound to collide with a car proceeding in the opposite direction. This is not true. Even during daytime hours, there are many long spaces between vehicles, and during the hours from midnight to 5 A. M., when the fatal accident problem is the greatest, most of the spaces between vehicles are several hundred feet long.

TABLE 6

FULL FREEWAY FATAL ACCIDENTS BY TYPE (1956, 1957 and 1958)

Item	Approach		Overtaking		Single Vehicle		Pedestrian		
	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	Total
1956 Fatal accs.	17	16.5	25	24.3	42	40.8	19	18.4	103
Persons killed	22	18.8	29	24.8	46	39.4	19	16.2	116
1957 Fatal accs.	27	18.3	28	18.9	69	46.6	24	16.2	148
Persons killed	46	24.1	34	17.8	87	45.5	24	12.6	191
1958 Fatal accs.	33	21.2	31	19.9	65	41.6	27	17.3	156
Persons killed	50	26.0	38	19.8	76	39.6	28	14.6	192
Total for Period of Study									
All fatal accs.	77	18.9	84	20.6	176	43.3	70	17.2	407
Persons killed	118	23.7	101	20.3	209	41.9	71	14.2	499
Persons killed per accident	1.53		1.20		1.19		1.01		1.23
Cross-Median:									
Fatal accs.	55	13.5	7	1.7	15	3.7	0	0	77 (18.9%)
Persons killed	88	17.6	7	1.4	17	3.4	0	0	112 (22.5%)

There are no data to indicate how many vehicles enter or cross the median without having an accident, but a clue may be had by examining the accidents that involve cars crossing the median.

For this purpose, the data on the 7,994 accidents of the basic study were used because there was a better chance of discerning a pattern by examining them than there was in the 407 accidents of the corollary study.

Figure 6 shows, by daily traffic volume groups, the chances of involvement with a vehicle traveling in the opposite direction when one vehicle crosses the median and is involved in an accident. Even when the car that crosses the median has an accident, the chance of colliding with an opposing vehicle varied from 12 percent to a maximum of 80 percent of the cases, depending on traffic volume.

DISTRIBUTION OF FATAL CROSS-MEDIAN ACCIDENTS

In the basic study it was seen that if past experience is a guide, the installation of positive barriers in "deterring-type" medians, when the volume is less than about 130,000 vehicles per day, would increase not only the total number of accidents, but the number of injuries and fatalities. On the other hand, the fact that, in three years, 19 percent of all fatalities on freeways were caused by cross-median collisions is extremely serious. The question is: would a reduction in the cross-median fatalities, accomplished by installing positive barriers, be accompanied by a rise in other types of fatalities that would more than offset the benefit?

To provide some guidance in resolving this dilemma, the geographic distribution of cross-median fatal accidents on freeways was examined.

The San Francisco and Los Angeles metropolitan areas accounted for 55 (89 percent) of the fatal cross-median accidents that involved more than one vehicle. The large majority of this type of accident have occurred on sections of a relatively few heavily-traveled freeways. Table 7 gives these freeways and their record of fatal cross-median accidents.

Figure 7 is a plot of the cumulative number of full freeway fatal cross-median accidents involving opposing vehicles against the cumulative miles of freeway in ascending order of traffic volume. From this figure we may read the percent of this type accident occurring on any given amount or percent of the freeway mileage. For example, 80 percent of the accidents occurred on the 32 percent of the mileage that had traffic volume exceeding 38,999 vehicles per day. Conversely, 382 mi, or 68 percent of the mileage, had traffic volumes of less than 38,000 vehicles per day and accounted for only 20 percent of the accidents. There is a "break" in the curve in the vicinity of 60,000 ADT. Below this point, 4/5 of the mileage accounts for only 1/3 of the accidents, and above this point, one-fifth of the mileage accounts for 2/3 of the accidents. At the time of the study, 1/5 of the mileage amounted to about 110 mi.

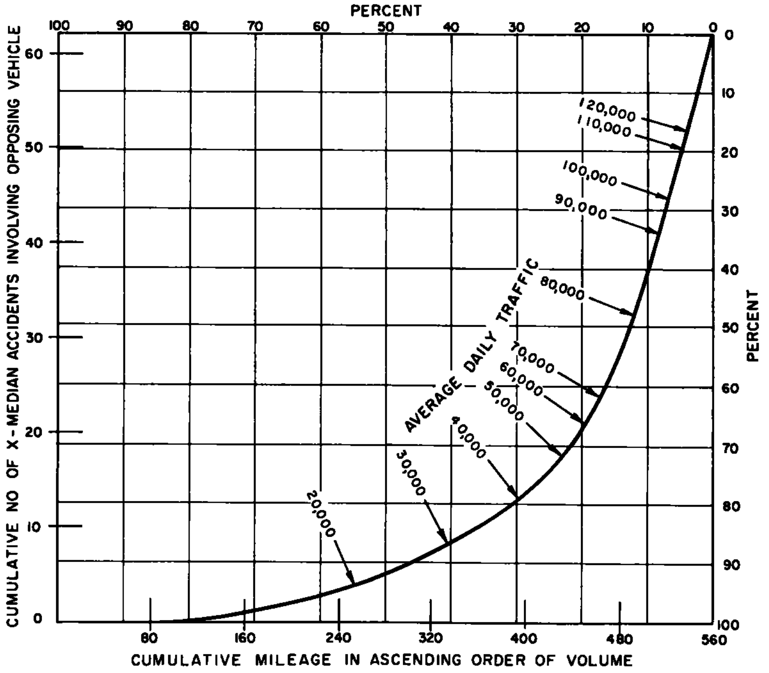


Figure 7. Fatal cross-median collisions by miles of freeway.

Figure 8 shows, as a function of traffic volume, the rate per mile for cross-median accidents that involve opposing vehicles for the deterring-type median. The rate varied from 0.1 to 9.0 accidents per mile-year for the period of the study.

Referring to Figure 7, 2/3 of fatal cross-median collisions would have been converted to some other type of accident by installation of an effective barrier on approximately 110 (as of 1958) mi of full freeway with traffic volumes in excess of 60,000 vehicles per day. However, the reported descriptions of these accidents, coupled with observation of full-scale crash tests (4) of median barriers, led to an inescapable conclusion that a rigid barrier seldom would have obviated a serious and possibly fatal accident. Further, it would appear that the injuries and fatalities in other types of accidents would be increased by the introduction of a barrier except for those highways carrying extremely high volumes of traffic.

MEDIAN BARRIER DESIGN

The relative effectiveness of various types of barriers may provide a solution to the dilemma. As may be seen in the table showing the severity of median accidents (Table 5), the barriers presently in place on those facilities with traffic volumes below 130,000 vehicles per day are not effective in reducing the severity of accidents involving the median. If these barriers were more effective in reducing the severity of these accidents, then possibly the volume at which barriers would be effective in reducing the over-all casualty rate would be considerably lower than the 130,000 vehicles per day indicated in this study.

For a barrier to be effective in reducing the severity of accidents, it must:

1. Prevent the vehicles from crossing the median.
2. Minimize the possible injury to occupants of the vehicle striking the barrier.
3. Prevent the vehicle from reflecting back into the traffic stream.

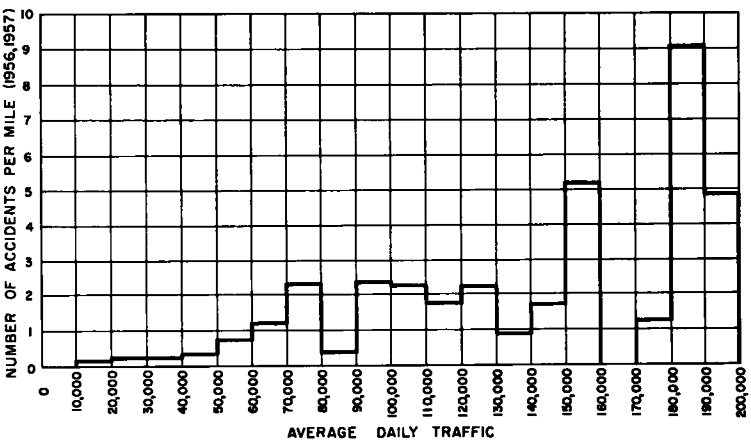


Figure 8. Cross-median accidents on deterring-type medians which involved opposing vehicles as a function of traffic volume, expressed in accidents per mile.

TABLE 7

FATAL CROSS-MEDIAN COLLISIONS ON SELECTED FULL FREEWAYS (1956, 1957 and 1958)

Freeway	Limits	Length (Mi) (1958)	No. of Fatal Cross-Median Accidents	Percent of Statewide Total
Los Angeles Area:				
San Bernardino Rte. 26	Santa Ana Freeway to Rte. 62 (West Covina)	18.5	7	11.3
Hollywood Rte. 2	Four Level to Lankershim	8.7	5	8.0
Santa Ana Rte. 2, 166, 174	Four Level to Rte. 175 (Orangethorpe Avenue)	21.7	12	19.4
Pasadena Rte. 165, 205	Four Level to Pasadena	8.2	3	4.8
Harbor Rte. 165	Four Level to Rte. 174 (Manchester)	7.8	4	6.5
	Sub-total	64.9	31	50.0
San Francisco Area:				
Eastshore Rte. 69	Fallon to Rte. 105 (Jackson)	14.5	7	11.3
Bayshore Rte. 68	Central Freeway (Rte. 2) to S.C.L. San Mateo	18.1	6	9.7
	Sub-total	32.6	13	21.0
	Total	97.5	44	71.0
Total in Los Angeles & San Francisco areas:		306.3	55	88.7
All other freeways:		252.2	7	11.3
	Grand total	558.5	62	100%

With the above criteria in mind, full-scale tests were made of 15 different designs for a barrier (4). In these tests, cars were driven into the rail at high speeds. Some of the designs failed (that is, the cars went over or through the railing) and most of the designs resulted in severe damage to the car and serious "injury" to the dummy occupant. However, three basic designs showed promise of fulfilling, to varying degrees, all of the criteria.

From the standpoint of over-all safety, a flexible-type barrier with chain link fence, light steel posts, and three 3/4-in. cables is the most effective. This barrier was the only type tested in which the deceleration within the test vehicle was tolerable to human occupants. However, if the median is narrow, deflection during the collision presents a problem. The minimum median width required for this type barrier would be in the range of 12 to 16 ft.

For median widths between 3 and 12 ft, either a steel rail system or a concrete wall would be effective.

The steel rail system consists of two W-section beam-type guardrails, blocked out 8 in. from douglas fir posts, together with supplemental channels 12 in. from the ground. The purpose of these channels and the blocking out is to prevent autos from "hooking" into the posts which causes a crash to be extremely severe.

For median widths less than 3 ft, a concrete wall would be the most effective type barrier in the space available.

With the use of one of these newly-developed designs, there is reason to hope that past unfavorable experience with guardrailing in medians can be reversed, at least on high volume roads. The question now becomes, what volume to use as the cut-off point?

Referring again to Figure 7, it is seen that if barriers were used only on highways with traffic volumes exceeding 100,000 vehicles per day, only about 27 percent of the cross-median fatal accidents would have been converted to other types of accident. In other words, it is necessary to include all highways where traffic exceeds a relatively low volume—60,000 vehicles per day—in order to effect a substantial reduction in the total number of this kind of accident (Fig. 7), and before the point of diminishing returns is reached.

The problem has two subdivisions: (1) installation of barriers on existing freeways, and (2) inclusion of barriers in plans for freeways yet to be constructed. On existing freeways, it would seem prudent to start at the top and work down, observing results as the work progresses. Before the 80,000 level is reached, there should be more actual field experience to use as a guide for further installations.

For future freeways, it appears that barriers should be provided whenever the initial volume is estimated at 60,000 ADT or more. It is not recommended that the design-year (20 years hence) volume be used for this purpose, because the barriers can be installed after the freeway is built if and when the volume builds up. An exception to this might be found where the design-year volume appears to warrant barriers, and installation of barriers would change the width otherwise required. It should be noted that if a barrier is used, there is not much to be gained by going beyond about 22 ft in total width, which would provide space for stalled vehicles and considerable maneuvering area on each side of the barrier.

SUMMARY OF FINDINGS AND CONCLUSIONS

The purpose of this study was to investigate the relative safety of various existing types of median designs, and to provide criteria for installation of positive median barriers on divided highways.

No attempt was made to evaluate the many factors other than safety which would influence the selection of a median type for a particular segment of highway.

Within the limitations of the data available, the following findings and conclusions appear to be warranted:

1. The type of median influences the number of accidents on divided highways. On highways with traffic volume between 15,000 and 130,000 vehicles per day, the accident rate was 92 accidents per hundred-million vehicle-miles for earth and low-curb medians, and 136 accidents per hundred-million vehicle-miles for the guardrail or concrete-wall-type median. Separate roadways had a rate of 139 in this volume range.

2. Traffic volume appears to be a factor in the relative safety of the various types of medians. Where traffic volumes were between 15,000 and 130,000 vehicles per day, the non-barrier-type median was superior. Where traffic volumes exceeded 130,000 vehicles per day, the advantage shifted to the non-traversable barrier-type median.

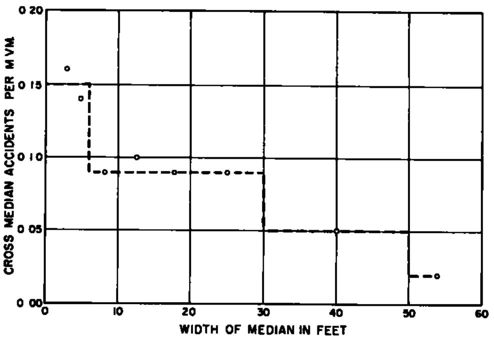


Figure 9. Cross-median accident rate by width of median for deterring-type medians.

3. The cross-median accident rate goes down as the median width goes up. However, there was no apparent relationship between the width of median and the all-accident rate in this study.

4. Widths of less than 50 ft will not prevent vehicles from crossing the median, although the probability is greatly reduced when that width (50 ft) is exceeded. A vertical barrier will prevent nearly all vehicles from crossing the median.

5. Cross-median accidents, although important, are only one phase of the traffic safety problem. Cross-median fatal collisions on freeways comprised 0.9 percent of traffic fatalities in California during the three years 1956, 1957 and 1958.

6. Traffic volumes appear to be the major criterion for the installation of median barriers. At volumes of 130,000 or more vehicles per day, it is indicated that median barriers will add to the safety of a divided highway.

7. Cross-median accidents can be converted to other kinds by the construction of vertical barriers. Because this kind of accident is responsible for 19 percent of fatalities on freeways, and because of compelling public demand, it is considered essential to convert them.

In order to make a significant attack on this problem, it is necessary to reach down to the 60,000 ADT level. Freeways carrying more than 60,000 vehicles per day accounted for 20 percent of the mileage and 67 percent of the cross-median collision-type fatal accidents during the 3 years 1956, 1957 and 1958.

8. If past experience continues into the future, going down to the 60,000 ADT level would result in an increase in accidents, injuries, and possible fatalities. However, newly-developed barrier designs hold promise of resulting in fewer casualties even though the accident rate may rise.

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APPENDIX A

Overtaking Fatal Accidents on Full Freeways

No.	No. Killed	Victim		Description	Victim Innocent
		Over-taking	Over-taken		
1.	1	1		Truck stalled in traffic lane, hit by car	No
2.	1	1		Truck sideswiped by car	No
3.	1		1	Car hit in the rear by other car, lost control	Yes
4.	1		1	Car hit in the rear by other car, overturned	Yes
5.	1		1	Truck hit by truck-trailer, lost control	Yes
6.	1	1		Driver had been drinking, hit other car in rear & lost control	No
7.	1		1	Car stopped on freeway to secure hood, hit by other car	Yes
8.	1	1		Truck hit by speeding car	No
9.	1	1		Car making U-turn, hit by other car	Yes
10.	1		1	Car making U-turn, hit by other car	No
11.	1	1		Car speeding, making unsafe lane change, hit pickup and lost control	No
12.	1	1		Car struck by motorcycle	No
13.	2	2		Car made unsafe lane change, bumped by other car and lost control	No
14.	1		1	Car stopping without lights, hit in rear by truck-trailer	No
15.	1	1		Pickup made unsafe lane change, hit other car and lost control	No
16.	1		1	Car struck in the rear by pickup, lost control	Yes
17.	1	1		Car hit rear of other car stopped in traffic lane	No
18.	1	1		Car made unsafe lane change, struck other car	No
19.	1		1	Car lost control when struck by pickup traveling at excessive speed	Yes
20.	2	2		Car failed to make turn onto freeway on-ramp, struck by truck-trailer	No
21.	1	1		Car was struck when driver cut in front of other car to enter off-ramp	No
22.	1		1	Truck-trailer ran into rear of slow-moving car	Yes
23.	3	2	1	Car struck other car in rear when attempting to pass at excessive speed	No
24.	1		1	Car lost control when struck by other car making unsafe lane change	Yes
25.	1		1	Car stopping in traffic lane, hit by truck trailer	No
26.	1	1		Driver asleep at wheel, drifted off road, over-corrected and struck pickup and trailer	No
27.	1		1	Car struck by car in the rear, lost control and struck bridge rail	Yes
28.	1	1		Pickup pushing car, hit by other pickup going 70 mph	No
29.	2	2		Truck parked on shoulder, hit by speeding vehicle	No
30.	1	1		Truck parked on traveled lane, driver asleep, hit by car in the rear	Yes
31.	1		1	Car slowing for accident ahead in fog, struck by truck-trailer	Yes
32.	1	1		Car driven by drunk driver at excessive speed hit truck-trailer in the rear	No
33.	1		1	Car ran over passenger fallen from motorcycle	Yes
34.	1		1	Car hit by truck-trailer in the rear	Yes
35.	1	1		Truck stopped behind stalled vehicle, hit in the rear by car	No
36.	2		2	Driver had been drinking, struck motorcycle stopped on shoulder	Yes

		Victim			
No.	No. Killed	Over-taking	Over-taken	Description	Victim Innocent
37.	1		1	Truck stopped in traveled lane, hit by car	Yes
38.	1	1		Slow-moving truck-trailer hit by car	No
39.	1	1		Truck-trailer entering highway from shoulder hit by car	No
40.	1	1		Motorcycle made unsafe lane change, hit by car	No
41.	2		2	Car slowed suddenly, hit by truck-trailer, caught fire	No
42.	1	1		Truck-trailer going upgrade, struck by car	No
43.	1	1		Car improperly parked, hit by car	Yes
44.	1		1	Truck-trailer hit pickup pushing other car	No
45.	1	1		Truck-trailer hit by car making unsafe turning movement	No
46.	2	2		Car speeding, making unsafe lane change, hit other car and lost control	No
47.	1	1		Truck-trailer hit in rear by car	No
48.	1	1		Car hit by other car which was speeding and making unsafe lane change	No
49.	1		1	Car stopped to pick up hitchhiker, struck by other car	Yes
50.	3	3		Car stalled on highway, struck by other car at high rate of speed	No
51.	1	1		Driver had been drinking, speeding, hit other car in rear	No
52.	1		1	Driver had been drinking, hit other car, causing it to lose control	Yes
53.	1	1		Car making U-turn through median, hit in rear by other car	Yes
54.	1		1	Vehicle lost control and struck concrete abutment when hit in the rear by speeding truck	Yes
55.	1		1	Driver had been drinking, made sudden stop to discharge passenger, struck in rear by truck	No
56.	1		1	Car stopped on shoulder, struck by speeding vehicle, overturned and burned	Yes
57.	1	1		Driver of motorcycle under influence of alcohol, struck car in the rear	No
58.	1		1	Car exceeded safe speed on wet pavement, hit car in rear	Yes
59.	2		2	Vehicle made unsafe lane change, knocked car across divider into path of oncoming car	Yes
60.	3	3		Vehicle traveling at excessive speed, struck rear of parked dumptruck	No
61.	1	1		Car following too close, struck car which was slowing for traffic ahead, then jumped divider & struck opposing car head-on	No
62.	1	1		Truck stopped due to accident ahead, struck in rear by car	No
63.	1	1		Driver had been drinking and speeding, struck truck-trailer	No
64.	1	1		Driver fell asleep, struck pole and bounced into other car	No
65.	1	1		Car made unsafe entry onto highway from shoulder, struck by other car	Yes
66.	1	1		Car made unsafe lane change, struck other car in rear and lost control	No
67.	1	1		Driver obviously drunk, made unsafe lane change, struck by other car, lost control	No
68.	1	1		Car traveling at excessive speed, struck other car in the rear, lost control	No
69.	1	1		Driver intoxicated, stopped on freeway without lights. struck by other car	Yes
70.	1	1		Car went across on-ramp to the right, struck pickup parked off road, then struck concrete wall	No
71.	1		1	Driver obviously drunk, going over 70 mph. struck other car in rear, causing it to catch on fire, and lost control	Yes
72.	1	1		Driver obviously drunk, speeding, struck car ahead slowing due to traffic congestion	No
73.	1	1		Car following too closely, struck other car in the rear which was slowing for traffic ahead	No
74.	1	1		Truck-trailer struck from behind by truck-trailer exceeding safe speed	No
75.	1	1		Driver had been drinking, exceeded safe speed, struck bus which was stalled on freeway	No
76.	1	1		Car exceeded safe speed, struck slow-moving truck in rear	No
77.	3	3		Driver apparently fell asleep, struck truck-trailer parked on shoulder. (Part of trailer was on roadway.)	No
78.	2	2		Car speeding, struck truck-trailer in rear-skidded sideways and was struck by other truck-trailer	No
79.	2		2	Driver apparently fell asleep, ran into car parked on traveled way	Yes
80.	1	1		Driver apparently asleep at wheel, struck truck-trailer in rear	No
81.	1	1		Car struck other car in rear which was slowing due to traffic ahead	No
82.	1		1	Car slowing for traffic ahead in heavy fog, struck in rear by speeding car	Yes
83.	1		1	Car stopping on freeway, struck by other car	No
84.	1	1		Car speeding at 90 mph, overtook and struck other car in rear	No

APPENDIX B

Cross-Median Fatal Accidents on Full Freeways

				Victim				
No.	Med. Width	Volume ADT	No. Killed	X-Median Vehicle	Other Vehicle	Description	X-Med Vehicle Innocent	No. of Vehicles Involved
1.	36'	65,000	1		Ped.	Driver under influence of alcohol, speeding, lost control of veh. Pedestrian on roadway rendering help to injured when hit by 4th car.	No	4
2.	6'	100,000	1		Pass.	Car leaped over divider, landed on hood of oncoming vehicle, cause unknown	Unk.	2
3.	36'	65,000	1	Dr.		Car traveling at very high rate of speed, lost control at curve, crossed median, hit fence	No	1
4.	6'	76,000	1	Dr.		Car wheels came in contact with curb on the right, lost control	No	1
5.	6'	34,000	1		Dr.	Car traveling at excessive speed, made unsafe lane change, lost control	No	2
6.	30'	13,000	2	Dr., Pass.		Dr., possibly intoxicated, hooked bumper in attempt to pass, lost control	No	2
7.	30'	13,000	1		Dr.	Driver of pickup under influence of alcohol, asleep at wheel	No	2
8.		12,000	3		Dr., 2 Pass.	Truck-trailer blew front tire, lost control	No	3
9.	6'	165,000	1		Dr.	Driver under influence of alcohol, lost control	No	2
10.	22'	57,000	1	Dr.		Reason unknown	Unk.	2
11.	8'	95,000	1	Dr.		Car coming up too fast on car ahead, applied brakes, lost control	No	4
12.	8'	95,000	1	Pass.		Pickup traveling at excessive speed, struck & pushed car across median	Yes	4
13.	8'	95,000	1	Dr.		Car at excessive speed, avoiding collision with car ahead, swerved across median	No	2
14.	22'	57,000	1		Dr.	Truck blew tire, lost control	No	2
15.	10'	132,000	1		Pass.	Pickup at excessive speed, struck and pushed car across divider	Yes	4
16.	32'	25,000	1		Pass.	Driver lost control of car when avoiding collision with car making unsafe lane change from the right	Yes	3
17.	12'	66,000	1	Dr.		Hood of veh. blew up, obscured vision of driver	No	2
18.	12'	66,000	1		Pass.	Car speeding, swerved left to avoid rear-end collision, hit curb, lost control	No	5
19.	12'	66,000	2	2 Pass.		Unknown	Unk.	3
20.	12'	66,000	3	Dr. Pass.	Dr.	Unknown	Unk.	2
21.	12'	66,000	1	Dr.		Unknown	Unk.	2
22.	40'	25,000	2	2 Pass.		Driver had been drinking, traveling at estimated speed of 85 mph, lost control	No	1
23.	6'	100,000	1	Dr.		Driver made unsafe lane change, locked bumpers, both cars lost control	No	2
24.	6'	100,000	6	Dr.	Dr.,4 Pass.	Car traveling at excessive speed, struck slow veh. ahead & lost control	No	4
25.	10'	127,000	4	Dr.	Dr.,2 Pass.	Driver had been drinking, avoiding collision with car changing lanes, lost control	No	4
26.	10'	127,000	1	Dr.		Unknown	Unk.	2
27.	10'	55,000	3	Dr.	Dr., Pass.	Car at excessive speed, attempting to slow for traffic ahead, wheel hit med. curb, lost control	No	4
28.	8'	55,000	1	Dr.		Unknown	Unk.	2
29.	35'	90,000	1		Dr.	Truck exceeded safe speed, swerved left to avoid truck changing lanes ahead, lost control	No	2
30.	16'	62,000	1		Dr.	Driver had been drinking, exceeded safe speed, lost control	No	4

No.	Med. Width	Volume ADT	No. Killed	Victim		Description	X-Med. Veh. Innocent	No. of Vehicles Involved
				X-Median Vehicle	Other Vehicle			
31.	16'	62,000	2	Dr.,Pass.		Driver asleep at wheel, ran off onto shoulder, over-corrected and lost control	No	2
32.	16'	32,000	3	Dr.	Dr.,Pass.	Unknown	Unk.	4
33.	12'	106,000	2		2 Pass.	Car speed racing with motorcycle, struck car ahead & pushed it across median	Yes	5
34.	32'	65,000	1	Pass.		Pickup swerved left to avoid car cutting in from the right, lost control	Yes	2
35.	32'	32,000	1	Dr.		Unknown	Unk.	3
36.	10'	153,000	1		Dr.	Car attempting to slow for traffic ahead, went into skid, lost control	No	3
37.		21,000	2	2 Pass.		Driver had been drinking, being pursued by police, going over 100 mph, lost control	No	1
38.		11,000	1	Dr.		Motorcycle made U-turn across median without stop, hit broadside by truck	No	2
39.	14'	30,000	1	Dr.		Unknown	Unk.	1
40.	14'	30,000	1		Dr.	Driver had been drinking, excessive speed, struck vehicle ahead and lost control	No	2
41.	14'	22,000	1	Pass.		Driver apparently asleep at wheel, skidded on wet pavement and lost control	No	1
42.	36'	80,000	1	Dr.		Driver obviously drunk, traveling at high speed, went onto shoulder, lost control, overturned	No	1
43.	36'	80,000	1	Dr.		Driver under influence of alcohol, speeding and lost control	No	3
44.	36'	80,000	1	Dr.		Driver had been drinking, estimated speed over 70 mph, lost control	No	1
45.	32'	80,000	1	Pass.		Car blew rear tire, lost control	Yes	1
46.	36'	72,000	1	Dr.		Unknown	Unk.	2
47.	16'	82,000	2	Dr.	Dr.	Driver under influence of alcohol, crossed med. & continued for 1 mile, hit car head-on	No	2
48.	36'	75,000	2	Dr.	Pass.	Driver obviously drunk, drove across median	No	2
49.	12'	82,000	1	Dr.		Car exceeded safe speed, lost control on wet pavement	No	2
50.		82,000	1	Dr.		Car exceeded safe speed, hit other car slowing for traffic ahead, lost control	No	3
51.	12'	41,000	1	Pass.		Car exceeded safe speed, swerved left to avoid slow traffic ahead, lost control	No	2
52.	12'	38,000	2	Dr., Pass.		Car made unsafe lane change, knocked other car across median	Yes	3
53.	12'	38,000	1		Dr.	Car traveling at 90 mph speed, wheel went onto shoulder, lost control	No	2
54.	10'	183,000	2	Dr.	Dr.	Speeding at over 70 mph, lost control	No	3
55.	10'	140,000	1	Dr.		Car in avoiding collision with slowing veh. ahead, ran onto median, lost control on wet pavement	No	2
56.	10'	130,000	2	Dr.,Pass.		Excessive speed, had been drinking, driver in avoiding slow veh. ahead, swerved left into median	No	2
57.	22'	130,000	1	Dr.		Car struck by other car when making unsafe lane change, lost control on wet pavement	No	3
58.	12'	125,000	4	Dr.	Dr.,2 Pass.	Unknown	Unk.	3
59.		40,000	1	Dr.		Driver under influence of alcohol, going 80 mph, on lane to off-ramp, swerved left to keep on freeway, & lost control	No	1
60.	10'	64,000	1		Dr.	Driver obviously drunk, speeding, lost control	No	3
61.	11'	47,000	1	Dr.		Driver lighting a cigarette, wheel hit median curb, lost control	No	3
62.		47,000	1	Pass.		Car traveling at excessive speed, hit car in front & lost control	No	3

				Victim				
No.	Med. Width	Volume ADT	No. Killed	X-Median Vehicle	Other Vehicle	Description	X-Med. Veh. Innocent	No. of Vehicles Involved
63.	32'	81,000	1	Dr.		Driver had been drinking, speeding, suddenly swerved across median	No	1
64.	12'	130,000	1	Dr.		Driver had been drinking, made unsafe lane change, lost control	No	2
65.	6'	130,000	1	Dr.		Raining, car slowing for traffic ahead was struck from behind and jumped divider	Yes	7
66.	6'	97,000	1		Dr.	Car blew right rear tire, lost control	No	2
67.		12,000	1	Dr.		Car going over 70 mph, weaving in and out, lost control	No	1
68.	34'	85,000	1	Dr.		Unknown	Unk.	3
69.	12'	103,000	1	Pass.		Exceeded safe speed, applied brakes due to traffic congestion ahead, lost control	No	4
70.	12'	103,000	4	Dr.	Dr.,2 Pass.	Unknown	Unk.	2
71.	12'	103,000	1	Dr.		Unknown	Unk.	1
72.		66,000	1	Dr.		Unknown	Unk.	5
73.		30,000	3		Dr., 2 Pass.	Unknown	Unk.	2
74.	30'	31,000	1	Pass.		Driver obviously drunk, going over 80 mph, hit median curb and lost control	No	1
75.	30'	31,000	1	Dr.		Unknown	Unk.	1
76.	16'	23,000	1	Dr.		Car at excessive speed, jumped divider	No	2
77.	6'	23,000	1	Dr.		Driver lost control on wet pavement (raining)	No	4

Cross-Median Accident Experience on the New Jersey Turnpike

JOHN R. CROSBY, Traffic Engineer
New Jersey Turnpike Authority, New Brunswick

● THE cross-median collision, of all accident types, probably holds the greatest promise of prevention. Initial highway design with inclusion of adequate median widths between opposing roadways can almost completely prevent the sensational head-on motor-vehicle accident. This, of course, is an impossibility on many of our existing highways where cross-sectional design cannot be improved substantially within existing right-of-way. The highway operating agency may, therefore, turn to other means of physically separating the opposing vehicular streams in an attempt to control these higher than normal fatal injury-producing collisions. The economic consideration of barrier erection may appear prohibitive and many questions remain unanswered as to the best design for a barrier and where and under what conditions a barrier should be erected.

The purpose of this study is to present the cross-median accident experience on the New Jersey Turnpike for the 7-yr period 1952 through 1958. This period constitutes the "before" accident experience, as during 1958 eighteen miles of medial guardrail were constructed on medians varying in width from 6 to 26 ft. It is hoped that the presentation of these data will assist highway and safety officials by answering some of the many questions that still remain about the frequency of cross-median collisions.

To assist in the proper evaluation of the total accident problem, data will be presented on the over-all accident experience of the highway so that areas of similar geometric design carrying dissimilar traffic volumes may be compared. Cross-median accidents will be analyzed with respect to severity, median width and type, and annual average traffic volumes. No attempt will be made to present data on the effectiveness of median barriers in this study, as insufficient time has elapsed to develop a pattern of accident types and severity since the erection of the barriers.

SITE DESCRIPTION

The New Jersey Turnpike is a 131-mi full-controlled-access toll highway interconnecting the Delaware Memorial Bridge and Pennsylvania Turnpike on the south and west with the three major Hudson River crossings on the north. This highway serves one of the heaviest traffic corridors in the east between such traffic generators as New York, Philadelphia, Baltimore, and the New England industrial area. Due to its proximity to the densely populated New York and North Jersey metropolitan areas, the northerly 42 mi of the highway is a primary commuter route in addition to carrying a heavy volume of transient vehicles.

The average trip length per vehicle currently is just under 30 mi. Trip length has consistently decreased since 1952, at which time it was

42 mi. Commercial traffic during the first year of operation amounted to 7.8 percent of the total traffic. This type of vehicle use has steadily increased amounting to 11 percent in 1958.

During the period of this study vehicular use of the Turnpike has more than doubled while miles traveled have increased more than sixty percent. These annual statistics as well as the yearly accident statistics are given in Table 1. It is noted that with the great increase in vehicle use the total accident experience has remained nearly constant during the 7-yr period. Injury accidents, however, have failed to follow any consistent pattern with respect to either vehicle exposure or total accident experience. They have varied from a low of 25 percent of all accidents in 1954 to a high of 37 percent in 1957 and averaged 31 percent during the 7-yr period. Personal injuries averaged 2.3 per injury accident varying from a low of 2.0 in 1956 to a high of 2.5 in both 1952 and 1953. It is interesting to note that this figure checks closely to the vehicle occupancy surveys that have been taken from time to time on the Turnpike.

The original project of the New Jersey Turnpike Authority was a 118-mi facility with 17 interchanges. This portion of the project was opened to traffic in January 1952. During 1956 two extensions were completed and opened to traffic. These added approximately 14 mi to the system and four additional interchanges. For the purpose of this study, detailed analysis of cross-median and head-on accidents will be limited to the through roadways of the initial 118-mi project. Accidents occurring within service areas, interchanges and their interconnecting roadways and ramps have been deleted.

The toll feature of this highway aids materially in an accident study of this type. This is particularly true for the calculation of vehicle mileage rates and daily traffic volumes. The daily auditing of every toll ticket (representing a vehicle) and the weekly, monthly and yearly summarization of the daily audits yield a wealth of extremely accurate information. This includes origin and destination by interchanges, daily volume by direction between successive pairs of interchanges, vehicle-miles of travel, average trip length by vehicle types, ramp volumes and many other useful details of great interest to the traffic engineer.

CRITIQUE

The Turnpike study site may not be typical of experience recorded on controlled-access freeways. The fact that toll booths are located at each interchange adds a degree of control that does not exist on public and some partial toll highways. At these points, vehicles are scrutinized as to loading and superficial mechanical condition including tires and lights. Drivers suspected of excessive alcoholic indulgence or fatigue may be detected, and if so, appropriate action is taken. During periods of brisk winds, house trailers are banned as this vehicle combination has had unfavorable accident experience.

A total of 63 weather and roadway condition warning signs are spaced at 5-mi intervals along the highway. These are used to caution drivers in advance of areas where a hazardous condition exists. In addition, when hazardous weather conditions prevail or the roadway is partially blocked due to construction, the normal posted speed limit of 60 mph is reduced to 35 mph. Officer enforcement is generally increased under these conditions although it is believed to be at a relatively high level during all periods with respect to other comparable facilities.

Even with these unique standard operating procedures, accidents continue to occur. The adoption of these procedures, however, probably accounts for the fact that total annual accidents have remained relatively stable during the 7-yr period, resulting in a rate reduction per one hundred million-vehicle-miles of 130.9 in 1952 to 81.0 in 1958. This trend in total accident rate is also given in Table 1, together with the trend of injury accidents and fatal accidents. The year 1955 would appear as an exception to the general trend of total accidents as well as injury accidents as portrayed by this figure. During 1955, 64 mi of the Turnpike were widened from a 4-lane divided highway to a 6-lane divided facility. Since early 1956, 84 mi of the Turnpike have had a 6-lane divided cross-section while the southern 34 mi remain unchanged. With one minor exception, all the widening took place beyond the existing traveled roadway without change in the median cross-section. The distraction of such a length of construction activity may account for the increased incident of accidents during 1955.

CROSS-MEDIAN FATAL ACCIDENTS

During the period 1952 through 1958, 48 of the 158 fatal accidents involved a vehicle crossing the median into the opposing trafficway. This amounts to 30.4 percent of the fatal accident experience on the Turnpike. Table 2 indicates the distribution of the fatal accidents under the four major collision types and one miscellaneous classification. A perusal of the yearly tabulations indicates an apparent instability in accident types resulting in fatal collisions. The fatal accident is apparently such a rarity that it lacks the stability needed for proper analysis and formulation of sound conclusions unless a large sample is available. In this particular study the yearly sample size is obviously too small for independent analysis.

An interesting comparison is presented in Table 3 between the Turnpike fatal accident types and those reported in the California Freeway

TABLE 1

N. J. TURNPIKE ACCIDENT STATISTICS (1952 THROUGH 1958)

	1952	1953	1954	1955	1956[a]	1957	1958	Total 1952-1958
Total accidents[b]	1,007	896	946	1,145	1,009	1,045	1,004	7,052
Accidents/100 motor vehicle-miles	130.9	102.9	101.8	121.6	94.3	86.6	81.0	100.4
Injuries	851	681	533	722	588	798	708	4,881
Injury accidents	340	277	233	312	287	385	327	2,166
Injuries/100 motor vehicle-miles	110.6	78.2	57.4	76.7	54.9	66.1	57.1	69.5
Fatalities	47	36	23	26	25	24	30	211
Fatal accidents	33	26	18	25	18	20	24	164
Fatalities/100 motor vehicle-miles	6.11	4.14	2.47	2.76	2.34	1.99	2.42	3.00
Vehicles in millions	18.2	22.2	24.7	26.1	31.8	39.5	41.8	204.3
Vehicle-miles in millions	769.1	870.4	929.3	941.9	1,070.3	1,206.4	1,238.9	7,026.5

[a] During 1956 nearly 14 mi of new highway were added to the original 118-mi system.

[b] Accidents include all types even those with negligible property damage. Accidents at service areas and interchanges also included.

Median Study 1958 (1). The proximity of the approach and pedestrian-type fatal accident percentages between the two studies is startling. Such a comparison must, however, be tempered as 22 of the approach-type accidents or 5.4 percent in the California Study did not involve a crossing of the median but rather head-on collisions between vehicles, one of which was driving against the normal flow of traffic. Taking this into account, the Turnpike actually had a higher percentage of out-of-control head-on collisions than were recorded in the California Study. Their comparable total was 55 accidents representing 13.5 percent of the total accidents.

TABLE 2

ANALYSIS OF FATAL ACCIDENT TYPES (1952 THROUGH 1958)

	1952	1953	1954	1955	1956	1957	1958	Total	Percent
Overtaking	14	5	7	2	5	8	7	48	30.4
Overtaking (cross-median)	2	-	-	1	-	1	-	4	2.5
Pedestrian	4	4	2	9	3	3	2	27	17.1
Head-on[1]	2	6	1	5	3	3	7	27	17.1
Single vehicle	10	4	4	5	4	2	4	33	20.9
Single vehicle (cross-median)	1	5	3	3	2	2	1	17	10.7
Miscellaneous (passenger fell from vehicle)	-	1	-	-	-	-	1	2	1.3
Total[2]	33	25	17	25	17	19	22	158	

[1] Two accidents in 1955 initiated as a rear-end collision and a sideswipe but resulted in head-on collisions.

[2] Total of annual fatal accidents does not always agree with those recorded in Table 1, as fatal accidents which occurred within interchange areas or on extensions have been deleted.

There is no apparent reason for the wide percentage spread noted between the two studies in overtaking and single-vehicle-type fatal accidents. The balance of the Turnpike fatal accidents or some 64.5 percent are nearly equally divided between the overtaking (32.9 percent) and single-vehicle (31.6 percent) accidents. These accident types constituted 63.9 percent of the freeway accident study and single-vehicle-type fatal collisions exceeded the overtaking type by a factor of in excess of 2 to 1.

No detailed information was available as to hourly traffic flow characteristics when the accidents occurred in the freeways studied, but it was reported that 66 percent of the fatal accidents occurred during the hours between 7 p.m. and 7 a.m. Although a similar hourly breakdown has not been undertaken, it is known that 55 percent of the Turnpike fatal accidents occurred during the hours of darkness. On a yearly average basis, the period of darkness might compare reasonably close to the 7 p.m. to 7 a.m. period. Assuming this to be true, there are at least two possible reasons to explain the difference in frequency of the two fatal-accident types apparent between the two studies: (1) Turnpike fatal accidents occur during periods of higher traffic density; (2) nighttime freeway traffic density is below that experienced on the Turnpike. Either of these statements may partially explain the noted difference, but are considered inconclusive. Further investigation to determine the true reasons for such an apparent difference in these fatal-accident types could prove worthwhile.

Table 3 further indicates close agreement between the two studies on both average fatalities per fatal accident and average fatalities per head-on-type accident the most significant factor to be noted here is with regard to the severity of the head-on collision. This collision type is more apt to produce two fatalities than one, while the probability for all types is reversed. This is certainly one reason why highway officials should be concerned with the prevention of head-on collisions even though they represent one of the lesser fatal-accident types.

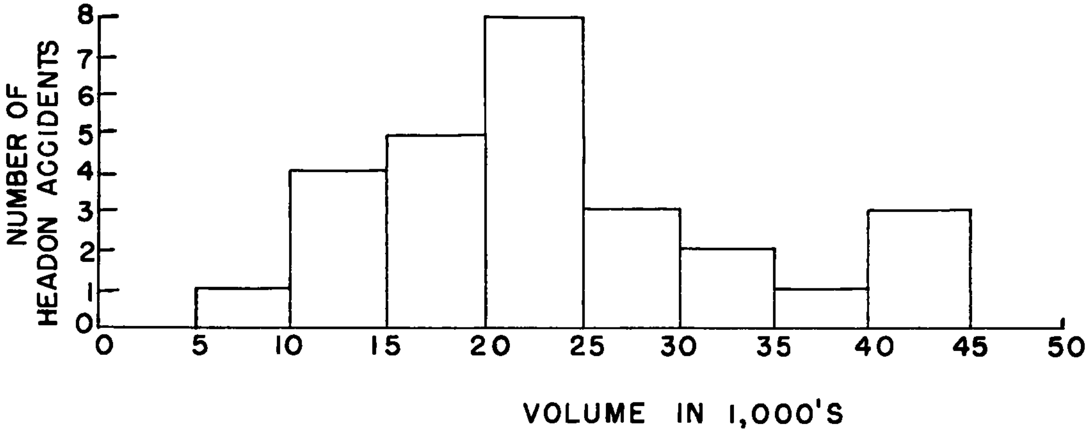

Figure 1. Number of head-on accidents as a function of two-way daily volume at the time of occurrence.

A further comparison of the two studies shows a wide variation in the cross-median fatal accident percentages. The Turnpike which recorded a 30.3 percent figure has had considerably worse experience when compared with the 18.9 percent recorded on the Freeways. The reasons for this difference is unknown but may be partially attributable to differences in median cross-section and width as well as traffic densities and normal vehicle speeds.

Table 4 gives a further analysis of the cross-median head-on fatal accidents during the 7-yr study period. In this tabulation the two-way traffic volume recorded on the day of the accident at point of occurrence is recorded as is the design width of the median crossed. The median widths shown as 18, 20 and 26 ft consist of a slightly mounded earth median with grass cover and penetration-type inner shoulders 5 ft in width on each side. The inner shoulders, which have a different texture from the bituminous roadway but are today nearly the same in color, are delineated by a well-maintained 6-in. reflectorized white paint line placed on the left edge of the inner traffic lane. The 6-ft median is a raised steel median with 9-in. barrier curbing immediately adjacent to the inner 12-ft traffic lanes. It is difficult to draw any conclusions from this tabulation as the mileage of the various median cross-sectional widths is of such unequal length and the annual average daily traffic volume varies so widely that they cannot be satisfactorily compared. The frequency of fatal crossings of the 26-ft designed width median makes it apparent that such a width is insufficient design to prevent the spectacular head-on collision.

Figure 1 shows the percentage of the fatal head-on accidents that occurred within certain daily volume ranges. Low or moderate opposing traffic volumes may reduce the statistical probability of a head-on collision but gives little, if any, assurance that they will not occur. The dynamics of vehicular movement are such that low probabilities of head-on occurrences may not be realistic as they are unable to cope with the defensive maneuvers that may be taken by either or both drivers. Detailed in-

TABLE 3

COMPARISON OF FATAL ACCIDENT TYPES ON TURNPIKE WITH CALIFORNIA FREEWAY EXPERIENCE

Accident Type	New Jersey Turnpike Study			California Freeway Median Study		
	No.	Percent of Total	Fatality Rate[c]	No.	Percent of Total	Fatality Rate[c]
Approach	27	17.1		77[a]	18.9[a]	
Overtaking	52	32.9		84	20.6	
Single vehicle[b]	50	31.6		176	43.3	
Pedestrian	27	17.1		70	17.2	
Total fatal accds.	158			407		
Total fatalities	205			499		
All accidents			1.30			1.23
Head-on accidents			1.66			1.53
Cross-median fatal accidents	48	30.3		77	18.9	

[a] These figures include accidents involving vehicles driving against the normal flow of traffic. Deleting such incidents results in 55 approach cross-median accidents or 13.5 percent of total.

[b] Single-vehicle-type fatal accidents include two miscellaneous types as presented in Table 2.

[c] Fatalities per accident.

TABLE 4

RESUME OF HEAD-ON FATAL ACCIDENTS ON N. J. TURNPIKE (1952 THROUGH 1958)

No.	Date	Milepost Location	Two-Way Daily Volume on Day of Accident	Median Width Including Inside Shoulders (ft)	Number Killed
1.	2/28/52	89	12,227	26	2
2.	11/30/52	110	44,706	6	1
3.	4/ 3/53	75	29,227	26	2
4.	5/15/53	22	14,004	26	1
5.	7/18/53	84	43,370	26	1
6.	8/14/53	34	24,020	26	1
7.	9/ 5/53	24	24,146	26	1
8.	11/ 6/53	50	12,782	26	5
9.	2/21/54	76	24,074	26	2
10.	4/ 3/55	67	26,931	26	2
11.	5/29/55	81	24,629	26	1
12.	7/22/55	66	25,213	26	1
13.	8/12/55	30	15,979	26	1
14.	11/10/55	89	24,019	26	1
15.	3/ 8/56	13	9,635	26	2
16.	3/16/56	63	16,267	26	1
17.	8/ 2/56	100	42,859	18	3
18.	4/29/57	39	19,772	26	3
19.	6/ 8/57	29	22,232	26	1
20.	7/13/57	40	31,869	26	2
21.	2/ 1/58	41	13,162	26	1
22.	4/26/58	50	23,072	26	1
23.	7/22/58	116	30,285	20	2
24.	9/21/58	56	37,542	26	2
25.	9/21/58	4	17,468	26	1
26.	10/15/58	61	22,981	26	1
27.	11/16/58	14	15,674	26	3

Note: 45 fatalities, 27 fatal accidents, 24 over 26-ft median, 1 over 20-ft median, 1 over 18-ft median, and 1 over 6-ft median.

vestigation into a number of these collisions gave an indication that in some cases the chosen defensive action actually was a primary contributing factor to the event.

FREQUENCY OF HEAD-ON ACCIDENTS AS RELATED TO VOLUME AND ROADWAY CROSS-SECTION

In an attempt to keep the head-on accident in the proper perspective to the over-all highway accident picture, Tables 5 and 6 are presented. The accident experience between successive pairs of interchanges by accident type for a recent 3-yr period are given in Table 5. The average daily traffic volume between the successive interchanges is noted. Where it became necessary to combine areas to yield a satisfactory sample size, the appropriate volumes are noted for the combined areas.

Overtaking accidents account for more than 60 percent of the total accidents, but vary from a low of 45 percent between interchanges 2 and 4 to a high of 79 percent between 15 and 16. There is undoubtedly a strong tendency for this percentage to vary directly with the traffic volume.

Single-vehicle accidents are classified under three sub-headings and are also summarized. Collisions of this type account for over 30 percent of the total accidents. Considering the twelve locations separately, it is found that the percentage varies from a low of 12 percent between interchanges 15 and 16 to a high of 45 percent between 2 and 3. When the percentages are reviewed with respect to traffic volumes, the tendency for this accident type to increase with decreasing traffic volumes is apparent. This tendency is probably a direct result of the higher speeds and decrease in driver attentiveness associated with low traffic density.

TABLE 5

N. J. TURNPIKE ACCIDENT TYPES BY LOCATION (1956 THROUGH 1958)

Between Interchange Number	Roadway Mileage	Average Daily Volume	Total All Accidents	Overtaking Accidents		Single-Vehicle Accidents					Head-on Accidents		Misc. or Unclassified[2]	
				No.	%	Out-of-Control Left	Out-of-Control Right	Other Types[1]	Total Number	7.1	No.	%	No.	%
1 - 2	12	14,476	114	61	54	16	23	7	46	40	3	3	4	3
2 - 3	13	14,946	110	50	45	20	24	6	50	45	6	6	4	4
3 - 4	8	16,490	130	58	45	21	30	5	56	43	12	9	4	3
4 - 5	10	20,152	177	101	57	20	36	7	63	36	5	3	8	4
5 - 7	9	(20,411 (26,515	129	69	53	15	23	7	45	35	6	5	9	7
7 - 8	15	26,527	275	161	58	20	47	13	80	29	5	2	29	11
8 - 9	15	26,154	280	161	57	23	50	13	86	31	5	2	28	10
9 - 10	7	32,630	122	73	60	13	19	10	42	35	3	2	4	3
10 - 13	10	(25,587 (38,003 (41,656	267	166	63	19	46	13	78	29	1	0	22	8
13 - 15	7	(40,761 (41,708	220	143	65	16	24	21	61	28	5	2	11	5
15 - 16	5	45,907	327	258	79	21	12	13	46	14	6	2	17	5
16 - 18	6	(26,212 (28,346	101	60	59	13	12	6	31	31	4	4	6	6
Total	117		2,252	1,361		217	346	121	684		61		146	
Percentage of total accidents				60.4		9.7	15.4	5.4	30.5		2.7		6.4	
Percentage of fatal accidents				36.2					39.7		22.4		1.7	

1/ Includes overturned on roadway, pedestrian and collision with other objects on roadway accidents.
2/ Includes unusual accident types such as unattended vehicles leaving roadway, jackknifing of utility trailer, chain broke on lumber truck striking adjacent car, wheel broke free and struck passing vehicle, etc.

Head-on accidents constitute the smallest portion of the accident experience, accounting for 2.7 percent of the total. The range for this collision type varies from 0 percent between interchanges 10 through 13 to a high of 9 percent between 3 and 4. The former percentage is relatively easy to explain as 8.5 mi of this 10-mi area has a median width of 94 ft. This analysis fails to reveal any accident pattern with respect to volume which possibly may be due to the infrequency of head-on accidents. In the earlier discussions, however, it was pointed out that the roadway cross-section was identical between interchanges 1 and 10, except that only four lanes are paved between 1 and 4 with six lanes from 4 to

10. In the 34-mi four-lane divided area 5.9 percent of the collisions have been head-on, while only 2.4 percent were of this type in the 56-mi six-lane section. This suggests the possibility that roadway width may be a modifying factor as it affects the total maneuvering width available to drivers. This theory was also suggested in the California Median Study 1958.

EFFECTIVE MEDIAN WIDTH VS ACTUAL MEDIAN WIDTH

A recent study (2) of lane volumes and speed presented a typical distribution of vehicles by traffic lanes for a three-lane one-way roadway. It was reported in the study that during periods when the roadway volume is below 500 vehicles per hour, the right lane carries more vehicles than either the center or left lanes. Above this figure, the center lane carries a volume in excess of the right lane but the left lane volume does not exceed the right lane volume until the total one-directional volume exceeds approximately 1,800 vehicles per hour. Furthermore, the volume carried by the left lane remains below the center lane volume until the roadway volume exceeds 3,600 vehicles per hour. This description of lane use partially illustrates the variability of "effective median width" as it may be applied to various hourly or daily roadway volumes. (Effective median width for purpose of this study is assumed to be the lateral distance from a vehicle traveling in any lane in one roadway to the nearest possible vehicle traveling the opposing roadway of a divided highway having a traversable median.)

Using further data from this study, it was reported that for a particular day when traffic flow for a short period of time approached the basic capacity, the left lane carried 33 percent, the center lane 40 percent and the right lane 27 percent of the total daily flow. These lane volume percentages may be restated in terms of "effective median width" for the vehicles occupying each of the three lanes in one roadway with respect to the inside lane of the opposing roadway as follows:

TABLE 6

N. J. TURNPIKE ACCIDENT FREQUENCY AND VEHICLE MILEAGE RATES FOR VARIOUS ACCIDENT TYPES BY LOCATION
(1956 THROUGH 1958)

Between Interch. Number[a]	Roadway Mileage	Typical Median Cross-Section (ft)	Average Daily Volume	Vehicle-Miles (in millions)	Accident Frequency (per mi)	Accident Rate (per 100 million veh-mi)	Overtaking Accidents (per 100 million veh-mi)	Single-Vehicle Accidents (per 100 million veh-mi)	Head-On Accidents (per 100 million veh-mi)	Misc. Accidents (per 100 million veh-mi)
1 - 2	12	26	14,476	190.4	9.5	59.9	32.0	24.2	1.6	2.1
2 - 3	13	26	14,946	212.9	8.5	51 6	23.5	23.5	2.8	1.9
3 - 4	8	26	16,490	144.6	16.3	89.9	40.1	38.7	8.3	2.8
4 - 5	10	26	20,152	220.9	17.7	80.1	45.7	28.5	2.3	3.6
5 - 7	9	26	(20,411 (26,515	214.7	14.3	60.1	32.1	21.0	2.8	4.2
7 - 8	15	26	26,527	436.1	18.3	63.0	36.9	18.3	1.1	6.6
8 - 9	15	26	26,154	430.0	18.7	65.1	37.4	20.0	1.2	6.5
9 - 10	7	26	32,630	250.3	17.4	48.7	29.2	16.8	1.2	1.6
10 - 13	10	94[b]	(25,587 (38,003 (41,656	418.9	26.7	63.7	39.6	18.6	0.2	5.2
13 - 15	7	20[c]	(40,761 (41,708	314.8	31.4	69.9	45.4	19.4	1.6	3.5
15 - 16	5	20[d]	45,907	251.6	65.4	130.0	102.5	18.2	2.4	6.8
16 - 18	6	20	(26,212 (28,346	184.1	16.7	54.9	32.5	16.8	2.2	3.2
Total	117			3,269.3	19.2	68.9	41.6	20.9	1.9	4.5

[a] The roadway cross-section between interchanges 1 through 4 is 4-lane divided with 6-lane divided elsewhere with one exception (Note b).

[b] Includes 0.7 mi of 20-ft and 0.8 mi of 8-lane dual-dual with 20-ft medians.

[c] Includes 1.4 mi of 18-ft median with 9-in. barrier curbs.

[d] Includes 1.0 mi of 6-ft median with double guardrail and 2.4 mi on bridges with 6-ft steel median with 9-in. barrier curbs and no outer shoulder.

1. Thirty-three percent of the vehicles had an "effective median width" equal to the median width.
2. Forty percent of the vehicles had an "effective median width" equal to the median width plus 12 ft (1 lane width).
3. Twenty-seven percent of the vehicles had an "effective median width" equal to the median width plus 24 ft (2 lane widths).

From the foregoing it is apparent that the designed median width is not a good base for evaluation of its effectiveness. The "effective median width" is a better measurement as it takes into account lane placement of vehicles. It is also obvious that a six-lane divided facility will have a greater "effective median width" for all conditions of traffic flow than a four-lane facility with identical median width. The cross-median accident experience of two facilities having equal or nearly equal design median width cannot be directly compared with any reasonable reliability unless the "effective median width" (that is, roadway cross-section and annual hourly lane volumes) are similar. Further investigation, beyond the scope of this study, is needed to better identify the relationships that may exist between these factors.

There would appear to be a direct application of this theory to traffic operations. Some states have eradicated the "keep right except to pass" rule, which formerly, when adequately enforced, tended to keep the practical maximum number of vehicles away from the roadway centerline. The relaxation of this regulation has resulted in a reduced "effective median width" and may increase the frequency of both cross-median and head-on-type accidents. This regulation is well posted and enforced on the Turnpike and may in part explain the fact that 60 percent more out-of-control single-vehicle accidents involved vehicles leaving the roadway to the right rather than the left. The tendency to keep right results in greater maneuvering area to the left with a lesser area on the right. This area on the right, for a vehicle traveling the right lane, includes only the 10- or 12-ft paved shoulder plus approximately 6 ft of berm. The area beyond this to the base of the ditch cannot be considered maneuver area as it is generally a 1 on 4 slope. Such a slope tends to "roll" vehicles traveling at the usual roadway speed.

Table 6 gives the accident rate experience between successive pairs of interchanges by accident type for the same period as in Table 5. Accident frequency per mile averaged 19.2 with a range of 8.5 to 65.4 There is a definite trend for this value to increase with volume although minor exceptions are noted. The peak frequency of 65.4 does not necessarily give a true picture of the conditions of operation between interchanges 15 and 16. This particular area has been approaching saturation during the morning and afternoon peak commuter period. A total length of 2.4 mi of high bridge structure of six-lane divided cross-section without breakdown shoulder and lengthy 3.0 percent grades has certainly exerted a great deal of influence on the over-all frequency experience of this 5-mi section of roadway. (Ultimate design of the area between interchanges 15 and 16 will result in twin structures of identical cross-section, each carrying one-way traffic flow on dual-dual roadways with full breakdown shoulder.)

With respect to the overtaking and single-vehicle accident rates per 100 million vehicle-miles, the rates tend to equalize in the lower volume areas. With increasing volume the overtaking accident rates generally tend to increase with a resulting decrease in single-vehicle accidents.

TABLE 7

SUMMARY OF CROSS-MEDIAN AND HEAD-ON ACCIDENTS AND ACCIDENT RATES FOR MAJOR AREAS OF SIMILAR CROSS-SECTION AND TRAFFIC VOLUMES (1952 THROUGH 1958)

Section	Between Interchanges or Mile	Mileage	Roadway Lanes	Median Cross-Section (ft)	Minimum and Maximum ADT[a]	Number Cross-Median Accids.	No. Cross-Median Accidents (per mi)	Cross-Median Rate (per 100 million veh-mi)	Number Head-On Accidents	Number Head-On Accidents (per mi)	Head-On Rate (per 100 million veh-mi)	Fatal Accids.	Vehicle-Miles (in millions)
A	1 and 4	33	4	5-16-5	13,400 14,800	127	3.8	10.8	44	1.3	3.7	7	1,178.0
B	4 and 10	56	4-1952-55 6-1956-58	5-16-5	18,900 27,400	231	4.1	7.3	62	1.1	2.0	17	3,144.1
C	10 and Mile 98	8	6	5-84-5	23,100 36,900	3	0.4	0.4	1	0.1	0.1	0	683.1
D	Mile 101 and Mile 107	6	6	5-10-5	36,000 37,600	35	5.8	6.2	11	1.8	2.0	0	560.5
E	16 and 18	5.6	4-1952-55 6-1956-58	5-10-5	23,600 24,400	19	3.4	5.5	4	0.7	1.1	1	346.8
Total	Interchange 1 to 18					455	3.9	6.8	134	1.1	2.0	27	6,706.4

[a] The minimum ADT is the average daily volume for the 7-yr period in the section of any area carrying the least amount of traffic. The maximum ADT is the similar figure for the section carrying the heaviest volume.

The head-on accident rate again yields no recognizable pattern. The low rate shown for the area between interchanges 10 and 13 speaks well for the safety of the 94-ft median through most of this area. Referring to Table 5, only one cross-median head-on occurrence was recorded on this 10-mi section for the 3-yr period, and was of minor consequence. However, such a width will not completely eradicate the head-on accident problem as during 1959 a vehicle involved in a minor sideswipe collision completely crossed this area striking an opposing vehicle and resulted in two fatalities.

CROSS-MEDIAN AND HEAD-ON ACCIDENT FREQUENCY

During the study period from January 1952 through December 1958, there were recorded 455 cross-median accidents, 134 of which resulted in a head-on collision. The total open highway experience for the same period resulted in 5,473 collisions of all types including those of negligible property damage. Cross-median accidents constitute 8.3 percent of all accidents and head-on collisions 2.4 percent. However, 29.5 percent of the cross-median accidents resulted in a head-on accident. These statistics would appear to minimize the importance of this accident type; except for the fact that a prior analysis indicates that over 30 percent of the fatal accident experience was a direct result of a cross-median accident and 17 percent involved a head-on impact. While highway officials have a difficult time justifying the expenditure of a very large sum of money to prevent 8.3 percent of the highway accidents, public sentiment appears to be more concerned with the prevention of the smaller number, but considerably higher percentage of fatal accidents.

Appendix A (an expansion of a similar tabulation included in a 1957 supplemental unpublished report to the Median Accident Report, December 1954, submitted to the New Jersey Turnpike Authority by Fred W. Hurd, Yale Bureau of Highway Traffic) is a log of cross-median and head-on accident frequency by 1-mi sections for the entire study area. The occurrence rates per 100 million vehicle-miles are presented as well as other pertinent information, including median cross-section and the average daily traffic for each 1-mi section. This detailed analysis is summarized in Table 7 by areas of similar roadway cross-section and traffic volume range. Very short areas of unusual cross-section have not been summarized in this tabulation due to the obvious statistical deficiencies associated with such analyses.

Several sections worthy of mention, which were discussed in an earlier study (3), are in the area between mile 107.2 and 110.6 detailed in the

Appendix. These consist of three median locations having back-to-back beam-type guardrail. The first section of 0.15 mi and last section of 0.25 mi are placed continuously through the transition from the 6-ft raised steel median to the beginning of the 20-ft standard cross-section. The middle section which has a length of 0.7 mi is positioned in the center of a 6-ft slightly depressed bituminous concrete surfaced median. During the 7-yr study period there is no record of a cross-median accident at either of these locations. The over-all experience with this barrier has been good as compared to the steel-curbed medians on the bridge structures.

A review of Table 7 reveals two significant items related to both median width and traffic volumes. Section C with its 94-ft median and carrying close to the highest average daily traffic volumes has what might be considered almost a perfect cross-median accident record. Section A which carries the lowest volumes of the entire study area has produced the worst cross-median and head-on accident statistics of any of the five sections with one minor and relatively unimportant exception. It may be directly compared to Section B which has an identical median cross-section but traffic volumes varying from 40 percent to more than 80 percent in excess of those carried in Section A. This comparison reveals that the cross-median and head-on rates are 48 percent and 85 percent, respectively, above the rates in Section B. Here again traffic volumes appear to have little relationship to this accident type. Design median width can also be ruled out as they are identical in both areas. The difference in "effective median width," which was earlier discussed, appears to be at least a partial explanation.

Sections D and E may also be directly compared as the roadway cross-sections are identical although the former section carried more than 50 percent higher daily volumes. At these locations, which have almost equal lengths, volume alone would appear to explain the higher cross-median and head-on accident rates. If, however, volume is assumed to be the major factor here, it becomes impossible to explain the fact that both Sections A and B have had considerably poorer experience with both lower volumes and wider medians.

SUMMARY AND CONCLUSIONS

The purpose of this study was to present the cross-median accident experience on the New Jersey Turnpike. This information, in addition to several other pertinent analyses, has been presented for evaluation of the subject.

In recognition of this evaluation it should be understood that the New Jersey Turnpike was constructed in conformance to high design standards. All opposing roadways were separated by reservations which were generally considered, in the highway field at that time, to be wide medians. Experience has proven that serious head-on collisions will occur across these slightly raised deterring-type earth medians having a cross-sectional width of 26 ft or less. On the other hand, the 94-ft deterring-type earth median of either slightly raised or depressed design, has proved adequate to prevent almost all cross-median accidents. Furthermore, medians of this cross-sectional design add valuable maneuver area permitting an errant driver to recover control of a vehicle without damage or injury. Highly raised or deeply depressed designs may be effective in preventing cross-median accidents with a lesser width, but tend to roll, deflect or trap vehicles that may have recovered without incident. A flat slope, of 1 on 6 or less, is equally important to median and drainage slope design beyond the outside shoulders. Further study of similar designs having widths between the range of 26 to 94 ft should prove of value in the determination of optimum width.

The following conclusions appear warranted as a result of the findings of this study:

1. Head-on collisions represent less than 3 percent of the total accident experience on the Turnpike but cannot be neglected from the engineering standpoint as they account for more than 17 percent of the fatal accidents and 22 percent of the fatalities.
2. There is no apparent relationship between total accident rates and roadway volumes for sections of road with comparable design features operating at or below their design capacity.
3. Overtaking and single-vehicle accidents (excluding pedestrian accidents) account for over 85 percent of the total accident experience on the Turnpike and nearly 65 percent of the fatal accidents. The former accident type exhibit a tendency to increase in frequency with increasing volume, whereas the latter diminish in frequency with increase in volume.
4. Pedestrian accidents, although constituting less than 5 percent of the accident experience, are responsible for 17 percent of the fatal accidents. More stringent controls and increased enforcement are deemed essential to prevent hitch-hiking which was responsible for more than one-third of these fatalities. The balance of the fatalities were motorists who were outside of their vehicles and in many cases legally parked on the shoulder due to vehicle disablement. A standardized pattern of rear lighting to specifically identify a stopped vehicle appears necessary, as in many cases a vehicle drove onto the shoulder striking the vehicle and motorist. Increased motorist education pointing out the hazard of leaving the vehicle under these conditions may be helpful.
5. There is no apparent relationship between design median width and total accident rate. Furthermore, there is little, if any, relationship between median width and cross-median accidents for designed widths varying from 6 to 26 ft. Available data at the lower extreme, however, were very limited and are, therefore, believed to be inconclusive. Within this range of median width several other factors including pavement cross-section and character, and driver attitude and attention may be controlling factors exerting a greater influence than physical median width itself.
6. For design median widths of 20 to 26 ft there appears to be little relationship between either cross-median or head-on collisions and roadway volumes experienced during the study period. A need for further study is indicated to develop the relationships suggested in the study between roadway cross-section, traffic volumes and cross-median accidents.

REFERENCES

1. "Median Accident Study: 1958." Traffic Department, California Division of Highways.

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3. Hurd, F. W., "Accident Experience with Traversable Medians of Different Widths." HRB Bull. 137, pp. 18-26 (1956).

Appendix

CROSS-MEDIAN AND HEAD-ON ACCIDENTS AND ACCIDENT RATES BY 1-MI SECTIONS
(CROSS-MEDIAN TOTALS INCLUDE HEAD-ON ACCIDENTS) (1952 THROUGH 1958)

Mile	Median Cross-Section (ft)	Number Cross-Median Accid.	Cross-Median Rate (per 100 million veh-mi)	Number Head-On Accid.	Head-On Rate (per 100 million veh-mi)	Fatal Accidents and Fatalities	Average Daily Traffic1/
Inter. 1							
1 - 2	5-16-5	-	-	-	-		13,400
2 - 3		2	6	-	-		
3 - 4		-	-	-	-		
4 - 5		3	9	1	3	(1)	
5 - 6		3	9	-	-		
6 - 7		1	3	-	-		
7 - 8		4	12	1	3		
8 - 9		6	18	2	6		
9 - 10		2	6	1	3		
10 - 11		8	24	3	9		
11 - 12		4	12	1	3		
12 - 13		4	12	-	-		
Inter. 2							
13 - 14	5-16-5	9	26	3	9	(2)	13,900
14 - 15		6	17	3	9	(3)	
15 - 16		2	6	-	-		
16 - 17		1	3	-	-		
17 - 18		-	-	-	-		
18 - 19		3	9	-	-		
19 - 20		3	9	-	-		
20 - 21		2	6	-	-		
21 - 22		2	6	1	3		
22 - 23		4	12	1	3	(1)	
23 - 24		3	9	-	-		
24 - 25		6	17	4	12	(1)	
25 - 26		-	-	-	-		
Inter. 3							
26 - 27	5-16-5	3	8	-	-		14,800
27 - 28		4	11	2	5		
28 - 29		4	11	1	3		
29 - 30		9	24	6	16	(1)	
30 - 31		7	19	3	8	(1)	
31 - 32		4	11	1	3		
32 - 33		7	19	4	11		
33 - 34		11	30	6	16		
Inter. 4							
34 - 35	5-16-5	3	7	1	2	(1)	18,800
35 - 36		10	21	2	4		
36 - 37		2	4	-	-		
37 - 38		6	13	1	2		
38 - 39		2	4	1	2		
39 - 40		3	6	1	2	(3)	
40 - 41		4	9	1	2	(2)	
41 - 42		5	11	1	2	(1)	
42 - 43		6	13	-	-		
43 - 44		5	11	2	4		
Inter. 5							
44 - 45	5-16-5	4	8	1	2		19,100
45 - 46		4	8	-	-		
46 - 47		3	6	-	-		
47 - 48		4	8	3	6		
48 - 49		4	8	1	2		
49 - 50		2	4	1	2		
50 - 51		4	8	2	4	(1) (5)	
Inter. 6							
51 - 52	5-16-5	8	15	2	4		21,800
52 - 53		6	11	-	-		
Inter. 7							
53 - 54		3	5	-	-		
54 - 55		6	11	-	-		
55 - 56		1	2	-	-		
56 - 57		5	9	3	5	(2)	
57 - 58		1	2	1	2		
58 - 59		1	2	-	-		
59 - 60		4	7	1	2		
60 - 61		4	7	-	-		
61 - 62		3	5	1	2	(1)	
62 - 63		3	5	1	2		
63 - 64		6	11	2	4	(1)	
64 - 65		4	7	1	2		
65 - 66		9	16	2	4		
66 - 67		3	5	1	2	(1)	
67 - 68		6	11	3	5	(2)	

CROSS-MEDIAN AND HEAD-ON ACCIDENTS AND ACCIDENT RATES BY 1-MI SECTIONS
(CROSS-MEDIAN TOTALS INCLUDE HEAD-ON ACCIDENTS) (1952 THROUGH 1958)
(Continued)

Mile	Median Cross-Section (ft)	Number Cross-Median Accid.	Cross-Median Rate (per 100 million veh-mi)	Number Head-On Accid.	Head-On Rate (per 100 million veh-mi)	Fatal Accidents and Fatalities	Average Daily Traffic[1]
Inter. 8							
68 - 69	5-16-5	10	18	2	4		22,500
69 - 70		5	9	1	2		
70 - 71		7	12	1	2		
71 - 72		2	4	-	-		
72 - 73		3	5	1	2		
73 - 74		2	3	-	-		
74 - 75		9	16	4	7		
75 - 76		5	9	2	4	(2)	
76 - 77		3	5	1	2	(2)	
77 - 78		2	3	1	2		
78 - 79		4	7	-	-		
79 - 80		4	7	-	-		
80 - 81		7	12	3	5		
81 - 82		3	5	1	2	(1)	
82 - 83		5	9	2	4		
Inter. 9							
83 - 84	5-16-5	4	6	2	3		27,400
84 - 85		3	4	1	2	(1)	
85 - 86		2	3	1	2		
86 - 87		1	2	-	-		
87 - 88		3	4	2	3		
88 - 89		1	2	-	-		
89 - 90		2	3	1	2	(1) (2)	
Inter. 10							
90 - 91	5-84-5	1	2	-	-		23,100
Inter. 11							
91 - 92	5-84-5	-	-	-	-		34,100
92 - 93		1	2	1	2		
93 - 94		-	-	-	-		
94 - 95		-	-	-	-		
95 - 96		1	2	-	-		
Inter. 12							
96 - 97	5-84-5	-	-	-	-		36,900
97 - 98		-	-	-	-		
98.5	5-10-5						
98 - 99		3	3	1	1		
99.2	Dual-dual						
99 - 100		4	4	1	1		
100 - 101	5-8-5	7	8	2	2	(3)	36,000
101.4							
101 - 102	5-10-5	6	7	2	2		
102-103		7	8	3	3		
103 - 104		7	8	1	1		
104 - 105		7	8	2	2		
Inter. 14							
105 - 106	5-10-5	5	5	-	-		37,600
106 - 107		3	3	3	3		
Inter. 15							
107 - 107.2	5-10-5	5	24	1	5		40,100
107.2 - 107.35	Guardrail	-	-	-	-		
107.35-108.65	6-ft steel	10	7	5	4		
108.65-109.25	Guardrail	-	-	-	-		
109.25-110.35	6-ft steel	6	5	1	1	(1)	
110.35-110.6	Guardrail	-	-	-	-		
110.6 - 111	5-10-5	2	5	-	-		
111 - 112		3	3	1	1		
Inter. 16							
112 - 113	5-10-5	1	1	1	1		23,600
Inter. 17							
113 - 114	5-10-5	4	7	-	-		24,400
114 - 115		2	3	-	-		
115 - 116		3	5	-	-		
116 - 117		8	13	2	3	(2)	
117 - 117.6		1	2	1	2		
Inter. 18							

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[1] Average daily traffic volume shown is the average for the 7 years (1952 through 1958) and may be converted directly to vehicle-miles of exposure for any 1-mi section using an expansion factor of 2557.

Dynamic Full-Scale Tests of Median Barriers

JOHN L. BEATON AND ROBERT N. FIELD, respectively, Supervising Highway Engineer, and Materials and Research Engineering Associate, Materials and Research Department, California Division of Highways, Sacramento

Full-scale dynamic tests were made of 15 proposed designs of traffic barriers for use in median areas. Of these, two proved to be worthy of trial installations.

This report describes the procedure used in testing median barriers by oblique, high-speed collisions with passenger vehicles and a 17,000-lb bus, and outlines the extensive instrumentation used in this test series.

Specific recommendations are made for use of a flexible-type barrier in wide medians and a semi-rigid type in narrow medians.

●THE ADVENT of the 4-lane highway and particularly the divided expressway and freeway has reduced the frequency of the deadly head-on collisions that were so prevalent on the 2-lane- and 3-lane-type highway. Unfortunately, this type accident has not been eliminated entirely, in that occasionally an out-of-control car will pass over even a wide median between the opposing roadways and may be involved in a head-on collision in the opposite roadway, resulting in the death of the majority of the occupants of both cars.

As outlined in the Report on Median Accidents (1) 20 percent of the fatal accidents that occur on freeways are the result of cross-median accidents.

It is the purpose of this report to outline the results of a test program to develop a median barrier that will prevent even a high-speed automobile from getting into the opposite lane while at the same time reducing so far as possible the severity of accidents that result from a vehicle striking the barrier.

After attaining operating experience with several types of median barriers in many locations, the Division of Highways launched an extensive study in an attempt to develop the optimum design for such barriers and to establish the conditions that justify their use. The Materials and Research Department was assigned the problem of making full-scale dynamic tests of various barrier systems so as to determine or develop the most efficient system for use as a barrier in a median strip.

In order of importance the following three functions were considered to be primary essentials of a median barrier: (1) positiveness of preventing crossing of median, (2) minimizing reflection of offending vehicle back into traffic stream, and (3) minimizing injury to occupants of offending vehicle.

In order that all pertinent factors would be considered, a median barrier committee was formed consisting of the Traffic, Design, Bridge, and Materials and Research Departments of the Division of Highways. In

April 1958 this committee met and approved for testing 12 basic designs of median barriers (Fig. 1). This original action was later revised by dropping one and adding four new designs making a total of 15 median barrier designs tested. The results of the tests are shown on the individual test data sheets (Figs. 3 through 22) in the Appendix.

TEST PROCEDURE

All the preliminary tests were conducted by driving a medium weight 4-passenger sedan automobile into the various test barriers at a speed of approximately 60 mph and an angle of collision of 30 deg. This same weight of car, speed, and approach angle were used to obtain as good a comparison as possible between the various designs. Final tests were made on the two designs, which were judged to be the most efficient after the preliminary program, by driving a 34-passenger bus into collision with them at 40 mph and an angle of 30 deg. (The bus at 40 mph represented slightly more than twice the kinetic energy developed by the cars at 60 mph.) One collision with a passenger car (Fig. 9) was made at a 20-deg angle of approach and was intended to determine the difference between a 20- and 30-deg angle of approach to the same type of barrier rather than as a comparative test of the barrier systems.

The 60-mph speed and the 30-deg angle of approach combination was selected as representative of the more severe type of oblique accident with a median barrier. (The primary aim was to test the resistance of the barrier.) This speed and angle were selected after studying the results of several actual cross-median accidents as well as analyzing this department's past experience with many different speeds and angles of approach used during the testing of bridge curbs and rails reported previously (2, 3).

Movements of the vehicle and barrier at the time of collision were recorded by a series of high- and normal-speed cameras placed approximately as shown on the typical test site layout diagram (Fig. 2) in the Apendix. Dynamic data were reduced from the film. These data were supplemented by deceleration recordings taken from accelerometers located in an anthropometric dummy restrained by a seat belt and located in the driver's seat of the test car. In addition to this, various dynamic strains were recorded by the use of SR4 gages located on some of the barrier systems. All physical changes in dimensions and condition of the barrier systems were listed as well as the observations and appraisals of damage to the car and visual action during and after the collision as recorded by trained observers at the site.

DISCUSSION

The reason for placing a barrier in a median between the opposing roadways of a divided highway is to prevent the crossing of that median by any traffic. However, it appears that such a barrier in order to be most effective must not only prevent crossing of the median but when struck by a car must minimize occupant injury and must minimize the tendency of the offending vehicle to be bounced back into the traffic stream.

Before discussing the findings of this study, the purpose of which was to develop a barrier that would be the most effective considering the foregoing three criteria, the attention of the reader should be directed to the fact that because of the cost of such a test program, it was necessary to hold the number of tests to the very minimum needed to provide a proper guide to engineering judgment rather than to attempt to collect sufficient information to develop mathematical parameters of all details. The following discussion of the test program is therefore tempered by the actual operating experience of the Division of Highways with several median barrier designs as well as a series of dynamic tests performed on barrier curbing and bridge rails during the years 1953, 1954, and 1955. Studies indicated in general that there are probably three broad classifications into which the various designs of median barrier can be placed. These are the (1) flexible type, (2) semi-rigid type, and (3) rigid type.

Flexible Barriers

The criteria used in this study for a flexible-type barrier was a design that would fulfill the barrier concept while at the same time flex and deform under collision such that the deceleration of the colliding car would be tolerable to its occupants and would provide safe maneuvering time and space for any cars in its own traffic stream. This being a new concept insofar as median barriers were concerned, no practical working designs could be found. During the study period prior to actual testing, several different designs were considered by the median barrier committee but were discarded for various reasons. The one design considered worthwhile for immediate testing was a combination of chain link fencing and wire rope cable properly anchored at the ends.

As shown in Figures 14, 16, 17, 18, 19, and 21, several tests were made to determine the proper details for such a system. The combination of 9-gage chain link fabric on 2 1/4-in. by 4.1-lb steel H posts seems to be reasonably well balanced in that during failure it provided sufficient resistance to decelerate both the test car and bus within a reasonable distance, while at the same time it allowed a deceleration rate tolerable to the occupants of the car.

It is of significance that transverse deceleration during test collision was in most cases less than longitudinal deceleration on this cable-chain link design. This illustrates the efficient trapping action of this design which brings the vehicle to a stop with a gradual transverse deceleration, not subjecting the occupants to the high transverse Gs usually resulting in ejections. The exception to this was Figure 18 which was a test of the proposed anchor and closure design. The results of this latter test proved that the anchorages immediately trap a car and cause a violent accident.

The deflection-time curves (Figs. 32 and 33) indicate the duration of encroachment on the opposing traffic lanes if this barrier is installed on median strips less than 16 ft between edges of pavement.

One of the secondary benefits of this design is that it will support a growth of ivy or other vines to serve as a headlight screen. It is probable that in some areas vines will not grow. It is suggested in these areas that wood or light metal strips could be inserted in the chain link fabric. In this case it is probable that the chain link fabric should be 48 in. wide rather than the 36 in. used in this series of tests. Indications are that this additional foot in height will not seriously affect the operation of the design as a barrier as long as the cable system remains undisturbed.

The lower cable has a double purpose of serving to distribute the collision load to the back posts, thereby stiffening the system in general, while at the same time allowing the wheel to pass over during initial impact and then serving as a trap to prevent the return of the front wheel and so helping to retain the car in the median area. The 9-in. height seems to be about right for this purpose.

The top cable is the most important structural item in this system. Its placement with respect to height is critical and its attachment to the post is critical. If the cable is placed too low, it will either permit the car to pass over the system or it will force the car to bounce back into its traffic stream. If placed too high, it might tend to slip over the car permitting it to pass on through and perhaps sever the superstructure.

This series of tests indicates that 30 in. above the ground is about the proper height for this top cable. This height is well above the center of gravity of most cars and pickups on the road today and therefore tends to prohibit any tendency for the car to roll. At the same time insofar as the average passenger car is concerned the cable will cut through the body sheet metal and slip over the colliding wheel; this helps to retain the car in the median area throughout and after collision. Figure 21 also shows this height to be effective in stopping a bus. Test No. 12 (Fig. 14) on a single top cable with load cells in the cable system indicates that a single cable will probably serve in this design. However, to be most effective a cable should be located on the collision side; this requires two cables. In addition, the risk involved in cutting one cable during collision is such that the factor of safety of having two cables is well worth the slight additional cost.

The fittings used to fasten the cable to the post must be so designed that they will clamp the cable firmly in place but, under collision loading, they will slip off the end of the post acting as a series of friction brakes. There should be no tendency to fix the cable to the post. If the cable were fixed to the posts, this would result in tripping the car rather than gradually snubbing it through a tolerable deceleration.

The effect of end anchorages is a definite problem. An anchorage strong enough to develop the strength of the cable is so strong that when struck it trips the car rather than snubs it to a gentle stop. This tends to cartwheel the colliding car in an uncontrolled manner with the possible unfortunate result that the car could pass on over the barrier, although it did not during the test of the anchorage system in this study. Under operating conditions the anchors should be placed at a point where other fixed objects occupy the median area. Insofar as distance between anchors is concerned, it has been determined that when subjected to a 60-mph passenger vehicle collision no permanent set occurred in the posts 150 ft behind impact and that the stress became negligible about 400 ft behind impact. The only practical limits to length would be those determined by the effects of temperature, topography or physical obstructions.

The cable should be placed and maintained in a snug condition but should contain little or no stress. To maintain the cable in this condition, turnbuckles should be placed about every 500 ft to provide for average seasonal changes as well as reasonable lengths for construction and replacement.

Semi-Rigid Barriers

The criteria used in this study for a semi-rigid-type barrier was a design that would be strong enough to fulfill the barrier concept, while at the same time capable of deforming into a smooth curve without pocketing under collision, such that a change of direction of the offending car would not be as abrupt as if the barrier were as completely rigid as a concrete wall. This would provide some opportunity for the occupants of the offending car to survive and allow a reflection of the car rapid enough for evasive action by close following cars.

During the study period prior to actual testing, many different designs were considered by the median barrier committee. A selection of designs shown in Figures 3-11, and 13 were selected to best investigate this general classification. These designs were selected for two reasons. The first was that almost all were already in use either in California or in other states or toll road authorities throughout the United States. The other was that the selection represented a good opportunity to investigate both types and spacing of posts as well as types and heights of rails. The results that came from testing this series of designs indicated that a composite design as shown in Figure 24 should be most successful. The two tests (Figs. 15 and 22) confirmed these findings.

The efficiency of the design used for Test No. 13 (Fig. 15) in lessening the chances of injury-producing impacts apparent in other tests on corrugated-beam guardrail mounted 30 in. above the ground is illustrated by the deceleration patterns shown in Figure 30. Note that the moderately high transverse Gs on the dummy occur when the vehicle is still in contact with the rail. It is apparent that the human body can sustain these moderate transverse Gs, taking the full load against the shoulder and arm, with less chance of critical injuries than the high longitudinal Gs which usually throw the occupant against the steering column and windshield.

Tests No. 1 and 2 (Figs. 3 and 4) were typical highway guardrail installations. In neither of these tests did the car pass over the barrier; however, the collision with the spring-mounted, curved-beam type resulted in the test car rolling along the top of the rail. Indications were that the car could have bounced across as well as coming to rest on the rail. The curved beam (Fig. 4) tended to pocket the car during impact whereas the corrugated beam (Fig. 3) formed a smooth curve and reflected the test car away from the rail. The necessity for good beam strength in metal-beam guardrails was well illustrated by these two tests which coincide with the findings of others (4).

In both of these tests the car rolled over after impact. This was caused by the rail, which was mounted at a 25-in. height (19 in. to center of rail), being forced back and downward under impact. This tended to impart a rolling motion to the car. This same action occurred at all mounting heights of rail, whenever no provision was made to prevent the rail from following the posts downward. At a 30-in. height the car tends to get under the rail forcing it upwards. This minimizes the tendency of the car to roll.

Test No. 3 (Fig. 5) was used to study the effect of steel spring posts. It was determined that the flexible posts deflected excessively under impact so that they formed the rail into a pocketed ramp, and the car passed on over the barrier. This system has no value as a barrier to high-speed vehicles.

Tests No. 4 and 5 (Figs. 6 and 7) were similar designs used to investigate the effect of doubling the number of posts at a 25-in. mounting height of rail. This height of barrier gave identical results as the guardrail Test No. 1 (Fig. 3) insofar as the reflected rollover-type accident was concerned in spite of the additional stiffness of adding the back rail in Test No. 4 and then doubling the posts in Test No. 5. The only effect of stiffening the system by doubling the number of posts was that, in the stiffer system, the car was reflected back more positively into the same traffic side of the rail.

Tests No. 6 and 7 (Figs. 8 and 9) duplicate barrier designs located in both the Los Angeles and San Francisco areas on existing freeways. These systems used the 30 in. mounting height above a 6-in. curb. One design is the corrugated-section beam and the other the curved-beam rail. Because these rails have approximately equivalent section modulus and were rigidly mounted on steel posts at 6-ft 3-in. centers, it was decided in advance that rather than using the exact speed and angle of approach for both designs, the angle of approach would be varied so as to note the difference between the two angles of approach. Both tests indicated that the railing was mounted at a proper height to provide positive barrier action and to prevent the rollover-type reflection. Unfortunately, this mounting height, with no means provided to prevent the offending car from going under the rail, results in the car colliding with the posts.

In Test No. 6 (Fig. 8), the 30-deg angle of approach, the car collided so hard with the post that it was trapped within 23 ft, resulting in decelerations far in excess of those that could possibly be tolerated by the occupants of the car, and in addition would give a following car little opportunity for evasive action. At the flatter angle of 20 deg in Test No. 7 the car again went under the rail, but due to the flat angle the frame of the car did not contact the post. The post severed the front wheel which went on through the barrier into the opposing traffic lane while the car reflected at a flat angle on its own side of the barrier. The free wheel itself could have caused a head-on collision.

These tests indicated that while the 30-in. mounting height was undoubtedly a workable height, if the normal 12-in. wide rail is used, there should be a means provided to prevent the undercarriage from being entrapped on the posts.

Test No. 8 (Fig. 10) made use of a double corrugated-metal rail mounted at an over-all height of 34 in. on each side of the steel post system so as to solve the entrapment problem. It did, but at the same time imparted a corkscrew rolling action to the car which resulted in the car tumbling on down the roadway similar to the 25-in. mounting height. This test seemed to verify that when no provision is made to prevent the rail from being downed with the posts, no matter what the height, it will impart a rolling tendency to the vehicle. In other words, to prevent roll the car must go under the rail so that the reaction of the rail on the car is downward.

There has been some belief that a spring system for mounting a guardrail would tend to minimize damage to the offending car. It may be true under light collisions; however, under heavy collisions as presented by Test No. 9 (Fig. 11), a flexible mounting tends to allow the rail to pocket between the posts. This results in a rail failure and the car passing on through the railing, thus it has little value as a positive barrier.

The designs shown in Figures 13 and 7 are identical except for height, so they can be considered as comparison of the effect of the change of height. There were two significant observations from these comparative tests. The first was that while there was some question from the action of the car whether or not it would pass on over the rail in Test No. 5 (Fig. 7), there was no question in Test No. 11 (Fig. 13). However, it was definitely shown that a 30-in. height of a single rail mounted directly to posts would result in a severe collision with the posts during high-speed, high-angle collisions.

These observations, coupled with the apparent operational success of blocked out guardrails used on the New Jersey Turnpike, led to the design shown in Figure 24. Here the rail is blocked out on timber posts and has a lower rail to prevent undercarriage entrapment. The 30-in. high blocked out design minimizes the rollover tendency of the car by allowing it to force under the metal guardrail, thus maintaining rail elevation, while the lower rail prevents the car from being trapped by the posts. Figures 15 and 22 show this design to be a success.

The decision to use timber posts was based on the observation that the timber post in earth under dynamic loading was more resilient and tended to give a smoother deceleration than did the steel post set in concrete. This was verified by static cantilever tests showing the 8- by 8-DF post to be nearly equivalent in strength to the 6-in.-wide flange 15.5-lb steel post with approximately twice the deflection. This resilience would be lost if the timber were set in concrete so it is suggested that in going over structures or in other areas where earth is not available, then either steel posts or a concrete wall barrier could be used.

The over-all width of this barrier design is about 27 in., and its deflection under heavy dynamic collision is about 3 ft. This design is efficient in narrow medians as a positive barrier. The reflection angle and speed of the offending car is such that evasive action is possible by following cars. The collision decelerations and the after travel of the offending car are such that the occupants have an opportunity of survival as long as there are no stalled vehicles in the road ahead.

Rigid Barriers

Rigid barriers are represented in this series by only one test (Fig. 20), but this test was supplemented by information gained during dynamic tests of five bridge rails performed and reported in 1955 and two concrete bridge rails tested during this series. As shown by the test data sheet, this design failed during tests.

Indications from the results of Test No. 22 (Fig. 20) are that the design of this rail needs only a slight amount of stiffening to make it serve under heavy collisions. Previous tests on bridge rails indicate that a wall as low as 27 in. in height could be effective as long as it did not fail. The reflective action from a properly designed concrete wall, as indicated by previous tests conducted on bridge rails, shows that the offending vehicle will reflect from the concrete wall with an abrupt change in direction and with high decelerations caused by the extremely rapid reflection of the vehicle from the non-deflecting surface. There is good opportunity, however, for evasive action by following cars in that the reflection angle is normally flat and due to the damaged colliding wheel the car tends to curve back into the rail and come to rest against it. There is even less opportunity of evading stalled traffic ahead after collision than there is with the semi-rigid-type barrier.

This rigid barrier is probably the only type that can be considered for those center strips where little or no space for a median barrier is available. In areas where it is felt that a great many brushing-type collisions will occur with such a center barrier, then consideration should be given to facing the rail with an undercut base or rubbing curb, as shown in the alternate design B in Figure 25. This undercut-type rubbing curb was found to be exceedingly efficient in controlling an offending car when subjected to low angles of collision (3).

The failure of the light concrete wall used in Test No. 22 served to illustrate again the fact that when a rail "lays over" during a heavy collision, no matter what the height, a high-speed colliding vehicle will tend to roll after reflecting from the barrier. Thus it is evident that any barrier design in which it is expected that measurable downward deflection will take place, then provision must be made to hold the restraining unit (rail, cable, etc.) at or above the center of gravity of the vehicle at the first instant of and throughout collision.

One other concrete median barrier was tested during this study. This barrier is shown in Figure 12 and consists of a series of truncated cone concrete posts placed at 5-ft centers. This design was not effective as a positive barrier.

Curbs

This series of tests included only two cases involving curbs placed in front of the test barriers. However, these two test supplemented by some 200 previous full-scale tests (3) performed on highway bridge curbing, are considered to be sufficient to support firm conclusions as to the effect of curbing in front of a median barrier. At high speeds the 6-in. high type of curb seems to have little effect on either the rise or deflection of the collision car. This is explained by the fact that the wheels and springs of the car were deflected over the 6-in. high curb with little appreciable change in elevation of the car itself. In other words, the center of gravity of the car and the frame of the car maintained their traveling elevation while the raise of the curb was taken up in the deflection of the tire and the springing system of the car. This effect would only be true for narrow medians and high angles of collision. At flatter angles of collision or wider medians, the rebound of the springing system would have time to lift a car to its new traveling elevation which would be 6 in. above its roadway elevation and due to spring reaction for a short period probably somewhat higher than this. Previous tests (3) indicate that this effect would no longer hold true for curbs 8 in. and higher. These higher curbs cause an immediate dynamic jump by the car. If such roadway curbs exist, then provision must be made in the design of the barrier to contain the dynamic jump.

INSTRUMENTATION

Collision Vehicles

The vehicles used for this 1959 Test Series were standard 4-door sedans, 1951 to 1955 models, supplemented by one 34-passenger 17,000-lb bus. The center of gravity of the various passenger cars was determined to be about the same and was between 21 and 23 in. above the pavement. The average weight of the vehicles with dummy and instrumentation was 4,000 lb. The rear seat and spare tire were removed to facilitate installation of the control instruments. The following modifications and installations were made in the test vehicles:

1. A Bendix Hydrovac booster was attached to the master brake cylinder for radio remote operation of the brakes.
2. The ignition system was bypassed and wired into the remote-radio control panel.
3. The gas tank was drained and the gas line rerouted into a 1-gal. tank mounted over the spare tire well. This tank was equipped with a relief valve and cut-off valve to prevent leakage of fuel when the vehicle rolled.
4. A mounting plate was welded to the floorboard in the front seat compartment for installation of the steering motor (Fig. 34).

5. Storage batteries and the steering pulser were bolted to the rear seat floorboard.

6. The remote radio control equipment was bolted to trunk compartment deck (Fig. 34). Whip antennae were mounted on the rear body of vehicle.

7. A seat belt was installed on the driver's side.

8. An adjustable pulley was clamped to steering wheel for control of vehicle through the steering motor.

Approximately 2 man-days' labor were required to modify each stock passenger vehicle to radio control.

Radio control of the vehicle along the 2,000-ft collision path was accomplished by means of 3 modulated tones and the R.F. carrier from a transmitter installed in the control truck (Fig. 35).

The five basic functions considered necessary for complete and flexible control of the test vehicles were: ignition on, ignition off, steer right, steer left, and brakes on. The accelerator linkage was wired in the full throttle position before push off. The vehicles attained a peak speed of 58 to 62 mph on impact, with a 2,000-ft collision path.

The ignition system was energized through a relay controlled by the R.F. carrier from the control truck transmitter. A failure in any of the radio control equipment opened the ignition relay allowing the car to stop under compression.

A signal to the steering motor pulser actuated the steering motor in incremental steps, variable in each direction from 1/8 to 1 in. per pulse. The pulse rate was variable from 2 to 20 pulses per second. The steering pulser was set after determining the amount of correction necessary to the steering of each vehicle by several trials before the actual test.

Deceleration Instrumentation

1. Two unbonded uni-axial strain-gage-type accelerometers were mounted on the right side of the vehicle frame at Station 10 (10 ft to the rear of the front bumper) for comparison to studies by others (5). The accelerometers are positioned with their axes 90 deg opposed to provide bi-axial sensing of the longitudiinal and transverse decelerations of the vehicle frame. Peak G readings are difficult to reduce from these oscillograph records because of high amplitude traces caused by the transient ringing inherent in the vehicle frame on impact with a semi-rigid object. Peak vehicle deceleration as reported on the data sheets represents an average of the peak decelerations recorded.

2. A Sierra Engineering Company, Model 157, 6-ft 0-in. 220-lb. anthropometric dummy positioned in the driver's seat was restrained by a conventional lap belt. The dummy was also instrumented with two accelerometers mounted in the chest cavity in the relative position of the heart, with the axes sensitive to the longitudinal and transverse deceleration of the upper torso. Deceleration readings from the dummy indicate the severity of injury-producing collisions as well as the general body areas injured on impact with the door or steering column of the crash vehicle, and can in most tests be considered the maximum Gs deceleration sustained during impact. This information may also be used for correlation to the work of others (5, 6).

Because of unforeseen failures due to the high "G" loading sustained by the accelerometer recording equipment mounted in the collision vehicles during the first ten tests, consistent deceleration readings could not be produced. Therefore "G" readings from the first ten test collisions were not considered valid and are omitted from this report. On subsequent tests a 300-ft tether line was connected from the accelerometers in the collision vehicle to the recording equipment in an instrument truck. The instrument truck followed parallel to and 30 to 50 ft behind the collision vehicle on the approach path. During two tests the tether line was severed a few milliseconds after impact; however, complete data were obtained on most of the Tests 11 through 22. In addition to the accelerometer data, the kinematics of the dummy under collision conditions were observed from the high-speed tower camera on the first seven tests.

The top of the vehicle from the windshield to 6 in. behind the driver's seat was cut away to allow total photographic coverage of the dummy reaction. It was apparent after an analysis of the data film records of these first seven tests that the kinematic pattern of the dummy was very similar during all of the semi-rigid barrier collisions.

Additional data of this type were not considered to be of enough significance to justify removal of the vehicle top on subsequent tests.

In all tests on semi-rigid and rigid barriers where the vehicle was not trapped by the posts, the vehicle was subjected to high transverse decelerations. The dummy was forced against the left door with sufficient energy to break the latching mechanism. On tests where those high transverse decelerations were imparted to the dummy while the side of the vehicle was not in contact with the barrier, the head and shoulders of the dummy protruded from the car. Had the dummy not been restrained with a lap belt, it would have been ejected from the vehicle. However, in cases where the dummy contacted the door at a time when the side of the car was in firm contact with the barrier, exemplified by Test No. 8, the rail prevented the door from opening completely.

An examination of the sequence photographs from the 25-in. high barrier tests as exemplified by Test No. 2 (Fig. 4) revealed that the rail retained only the lower portion of the door and allowed the top of the door to be forced open as much as 1 ft. In these cases the head of the dummy protruded from the vehicle, which resulted in critical head injuries.

When the dummy experienced excessive longitudinal decelerations, such as in Test No. 6 (Fig. 8) the torso of the dummy pivoted about the femur, striking the head and chest violently against the steering wheel, windshield, and instrument panel. This action was typical on all tests where the front wheel assembly was trapped by the posts.

Deceleration data from all tests of cable-chain link barriers show very low transverse decelerations (2-9 Gs) and low longitudinal deceleration (3-7 Gs). If the dummy did impart a loading great enough to spring the door latching mechanism, the door did not open because the vehicle was firmly against the upper cables when peak transverse decelerations occurred.

Photographic

This department has determined from experience on previous collision tests that photographic coverage of this type event will yield the maximum of significant data for the lowest initial investment. As it was necessary that the final analysis and presentation be in the form of a film report in addition to a written report, the data cameras had to function also as documentary cameras. A frame rate of 1200 per second was used for the tower mounted camera to record information on impact velocity, approach angle, and average vehicle deceleration. The field of view from this camera was 30 by 40 ft covering from 20 ft before impact to 20 ft beyond impact parallel to the rail. To provide documentary coverage, a 200 frame per second camera with the same field of view was mounted adjacent to the data camera. The field of view from this camera covered from 10 ft behind to 30 ft beyond impact parallel to the rail.

Due to the variable post collision trajectories of the test vehicles, it was found necessary to orient all but the tower-mounted data cameras at different locations for each test. The relative location of the cameras, barrier, collision vehicles, control and instrument vehicles for a typical test are shown in Figure 1. This was varied to meet the expected reflection action of each test. Standard photographic coverage of each collision included: one turret-mounted front data camera, one rear data camera, two overhead data cameras, and two documentary cameras panning the vehicle through collision to the terminal point. In addition to the foregoing photographic coverage, a 70-mm sequence camera operating at 20 frames per second was used to record a documentary series that could be enlarged and analyzed for details. The pictures exhibited at the top of each test data sheet are reproductions of the most significant frames from this sequence camera coverage.

Following is a description of the data and documentary cameras:

Camera Number	Type	Frames /Sec	Lens	Film	Location	Function
1	Fastax	1200	12.5mm	16mm 100-ft roll	Tower	Data
2	Gordent 200	200	13 mm	16mm 100-ft mag.	Tower	Data
3	Gordent 200	200	4 in.	16mm 100-ft mag.	Front turret	Data
4	Gordent 200	200	4 in.	16mm 100-ft mag.	Rear	Data
5	Hulcher 70	20	6.5 in.	70mm 100-ft roll	Rear platform	Doc. sequence
6	Bolex 16	24	Zoomar	16mm 100-ft roll	Various	Doc. pan
7	Bell & Howell	24	1 in.	16mm 100-ft roll	Various	Doc. pan
8	G.S.A.P.	64	1 in.	16mm 50-ft mag.	Various	Doc.

As each type camera motor required a different time interval to reach operating speed and each camera had a different operating frame speed, it was necessary to control them manually and in sequence from the camera control center.

A typical sequence for camera and flash bulb operation follows:

Impact minus 3 sec, camera #8
Impact minus 2 sec, cameras #2, 3, 4
Impact minus 1 sec, camera #1
Impact minus 200 millisec, flash bulb #4

For certain barrier tests additional data cameras were positioned at strategic points to cover wheel or front suspension reaction, post and rail reaction.

For a closer view of the dummy reaction during the two bus tests, a 200-fps data camera was rigidly mounted above the rear window of the collision vehicle to record a full kinematic study of dummy reaction. This camera was connected to a 10-sec time delay relay starting the camera when the collision vehicle was within 10 sec of impact. A spring loaded microswitch mounted on the rear bumper actuated the time delay relay when the power assist truck released the collision vehicle on the collision path.

As data camera #1 was the only camera with 1000 cycle timing pips, it was necessary to provide a method of timing the other data cameras. A segmented drum revolving at approximately 1600 rpm was mounted directly below the tower in view of all data cameras. Analysis of the revolving drum image and the timing pips on the film from camera #1 provided a time-in-space correlation for all data cameras. It was thus possible to correlate the information from any film frame on the data cameras with the film from the #1 camera.

Two pressure sensitive electrical switches were mounted on the pavement on the collision path and positioned 5 and 15 ft before the collision point. As the vehicle passed over the switches, flash bulbs positioned behind the barrier in view of the high-speed overhead data camera were fired. By analysis of the flash bulb images and the 1000 cycle timing pips on the high-speed data film from camera #1, the average speed of the test vehicle 10 ft before impact was determined.

A third flash bulb mounted on the collision vehicle was fired on impact by a "G" switch set to close when the deceleration approached 2 "G". A photocell mounted adjacent to the flash bulb transmitted this event marker pulse to the instrument truck accelerometer recorder through the tether line and onto the oscillograph recorder film. This pulse provided a correlation pip between the high-speed data camera and the deceleration recordings.

When strain gages were mounted on the barrier rails to measure the transmission of stress through the rail members, it was possible to correlate the stress recording oscillograph to the data cameras through a similar flash bulb/photocell unit positioned behind the barrier and in view of data camera #1. This flash bulb was triggered manually from the camera control center a few milliseconds prior to impact. This report does not contain the complete stress and strain information. This data was used merely to verify existing specification joint requirements.

TRIAL INSTALLATIONS

The barriers (Table 1) conforming to the recommendations of this report either have been or are being placed on California freeways. These installations are considered to be experimental and will be carefully observed under operating conditions.

CONCLUSIONS

Of the 15 median barrier designs tested, only two barriers satisfied to some degree all essential requirements for an efficient barrier when subjected to high-speed collision. The preferred barrier design to be used is determined primarily by the width between edges of pavement.

The combination cable-chain link barrier (Fig. 23) is over-all the most effective barrier but is limited to use in median strips where a deflection of about 8 ft can be tolerated. This barrier met all three requirements.

1. It acted as a positive barrier.
2. It minimized the possibility of the overtaking-type accident by retaining the vehicle within the median.
3. It decelerated the colliding vehicle gradually and so minimized the probability of injury to the occupants.

TABLE 1

MEDIAN BARRIER INSTALLATIONS

Contract	Location	Barrier	Length (ft)	Median Width E.P. to E.P. (ft)	1958 ADT
60-7VC-29FI	Santa Ana Freeway VII-LA-166-A	Cable-chain link	16,835	12	98,878
60-7VC-29FI	Santa Ana Freeway VII-LA-166-A	Blocked out rail	11,357	8 to 12	98,878
60-7VC-29FI	Hollywood Freeway VII-LA-2-D	Blocked out rail	7,138	12	130,500
60-7VC-15	Ventura Freeway VII-LA-2-LA	Cable-chain link	12,500	22	New construction
60-4TC-42	Bayshore Freeway IV-SF-68-SF	Blocked out rail	7,484	Curbed 6 to 16	86,100
60-4TC-40	Nimitz Freeway IV-Ala-69-C	Cable-chain link	20,200	12	82,400
60-4TC-40	Nimitz Freeway IV-Ala-69-C	Blocked out rail	14,797	2.5 to 12	82,400

Note: LA—Los Angeles County;
SF—San Francisco County;
Ala—Alameda County.

The blocked out metal beam barrier design shown in Figure 24 is the most effective for narrow medians and traffic conditions where deflections allowed by the cable-chain link type could not be tolerated. During the tests this barrier satisfied all three criteria to some degree.

1. It acted as a positive barrier.
2. Although it reflected the colliding vehicle back into its traffic stream, the exit speed and angle were such that close following traffic would have had some opportunity for evasive action.
3. It resulted in decelerations of the colliding car which, while high, would be within the possible limits of human tolerance. There would be a good probability of surviving a severe collision with this barrier.

RECOMMENDATIONS

Results of Test Program

The two designs shown in Figures 23 and 24 are recommended for use as traffic barriers between divided roadways subject to the following:

1. The cable-chain link barrier shown in Figure 23 be used as a barrier in medians where the width available will allow for at least 8-ft deflection of the barrier. It could be used in a median of lesser width depending on the degree of risk involved in allowing a momentary encroachment into the opposing roadway.
2. The blocked-out metal beam barrier shown in Figure 24 be used in narrow medians down to 3 ft when the space is insufficient for the cable-chain link barrier. By eliminating the metal beams and the wood block from one side of this design, it could be used where a definite barrier-type guardrail is needed, such as at bridge ends, tight curves, or other hazardous areas.

Future Study Suggestions

1. In medians where a rigid barrier is needed, such as between undivided multilane roads, tests performed on bridge rails during this program and in the past (2) indicate concrete to be the most efficient ma-

terial. No attempt was made to develop final details of such a barrier in this program; however, tests to date indicate Designs A and B in Figure 25 might be effective.

It is therefore suggested that if a study is undertaken to develop a rigid barrier, Designs A and B be included in such a program.

2. The limited tests of guardrail performed during this study indicated a definite need for the dynamic development of a guardrail design. Such a study should include both posts and rails. Post studies should include both dimensional and material design for each of the major construction materials: wood, steel, and reinforced and prestressed concrete. Rail studies should include not only geometric design but also materials other than steel, such as fiberglass reinforced plastics and aluminum.

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1. "Median Accident Study: 1958." Traffic Department, California Division of Highways.
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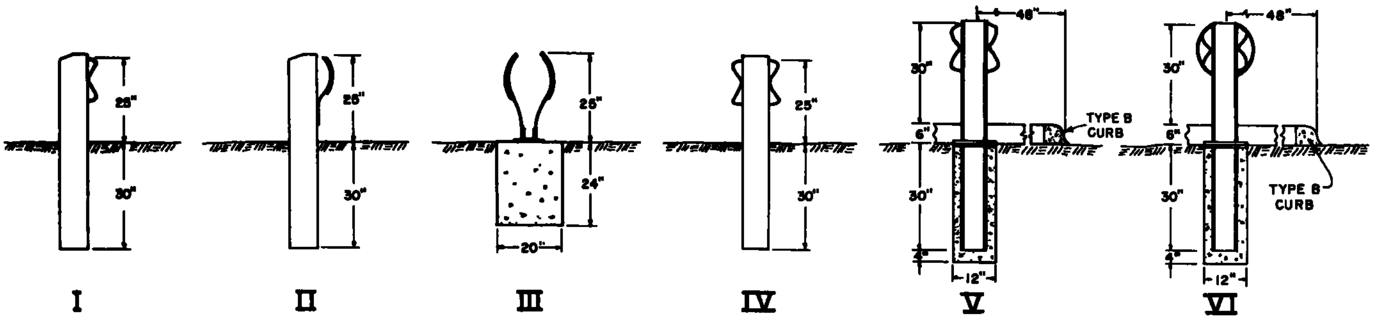
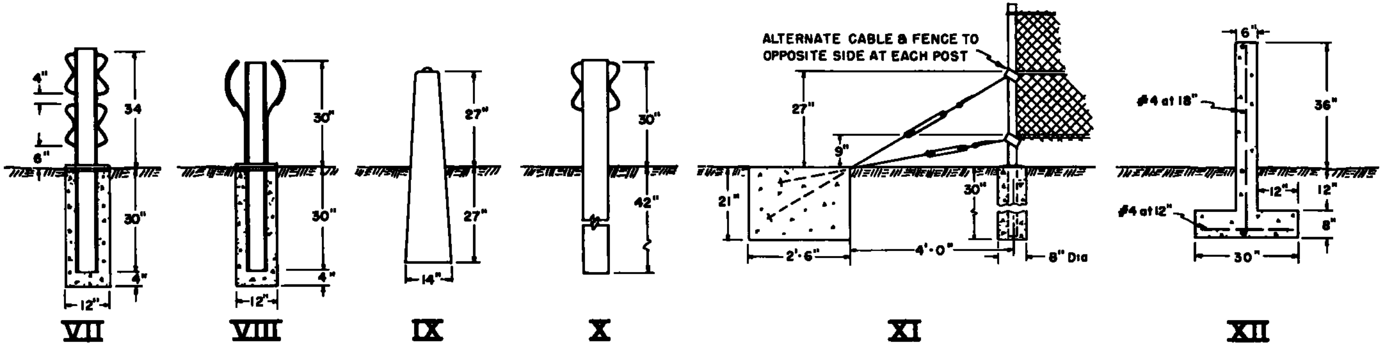
3. "Final Report of Full-Scale Dynamic Tests of Bridge Curbs and Rails." Materials and Research Department, California Division of Highways.
4. Lundstrom, L.C., and Skeels, P.C., "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests." HRB Proc., 38:353-355 (1959).
5. Severy, D.M., Mathewson, J.H., and Siegel, A.W., "Automobile Head-on Collisions, Series II." Univ. of California, Institute of Transportation and Traffic Engineering. (Presented at SAE meeting, Detroit, Mich., March 4-6, 1958).
6. "Seat Belt Hearings in the U.S. House of Representatives, May 1957." Automotive Crash Injury Research, Cornell Univ. Medical College.

HRB:OR-375



RAIL	CORRUGATED BEAM	CURVED BEAM	CURVED BEAM	CORRUGATED BEAM	CORRUGATED BEAM	CURVED BEAM
BRACKET	NONE	HG15N	HG 26 N	NONE	NONE	HG 32 N
POST	8" x 8" D F	8" x 8" D F	HG 26N	8" x 8" D F	6" WF 15 5 #	6" WF 15.5 #
POST SPACING	12'-6" CTRS.	10' CTRS	6'-3" CTRS	12'-6" CTRS	6'-3" CTRS	6'-3" CTRS



RAIL	CORRUGATED BEAM	CURVED BEAM	NONE	CORRUGATED BEAM	2-3/4" CABLE & CHAIN LINK	6" RIENF CONC.
BRACKET	NONE	HG15N	NONE	NONE	NONE	NONE
POST	6" WF 15 5 #	6" WF 15 5 #	P C C	8" x 8" D F	2 1/4" H 4 1 #	NONE
POST SPACING	6'-3" CTRS	6'-3" CTRS	5'CTRS	6'-3" CTRS	8' CTRS	NONE

Figure 1. Trial designs.

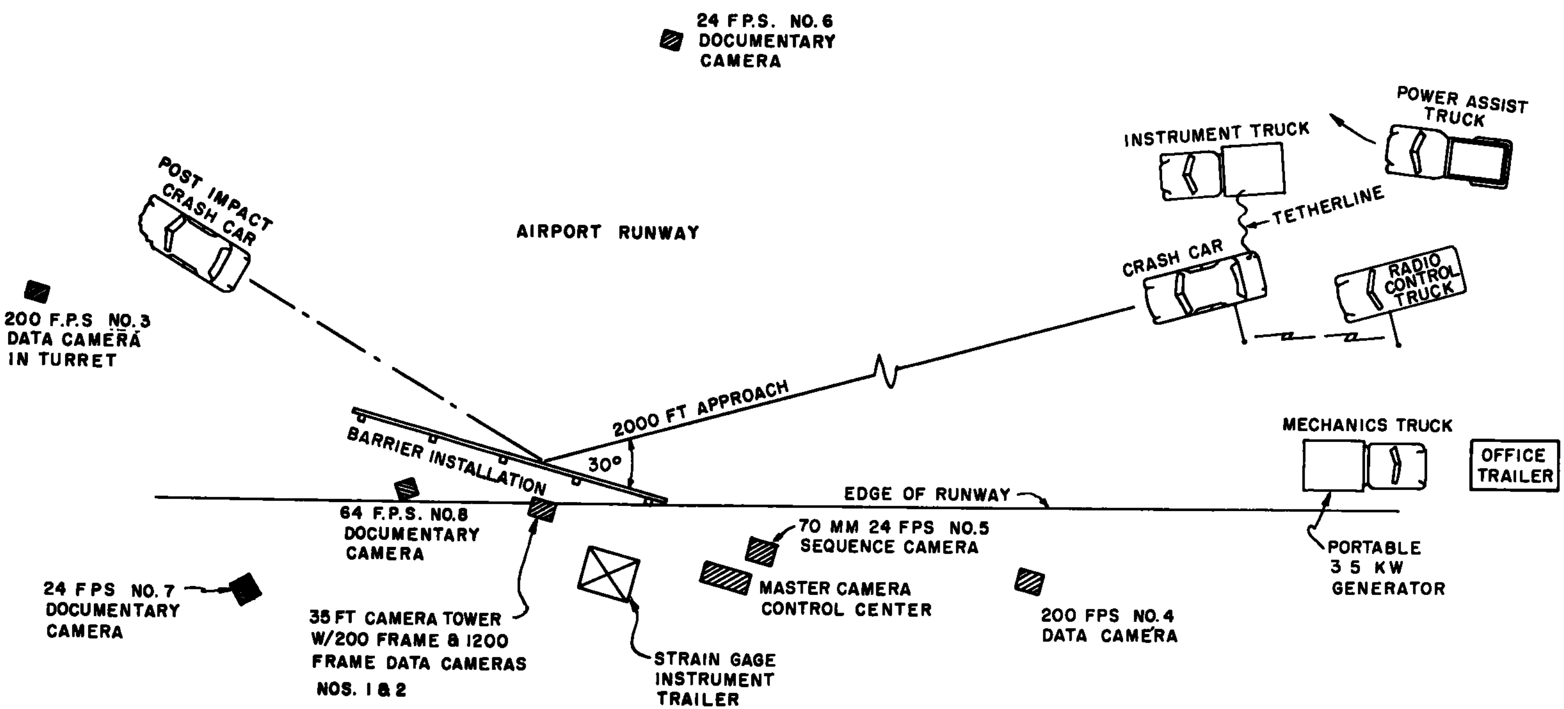
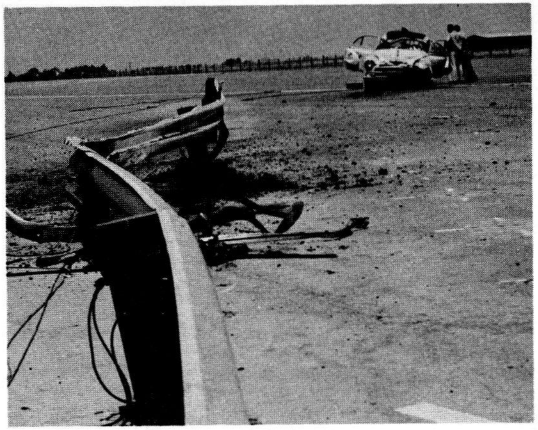


Figure 2. Plan view of test site.



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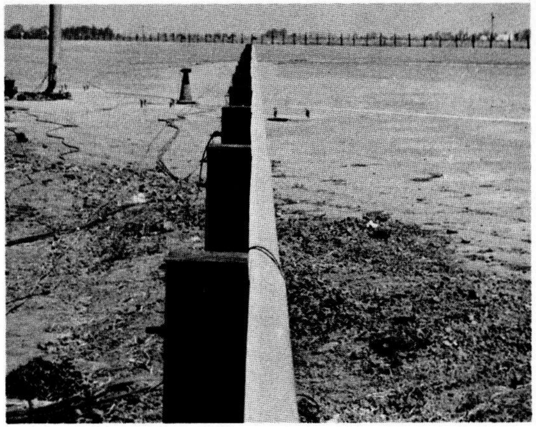

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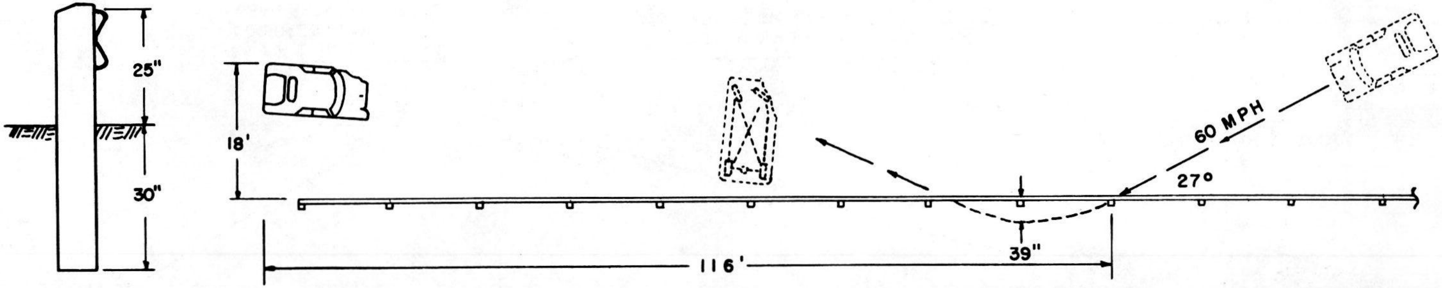
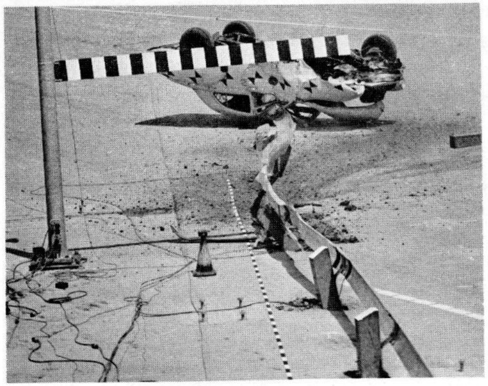


GUARDRAIL .... W Section
BRACKET .... None
POST .... 8x8 D.F.
POST SPACING............. 12'-6" O.C.
LENGTH OF INSTALLATION... 212.5'
GROUND CONDITION......... Dry

DUMMY INJURY........................ Left shoulder & side injuries. Possible concussion.
GUARDRAIL DAMAGE .... 3 Sections damaged beyond repair.
POST DAMAGE .... 2 Posts damaged beyond repair.
12 Posts out of alignment.
VEHICLE DAMAGE .... Total loss
MAX. DYNAMIC DEFLECTION OF RAIL... 48"

TEST NO. 1
DATE 7-10-58
VEHICLE ....Chev. 52 Sedan
SPEED ....60 MPH
IMPACT ANGLE...... 27°
VEHICLE WEIGHT...3980
(W/DUMMY & INSTRUMENTATION)

Figure 3. Test data information sheet



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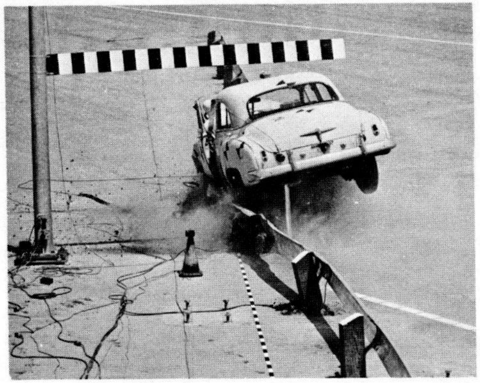

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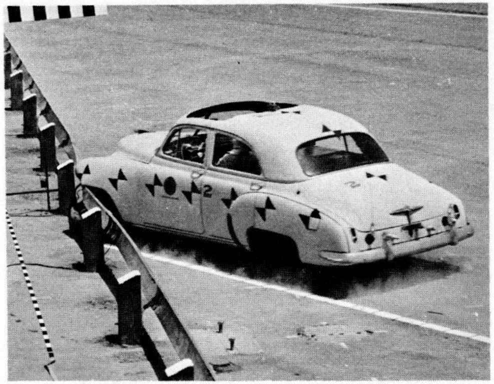

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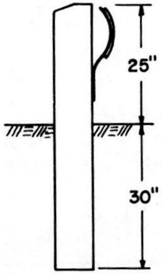
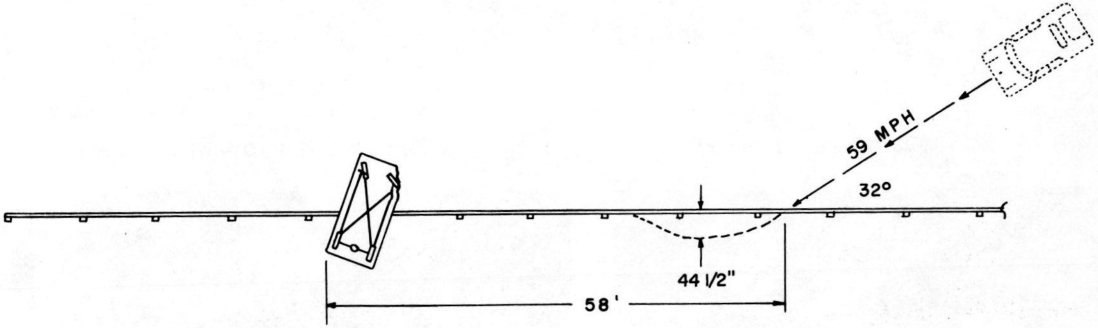


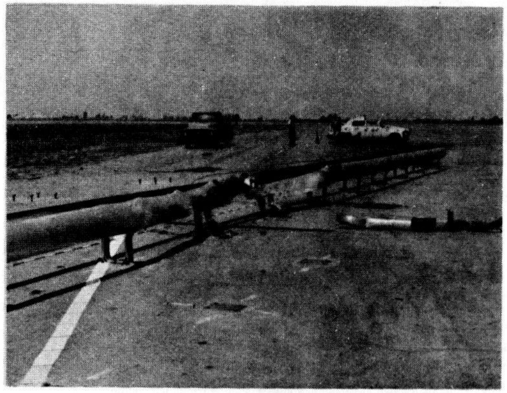


GUARDRAIL ....Tuthill
BRACKET HG15N
POST ....8x8 D.F.
POST SPACING ....10' O.C.
LENGTH OF INSTALLATION ... 200'
GROUND CONDITION ....Dry

DUMMY INJURY .... Severe head, neck, chest, & internal injuries.
GUARDRAIL DAMAGE .... 4 Sections damaged beyond repair.
POST DAMAGE .... 5 Posts damaged beyond repair.
10 Posts out of alignment.
VEHICLE DAMAGE .... Total loss
MAX. DYNAMIC DEFLECTION OF RAIL ... 55 1/2"

TEST NO. 2
DATE 7-23-58
VEHICLE ....Chev. 50 Sedan
SPEED .... 59 MPH
IMPACT ANGLE ..... 32 °
VEHICLE WEIGHT.... 3980
(W/DUMMY & INSTRUMENTATION)

Figure 4. Test data information sheets.



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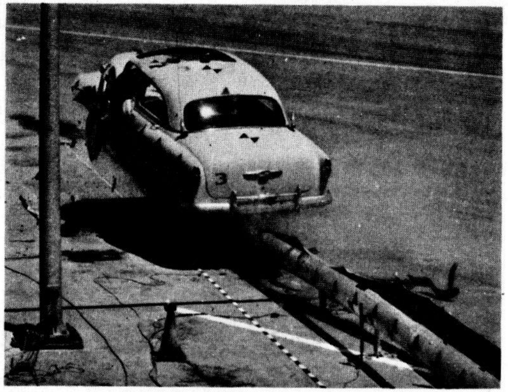

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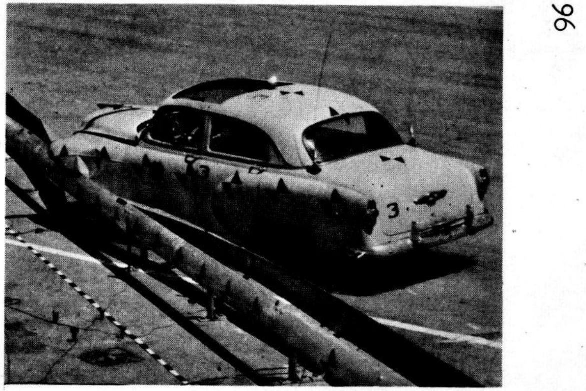

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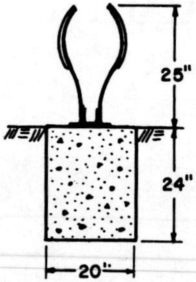
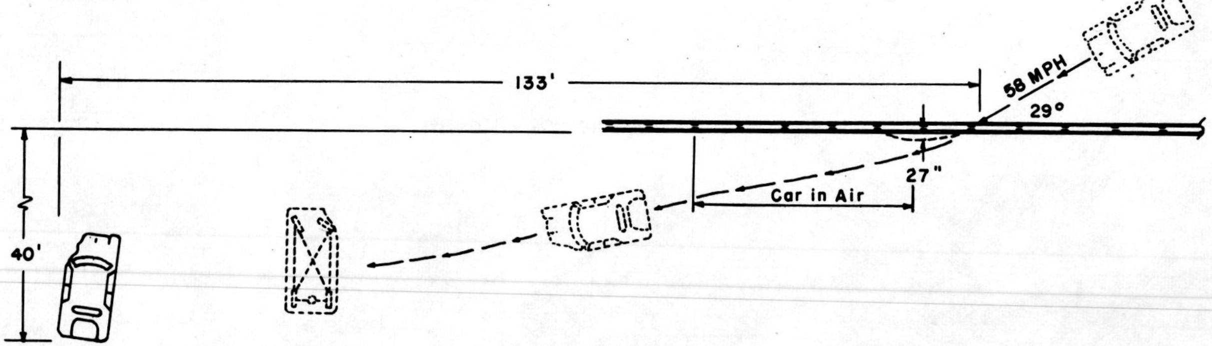




GUARDRAIL ....Tuthill
BRACKET .... HG 26 N
POST ....HG26 N
POST SPACING ....6'-3" O.C.
LENGTH OF INSTALLATION... 100'
GROUND CONDITION ....Dry

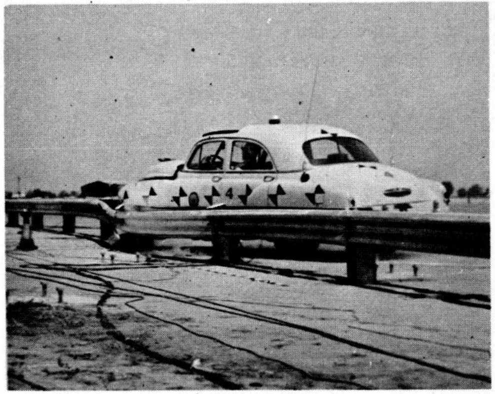
DUMMY INJURY ....Left shoulder & side injuries. Possible concussion.
GUARDRAIL DAMAGE ....4 Sections damaged beyond repair. Inside rail failed.
POST DAMAGE ....6 Brackets damaged beyond repair.
VEHICLE DAMAGE ....Total loss
MAX. DYNAMIC DEFLECTION OF RAIL... 27" Before failure.

TEST NO. 3
DATE 8-6-58
VEHICLE ....Chev. 53 Sedan
SPEED ....58 MPH
IMPACT ANGLE ..... 29°
VEHICLE WEIGHT... 3980
(W/DUMMY & INSTRUMENTATION)

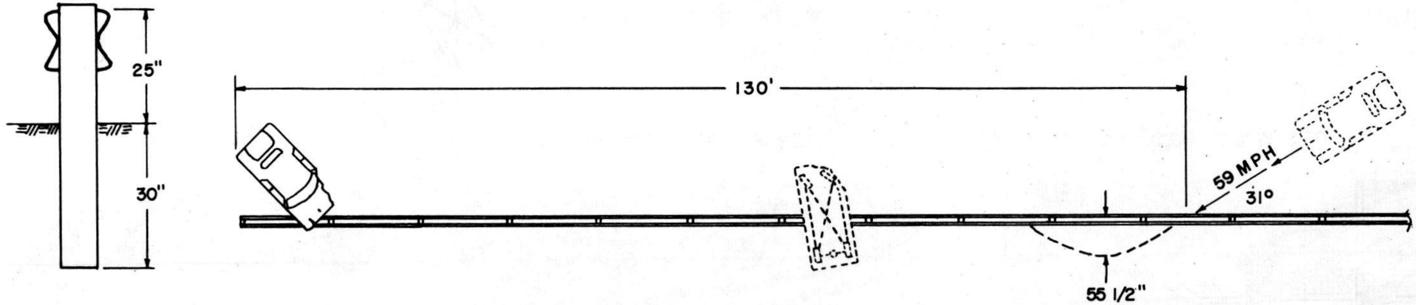
Figure 5. Test data information sheets.

POST IMPACT

IMPACT + 450 M SEC.



IMPACT + 100 M SEC.



GUARDRAIL	W Section
BRACKET	None
POST	8x8 D.F.
POST SPACING	12'-6" O.C.
LENGTH OF INSTALLATION	200'
GROUND CONDITION	Dry

DUMMY INJURY	Severe neck, head & left shoulder injuries.
GUARDRAIL DAMAGE	3 Sections damaged beyond repair.
POST DAMAGE	1 Post damaged beyond repair. 7 Posts out of alignment.
VEHICLE DAMAGE	Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL	60"

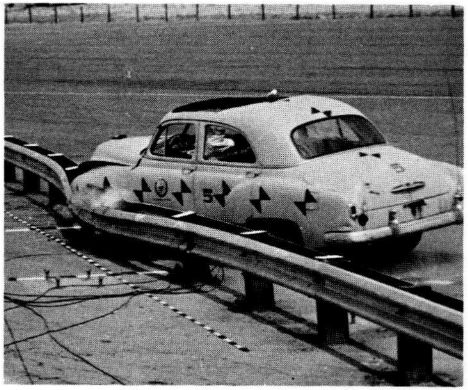
TEST NO.	4
DATE	8-20-58
VEHICLE	Chev. 51 Sedan
SPEED	59 MPH
IMPACT ANGLE	31°
VEHICLE WEIGHT	3980

(W/DUMMY & INSTRUMENTATION)

Figure 6. Test data information sheets.

POST IMPACT

IMPACT + 500 M SEC.



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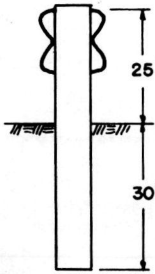
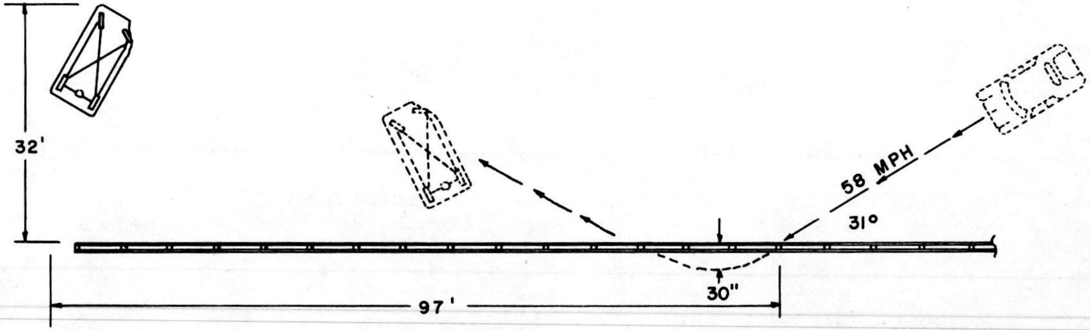


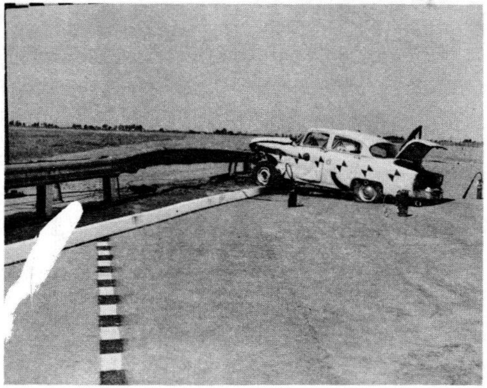


GUARDRAIL .... W Section
BRACKET .... None
POST .... 8x8 D.F.
POST SPACING .... 6'-3" O.C.
LENGTH OF INSTALLATION... 200'
GROUND CONDITION .... Dry

DUMMY INJURY .... Severe left shoulder & arm, head & neck injuries
GUARDRAIL DAMAGE .... 2 Sections damaged beyond repair.
POST DAMAGE .... 3 Posts damaged beyond repair.
5 Posts out of alignment.
VEHICLE DAMAGE .... Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL... 40.5"

TEST NO. 5
DATE 8-27-58
VEHICLE .... Chev. 51 Sedan
SPEED.............. 58 MPH
IMPACT ANGLE ...... 31°
VEHICLE WEIGHT... 3980
(W/DUMMY & INSTRUMENTATION)

Figure 7. Test data information sheets.



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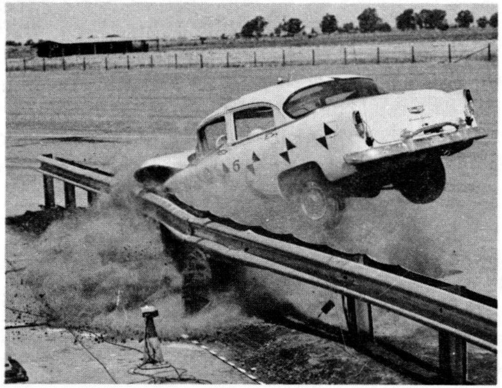

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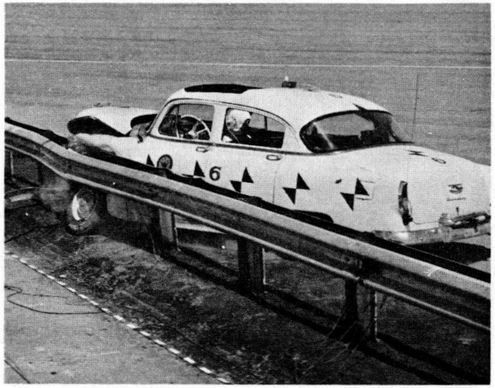

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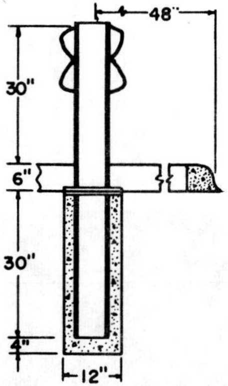
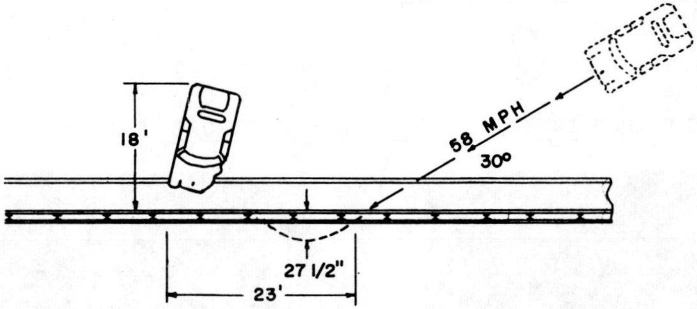


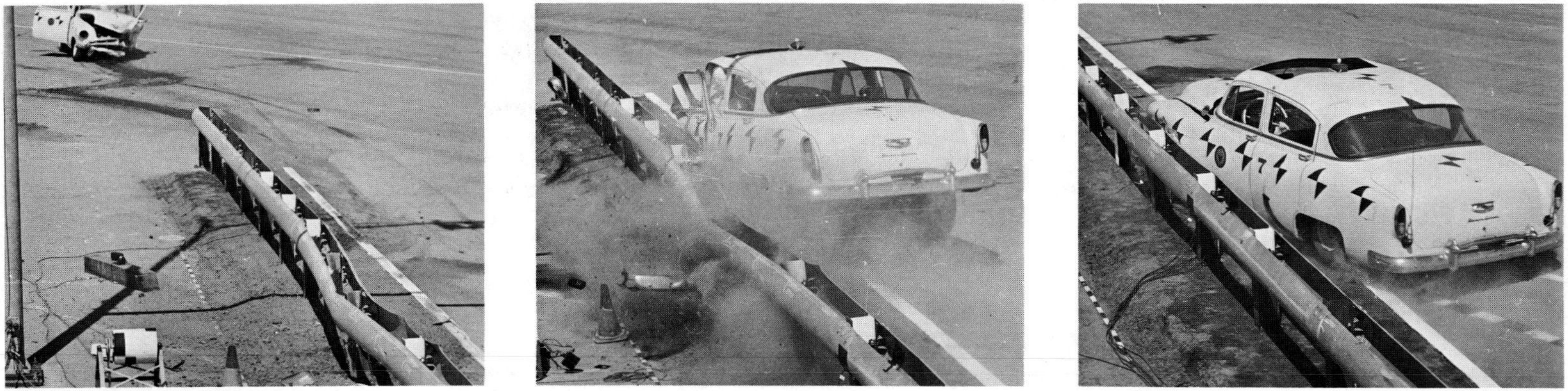


GUARDRAIL	W Section
BRACKET	None
POST	6" WF 15.5 #
POST SPACING	6'-3" O.C.
LENGTH OF INSTALLATION	100'
GROUND CONDITION	Dry

DUMMY INJURY	Severe head, chest & neck injuries.
GUARDRAIL DAMAGE	4 Sections damaged beyond repair.
POST DAMAGE	3 Posts knocked out. 2 Posts out of alignment.
VEHICLE DAMAGE	Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL	36"

TEST NO.	6
DATE	9-10-58
VEHICLE	Chev. 54 Sedan
SPEED	58 M P H
IMPACT ANGLE	30°
VEHICLE WEIGHT	4000
(W/DUMMY & INSTRUMENTATION)	

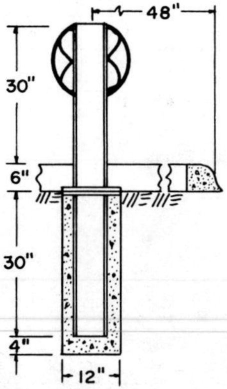
Figure 8. Test data information sheets.

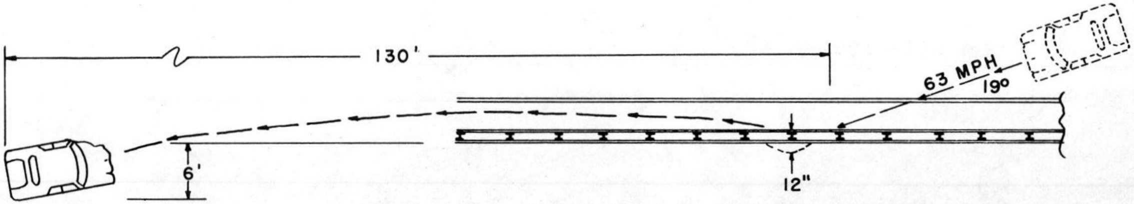


POST IMPACT

IMPACT +350 M SEC.

IMPACT + 50 M SEC.





GUARDRAIL .... Tuthill
BRACKET .... HG 32 N
POST .... 6" WF 15.5 #
POST SPACING .... 6'-3" O.C.
LENGTH OF INSTALLATION... 100'
GROUND CONDITION .... Dry

DUMMY INJURY .... Severe head, chest & internal injuries.
GUARDRAIL DAMAGE .... 2 Sections damaged beyond repair.
POST DAMAGE .... 2 Posts damaged beyond repair.
2 Posts out of alignment.
VEHICLE DAMAGE .... Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL... 19"

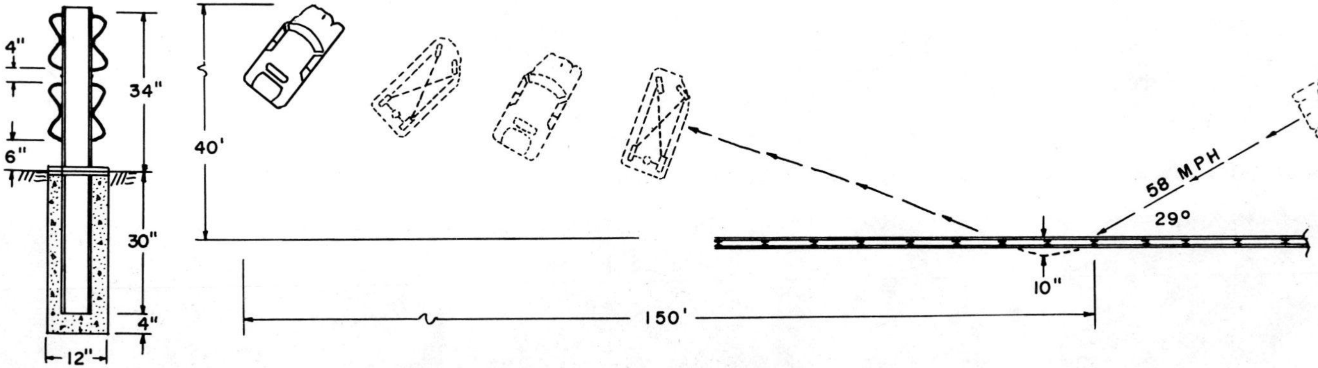
TEST NO. 7
DATE 9-18-58
VEHICLE .... Chev. 54 Sedan
SPEED .... 63 M P H
IMPACT ANGLE ...... 19°
VEHICLE WEIGHT.... 4050
(W/DUMMY & INSTRUMENTATION)

Figure 9. Test data information sheets.

POST IMPACT

IMPACT + 500 M SEC.

IMPACT + 100 M SEC.

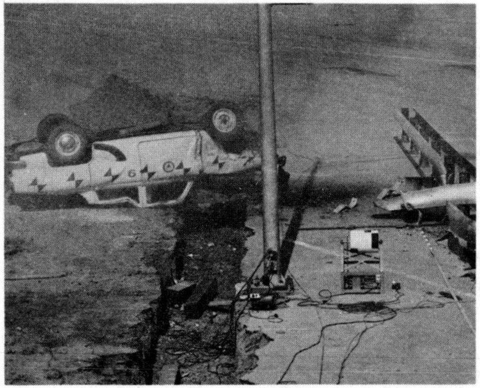


GUARDRAIL .... W Section
BRACKET .... None
POST .... 6" WF 15.5 #
POST SPACING .... 6'-3" O.C.
LENGTH OF INSTALLATION... 100'
GROUND CONDITION .... Dry

DUMMY INJURY .... Severe head, shoulder & arm injuries. Multiple lacerations & concussion.
GUARDRAIL DAMAGE .... 2 Sections damaged beyond repair.
POST DAMAGE .... All can be repaired. 5 Posts out of alignment.
VEHICLE DAMAGE .... Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL... 15"

TEST NO 8
DATE 10-2-58
VEHICLE .... Chev. 52 Sedan
SPEED .... 58 M.PH
IMPACT ANGLE...... 29°
VEHICLE WEIGHT... 4050
(W/DUMMY & INSTRUMENTATION)

Figure 10. Test data information sheets.



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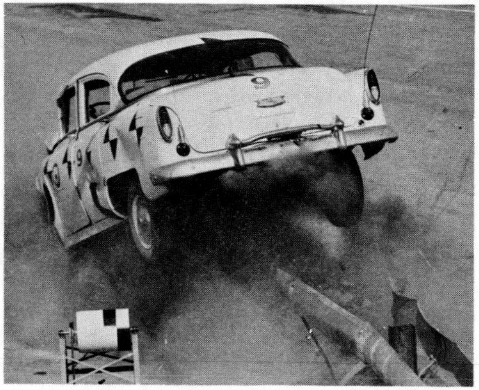

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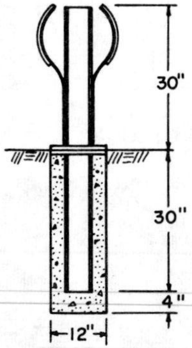
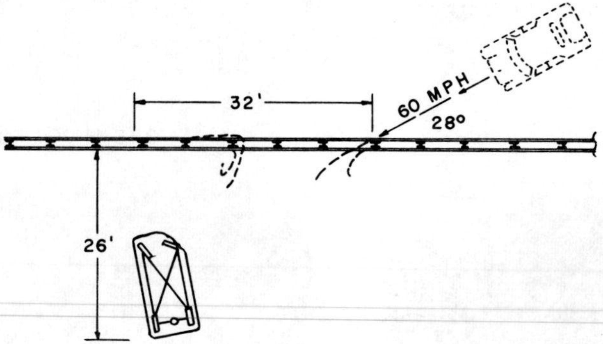




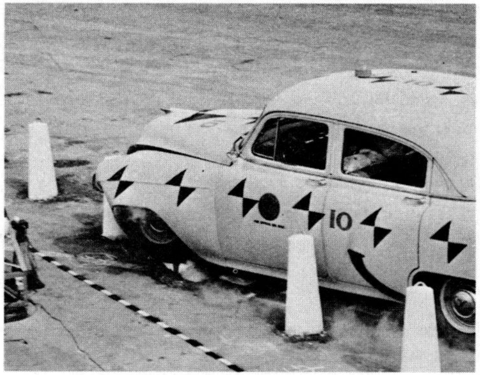
GUARDRAIL ....Tuthill
BRACKET HG15N
POST ....6" WF 15.5 #
POST SPACING ....6'-3" O.C.
LENGTH OF INSTALLATION...100'
GROUND CONDITION ....Dry

DUMMY INJURY ....Head, neck, chest & possible internal injuries.
GUARDRAIL DAMAGE ....4 Sections damaged beyond repair.
Both rails failed.
POST DAMAGE ....2 Posts damaged beyond repair.
2 Posts out of alignment.
VEHICLE DAMAGE ....Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL... 15" Before failure.

TEST NO. 9
DATE 10-15-58
VEHICLE ....Chev. 54 Sedan
SPEED ....60 MPH
IMPACT ANGLE.....28°
VEHICLE WEIGHT...3970
(W/DUMMY & INSTRUMENTATION)

Figure 11. Test data information sheets.

POST IMPACT



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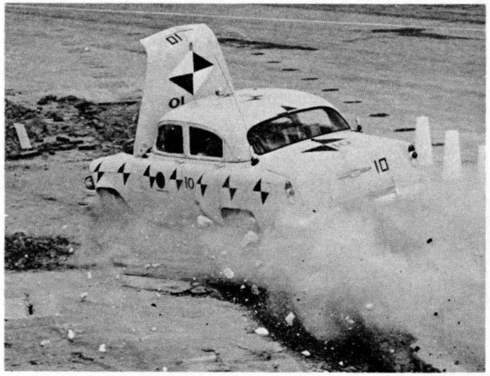

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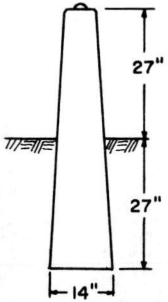
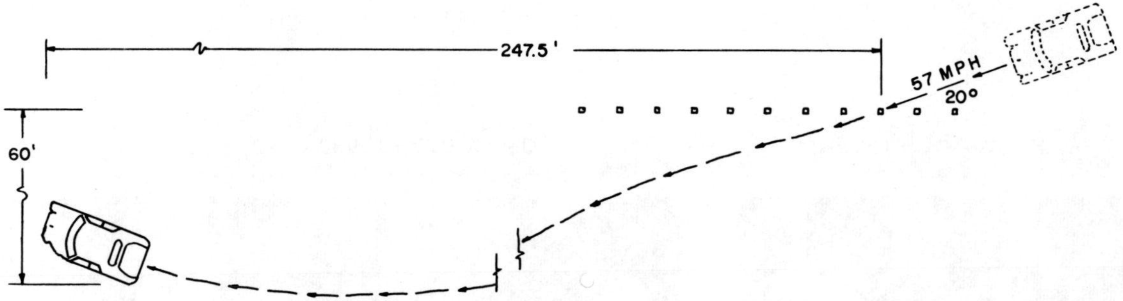




GUARDRAIL..................None
BRACKET..................None
POST..................P.C.C.
POST SPACING............5' O.C.
LENGTH OF INSTALLATION...60'
GROUND CONDITION.......Dry

DUMMY INJURY......................Minor Bruises
GUARDRAIL DAMAGE................No rail.

POST DAMAGE..................3 Posts demolished.
1 Post out of alignment.
VEHICLE DAMAGE................Est. $500.
MAX. DYNAMIC DEFLECTION OF RAIL...No rail.

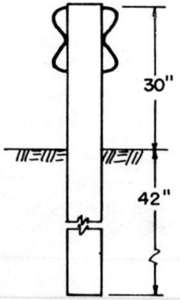
TEST NO. 10
DATE..............10-23-58
VEHICLE.........Chev. 53 Sedan
SPEED...........57 MPH
IMPACT ANGLE....20°
VEHICLE WEIGHT...3970
(W/DUMMY & INSTRUMENTATION)

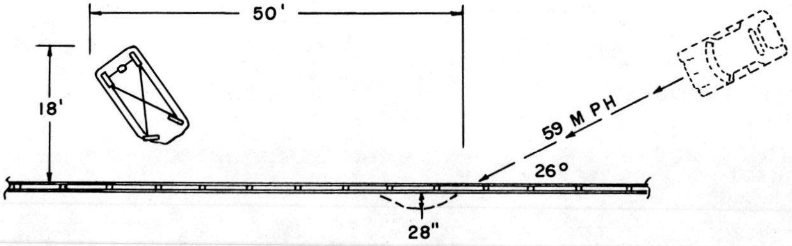
Figure 12. Test data information sheets.

POST IMPACT

IMPACT + 450 M SEC.

IMPACT + 50 M SEC.





GUARDRAIL ....W Section
BRACKET ....None
POST ....8x8 D.F.
POST SPACING ....6'-3" O.C.
LENGTH OF INSTALLATION...200'
GROUND CONDITION ....Dry

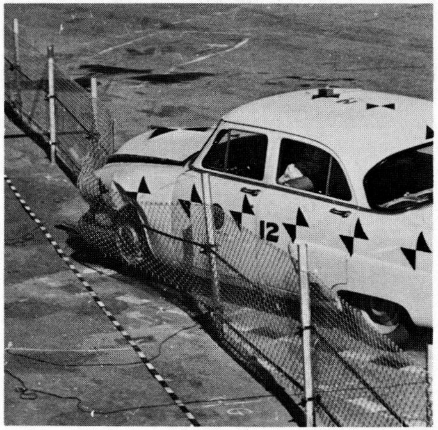
DUMMY INJURY ....Left shoulder & side, chest & internal injuries.
GUARDRAIL DAMAGE ....6 Sections damaged beyond repair.
POST DAMAGE ....3 Posts damaged beyond repair.
3 Posts out of alignment.
VEHICLE DAMAGE ....Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL...40"

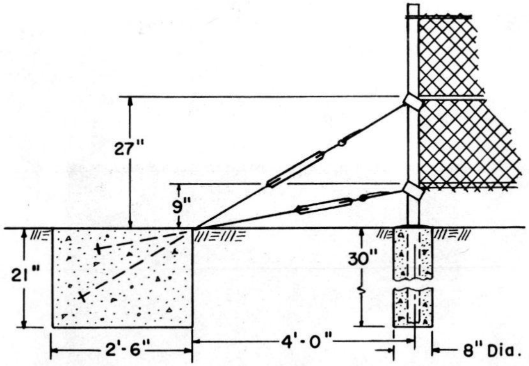
TEST NO. 11
DATE 10-30-58
VEHICLE ....Ford 55 Sedan
SPEED ....59 MPH
IMPACT ANGLE .....26°
VEHICLE WEIGHT...4050
(W/DUMMY & INSTRUMENTATION)

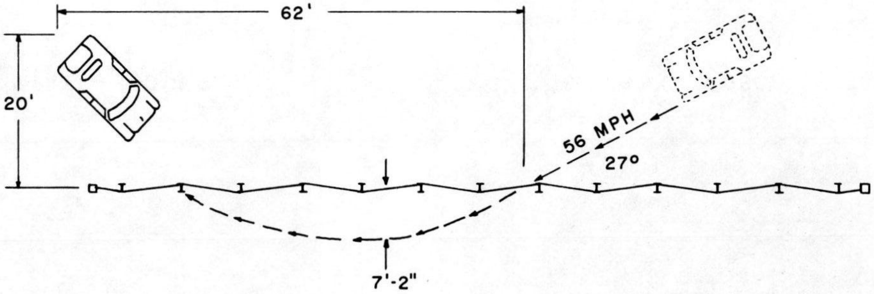
Figure 13. Test data information sheets.


POST IMPACT


IMPACT +500 M SEC.


IMPACT + 50 M SEC.



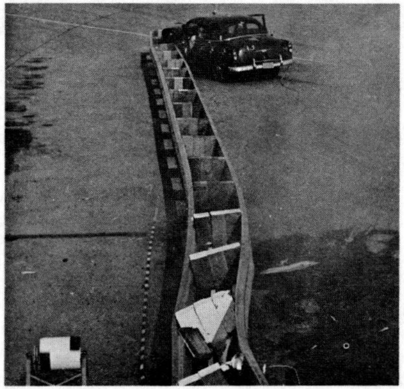


GUARDRAIL	Chain Link Fence w/ 3/4" cables 9" & 27" above Pvmt.
POST	2 1/4"-4.1 # H Section Fence Post.
POST SPACING	8' O.C.
LENGTH OF INSTALLATION	96'
GROUND CONDITION	Dry

DUMMY INJURY	Possible neck injuries & minor bruises.
GUARDRAIL DAMAGE	50' of Fence knocked out. No damage to Cable.
POST DAMAGE	7 Posts damaged beyond repair. 6 Posts Bent.
VEHICLE DAMAGE	$600.
MAX. DYNAMIC DEFLECTION OF RAIL	7'-2"
VEHICLE DECELERATION (PEAK)	Long. 69 G ... Transv. 154 G
DUMMY DECELERATION (PEAK)	Long 7 G ... Transv. 9.5 G

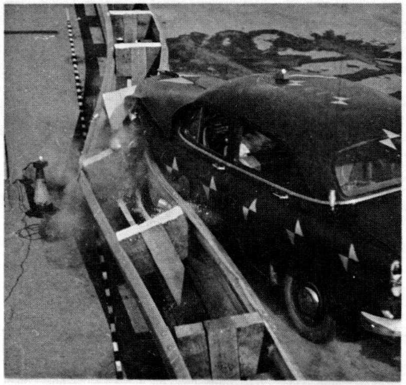
TEST NO.	12
DATE	11-13-58
VEHICLE	Ford 52 Sedan
SPEED	56 MPH
IMPACT ANGLE	27°
VEHICLE WEIGHT	4002 (W/DUMMY & INSTRUMENTATION)

Figure 14. Test data information sheets.

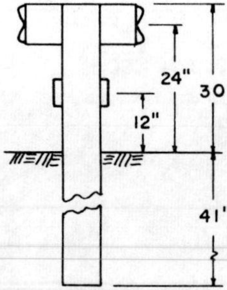


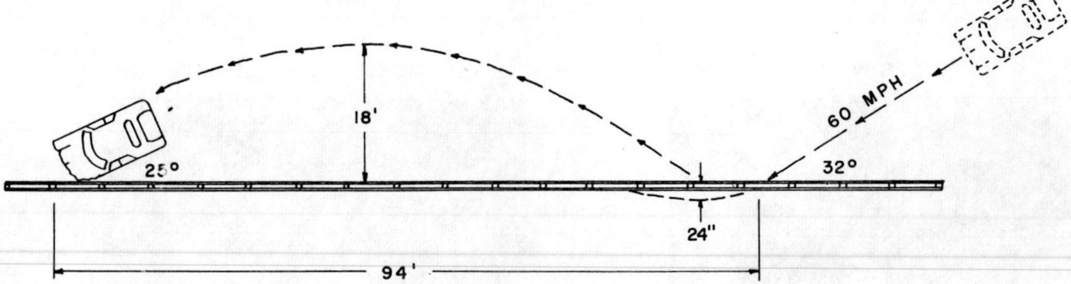
POST IMPACT

IMPACT + 500 M SEC.



IMPACT + 100 M SEC.





GUARDRAIL .... W Section
CHANNEL .... 6" ⊓ 8.2 #
BRACKET .... 8x8x12 D.F Block
POST .... 8x8 D.F.
POST SPACING .... 6'-3" O.C.
LENGTH OF INSTALLATION ... 125'
GROUND CONDITION .... Dry

DUMMY INJURY .... Possible left shoulder, arm & side injuries.
GUARDRAIL DAMAGE .... 4 Sections damaged beyond repair.
CHANNEL DAMAGE .... 4 Sections damaged beyond repair.
POST DAMAGE .... 3 Posts damaged beyond repair.

VEHICLE DAMAGE .... $ 900
MAX. DYNAMIC DEFLECTION OF RAIL ... 37"
VEHICLE DECELERATION (PEAK) .... Long. 104 G ... Transv. 198 G
DUMMY DECELERATION (PEAK) .... Long. 16 G ... Transv. 18 G

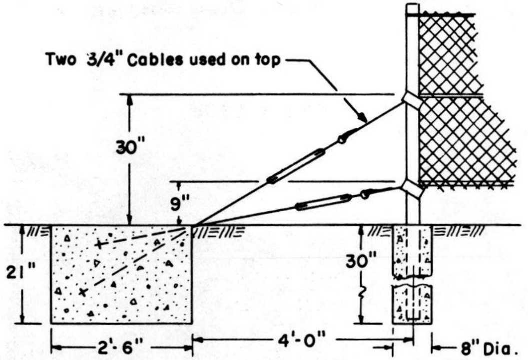
TEST NO. 13
DATE 12-18-58
VEHICLE .... Chev. 53 Sedan
SPEED .... 60 MPH
IMPACT ANGLE .... 32°
VEHICLE WEIGHT ... 4000
(W/DUMMY & INSTRUMENTATION)

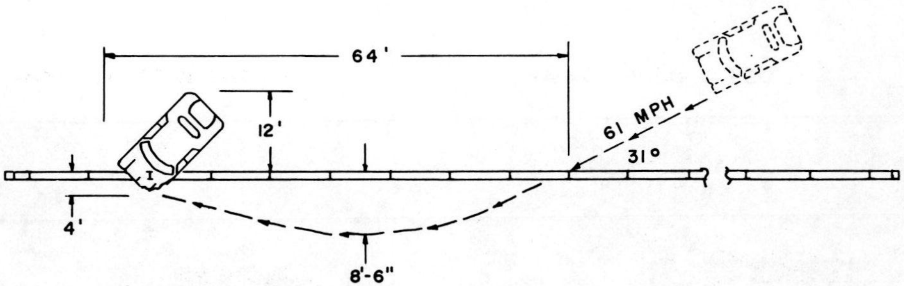
Figure 15. Test data information sheets.

POST IMPACT

IMPACT + 400 M SEC.

IMPACT + 150 M SEC.



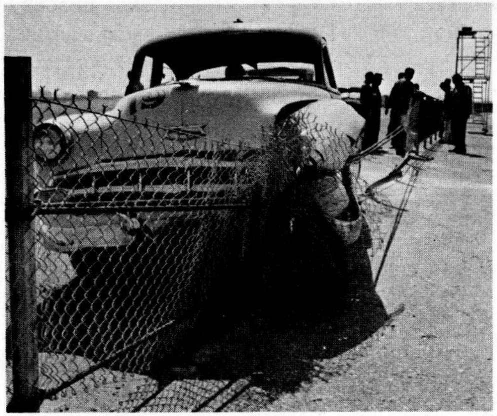


GUARDRAIL .... Chain Link Fence w/ 3/4" cables 9" & 30" above Pvmt.
POST .... 2 1/4"-4.1# H Section Fence Post.
POST SPACING .... 8' O.C.
LENGTH OF INSTALLATION ... 192'
GROUND CONDITION ...... Dry

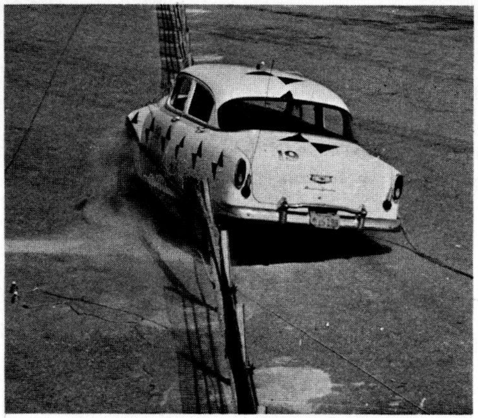
DUMMY INJURY .... Minor Bruises & possible neck injuries.
GUARDRAIL DAMAGE .... 80' of Fence knocked out. No damage to Cables.
POST DAMAGE .... 11 Posts damaged beyond repair.
VEHICLE DAMAGE .... $600.
MAX. DYNAMIC DEFLECTION OF RAIL... 8'-6"

TEST NO. 14
DATE 12-26-58
VEHICLE .... Chev. 53 Sedan
SPEED .... 61 MPH
IMPACT ANGLE .... 31 °
VEHICLE WEIGHT ... 4000
(W/DUMMY & INSTRUMENTATION)

Figure 16. Test data information sheets.

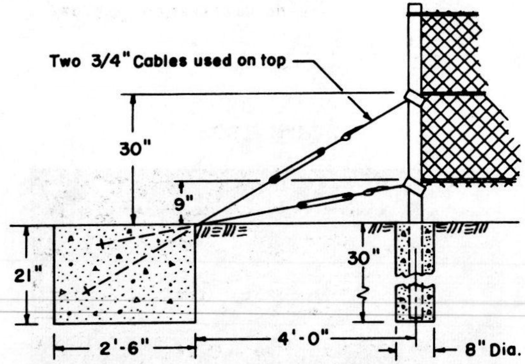


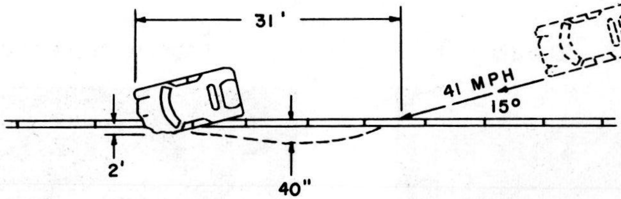
POST IMPACT



IMPACT + 350 M SEC.

IMPACT + 100 M SEC.



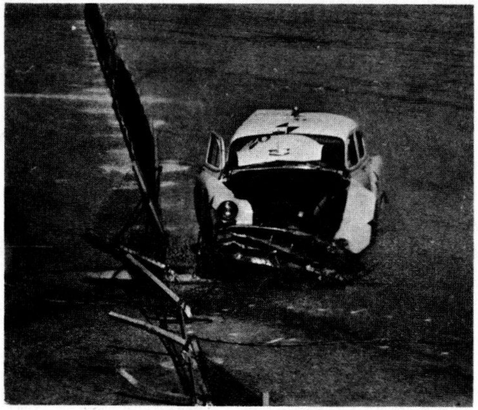


GUARDRAIL .... 36" Chain Link Fence w/3/4" cables 9" & 30" above pvmt.
POST .... 2 1/4"-4.1 # H Section Fence Post
POST SPACING .... 8' O.C.
LENGTH OF INSTALLATION ... 400'
GROUND CONDITION .... Dry

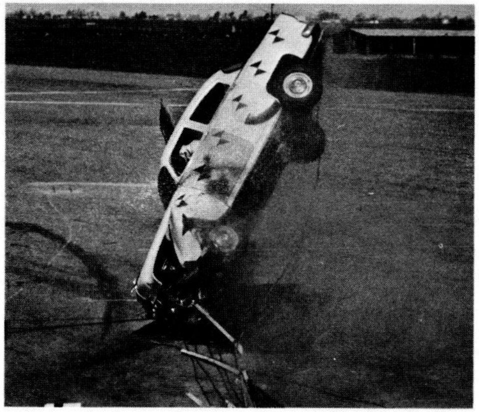
DUMMY INJURY .... Minor Bruises
GUARDRAIL DAMAGE .... 35' of Fence knocked out. No damage to cables.
POST DAMAGE .... 4 Posts damaged beyond repair.
VEHICLE DAMAGE .... $ 400.
MAX. DYNAMIC DEFLECTION OF RAIL ... 40"
VEHICLE DECELERATION (PEAK) ... Long. 55 G ... Transv. 22 G
DUMMY DECELERATION (PEAK) ..... Long. 3 G ... Transv. 2 G

TEST NO 19
DATE 3-5-59
VEHICLE .... Chev. 53 Sedan
SPEED .... 41 MPH
IMPACT ANGLE ..... 15°
VEHICLE WEIGHT .... 3700 (W/DUMMY & INSTRUMENTATION)

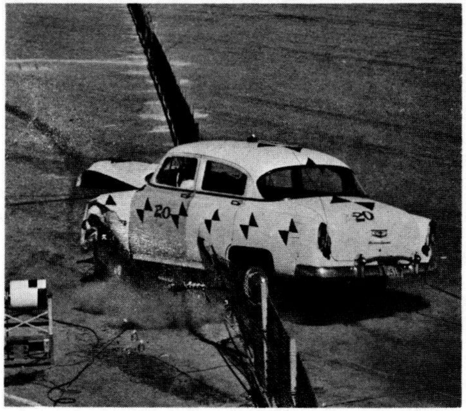
Figure 17. Test data information sheets.



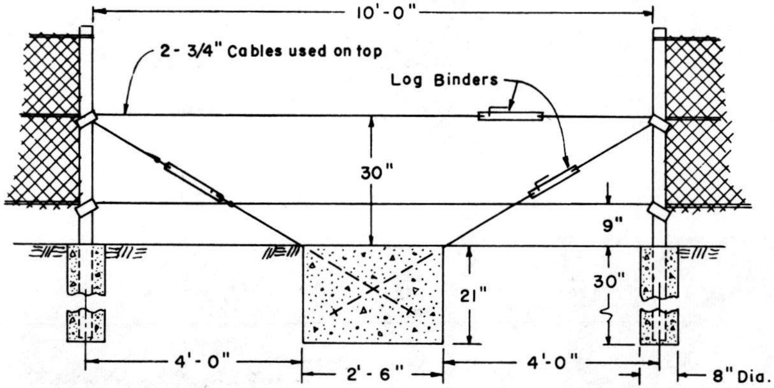
POST IMPACT

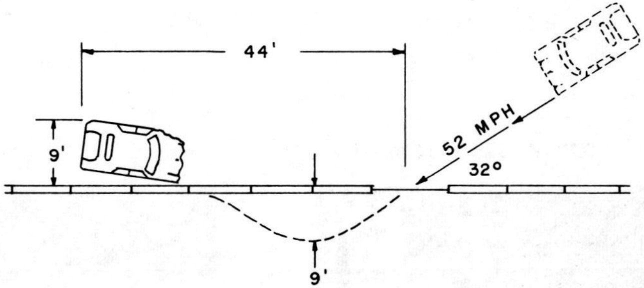


IMPACT + 1000M SEC.



IMPACT + 150 M SEC.





GUARDRAIL .... 36" Chain Link Fence w/3/4" cables 9" & 30" above pvmt. Impact point at center of emergency crossover.

POST .... 2 1/4"-4.1 # H Section Fence Post

POST SPACING .... 8' O.C.

LENGTH OF INSTALLATION ... 400'

GROUND CONDITION ....Dry

DUMMY INJURY .... Severe Chest & Internal Injuries

GUARDRAIL DAMAGE .... 24' of Fence knocked out.
10' of Cable damaged.

POST DAMAGE .... 4 Posts damaged beyond repair.
2 Posts Bent.

VEHICLE DAMAGE .... Total Loss

MAX. DYNAMIC DEFLECTION OF RAIL .. 9'

VEHICLE DECELERATION (PEAK) .... Long. 53 G ... Transv. 34 G

DUMMY DECELERATION (PEAK).... Long. NG ... Transv. 6 G

TEST NO. 20

DATE 3-10-59

VEHICLE .... Chev. 54 Sedan

SPEED .... 52 MPH

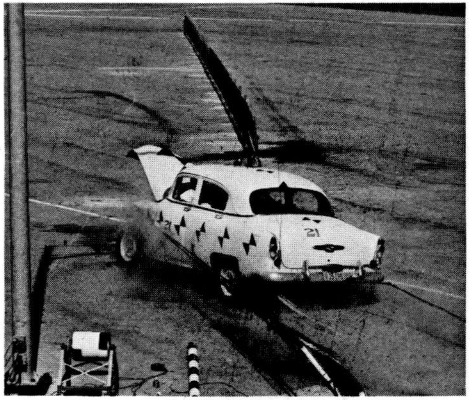
IMPACT ANGLE .... 32°

VEHICLE WEIGHT ... 3700
(W/DUMMY & INSTRUMENTATION)

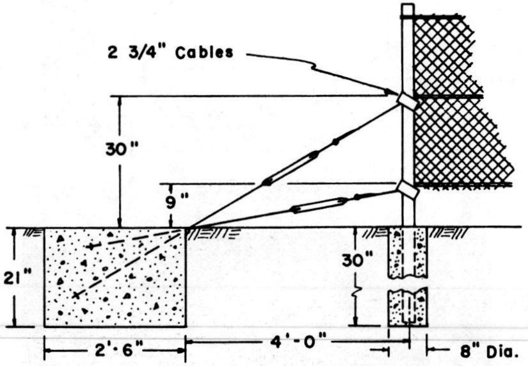
Figure 18. Test data information sheets.

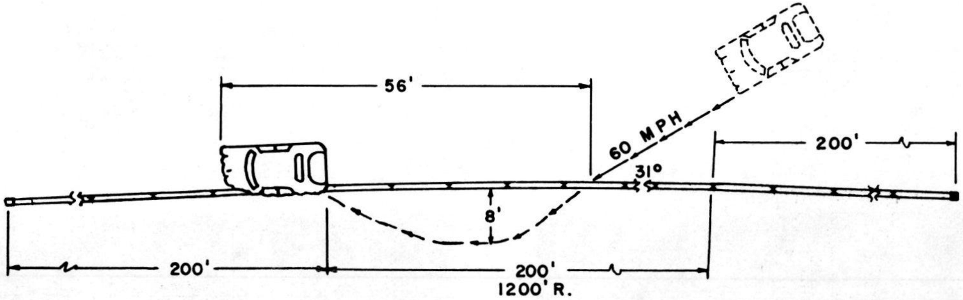
POST IMPACT

IMPACT + 750 M SEC.



IMPACT + 225 M SEC.



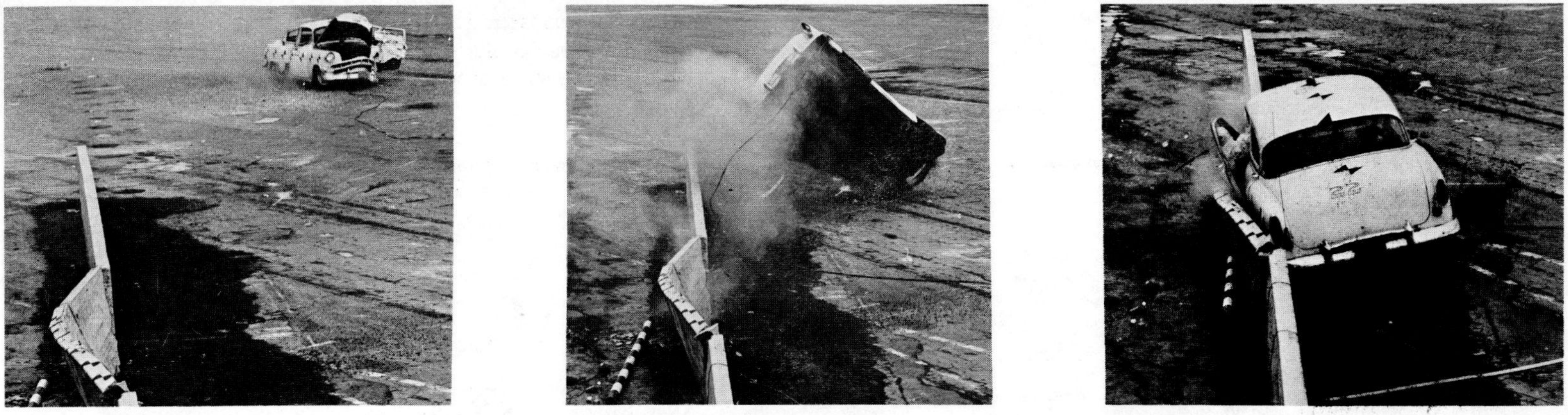


GUARDRAIL .... 36" Chain Link Fence w/2 3/4" cables 9" & 30" above pvmt.
POST .... 2 1/4" - 4.1 # H Section Fence Post.
POST SPACING .... 8' O.C.
LENGTH OF INSTALLATION... 600'
GROUND CONDITION .... Wet

DUMMY INJURY .... Scalp laceration, possible chest injuries.
GUARDRAIL DAMAGE .... 56' of fence knocked out. No damage to cables.
POST DAMAGE .... 12 posts damaged beyond repair.
VEHICLE DAMAGE .... Total loss.
MAX. DYNAMIC DEFLECTION OF RAIL ... 8'
VEHICLE DECELERATION (PEAK) ... Long. NG ...Transv. NG
DUMMY DECELERATION (PEAK) ..... Long. 6G ...Transv. 4G

TEST NO. 21
DATE 3-20-59
VEHICLE .... Chev. 53 Sedan
SPEED .... 60 MPH
IMPACT ANGLE ... 31°
VEHICLE WEIGHT... 3850
(W/DUMMY & INSTRUMENTATION)

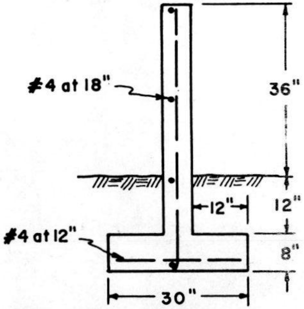
Figure 19. Test data information sheets.

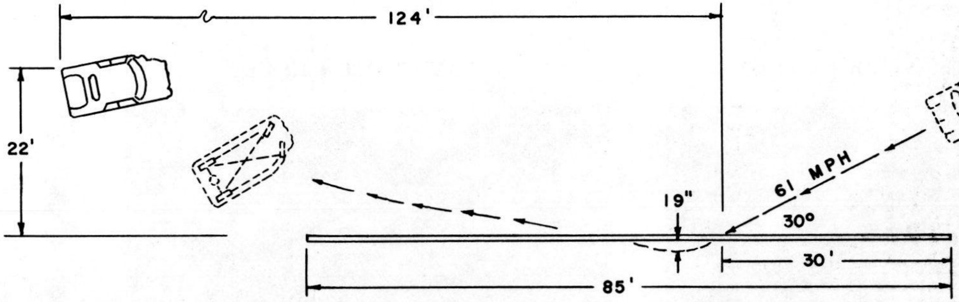


POST IMPACT

IMPACT + 750 M SEC.

IMPACT + 150 M SEC.





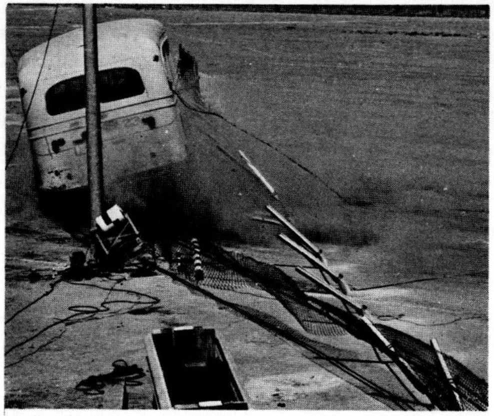
GUARDRAIL . . . . 36" Conc.
Wall, 6" Thick.
REINFORCING BAR SPACING . . #4 at 12" Vert.
#4 at 18" Horiz.
LENGTH OF INSTALLATION . . . 85'
GROUND CONDITION . . . . . . Wet

DUMMY INJURY . . . . Concussion, severe shoulder & chest injuries.
GUARDRAIL DAMAGE . . . . 20' Wall broken
VEHICLE DAMAGE . . . . Total loss
MAX. DYNAMIC DEFLECTION OF RAIL . . 22"
VEHICLE DECELERATION (PEAK) . . . . . Long. 112G . . . Transv. 72G
DUMMY DECELERATION (PEAK) . . . . Long. 21G . . . Transv. 25G

TEST NO. 22
DATE 3-30-59
VEHICLE . . . . Chev. 53 Sedan
SPEED . . . . 61 MPH
IMPACT ANGLE . . . 30°
VEHICLE WEIGHT . . . 3850
(W/DUMMY & INSTRUMENTATION)

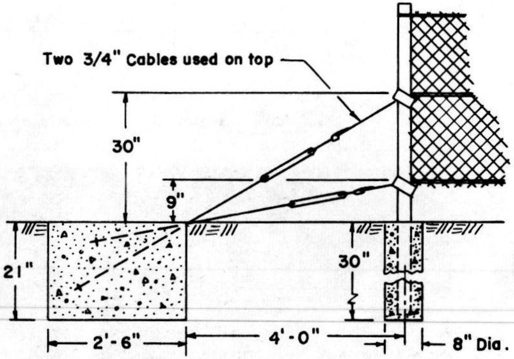
Figure 20. Test data information sheets.

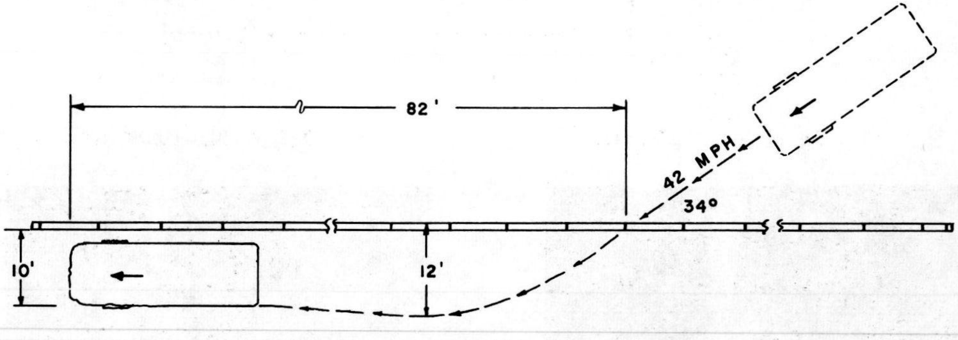
POST IMPACT



IMPACT + 900 M SEC.

IMPACT + 100 M SEC.





GUARDRAIL ....36" Chain Link fence w/ 3/4" cables 9" & 30" above pvmt.
POST ....2 1/4"-4.1# H Section Fence Post.
POST SPACING .... 8' O.C.
LENGTH OF INSTALLATION... 304'
GROUND CONDITION ....Dry

DUMMY INJURY .... Left shoulder injuries.
GUARDRAIL DAMAGE .... 90' of fence knocked out. No damage to cables.
POST DAMAGE .... 23 Posts damaged beyond repair.
VEHICLE DAMAGE .... $ 1200
MAX. DYNAMIC DEFLECTION OF RAIL . .. 12'
DUMMY DECELERATION (PEAK) .... Long. 2.8G .. Transv. 9.3 G

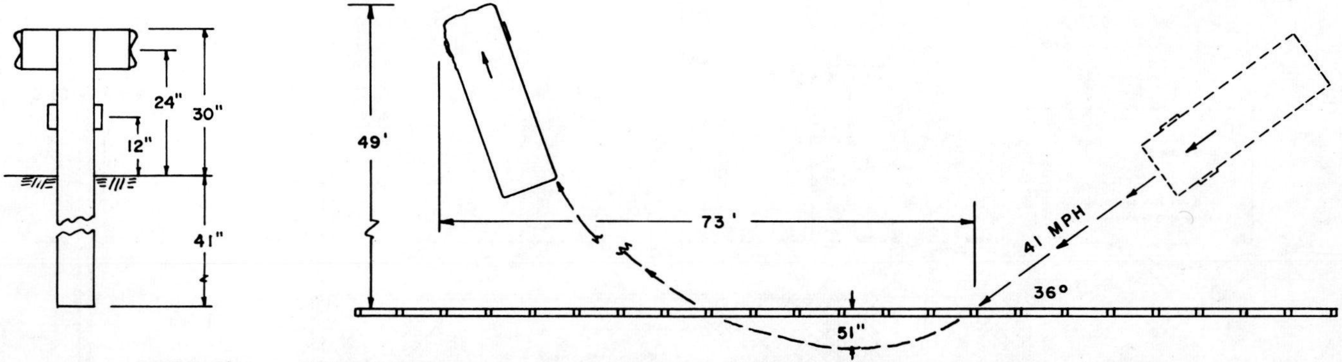
TEST NO. 23
DATE 4-21-59
VEHICLE .... 1937-40 pass. Bus
SPEED........... 42 MPH
IMPACT ANGLE ..... 34°
VEHICLE WEIGHT ...17,500
(W/DUMMY & INSTRUMENTATION)

Figure 21. Test data information sheets.

POST IMPACT

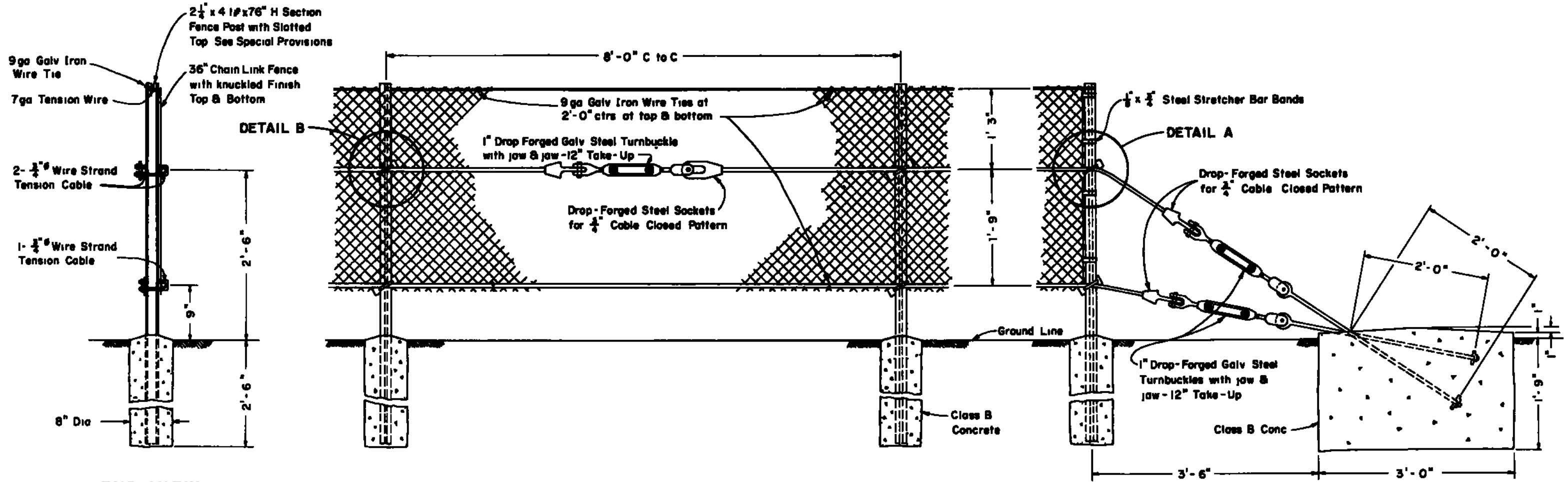
IMPACT + 800 M SEC.

IMPACT + 150 M SEC.



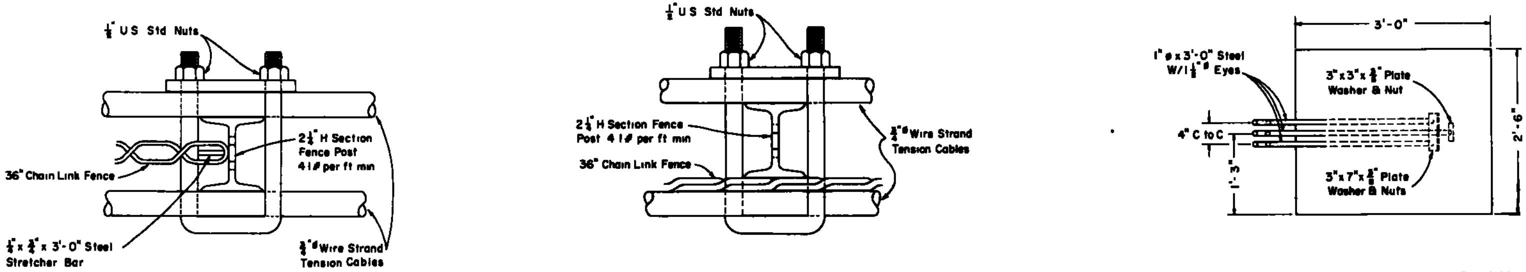
GUARDRAIL	W Section	DUMMY INJURY	Critical head, neck & shoulder injuries; severe body bruises.	TEST NO.	24
CHANNEL	6" ⊓ 8.2 #	GUARDRAIL DAMAGE	7 Sections damaged beyond repair.	DATE	4-30-59
BRACKET	8x8x12 D.F. Block	CHANNEL DAMAGE	4 Damaged beyond repair.	VEHICLE	1937-40 pass. Bus.
POST	8 x 8 D.F.	POST DAMAGE	5 Damaged beyond repair.	SPEED	41 MPH
POST SPACING	6'-3" O.C.	VEHICLE DAMAGE	$ 1,500	IMPACT ANGLE	36°
LENGTH OF INSTALLATION	125'	MAX. DYNAMIC DEFLECTION OF RAIL	58"	VEHICLE WEIGHT	17,500
GROUND CONDITION	Dry	DUMMY DECELERATION (PEAK)	Long. 6G ... Transv. 25 G	(W/DUMMY & INSTRUMENTATION)	

Figure 22. Test data information sheets.



END VIEW

ELEVATION



DETAIL A
END POST ASSEMBLY

DETAIL B
LINE POST ASSEMBLY

ANCHOR BLOCK PLAN

Figure 23. Cable-chain link barrier.

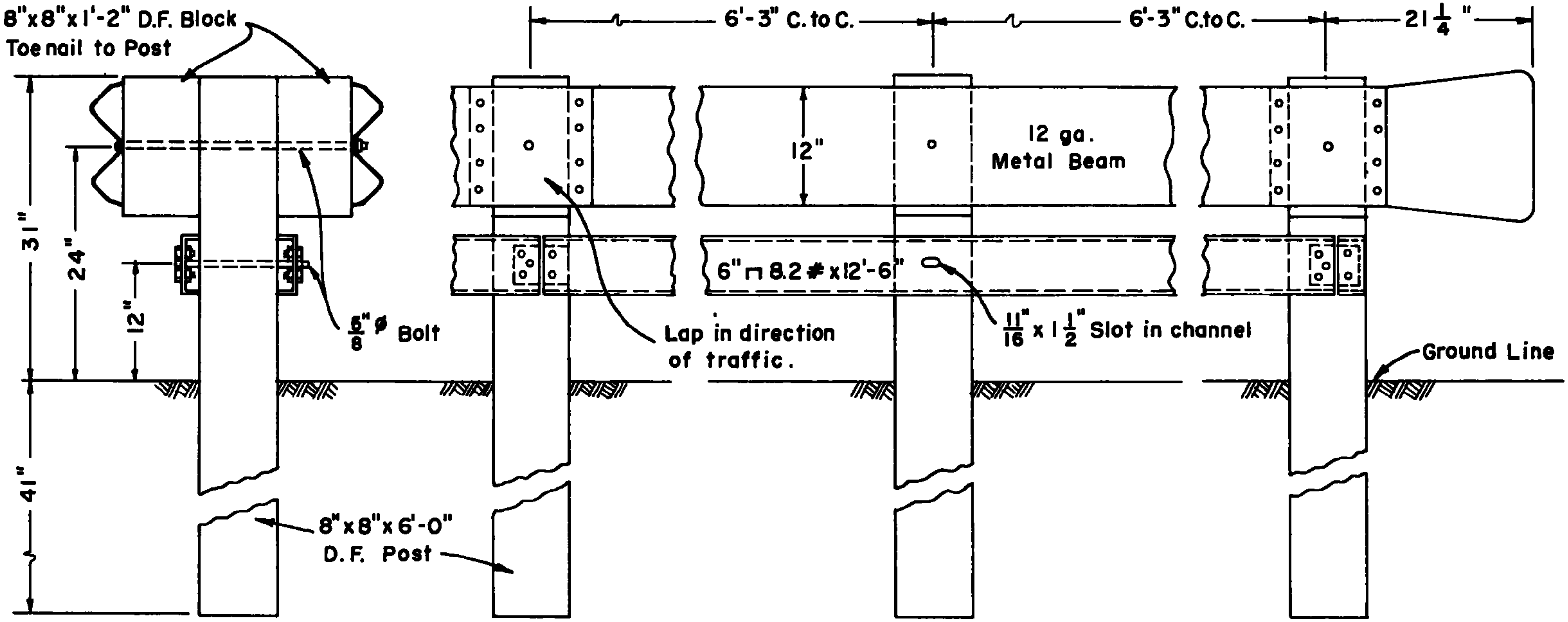


Figure 24. Blocked out metal beam barrier.

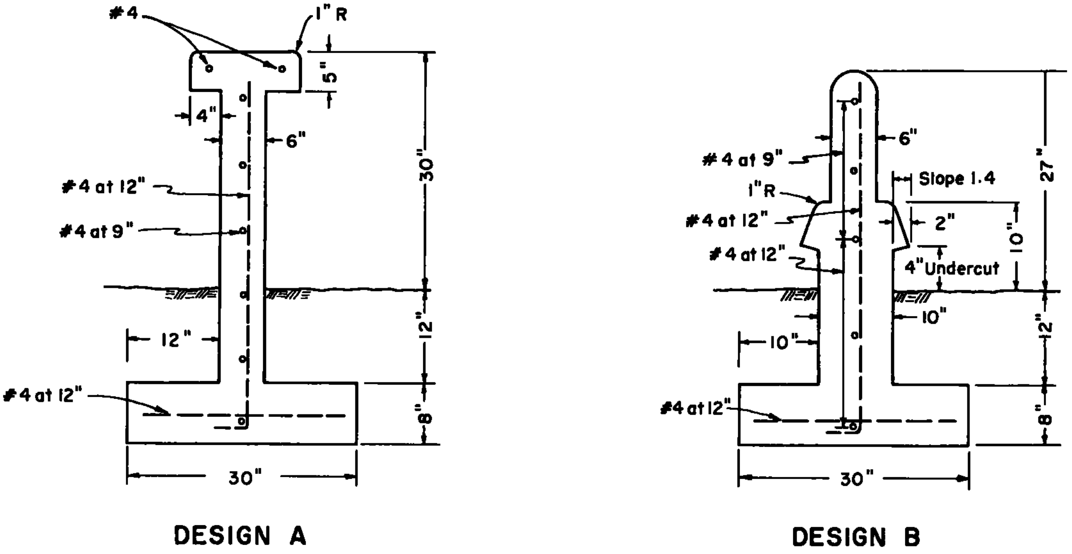


Figure 25. Concrete wall barrier.

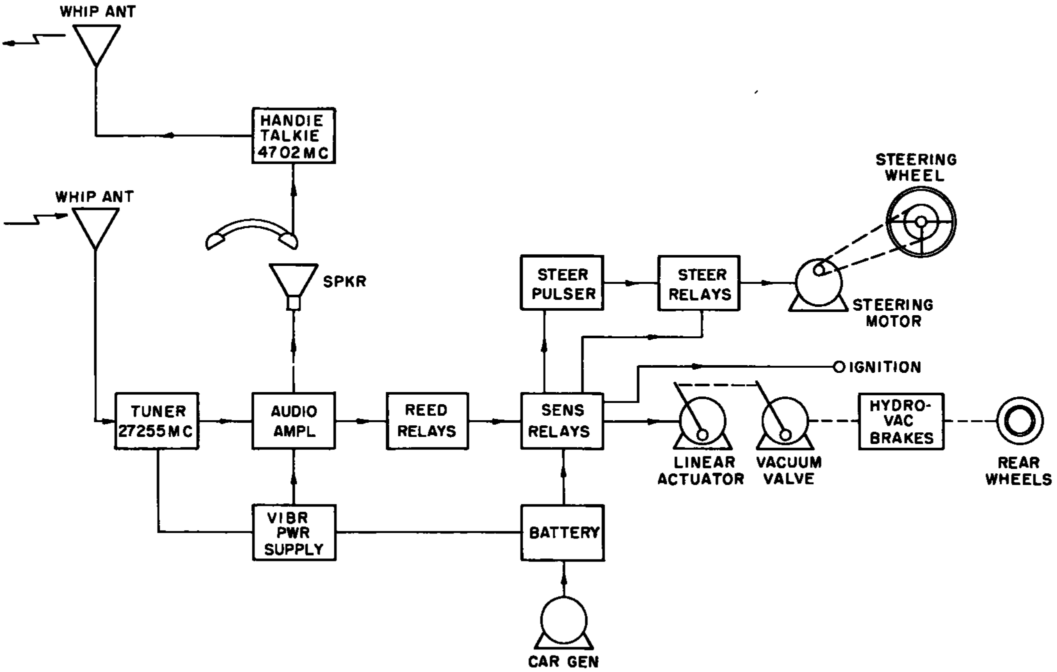


Figure 26. Block diagram—crash car remote controls.

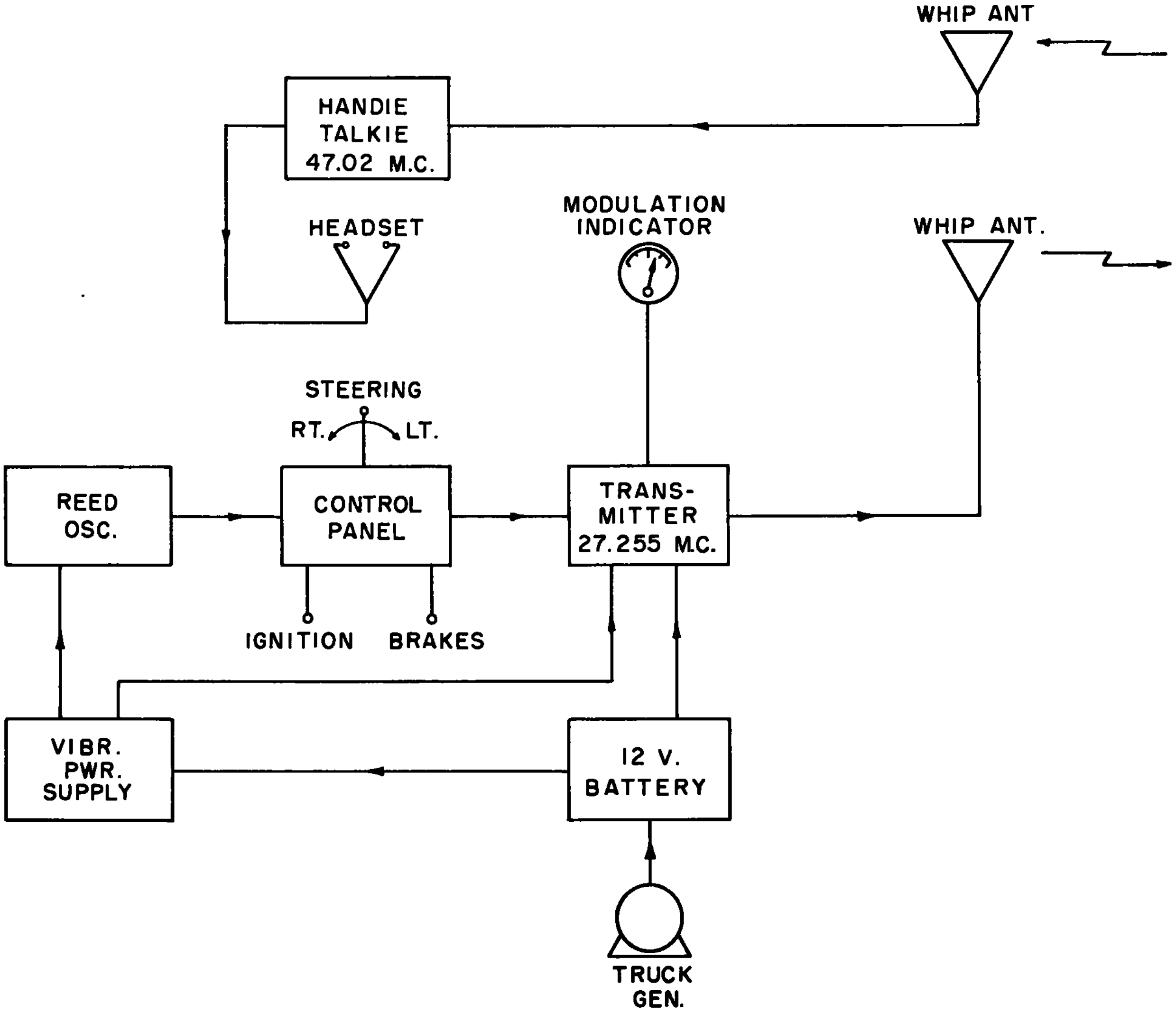


Figure 27. Block diagram—control car radio control.

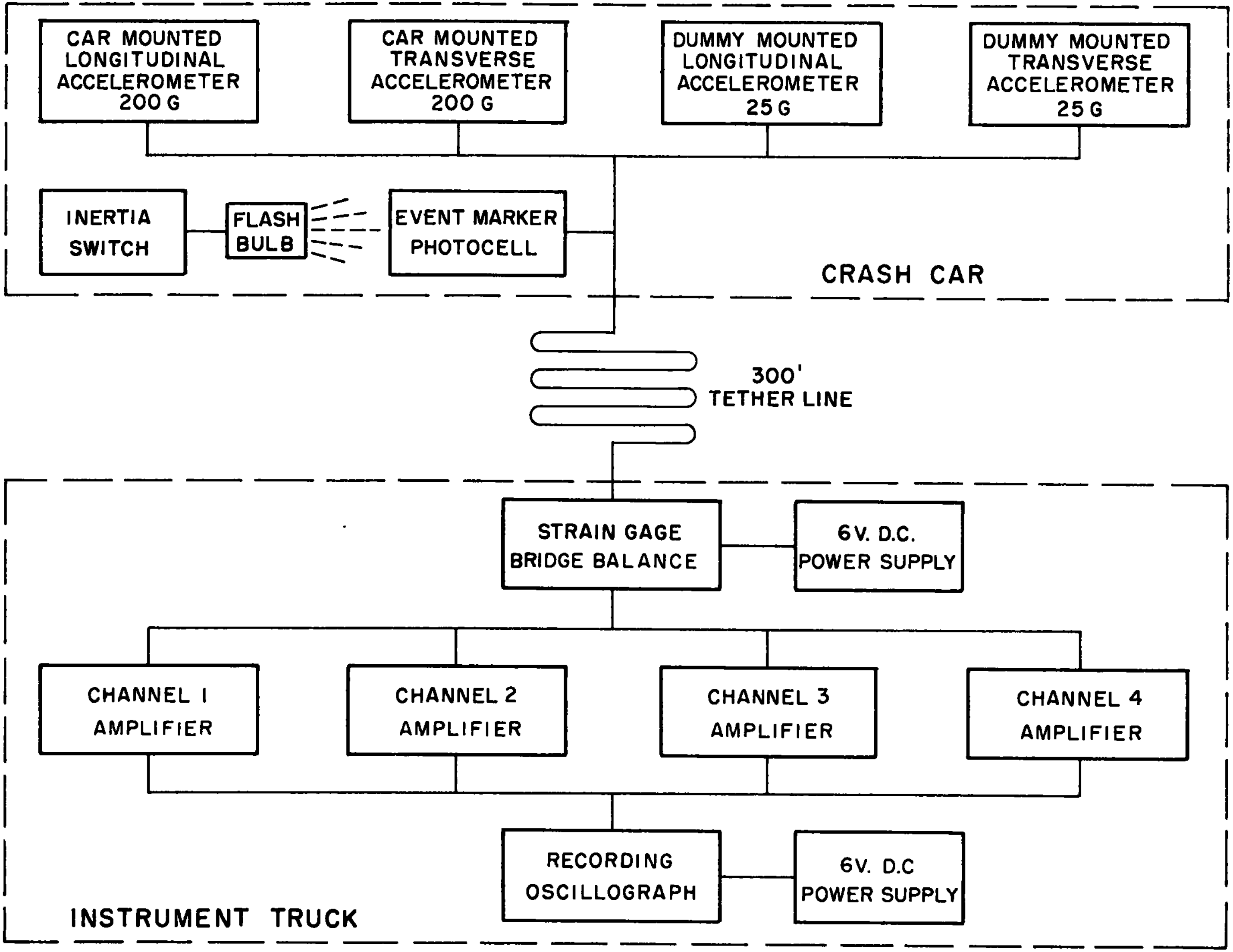
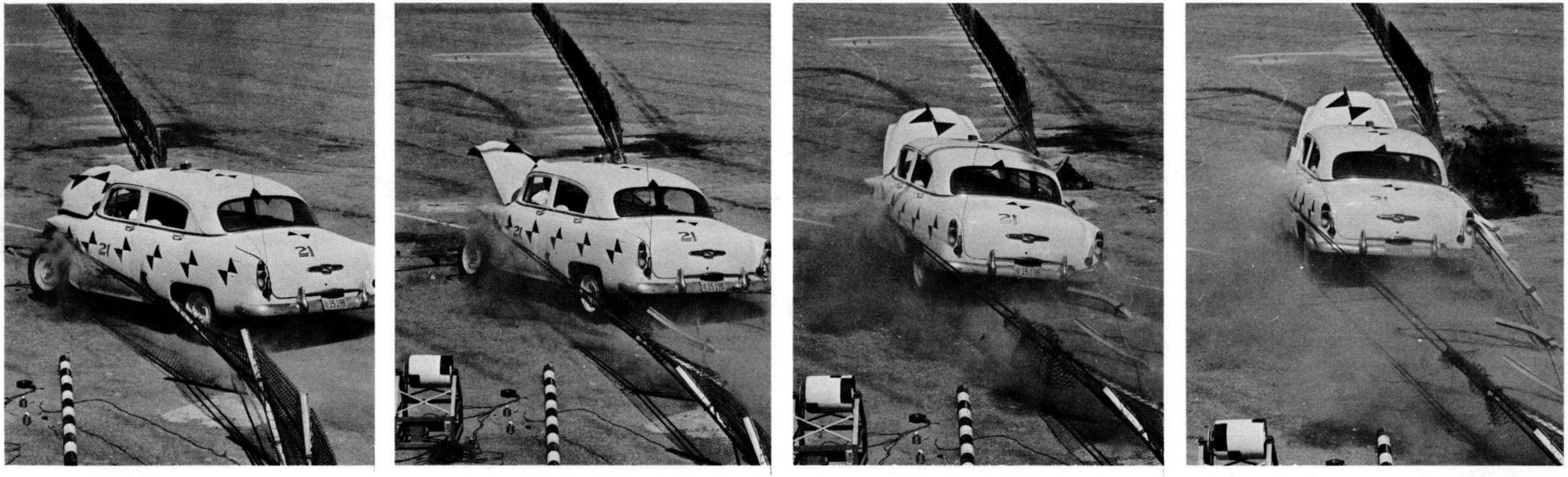


Figure 28. Deceleration instrumentation.



IMPACT + 175 M Sec. IMPACT + 275 M Sec. IMPACT + 425 M Sec. IMPACT + 675 M Sec.

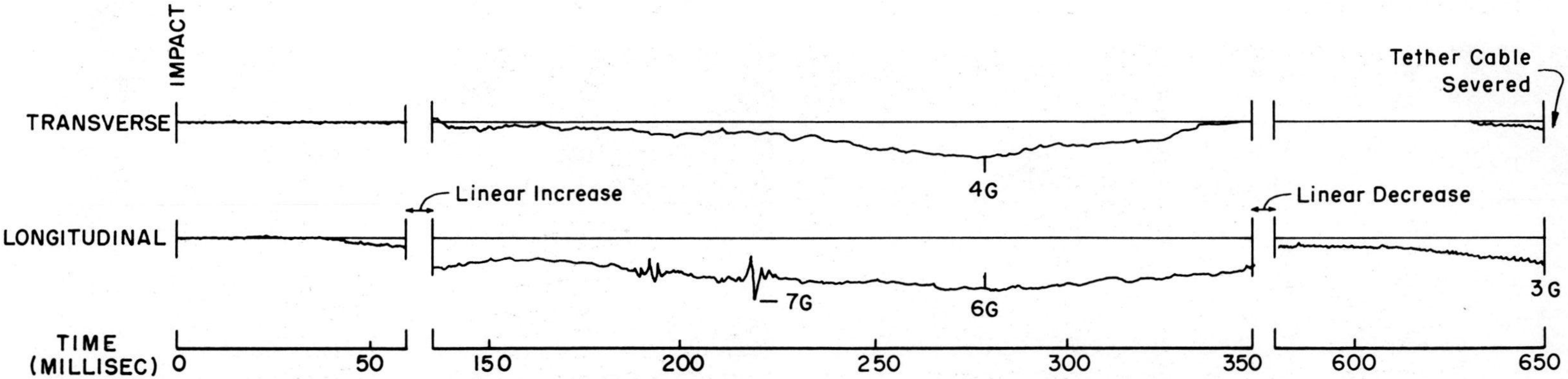


Figure 29. Deceleration record of cable-chain link (Test 21) barrier.

IMPACT + 200 M Sec. IMPACT + 250 M Sec. IMPACT + 800 M Sec. IMPACT + 3050 M Sec.

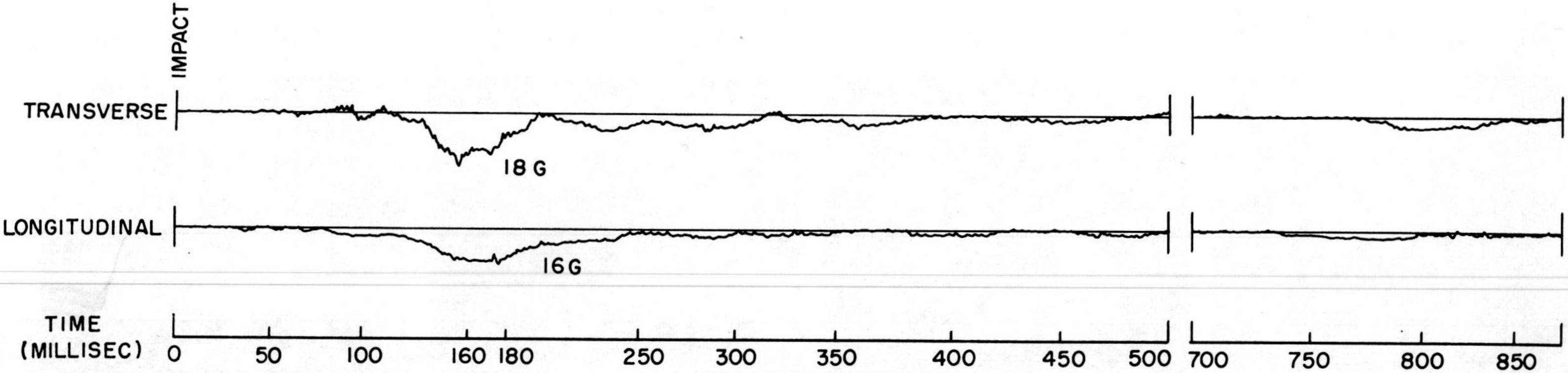
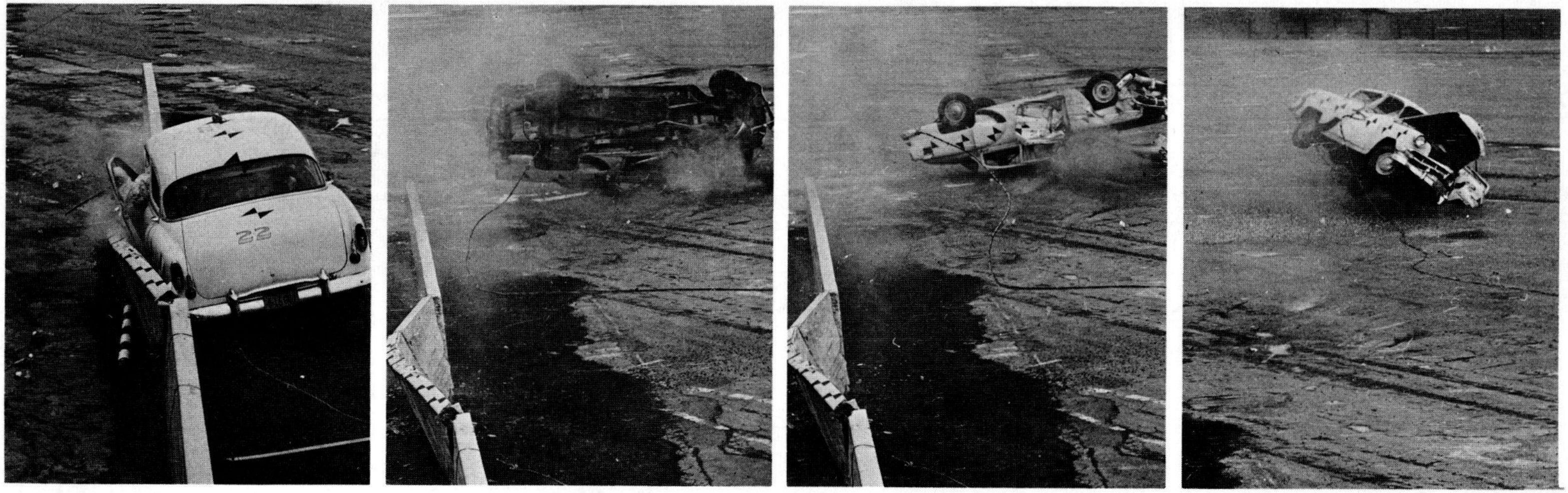


Figure 30. Deceleration record of blocked out metal beam (Test 13) barrier.



IMPACT + 150 M Sec. IMPACT + 1100 M Sec. IMPACT + 1350 M Sec. IMPACT + 2700 M Sec.

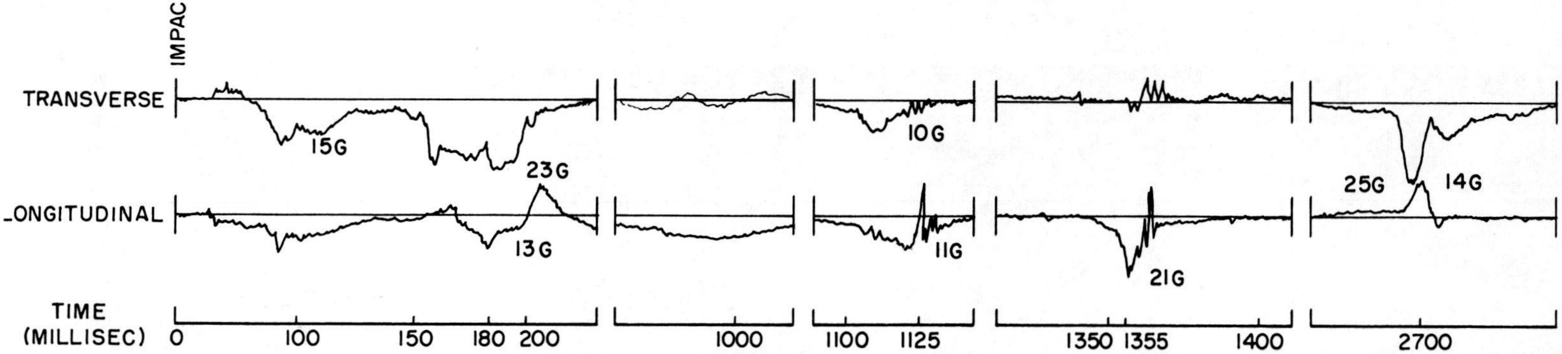


Figure 31. Deceleration record of concrete wall (Test 22) barrier.

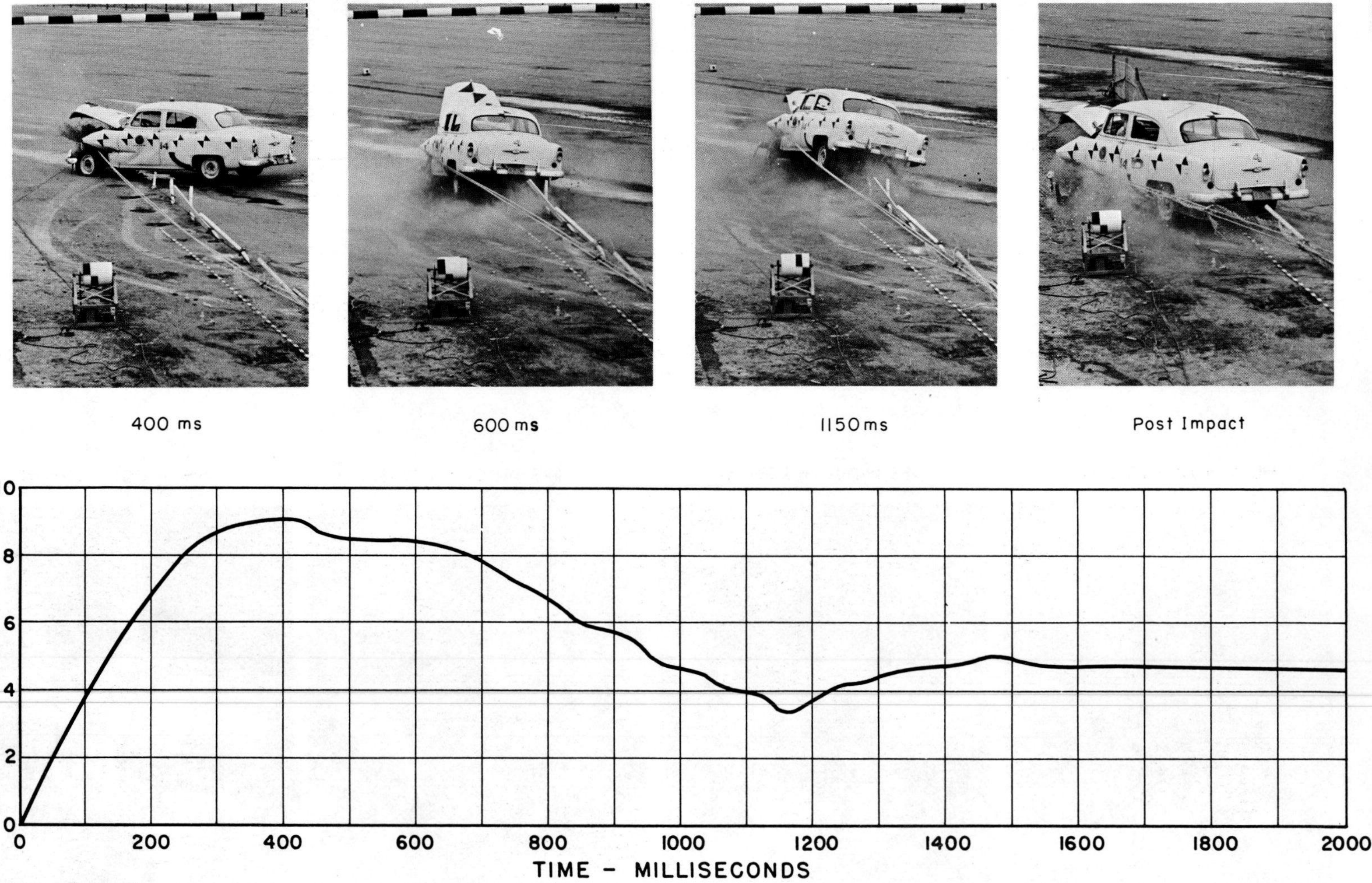
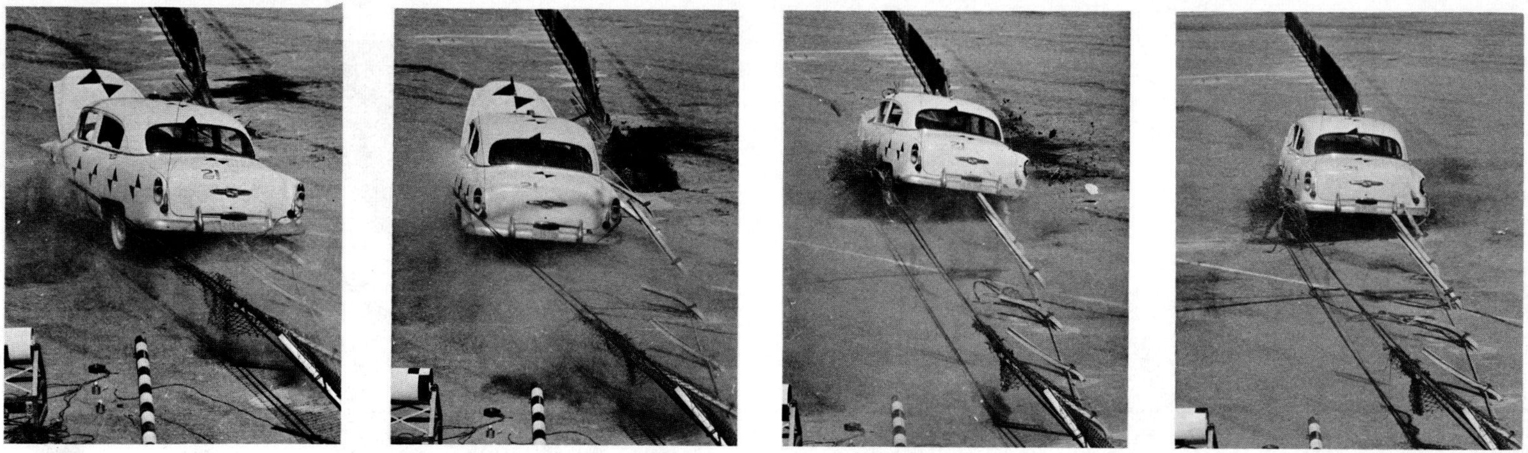


Figure 32. Time-deflection graph cable-chain link barrier (Test 14).



300 ms

800 ms

1000 ms

Post Impact

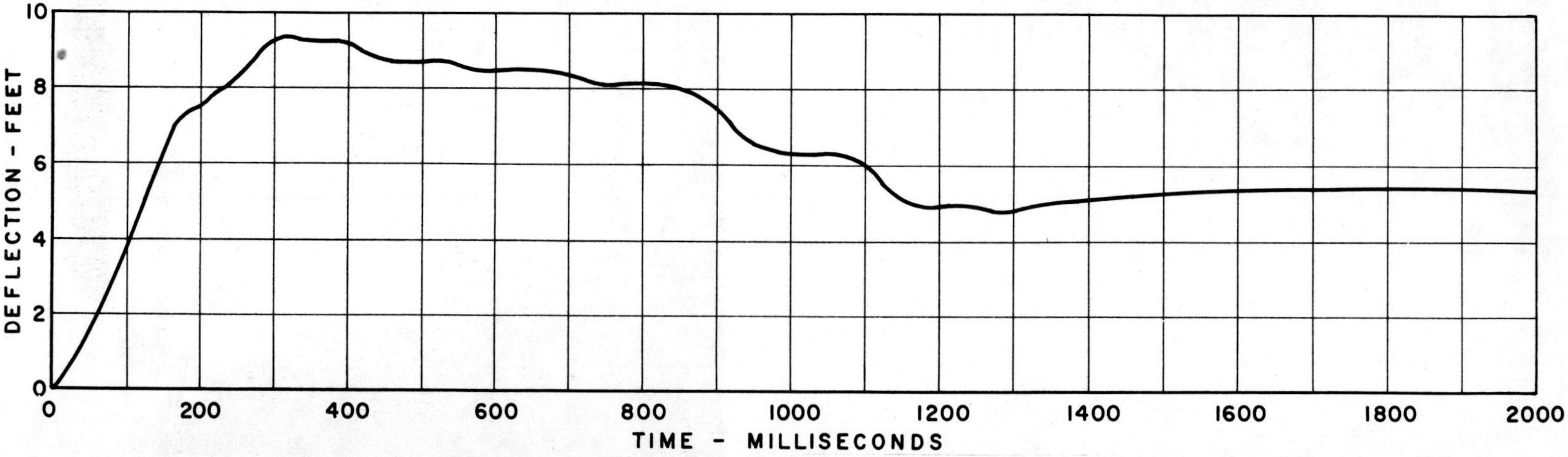


Figure 33. Time-deflection graph cable-chain link barrier (Test 21).

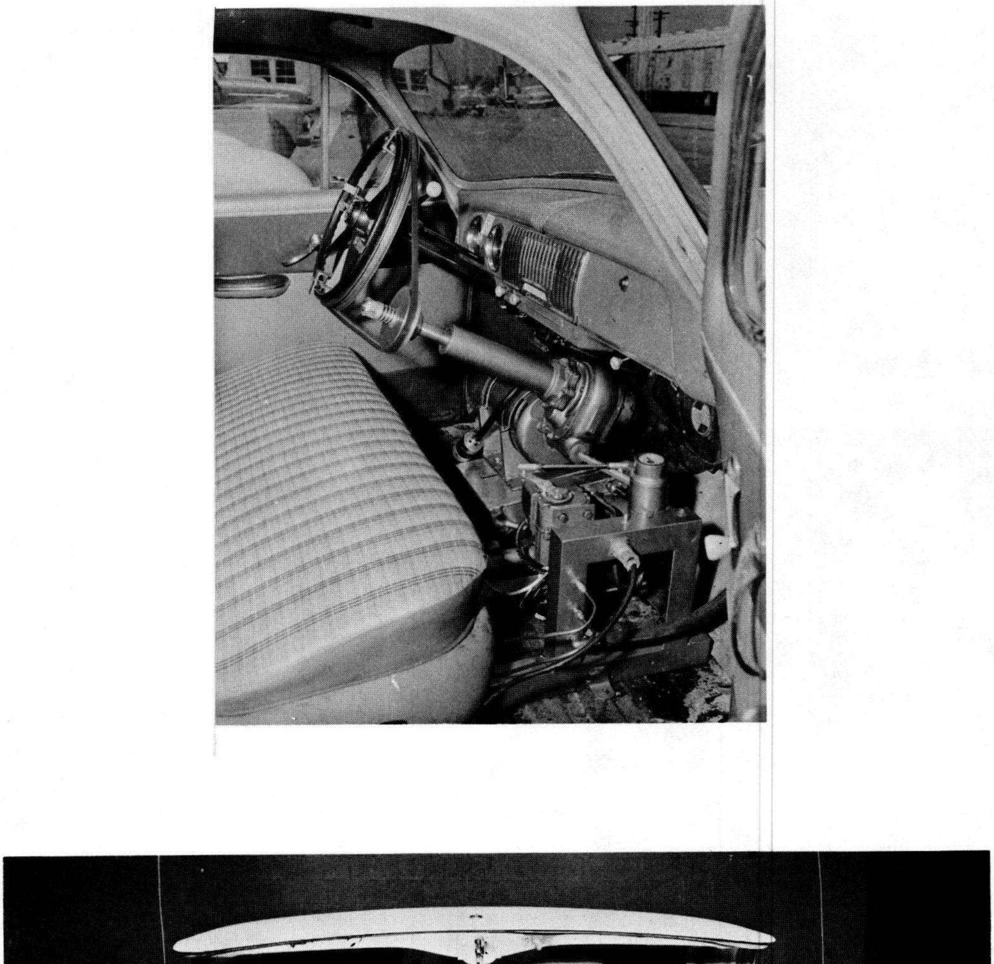


Figure 34. Photographs of crash car instruments.

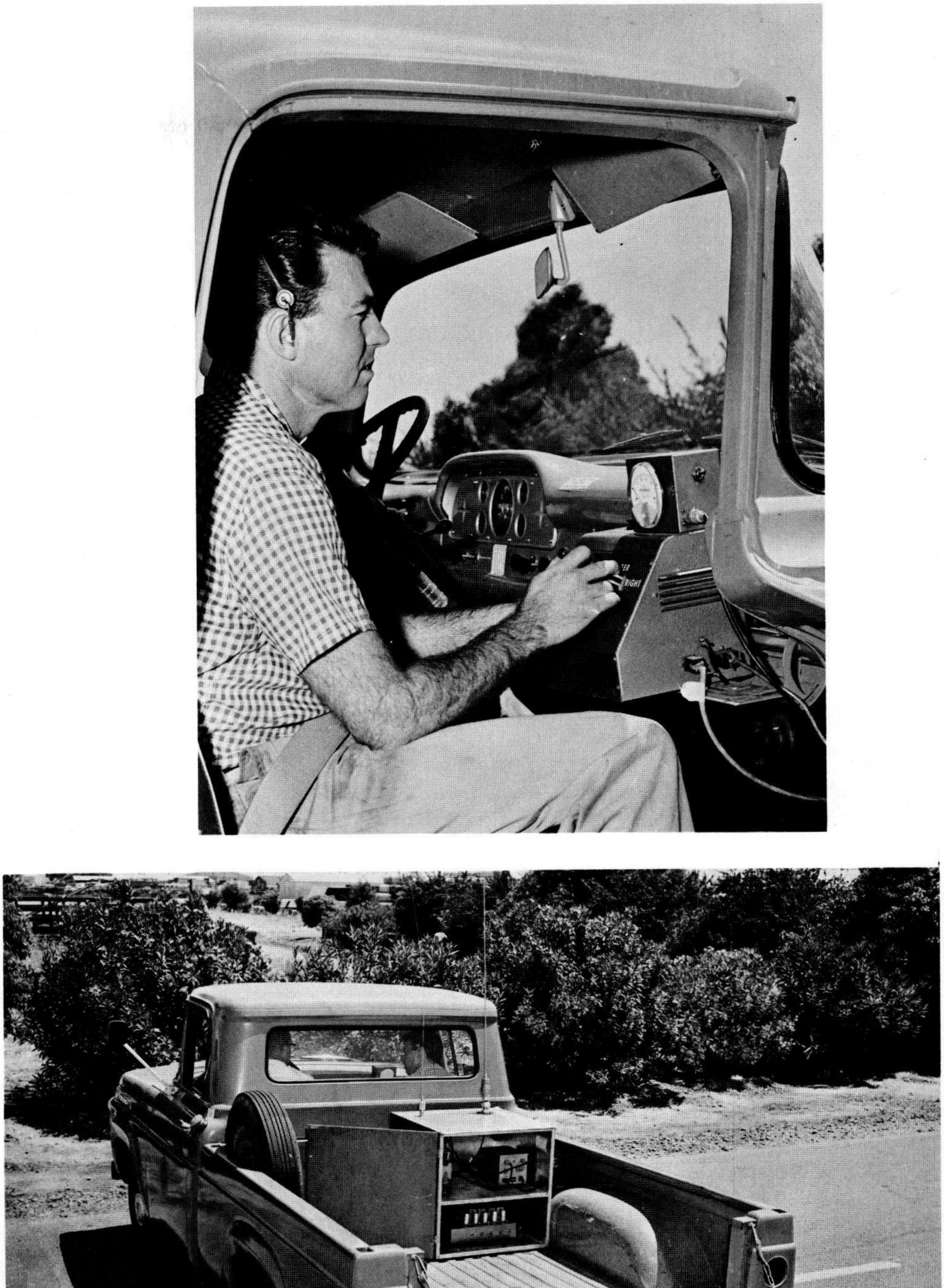


Figure 35. Photographs of control car instruments.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.