The Effect of Ramp Type and Geometry On Accidents

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This study was made to learn more about freeway ramps, to determine which geometric features play important roles in ramp safety, and to classify these features according to ramp type and relative safety merits.

The study involved 722 freeway ramps. In a period of about 3 years, over 2 billion vehicles used these ramps, and during this time 1643 accidents occurred.

The accident rates of on-ramps were consistently lower than off-ramp accident rates. (Accident rate = number of ramp accidents per million vehicles using the ramp.) The average on-ramp rate is 0.59 Acc/MV (accidents per million vehicles), whereas the average off-ramp rate is 0.95 Acc/MV. The on-ramp rates vary from about 0.40 Acc/MV to about 0.93 Acc/MV depending on the type of ramp. The off-ramp rates vary from about 0.62 Acc/MV to about 2.19 Acc/MV.

Ramps were classified as to type (diamond, trumpet, cloverleaf, etc). Accident rates were determined for each ramp type and further subdivided by on- or off-ramp, and by the relative freeway-to-ramp grades.

Correlations were found between accident rates and ramp type, relative freeway-to-ramp grades, fixed objects, speed-change lane lengths, possible safe entrance speeds at on-ramp noses, and off-ramp radius.

No correlation was found to exist, or the study was unable to determine if a correlation existed, between ramp accident rates and on-ramp curvature, ramp lighting, ramp traffic volumes, and the magnitude of the ramp central angle.

•PRESENT-DAY geometric standards of ramps were developed through a long process of evolution involving experience in both design and operation. This study was initiated as a continuing effort to increase our knowledge of ramp operations and to better understand the effect of the design on ramp safety.

The 722 ramps involved are primarily located on the same freeways used in the "Comparative Freeway Study" (1). Figure 1 shows the general location of the ramps. The descriptions of the locations and the study periods used are listed in the Appendix.

The Appendix is divided into two parts, A and B. For group A ramps, the specific ramp geometry was not readily ascertainable. However, it was known whether the accidents occurred on the ramp proper or its speed change lane section. For group B ramps, the geometric details were determined, but it could not be readily determined (without reading several hundred reports) whether the accident occurred on the ramp proper or on its speed change lane.

The study period was from 1958 through 1962, with 3 years of experience available for most locations. Approximately 2 billion vehicles used these ramps, and 1643 accidents occurred during the study period.

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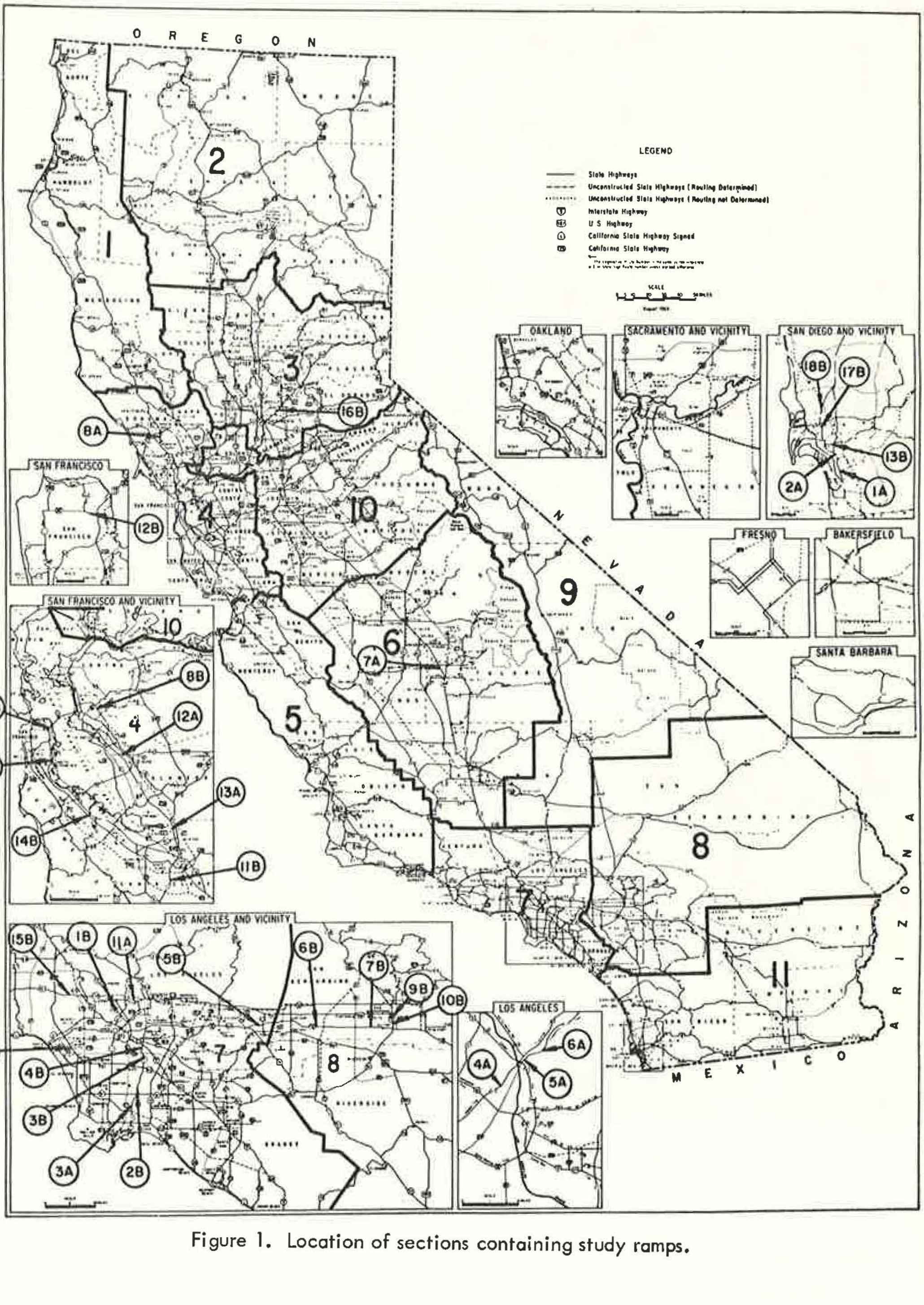


Figure 1. Location of sections containing study ramps.

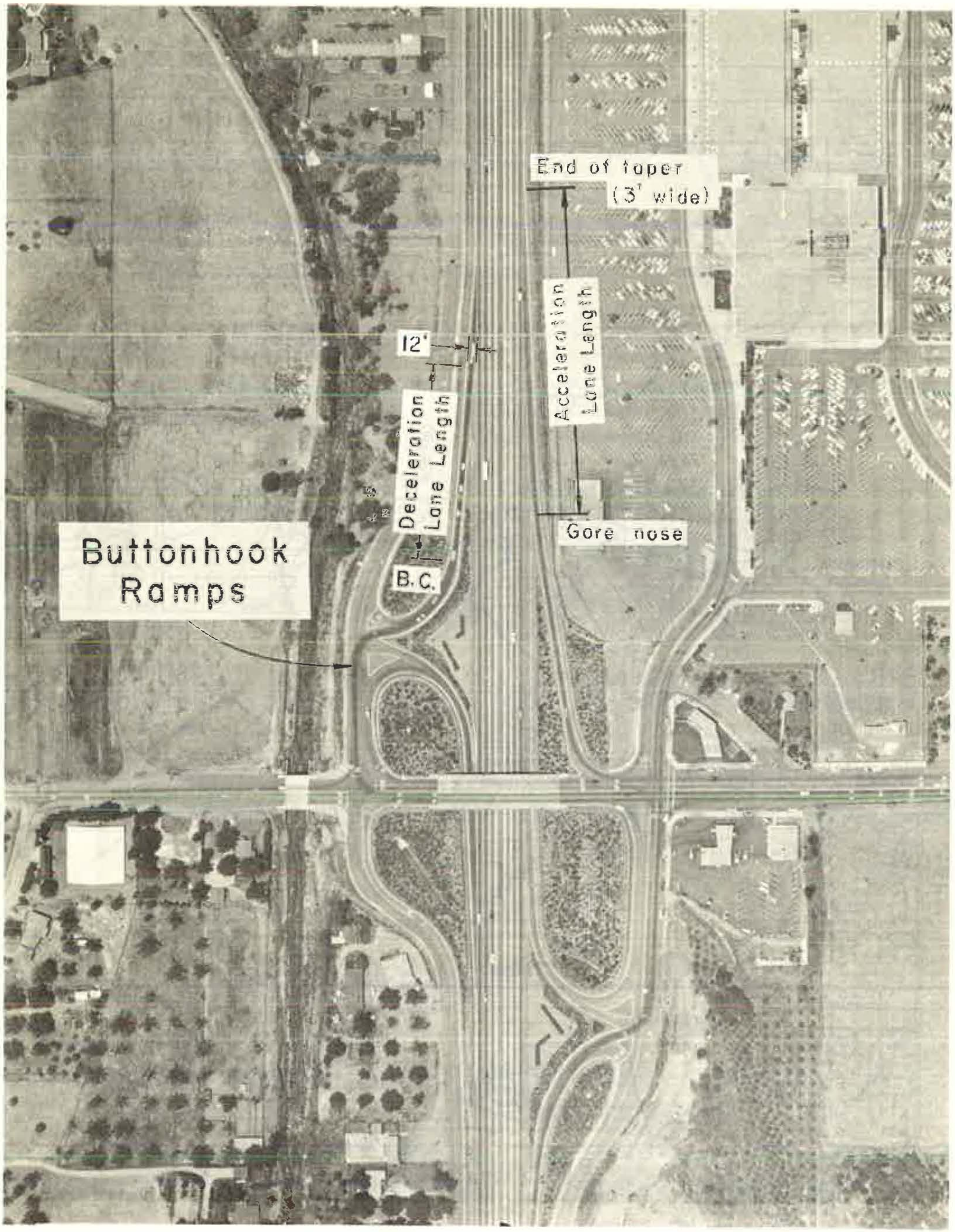


Figure 2. Example of modified diamond ramp and typical buttonhook ramp.

STUDY METHODS

The ramps were grouped into 10 basic types:

1. Diamond ramps,
2. Trumpet ramps,
3. Cloverleaf ramps without collector-distributor roads,

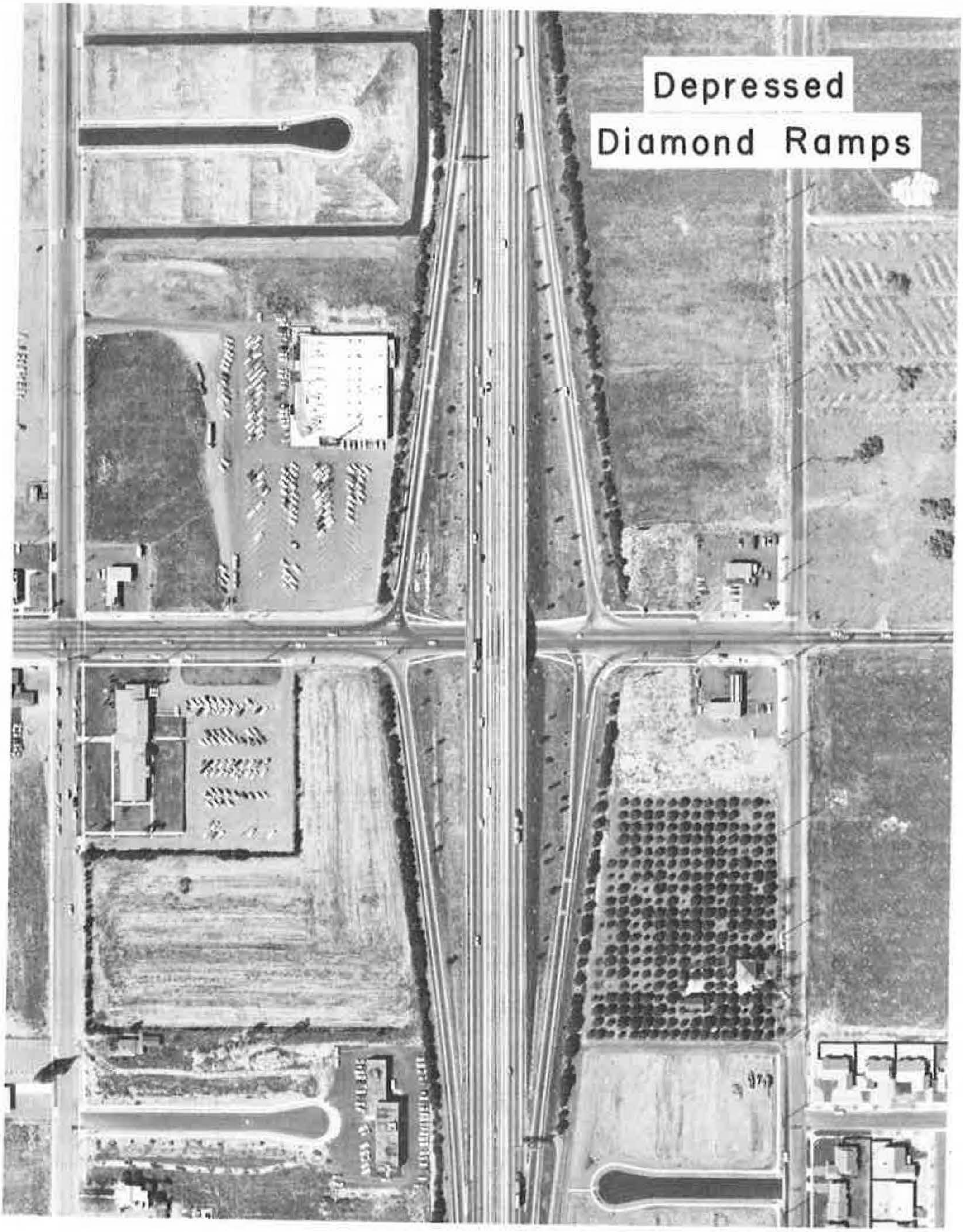


Figure 3. Depressed diamond ramp connecting to cross street.

4. Cloverleaf ramps with collector-distributor roads,
5. Loops without collector-distributor roads,
6. Cloverleaf loops with collector-distributor roads,
7. Left side ramps,
8. Direct connections,
9. Buttonhook ramps, and
10. Scissors ramps.

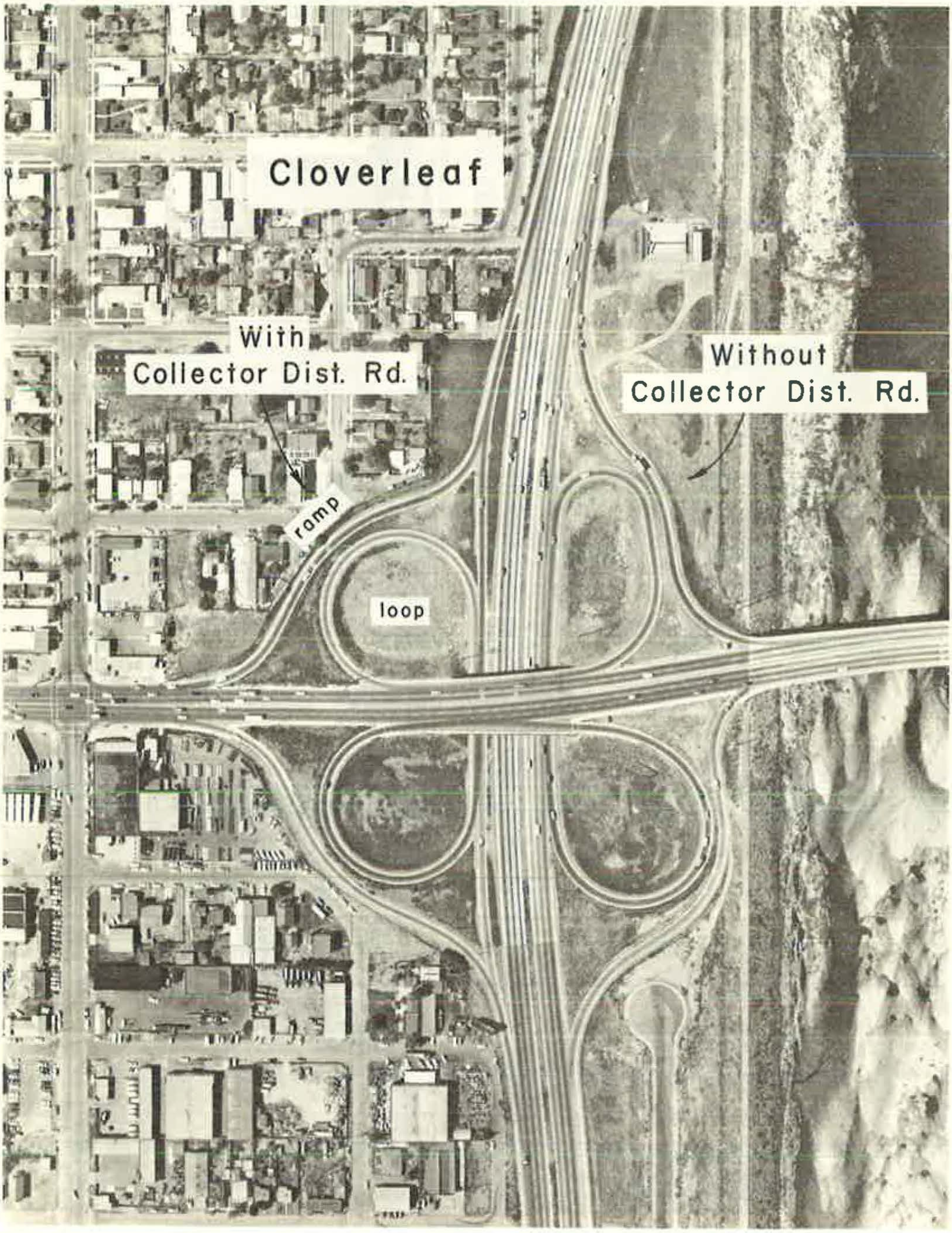


Figure 4. Cloverleaf ramps and loops with and without collector-distributor roads.

A right-turning ramp with over 180 deg of curvature and which connects crossing roadways is called a loop. Loop ramps are normally associated with cloverleaf and trumpet type interchanges; this distinction has been made in the above classifications. All loops that connected to collector-distributor roads were the cloverleaf type. No. 5 loops without collector-distributor roads are made up of both cloverleaf and trumpet loops.

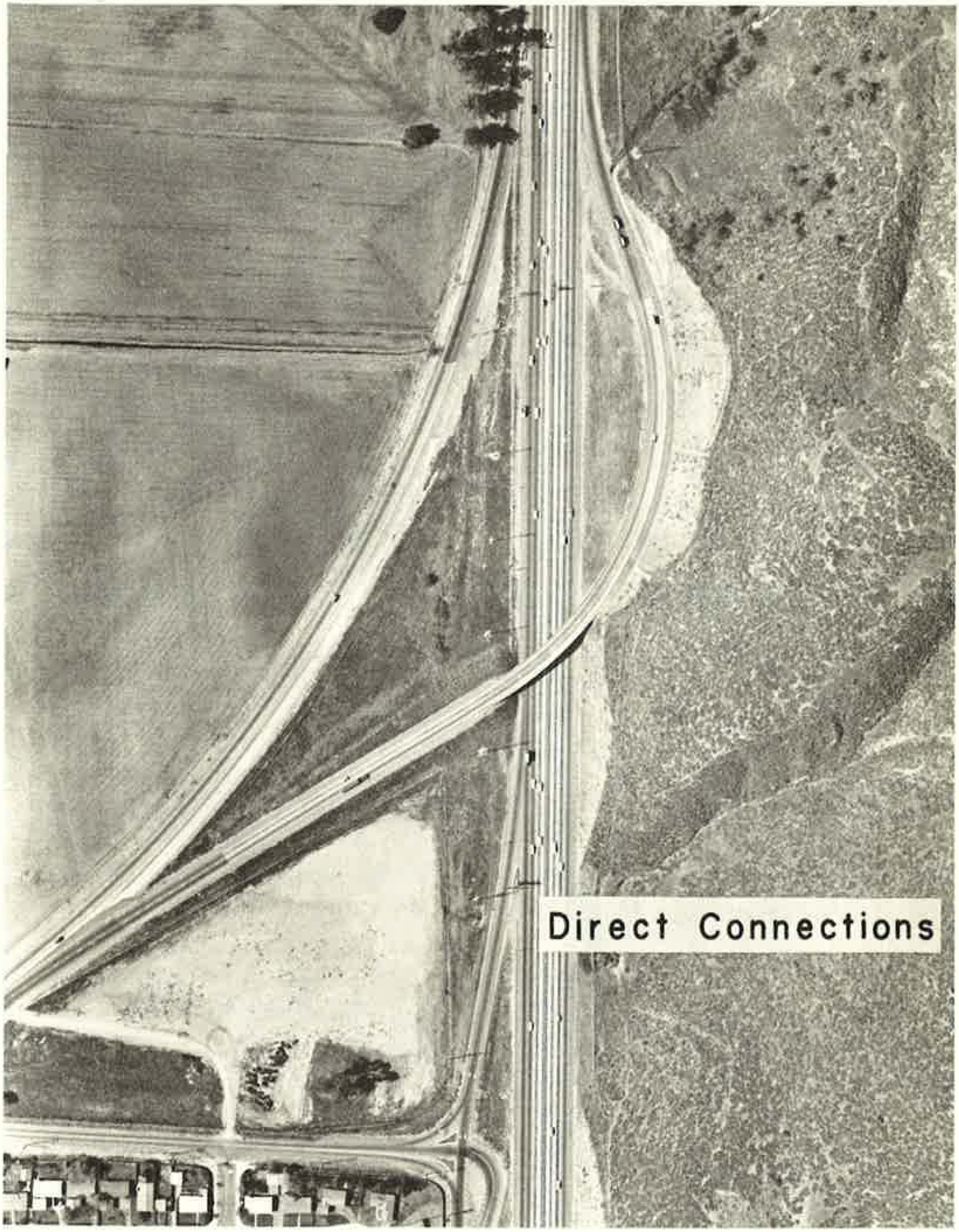


Figure 5. Example of direct connection designed for high-speed maneuvers.

The ramps are not necessarily classified by interchange types because some interchanges are mixtures of 2 or more ramp types. For example, Figure 2 shows a modified diamond ramp on the right side and 2 pairs of typical buttonhook ramps on the lower right and upper left sides. The diamond ramp is basically straight and always connects to the cross street as shown in Figure 3. The buttonhook ramps usually are not associated with a crossing structure or are at a considerable distance from the

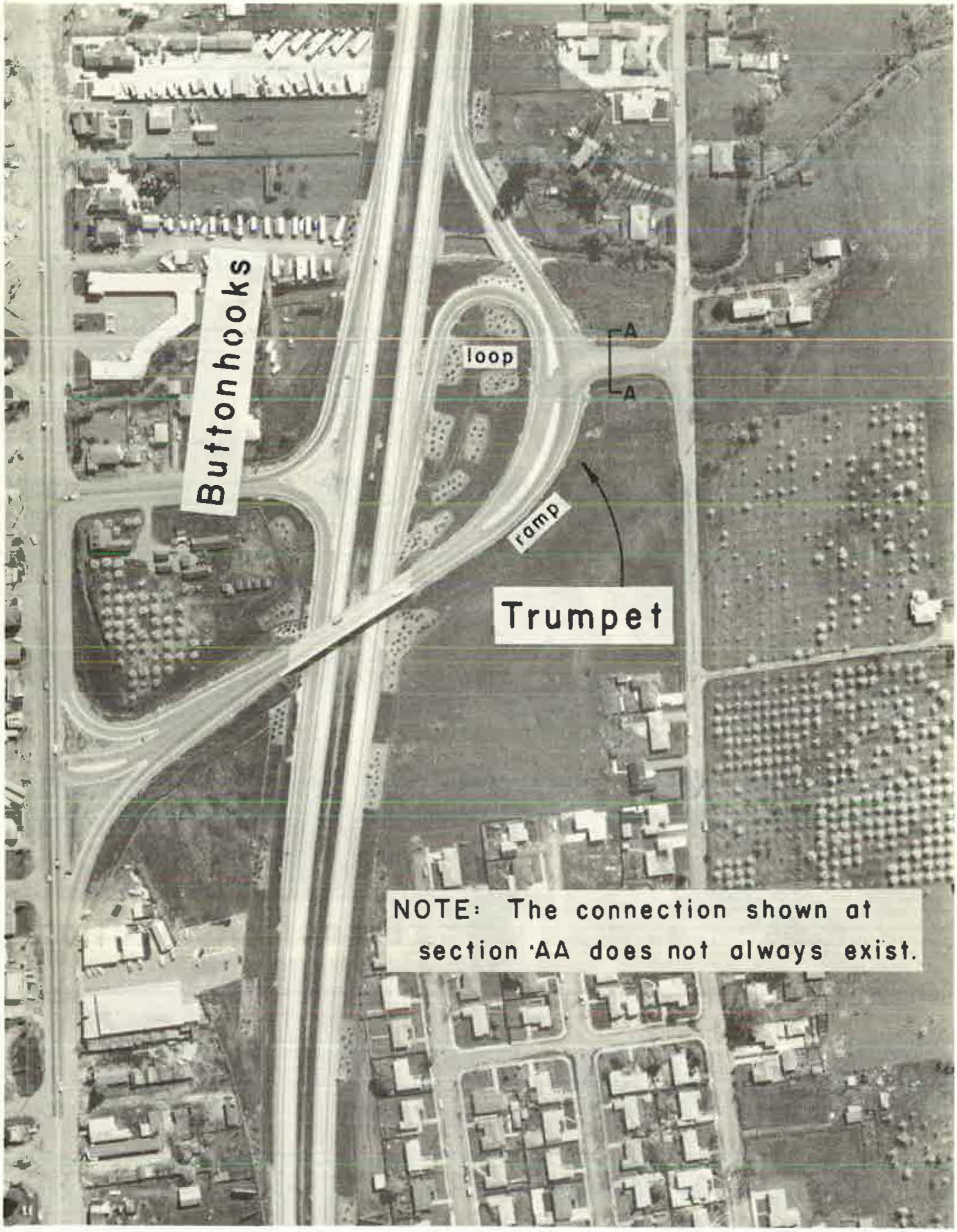


Figure 6. Direct connection to trumpet loop.

structure. In many cases, there is no structure at all and the ramps simply serve as access to or from the adjacent land on one side of the freeway only.

The cloverleaf ramps and loops are illustrated in Figure 4. The left half of the interchange employs a collector-distributor road and the loops connect to the collector-distributor road. The right side of the interchange does not employ the collector-

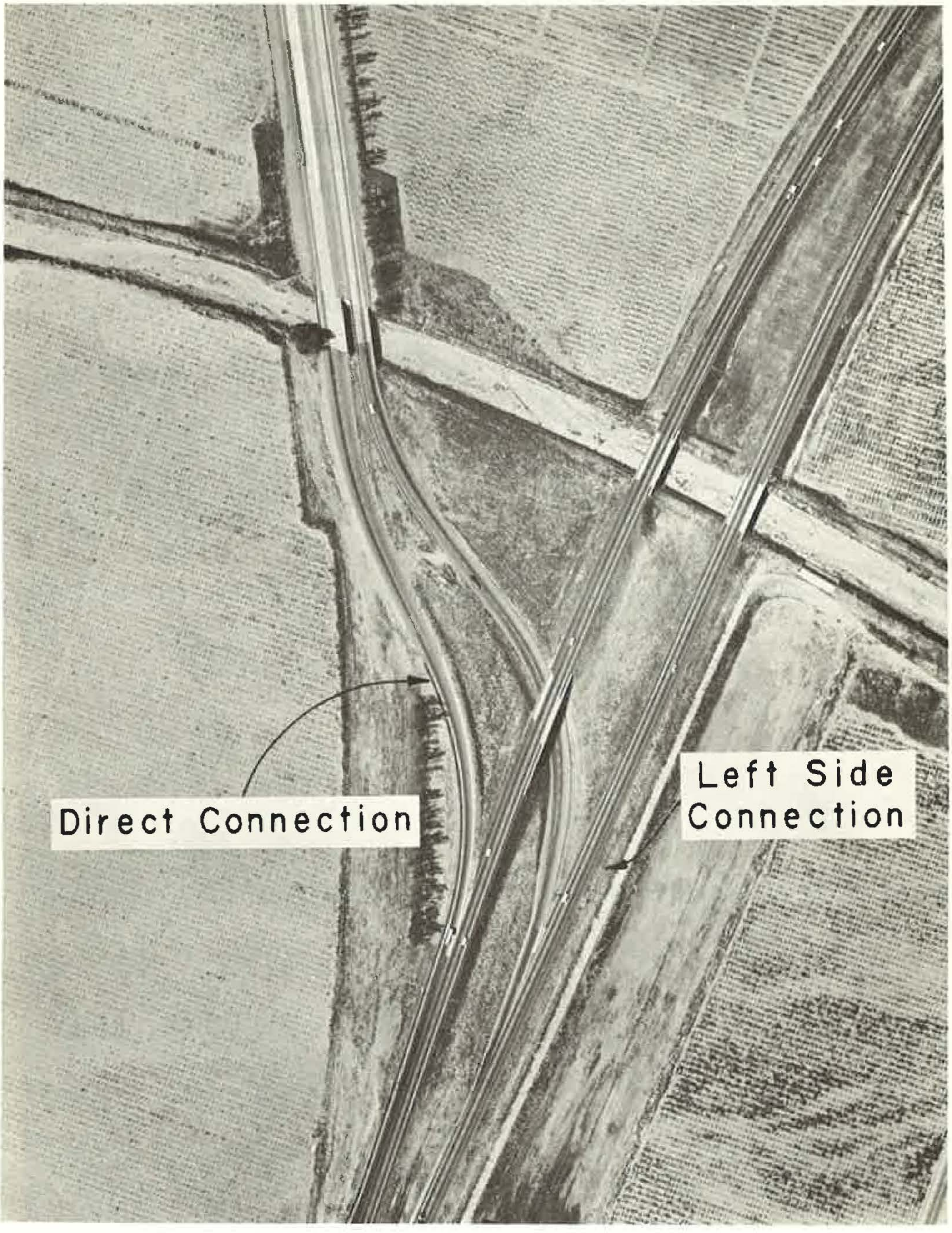


Figure 7. Example of left side connection.

distributor road, and the loops connect directly to the freeway. The loops are not necessarily circular, and the cloverleaf ramps do not always reverse curvature to bypass the loop.

Direct connections (Fig. 5) are usually designed for high-speed maneuvers. If an off-ramp loop were employed such that two-way traffic would result on the overcrossing,

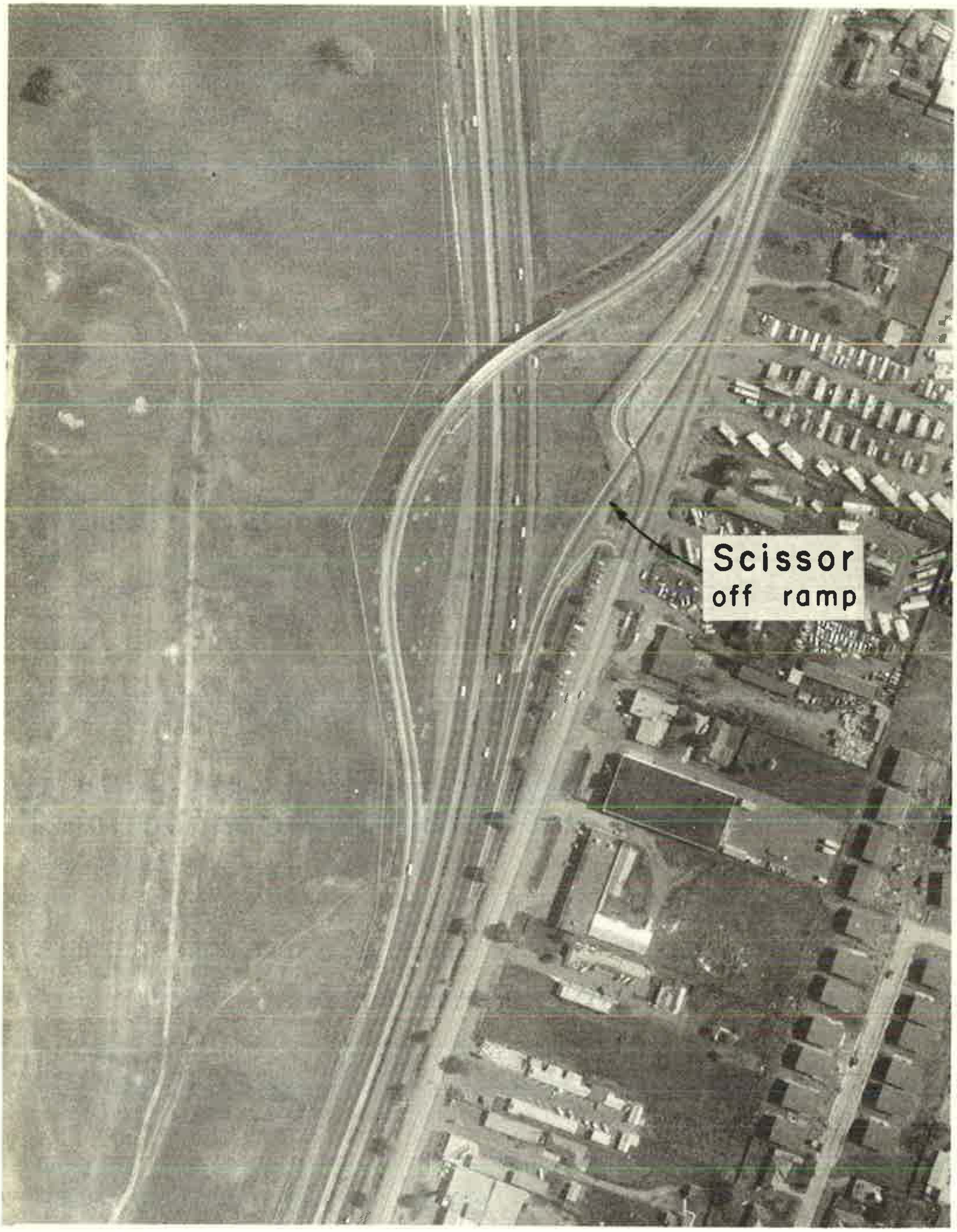


Figure 8. Example of scissor ramp.

the arrangement would become a trumpet ramp and a trumpet loop (Fig. 6). The ramp on the far left would remain a direct connection.

Any ramp that connects to the inside (high-speed) lane of the freeway is called a left side connection (Fig. 7). A scissor ramp (Fig. 8) is one that has opposing traffic crossing the ramp traffic. The ramp traffic has the right of way and a stop sign is placed to stop the crossing vehicle.

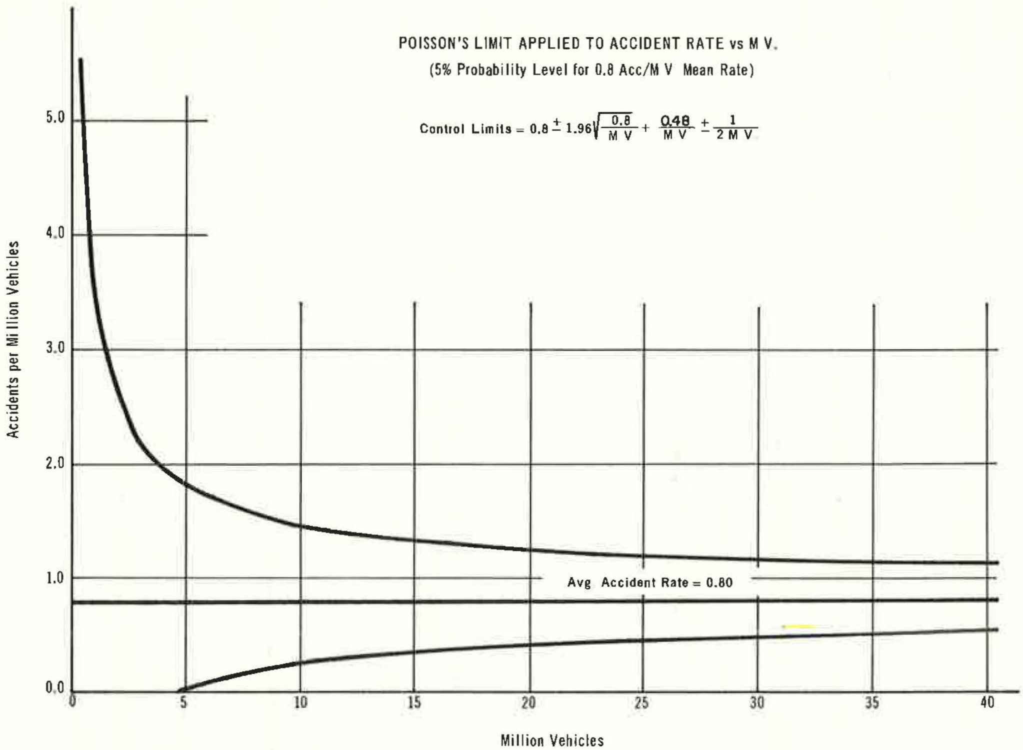


Figure 9.

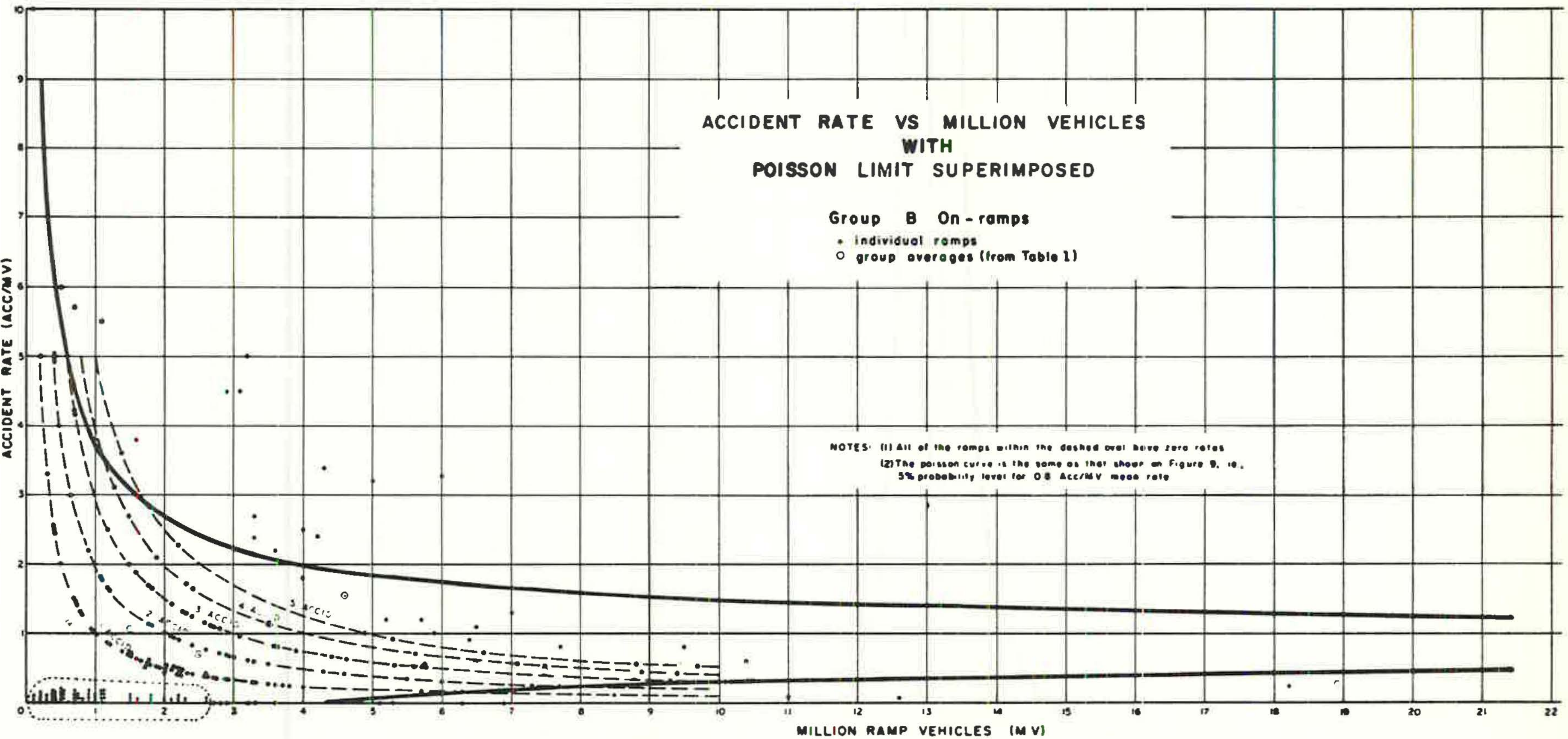
Million vehicle miles of experience is normally used as the denominator in the calculation of accident rates. In this study, the ramp accident rates have been calculated on the million ramp vehicle basis. The assumption is that the ramp experience is essentially related to the number of vehicles entering or leaving without regard to the distance traveled.

The accuracy of the accident rate, Acc/MV (number of accidents per million vehicles using the ramps), depends on the accuracy of the accident counting, and on the accuracy of the estimated amount of exposure, MV. Extreme care was taken in determining these values to assure a reasonable degree of accuracy.

The accident rate depends on the chance occurrence of accidents. The present accepted method of reducing the effect of chance occurrence is to use a large volume of experience, thus overshadowing the factor of chance. This study does contain a fairly large amount of experience (2 billion ramp vehicles), but unfortunately this experience is in many instances spread thin due to the sorting of ramps by geometric features and types, etc. The question then becomes: what amount of experience is necessary to obtain a reasonably reliable accident rate?

The Poisson distribution was used for estimating the probability of chance occurrence and the relative stability of the calculated rates. Figure 9 is a plot of this distribution using a 95 percent confidence level. The accident rate is plotted as the ordinate and the amount of experience (measured by number of vehicles) is the abscissa. The distribution was plotted for a mean accident rate of 0.80 accidents per MV. This rate was used since it closely represents the average rate for ramps based on our experience of 2 billion vehicles.

To understand the significance of this graph, let us assume that in a large number of ramps, each has an exposure of 5 MV. Let us further assume that the mean accident rate of the group is 0.80 Acc/MV. If the accident rate for each individual ramp


ACCIDENT RATE VS MILLION VEHICLES
WITH
POISSON LIMIT SUPERIMPOSED
Group B On-ramps
• individual ramps
○ group averages (from Table 1)
NOTES: (1) All of the ramps within the dashed oval have zero rates
(2) The poisson curve is the same as that shown on Figure 9, ie.,
5% probability level for 0.8 Acc/MV mean rate
ACCIDENT RATE (ACC/MV)
MILLION RAMP VEHICLES (M V)
0
1
2
3
4
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12
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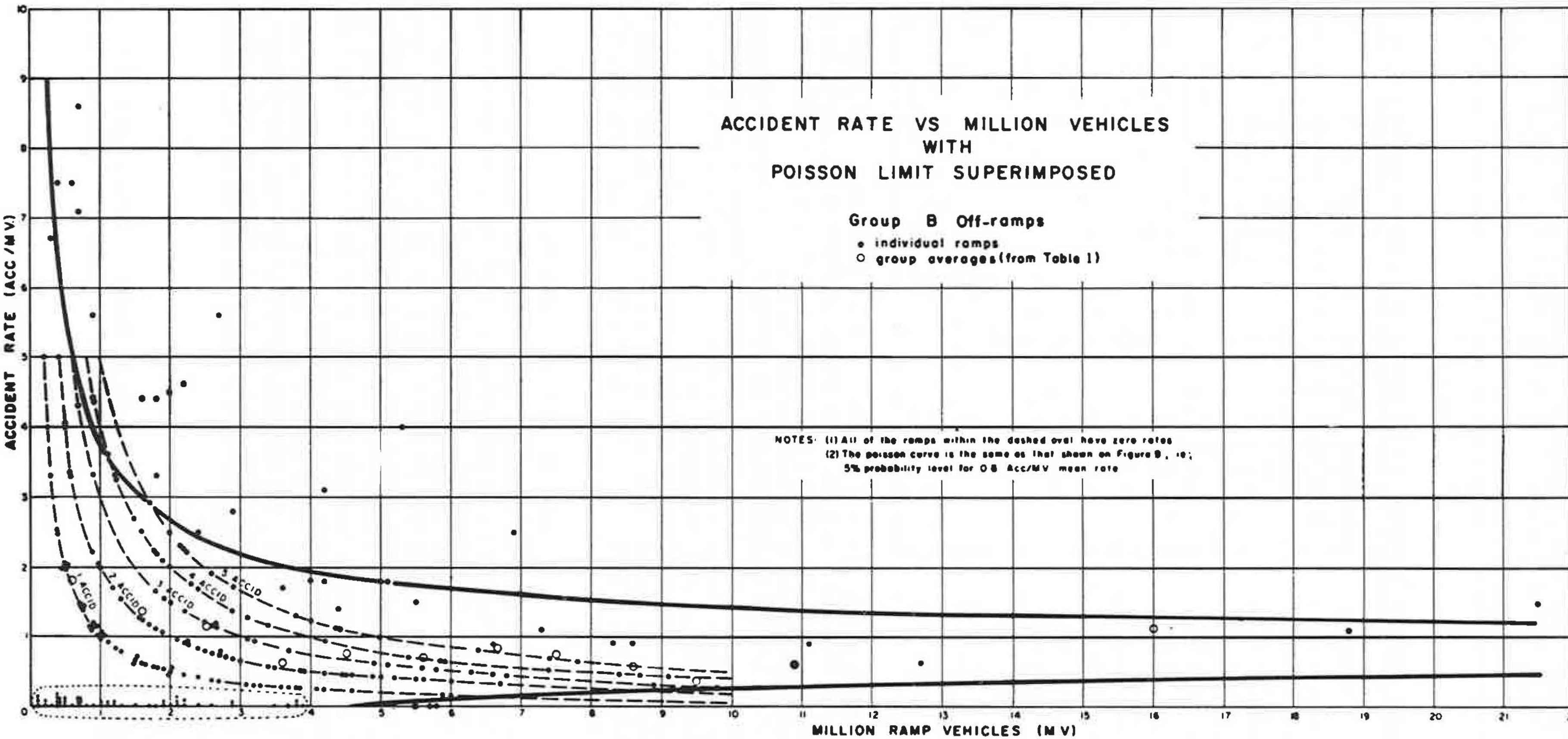
Figure 10.



ACCIDENT RATE VS MILLION VEHICLES
WITH
POISSON LIMIT SUPERIMPOSED
Group B Off-ramps
• individual ramps
○ group averages (from Table 1)
NOTES: (1) All of the ramps within the dashed oval have zero rates
(2) The poisson curve is the same as that shown on Figure 9, 10;
5% probability level for 0.8 Acc/MV mean rate
1 ACCID
2 ACCID
3 ACCID
4 ACCID
5 ACCID
ACCIDENT RATE (ACC/MV)
MILLION RAMP VEHICLES (MV)
0
1
2
3
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Figure 11.

TABLE 1

RAMP ACCIDENT RATES FOR 1 MV INCREMENTS OF EXPERIENCE—GROUP B RAMPS

M.V. Groups	Ramps		Accidents		M.V		Avg. M.V.		Avg. Rate	
	On	Off	On	Off	On	Off	On	Off	On	Off
0 to 1 M V	66	65	39	74	36.4	39.9	0.6	0.6	1.07	1.85
Over 1 to 2 M V.	50	45	60	104	77.5	73.7	1.57	1.6	0.77	1.41
Over 2 to 3 M V	45	40	63	124	111.4	99.6	2.5	2.5	0.57	1.24
Over 3 to 4 M V.	23	23	71	53	81.3	83.5	3.5	3.6	0.87	0.63
Over 4 to 5 M V	7	14	46	38	32.2	63.0	4.6	4.5	1.43	0.60
Over 5 to 6 M V	15	19	45	74	83.7	105.9	5.6	5.6	0.54	0.70
Over 6 to 7 M V	8	7	29	39	52.2	46.3	6.5	6.6	0.56	0.84
Over 7 to 8 M V	5	4	18	22	37.3	29.9	7.5	7.5	0.48	0.74
Over 8 to 9 M V	3	5	10	25	26.3	42.9	8.8	8.6	0.38	0.58
Over 9 to 10 M V	4	2	20	7	38.0	18.9	9.5	9.5	0.53	0.37
Over 10 to 11 M V	3	1	10	6	31.5	10.9	10.5	10.9	0.32	0.55
Over 11	3	4	14	71	56.8	64.1	18.9	16.0	0.25	1.11
TOTALS	232	229	425	637	664.6	678.6	2.8	2.9	0.64	0.94

is then plotted on the vertical line representing 5 MV on the graph, 95 percent of these points would be expected to fall within the confidence limits of 0.06 and 1.83 Acc/MV. In other words, the accident rates of 95 percent of the ramps each having an exposure of 5 MV would be expected to fall between these limits.

On the other hand, if the experience is 35 MV per ramp, the expected fluctuation is not as great (0.52 to 1.14). In essence, the element of chance is overshadowed as more experience is gained; the graph serves to indicate the expected accuracy of accident rates based on various amounts of experience.

In this report, the tables showing accident rates also show the amount of experience on which the rates are based. If the rate is obviously unstable (under 10 MV), it was either omitted or some statement concerning the confidence level is made. It is felt that the various rates given in this report are significant.

NON-GEOMETRIC FACTORS

The ramps in this study accounted for approximately 18 percent of the accidents on the freeways which they serve. In 1963, ramp accidents on all the freeways in California accounted for 14.4 percent of the freeway accidents.

Out of 722 ramps studied, 232 (32 percent) were accident free. However, these accident-free ramps carried only 327 MV or 16 percent of the total ramp experience. No particular design differences were noted between ramps that had no accidents and ramps that did. However, a large percentage of accident-free ramps might be expected because the average experience per ramp was only 2.9 MV for the 722 ramps studied and only 1.4 MV for the 232 accident-free ramps.

Figures 10 and 11 are plots of the accident rate vs exposure in million ramp vehicles for all of the group B ramps. The Poisson distribution has been superimposed to show that a large percentage of zero rates can be expected in the low exposure range. The large circles represent the group average accident rate for the various million vehicle (MV) groups shown in Table 1.

Accident Severity

A breakdown in ramp accidents by severity (Table 2) shows no significant difference in percentage occurrence between the ramp and the main line accidents, or between

TABLE 2

RAMP ACCIDENTS BY SEVERITY

Category	Percent of Total Accidents		
	On-Ramps	Off-Ramps	Freeway Avg.
Fatal accidents	1.5	1.5	1.8
Injury accidents	42.5	41.5	42.9
Property-damage only accidents	56.0	57.0	55.3
Total	100.0	100.0	100.0
Number of injuries per accident	0.58	0.58	0.74

TABLE 3

SINGLE AND MULTIPLE VEHICLE ACCIDENTS

Type	Total Accidents (percent)			Accident Rates (Acc/MV)	
	On-Ramps	Off-Ramps	Freeway Avg.[a]	On-Ramps	Off-Ramps
Single vehicle	31	51	28	0.18	0.48
Two vehicle	57	43	53	0.34	0.41
Three or more vehicle	12	6	19	0.07	0.06
Total	100	100	100	0.59	0.95

[a]Taken from Table 10, p. 168, Ref. (1).

on-ramps and off-ramps. The ramp accidents do, however, seem to have fewer injuries per accident. This is probably due, in part, to the lower ramp speeds.

Ramps, especially off-ramps, have a large number of fixed objects adjacent to them (Figs. 12, 13 and 14). Because of this, one would expect the ramps to have a higher proportion of injury accidents than the main line sections of the freeways. This is not the case, however, probably because of the lower speeds associated with ramps.

Single and Multiple Vehicle Accidents

A breakdown by single and multiple vehicle accidents (Table 3) revealed that, in general, there is a higher percentage of single vehicle accidents on ramps than the normal freeway average. This increased percentage in the single vehicle category is primarily offset by a decrease in 3-or-more vehicle accidents. A closer look reveals that about the same breakdown exists at on-ramps as the freeway average, but there is a considerably higher percentage of single vehicle accidents at off-ramps.

If the ramp rates from Table 10 are split according to the given percentages, the rate for single, 2 vehicle, and 3-or-more vehicle accidents can be obtained. This breakdown is also shown in Table 3 and it reveals a very low rate for single vehicle, on-ramp accidents. The on-ramps also show a higher multiple vehicle rate, but the primary difference in the total on- vs off-ramp rates (on = 0.59; off = 0.95) is due to single vehicle off-ramp accidents. In other words, if the off-ramps had the same vehicle rate as the on-ramps, the total rate would be 0.18 + 0.41 + 0.06 = 0.65 Acc/MV as compared to the 0.59 Acc/MV on-ramp rates.

Assuming that the single vehicle accident is most likely to occur on the ramp proper (as opposed to the diverging area), it might be concluded that the off-ramp geometry is

TABLE 4

RAMP FIXED OBJECTS AS PERCENTAGE OF TOTAL FREEWAY FIXED OBJECTS[a]

Type	On-Ramps	Off-Ramps	On + Off
Guardrail[b]	13.7	15.5	29.2
Light standards	10.3	12.9	23.2
Signs[c]	1.8	6.1	7.9
Piers, abutments, and bridge rails	1.9	1.3	3.2
Total, ramp	27.7	35.8	63.5
Freeway fixed objects			36.5
Total			100.0

[a]From Table 6, p. 166, Ref. (1).
[b]Guardrail was counted in 50-ft lengths as one fixed object.
[c]Includes wood or steel posts, with or without guardrail.

TABLE 5

RAMP FIXED OBJECTS AS A PERCENT OF TOTAL RAMP FIXED OBJECTS

Type	On-Ramps	Off-Ramps	On + Off
Guardrail[a]	49.5	43.2	45.9
Light standards	37.2	36.0	36.5
Signs[b]	6.6	17.0	12.5
Piers, abutments, and bridge rails	6.7	3.8	5.1
Totals	100.0	100.0	100.0

[a]Guardrail was counted in 50-ft lengths as one fixed object.
[b]Includes wood or steel posts, with or without guardrail.

TABLE 6

FIXED OBJECT ACCIDENTS VS TOTAL FIXED OBJECTS

Type	a Fixed Object Accidents (%)	b Total Fixed Objects (%)	$\frac{a}{b}$
	On-Ramps		
Guardrails	49.3	49.5	1.00
Light standards	16.4	37.2	0.44
Signs	32.8	6.6	4.97
Piers, abutments, and bridge rails	1.5	6.7	0.22
Totals	100.0	100.0	
	Off-Ramps		
Guardrails	43.3	43.2	1.00
Light standards	10.4	36.0	0.29
Signs	38.8	17.0	2.28
Piers, abutments, and bridge rails	7.5	3.8	1.97
Totals	100.0	100.0	

difficult to maneuver. In other words, to maneuver through curves, etc., while the vehicle is decelerating requires more precise judgment than the same maneuver would involve if the vehicle were accelerating. This is also indicated by the fact that 22 percent of the off-ramp accidents involved a driver who had been drinking, whereas only 15 percent of the on-ramp accidents involved drinking drivers, indicating that the "had been drinking" driver can negotiate the on-ramp easier than the off-ramp.

An investigation concerning straight ramps and curved ramps is presented later in this report under sections entitled "Ramp Curvature" and "Off-Ramp Geometry."

Fixed Objects

Some 28 percent of all freeway (including ramps) accidents involve fixed objects. Fixed objects are involved in about 22 percent of all on-ramp accidents and about 42 percent of all off-ramp accidents. About 64 percent of all freeway fixed objects are located in the ramp areas. Off-ramp areas contain about 36 percent of the total freeway fixed objects and the on-ramp areas contain about 28 percent (Table 4).

Table 4 shows the percentage of the 4 most prevalent types of objects as compared to the total of other types on freeways. Table 5 was made by assuming that these 4 types of fixed objects represented 100 percent of the total ramp fixed objects. The percentage values in Table 4 were then adjusted so that the totals would equal 100 percent.

Accidents involving fixed objects were tabulated for both on- and off-ramps. Table 6 is a comparison between fixed object accidents and the total fixed objects in place.

The comparisons in Table 6 are based on relatively small samples of exposure. Therefore, the figures are at best approximate. The percentages could change considerably depending on what length of guardrail is chosen as one fixed object. The 50-ft guardrail length was selected to give a value of 1.00 for guardrail in the a/b column. Regardless of the chosen guardrail length, the signs appear, in both the on- and off-ramp situations, to be the most vulnerable type of fixed object (a/b = 4.97 and 2.28). Signs are normally placed on the outside edge of curves and in the ramp gore nose. Out-of-control vehicles normally leave the roadway on the outside edge of the curve rather than on the inside edge; and, in the case of off-ramps, the gore is extremely vulnerable to drivers who misjudge the ramp exit.

Piers, abutments and bridge rails are more vulnerable in the off-ramp situation than in the on-ramp situation. This is not surprising since, in a normal interchange situation, the off-ramp vehicles will have a structure dead ahead more often than the on-ramp vehicles. It also seems that the decelerating vehicle is harder to keep in control than the accelerating vehicle.

Examples of situations involving fixed objects are shown in Figures 12 through 20. Figure 12 also shows a location where the alignment and pavement texture give the appearance that the ramp is the main line. Guardrail is frequently used as delineation (Fig. 13). It would seem that something less rigid (and not as expensive) could be substituted if delineation is the prime objective. Curbs are also used for delineation as well as for drainage purposes. A curb can act as a fulcrum when struck by a vehicle skidding broadside and cause the vehicle to overturn.

Ramp Lighting

Light standards represent about 36 percent of the ramp fixed objects, and they are involved in about 10 to 16 percent of the ramp fixed object accidents. The elimination of the standards would no doubt reduce the total fixed object accidents, but the absence of the illumination which the standards support might well cause an increase in total accidents.

Table 7 shows the percentage of all types of accidents which occurred under various light conditions. A large percentage of the total freeway accidents are "dark—no street lights." This is because only the interchanges have lighting. For the ramps, a low percentage is in this category because very few ramps are without lighting. A rough comparison between the ramps and the total freeway shows the total freeway can be considered as being partly illuminated, and the ramps as being almost totally illuminated.

Figure 12. Numerous fixed objects and also the pavement texture and alignment which makes the ramp appear to be the mainline.

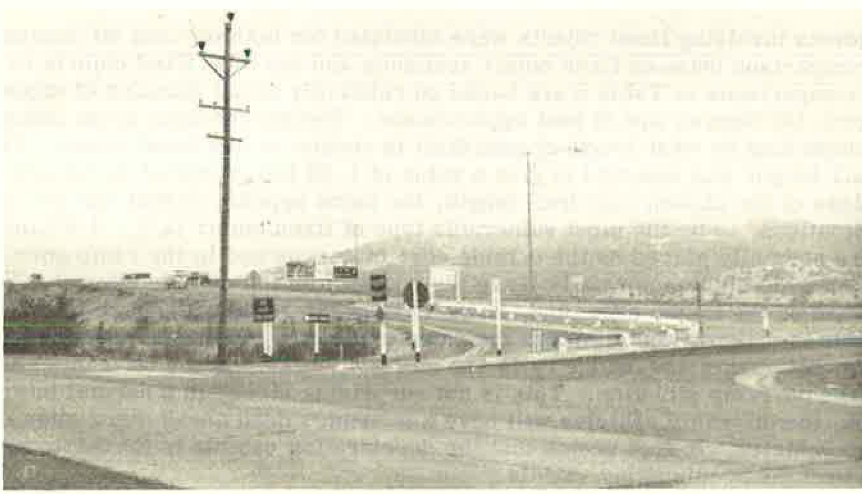


Figure 13. Guardrail used as delineation.

Figure 14. Cure as bad as the disease—guardrail needed only around sign post.

Figure 15. Is the guardrail necessary where the embankment is shallow?

Figure 16. Why the guardrail in the gore?

Figure 17. Curbs used for drainage, delineation and barrier.

Figure 18. Light standard on outside of curve (not present design practice, however).

Figure 19. Except for the light standard, there is ample unobstructed recovery space here.

Figure 20. Tree protected guardrail.

TABLE 7

ACCIDENTS UNDER VARIOUS LIGHT CONDITIONS

Light Conditions	Percent of Accidents		
	On-Ramp	Off-Ramp	Total Freeway
Daylight	66	57	52
Dusk or dawn	5	3	3
Dark—no street lights	6	8	25
Dark—with street lights	23	32	20
Totals	100	100	100
Total dark (all except daylight)	34	43	48

TABLE 8

ACCIDENT RATES—DAYLIGHT, NIGHT, COMBINED

Type	"All Day" (24-hr) Accident Rate[a]	Daylight $\frac{\%}{\%}$ Rate	Nighttime $\frac{\%}{\%}$ Rate	Percent Increase Night/Day
On-ramps	0.59 Acc/MV	$\frac{0.66}{0.70}$ 0.56	$\frac{0.34}{0.30}$ 0.67	20
Off-ramps	0.95 Acc/MV	$\frac{0.57}{0.70}$ 0.77	$\frac{0.43}{0.30}$ 1.36	77
Total freeway	1.29 Acc/MV	$\frac{0.52}{0.70}$ 0.96	$\frac{0.48}{0.30}$ 2.06	115

[a]See Table 10.

Traffic count data show that roughly 70 percent of freeway travel occurs during daylight and the remaining 30 percent occurs during dawn, dark or dusk hours. Assuming that the same breakdown for day-night exposure exists for the ramps as the main line, then a day and a night accident rate can be calculated for the ramps and the total freeway by multiplying the actual accident rate by the percentage of accidents and dividing the product by the percentage of exposure. For example,

$$\text{accident rate} \times \frac{\%\text{ of daylight accidents}}{\%\text{ of daylight exposure}} = \text{daylight accident rate}$$

Table 8 indicates that nighttime accident rates are higher than daylight rates and that a substantial percentage decrease in nighttime rates is realized in ramp areas (where illumination is present). It is difficult to determine exactly how much of this decrease, if any, is attributable to lighting. A more detailed study (2), recently completed, did not show conclusively that lighting does or does not reduce the occurrence of nighttime accidents.

Effect of Ramp Traffic Volumes

Table 9 shows ramp accident rates for various ramp volume groups. The data shown in the table were taken from group B ramps.

Figure 21 was obtained by plotting the accident rate as the ordinate and the volume as the abscissa. The MV used to calculate each coordinate is printed next to the coordinate it represents. Figure 21 shows a decrease in accident rate with increasing

TABLE 9

RAMP ACCIDENT RATES (ACC/MV) VS RAMP VOLUMES—GROUP B RAMPS

ADT[1] Groups	ON					OFF					TOTALS				
	No. of Ramps	Acc	M V	Rate	Avg. ADT	No. of Ramps	Acc	M V	Rate	Avg ADT	No. of Ramps	Acc	M V.	Rate	Avg. ADT
0 – 1,000	54	35	26.2	1.34	518	54	60	30.0	2.00	594	108	95	56.2	1.69	557
1,001 – 2,000	63	62	94.2	0.66	1,530	49	94	71.7	1.31	1,496	112	156	165.9	0.94	1,516
2,001 – 3,000	38	58	93.1	0.62	2,440	39	123	91.7	1.34	2,379	77	181	184.8	0.98	2,407
3,001 – 4,000	29	85	95.3	0.89	3,442	34	90	116.4	0.77	3,485	63	175	211.7	0.83	3,456
4,001 – 5,000	10	50	45.8	1.09	4,488	13	46	62.8	0.73	4,407	23	96	108.6	0.88	4,442
5,001 – 6,000	15	49	89.8	0.55	5,520	17	40	96.5	0.41	5,417	32	89	186.3	0.48	5,465
6,001 – 7,000	7	21	48.6	0.43	6,677	8	47	54.1	0.87	6,478	15	68	102.7	0.66	6,571
7,001 – 8,000	3	10	21.5	0.47	7,356	7	50	52.6	0.95	7,563	10	60	74.1	0.81	7,501
8,001 – 9,000	7	31	61.8	0.50	8,464	3	10	27.8	0.36	8,497	10	41	89.6	0.46	8,474
9,001 – 10,000	2	9	20.5	0.44	9,350	1	6	10.9	0.55	9,933	3	15	31.4	0.48	9,543
10,001 – 11,000	1	1	11.0	0.09	10,053	1	10	11.1	0.90	10,150	2	11	22.1	0.50	10,102
11,001 – 12,000	1	1	12.6	0.08	11,560	1	8	12.7	0.63	11,566	2	9	25.3	0.36	11,563
Over 12,000	2	13	44.2	0.29	20,000	2	53	40.3	1.32	18,412	4	66	84.5	0.78	19,203
TOTALS	232	425	664.6	0.64	2,811	229	637	678.6	0.94	2,903	461	1,062	1,343.2	0.79	2,857

(1) Average daily traffic

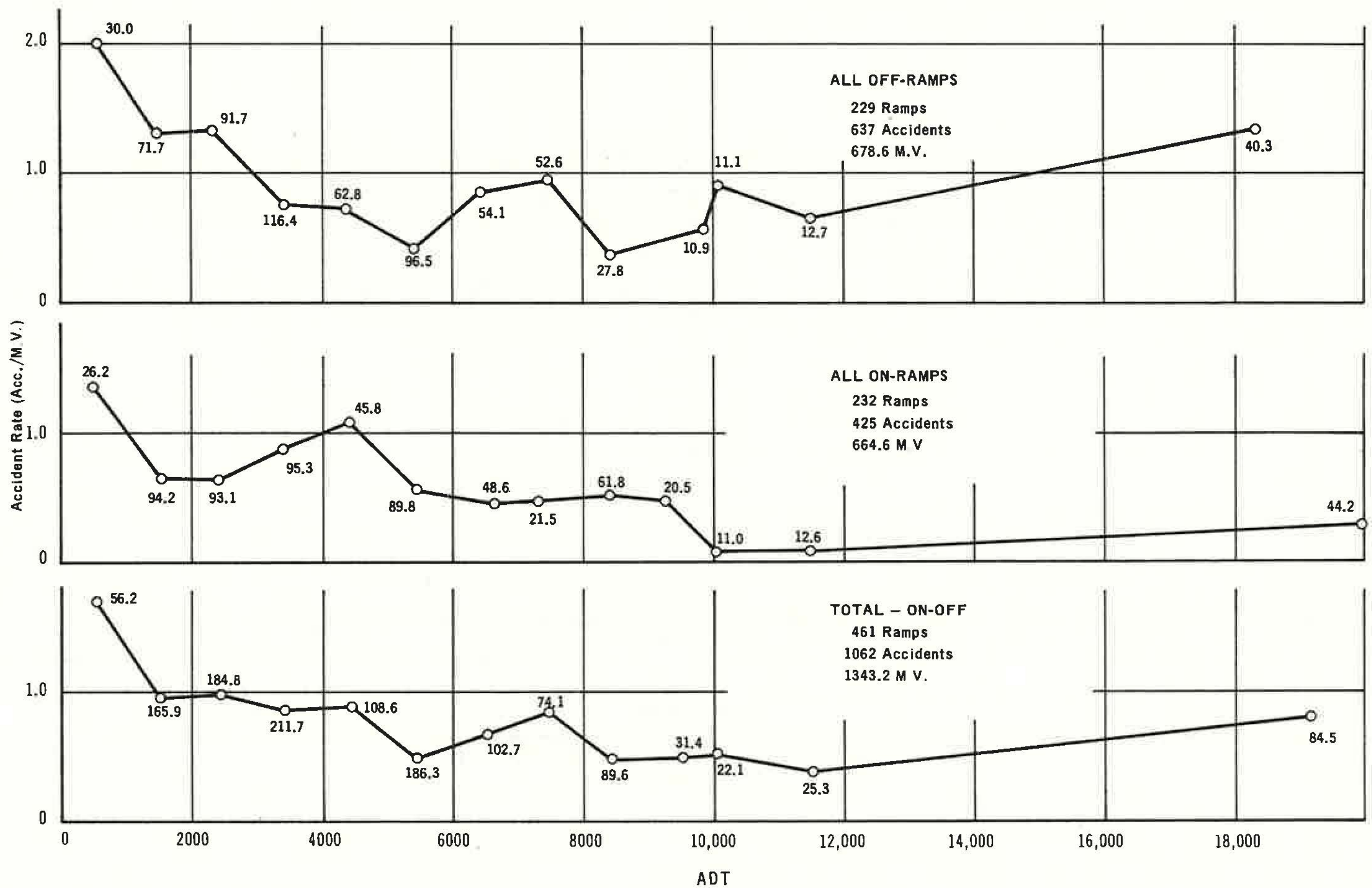


Figure 21. Accident rate vs average daily traffic.

TABLE 10

RAMP ACCIDENT RATES (ACC/MV) BY RAMP TYPE

	Overcrossing [b]								Undercrossing [b]								Sub-Total											
	On				Off				On				Off				On				Off				Total			
Type of Ramp	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate	No. Ramps	No. Acc.	M V	Rate
Diamond Ramps	53	44	124.9	0.35	45	67	99.4	0.67	32	44	95.4	0.46	44	73	109.8	0.66	85	88	220.3	0.40	89	140	209.2	0.67	174	228	429.5	0.53
Trumpet Ramps	9	22	28.7	0.77	7	21	24.6	0.85	2	5	3.5	1.43	0	–	–	–	11	27	32.2	0.84	7	21	24.6	0.85	18	48	56.8	0.85
Cloverleaf Ramps without Collector Distributor	48	83	111.2	0.75	59	135	155.8	0.87	27	72	105.4	0.68	19	86	76.0	1.13	75	155	216.6	0.72	78	221	231.8	0.95	153	376	448.4	0.84
Cloverleaf Ramps with Collector Distributor	15	37	73.3	0.50	16	56	82.0	0.68	5	2	14.3	0.14	5	3	13.0	0.23	20	39	87.6	0.45	21	59	95.0	0.62	41	98 [a] 13 111	182.6	0.61
Loops without Collector Distributor	46	64	84.2	0.76	34	59	70.7	0.83	17	44	53.7	0.82	19	47	50.0	0.94	63	108	137.9	0.78	53	106	120.7	0.88	116	214	258.6	0.83
Cloverleaf Loops with Collector Distributor	9	14	36.3	0.39	10	19	36.5	0.52	5	3	8.0	0.38	5	1	13.2	0.08	14	17	44.3	0.38	15	20	49.7	0.40	29	37 [a] 28 65	94.0	0.69
Left Side Ramps	5	14	18.9	0.74	11	81	46.4	1.74	2	11	8.0	1.38	4	124	47.0	2.64	7	25	26.9	0.93	15	205	93.4	2.19	22	230	120.3	1.91
Direct Connections	14	55	101.2	0.54	11	53	61.5	0.86	2	10	28.6	0.35	2	30	29.9	1.00	16	65	129.6	0.50	13	83	91.4	0.91	29	148	221.2	0.67
Buttonhook Ramps																	62	77	120.8	0.64	67	111	115.1	0.96	129	188	235.9	0.80
Scissor Ramps																	3	8	9.7	0.88	8	27	18.3	1.48	11	35	27.4	1.28
TOTALS	264	418	708.6	0.59	268	629	710.3	0.89	92	191	316.9	0.60	98	364	338.9	1.07	356	609	1025.5	0.59	366	993	1049.2	0.95	722	1643	2074.7	0.79

[a] Accidents occurring on collector Distributor Roads

[b] If the crossroad crosses under the freeway (main line), the ramps are associated with an undercrossing. If the crossroad crosses over the freeway (main line), the ramps are associated with an overcrossing.

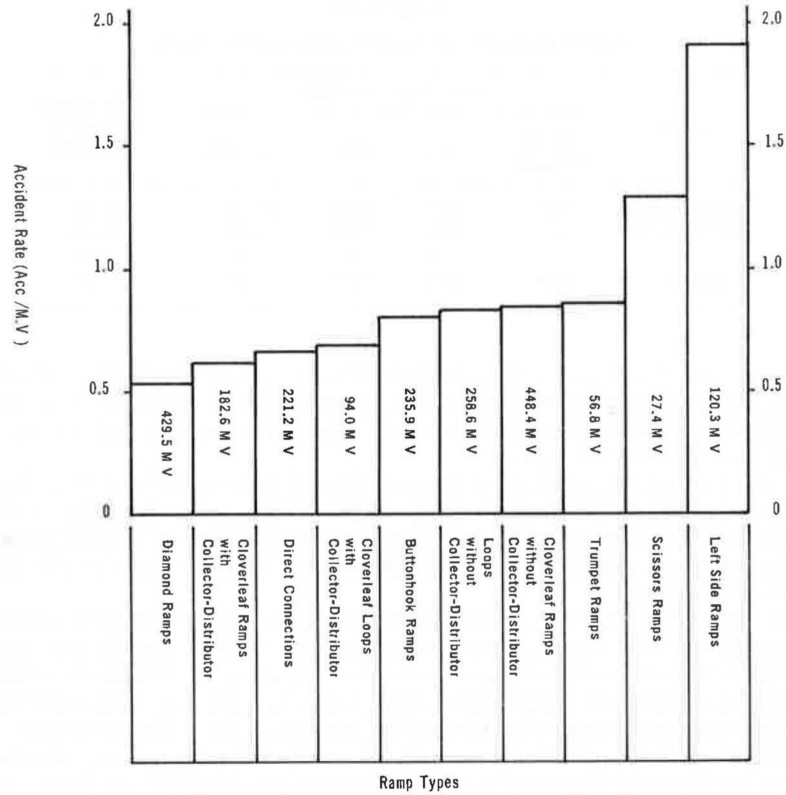


Figure 22. Accident rates by ramp types (total of on and off).

ramp volumes. However, it is felt that this decrease is not entirely attributable to the volume as such because the ramps that carry high volumes were designed to carry these volumes and, therefore, generally have better design standards than the low volume designs. An attempt was made to correlate accident rate and traffic volumes for each of the 10 ramp types, but the experience (MV) for each average daily traffic (ADT) group was too small. This attempt ended in extreme rate fluctuations and a trend was not observed.

EFFECT OF GEOMETRIC FACTORS

Ramp Type

The accident rates calculated for the 10 basic types of ramps are listed in Table 10. The diamond ramps have the lowest over-all rate (0.53 Acc/MV). The direct connections and the cloverleaf ramps and loops with collector-distributor roads have rates between 0.6 and 0.7 Acc/MV. The buttonhook, trumpet and cloverleaf ramps without collector-distributor roads and the loops without collector-distributor roads have rates between 0.8 and 0.9 Acc/MV. The scissors and left side ramps have the highest rates (1.28 and 1.91, respectively). Figure 22 is a bar graph illustrating the over-all rates for each ramp type.

The accident rate calculated for the scissors type ramps is probably not as accurate as the rates calculated for the other ramp types because (a) the sample is small in comparison with the other types, and (b) it is difficult to determine the actual number of accidents that occurred. The scissors type ramp is normally crossed by a facility that is not maintained by the California Division of Highways. The reports of the

TABLE 11

COMPARISON OF RAMP ACCIDENT DATA

Type	Los Angeles Data				This Study
	No. of Ramps	Acc	MV	Acc/MV	Acc/MV
On-ramps	140	147	272	0.54	0.59
Off-ramps	134	252	244	1.03	0.95
Total	274	399	516	0.77	0.79

accidents that occurred at these crossings were not always available. An attempt was made to obtain accidents reports from other agencies but it is difficult to determine the completeness or reliability of the records. In any case, the calculated rates shown are probably low rather than high.

On scissors ramps, the primary concentration of accidents occurs at the scissor or cross-over (ramp with local road) facility. From reading the reports, it was apparent that the collisions usually involve faulty judgment on the part of the frontage road drivers as to the ramp vehicle's speed of approach. This is true for both the on-ramp and off-ramp situation.

The ramp type accident rates shown in this section and in Table 10 are average rates for the ramps only. The rates or relative magnitude of the rates do not necessarily reflect the relative safety of various interchange types; e.g., the diamond ramp has a lower rate than the cloverleaf ramp and loop, but this does not mean that diamond interchanges are necessarily safer than cloverleaf interchanges. The reason is that this ramp study shows the rates for ramp accidents only and does not include the crossroad accidents and the freeway mainline accidents within the interchange area. It is quite possible, for instance, that there may be a greater number of accidents on the crossroad with diamond interchanges (due to left-turning vehicles), than with cloverleaf interchanges, and that this difference in accidents on the crossroad is greater than the increase in accidents on the cloverleaf ramps and loops.

On-Ramps vs Off-Ramps

Table 10 also has an on-ramp vs off-ramp breakdown. The on-ramps as a group have an accident rate of 0.59 Acc/MV, which is 38 percent lower than the off-ramp group (0.95 Acc/MV). These rates are similar to those obtained in another study by the Los Angeles District of the California Division of Highways in 1962, using 1961 data for the following freeways in the Los Angeles area:

1. LA-11-Harbor Freeway (Milepost 1.7 to 23.7)—the 22-mile portion between the beginning of the freeway in Wilmington and the 4-level structure.
2. LA-110, 10-San Bernardino Freeway (Milepost 0.0 to 0.7 on Route 110; Milepost 18.4 to 26.8 on Route 10)—the 9.1-mile portion between the Santa Ana Freeway and Rosemead Boulevard.
3. La-101-Hollywood Freeway (Milepost 1.6 to 11.4)—the 9.8-mile portion between the 4-level structure and the Ventura Freeway.
4. LA-101-Ventura Freeway (Milepost 11.4 to 21.7)—the 10.3-mile portion between the Hollywood Freeway and the Wilbur Avenue undercrossing.

The data are summarized in Table 11. It is interesting to note that the on-ramp rates are consistently lower than the off-ramp rates even when the ramps are split by type. The trumpet ramps are an exception with both the on- and off-ramp rates approximately 0.85 Acc/MV.

Figure 23 shows the accident rates by ramp type for both on- and off-ramps. Both the scissors and left side ramps have a large difference in on-ramp vs off-ramp rates. The ramps and loops with collector-distributor roads are not shown in this figure

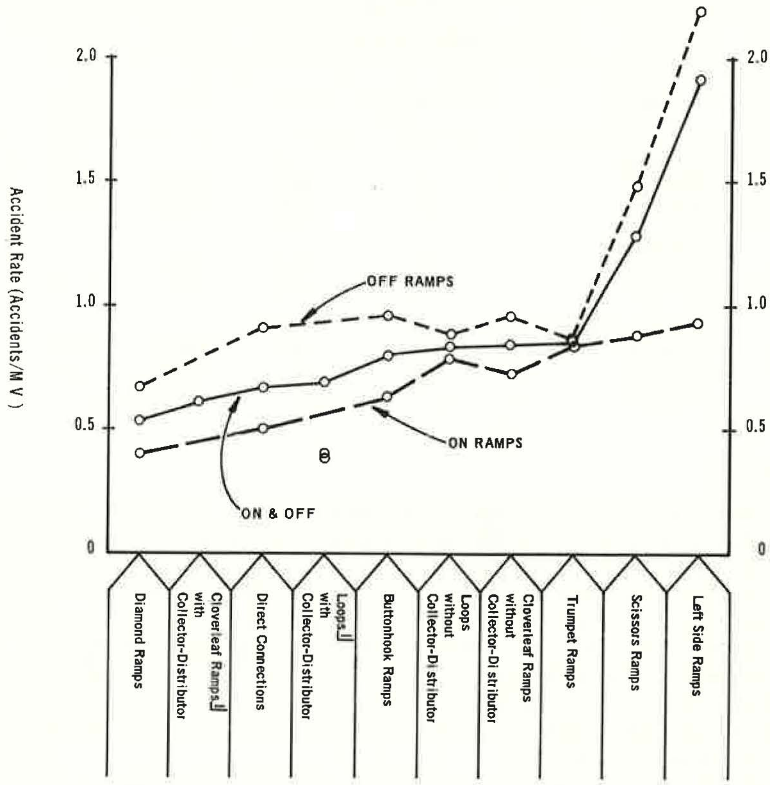


Figure 23. Accident rates by ramp type. (On-off split not shown because collector road accidents cannot be charged to either.)

because the accidents that occurred on the collector-distributor roads cannot be charged to the total or combination of the two.

Overcrossing vs Undercrossing

If a ramp grade approaches the main line from some level above the main line, the ramp is associated with an overcrossing. With this arrangement, an on-ramp vehicle will be on a downhill grade relative to the main line when using an overcrossing facility. The off-ramp vehicle will be on an uphill grade relative to the main line.

If the ramp grade approaches the main line from some level below the main line, the ramp is associated with an undercrossing. The undercrossing situation places the on-ramp vehicle on a relative upgrade and the off-ramp vehicle on a relative downgrade.

Table 10 has an undercrossing vs overcrossing breakdown. Overall, the on-ramps seem to have the same rates for both the downgrade (0.59 Acc/MV) and upgrade (0.60 Acc/MV) situations. The uphill off-ramps have a combined rate of 0.89 Acc/MV compared to a rate of 1.07 Acc/MV for the downhill ramps. The difference in off-ramp rates may be due to the gravity aid in deceleration in the case of the uphill off-ramps. Gravity, of course, hinders deceleration when the grade is downhill. It is true, however, that many of these ramps are on a true flat grade and the main line has a downhill grade. At attempt was made to sort those ramps with a true uphill or downhill grade. However, only a few actually possessed level grades and the rates were approximately the same.

TABLE 12

RAMP CURVATURE

Ramp	No. of Ramps	Acc	MV	Acc Rate
On-ramps				
Straight	180	282	524.5	0.54
Curved	150	229	335.2	0.68
Off-ramps				
Straight	188	420	536.0	0.78
Curved	142	258	310.1	0.81
Total on and off				
Straight	368	702	1060.5	0.66
Curved	292	487	645.3	0.75

Ramp Curvature

Table 12 was compiled by grouping the ramp types in Table 10. The diamond and cloverleaf (with or without collector-distributor[1]) ramps were considered basically straight. The loops (with or without collector-distributor[1]) along with the trumpet and buttonhook ramps were taken as basically curved. The scissors and left side ramps along with the direct connections were omitted from the tabulation because they are not basically straight or curved. It should be noted that the table represents a mere generalization since the standards for straight or curved are not rigidly set and there is some deviation within the ramp types. The generalization made in classifying ramp curvature by ramp type undoubtedly has caused a decrease in the difference in rates for the curved vs straight ramps.

The results of this tabulation show that the straight ramps have a 12 percent lower overall (on and off) accident rate than the curved ramps. The straight off-ramps have only a 4 percent lower rate than the curved off-ramps.

It might be suspected that the difference in the on-ramp and off-ramp rates would be due to the difficulty in negotiating the off-ramp turns. Table 12 does not bear this out, but other investigations (discussed later) show slight trends in this direction.

Location of Ramp Accidents

The accident data available for the group A[2] ramps were such that a breakdown by merging area was possible. A merging area is defined as the area between the ramp gore nose and the end of the speed change lane taper. The ramp area is behind the gore nose and on the ramp itself.

Table 13 is a percentage breakdown of accidents occurring in the merging area and in the ramp area. The point of impact determined the area in which the accident was assigned. Undoubtedly some of the accidents assigned to the ramp area were actually caused by some disturbance in the merging or diverging area. An example would be an accident caused by a vehicle running into the rear of another vehicle, which was stopped because of freeway congestion. If an accident occurred in the merging area but was not caused by a merging movement, it was excluded from the study.

Table 13 shows an on-ramp accident split of about 52 percent merge and 48 percent ramp. The off-ramp split is about 44 percent diverge and 56 percent ramp.

Table 14 is the result of splitting the accident rates from Table 10 according to the percentage in Table 13. The loops with collector-distributor roads and the scissors ramps are missing because the group A ramps did not contain ramps of this type. The trumpet, left side and cloverleaf ramps without collector-distributor samples are also

[1]The accidents that occurred on the collector road were omitted in this tabulation.

[2]The sections listed in the Appendix are designated either A or B. The form in which the accident data were available allowed a precise accident location for the A section ramps.

TABLE 13

MERGING AND DIVERGING ACCIDENTS VS RAMP ACCIDENTS—GROUP A RAMPS

	Number of Accidents									% of Total Accidents					
	ON			OFF			TOTAL			ON		OFF		TOTAL	
Type of Ramp	Merge	Ramp	Total	Diverge	Ramp	Total	Merge & Diverge	Ramp	Total	Merge	Ramp	Diverge	Ramp	Merge & Diverge	Ramp
Diamond Ramps	17	18	35	22	33	55	39	51	90	48.6%	51.4%	40.0%	60.0%	43.3%	56.7%
Trumpet Ramps	2	0	2	4	2	6	6	2	8	100%	—	66.7%	33.3%	75.0%	25.0%
Cloverleaf Ramps without Collector Distributor	26	14	40	15	36	51	41	50	91	65.0%	35.0%	29.4%	70.6%	45.1%	54.9%
Cloverleaf Ramps with Collector Distributor	2	4	6	9	5	14	11	9	20	33.3%	66.7%	64.3%	35.7%	55.0%	45.0%
Loops without Collector Distributor	13	17	30	4	12	16	17	29	46	43.3%	56.7%	25.0%	75.0%	37.0%	63.0%
Loops with [1] Collector Distributor	—	NA	—	—	NA	—	—	NA	—	—	NA	—	NA	—	NA
Left Side Ramps	2	9	11	81	50	131	83	59	142	18.2%	81.8%	61.8%	38.2%	58.5%	41.5%
Direct Connections	16	11	27	14	21	35	30	32	62	59.3%	40.7%	40.0%	60.0%	48.4%	51.6%
Buttonhook Ramps	18	15	33	8	40	48	26	55	81	54.5%	45.5%	16.7%	83.3%	32.1%	67.9%
Scissors Ramps [1]	—	NA	—	—	NA	—	—	NA	—	—	NA	—	NA	—	NA
Total Ramps	96	88	184	157	199	356	253	287	540	52.2%	47.8%	44.1%	55.9%	46.9%	53.1%

[1] The loops with collector-distributor roads and the scissors ramps are missing because the "Group A" ramps did not contain ramps of this type.

TABLE 14

ACCIDENT RATES: MERGING VS RAMP

	ON RAMPS					OFF RAMPS					TOTAL ON+OFF				
	% Split (1)		Acc. Rates			% Split (1)		Acc. Rates			% Split (1)		Acc. Rates		
	Merge	Ramp	Total (2)	Merge	Ramp	Merge	Ramp	Total (2)	Merge	Ramp	Merge	Ramp	Total (2)	Merge	Ramp
Diamond Ramps	49	51	0.40	0.20	0.20	40	60	0.67	0.27	0.40	43	57	0.53	0.23	0.30
Trumpet Ramps	100 (3)	0	0.84	0.84	0.00	67 (3)	33	0.85	0.57	0.28	75	25	0.85	0.64	0.21
Cloverleaf Ramps without Collector Distributor	65	35	0.72	0.47	0.25	29	71	0.95	0.28	0.67	45	55	0.84	0.38	0.46
Cloverleaf Ramps with Collector Distributor	33 (3)	67	0.45	0.15	0.30	64 (3)	36	0.62	0.40	0.22	55	45	0.61	0.34	0.27
Loops without Collector Distributor	43	57	0.78	0.34	0.44	25 (3)	75	0.88	0.22	0.66	37	63	0.83	0.31	0.52
Loops with Collector Distributor	N.A.	←												→	N.A.
Left Side Ramps	18 (3)	82	0.93	0.17	0.76	62	38	2.19	1.36	0.83	58	42	1.91	1.11	0.80
Direct Connections	59	41	0.50	0.30	0.20	40	60	0.91	0.36	0.55	48	52	0.67	0.32	0.35
Buttonhook Ramps	54	46	0.64	0.35	0.29	17	83	0.96	0.16	0.80	32	68	0.80	0.26	0.54
Scissors Ramps	N.A.	←												→	N.A.
Total Ramps	52	48	0.60	0.31	0.29	44	56	0.86	0.38	0.48	47	53	0.78	0.37	0.41

(1) From Table 2; (2) From Table 3; (3) Calculated from very weak sample

TABLE 15

STANDARDS FOR LENGTH OF SPEED CHANGE LANES—SUPERSEDED PRACTICE

		HIGHWAY DESIGN SPEED (V) M.P.H.		
		40	50	60
Average Speed of Travel (0.7V)		28	35	42
		TAPER-FEET		
DECELERATION		120	150	180
ACCELERATION		180	240	270
Turning Speed	Minimum Curve Radius	DECELERATION LANE-FEET - Including Taper -		
20	100	140	230	300
30	200	120	150	240
40	400	120	150	180
50	600		150	180
		ACCELERATION LANE-FEET - Including Taper -		
20	100	180	410	750
30	200	180	240	510
40	400	180	240	270
50	600		240	270

very small. The results are in accordance with the analysis of single vs multiple vehicle; i.e., the primary difference in on-ramp and off-ramp accident rates lies in the increase in the accidents on the off-ramp proper.

Table 14 also shows that although the left side off-ramps experience most of their trouble in the diverge area, even the ramp proper possesses a higher rate than any other type ramp. (The on-ramp sample is too small to be reliable.) The buttonhook off-ramp seems to have an extremely good diverging rate and the ramp proper is responsible for the majority of the accidents. This is not true in the case of the buttonhook on-ramps where the merge area has a higher rate than the ramp.

Acceleration Lane Length

Acceleration lane length is measured from the on-ramp gore nose to the point where the acceleration lane taper is 3 ft wide (Figs. 2, 24, 25). Present California practice provides for over 900 ft of acceleration lane and this appears to be quite adequate.

The acceleration and deceleration lengths of most ramps included in this study were based on the old AASHO standard, which based these lengths on distances required to accomplish the speed change between 70 percent of the freeway design speed, and the maximum safe speed of the ramp curve at the ramp nose (Table 15 and Fig. 24). California standards have since been made considerably more generous (Fig. 25). The old practice provided variable acceleration lengths, whereas the present practice provides a single standard length. Table 15 does, however, represent minimum standards, and actual lengths frequently exceeded the 750 ft shown in the table.

Table 16 and Figures 26 and 27 illustrate the results of an investigation involving the group B on-ramps plus 13 other on-ramps located near Ontario on the San Bernardino Freeway. During the study period, the 13 ramps had extremely short acceleration lanes and extremely high accident rates. The ramps are basically of the diamond type and the entrance speeds (speed at the gore nose when entering the freeway) are approximately 40 mph. The 13 on-ramps experienced a rate of 3.32 Acc/MV during the

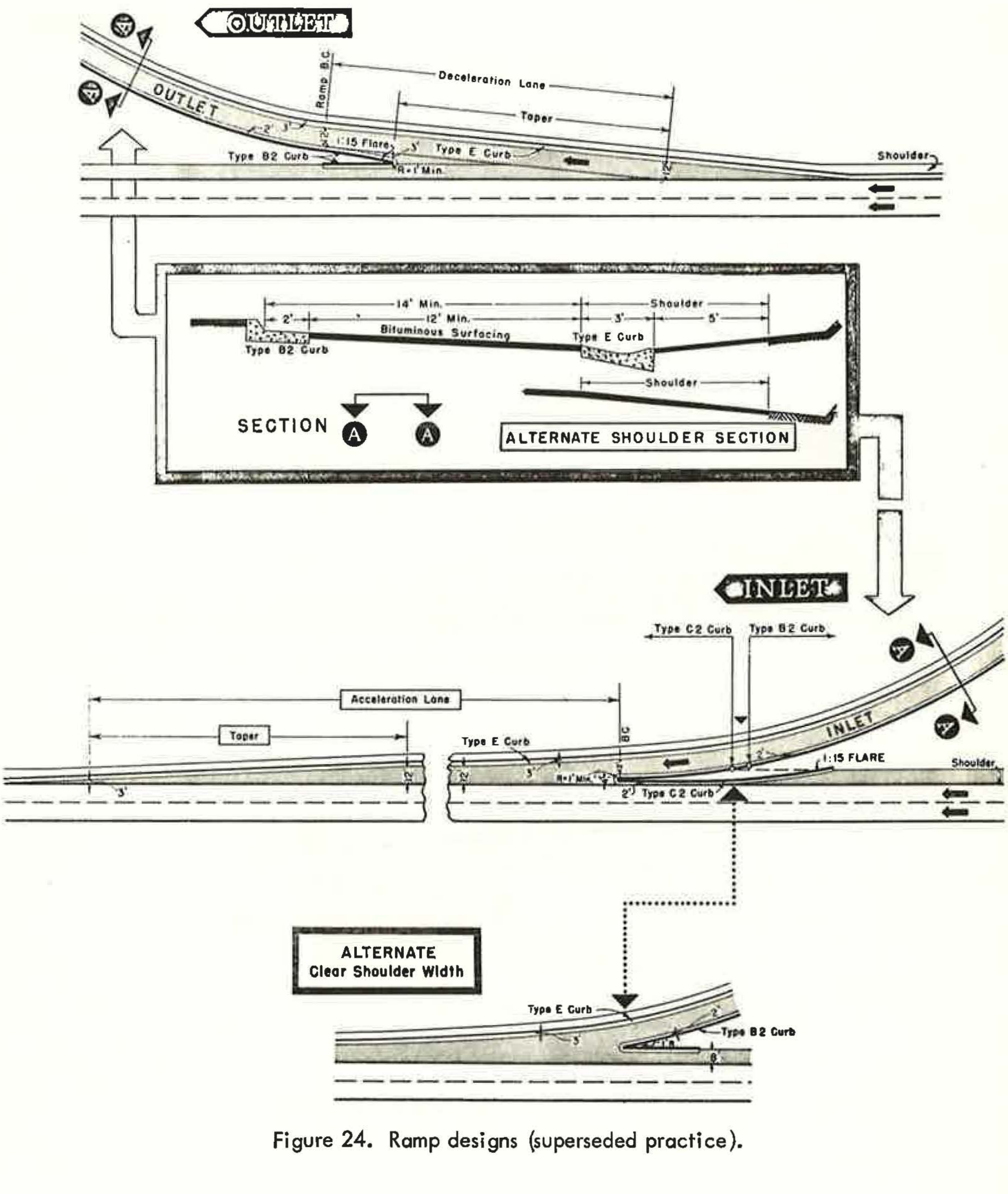
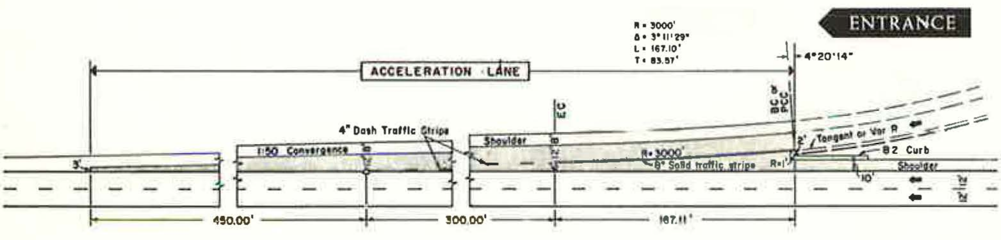


Figure 24. Ramp designs (superseded practice).



EXIT

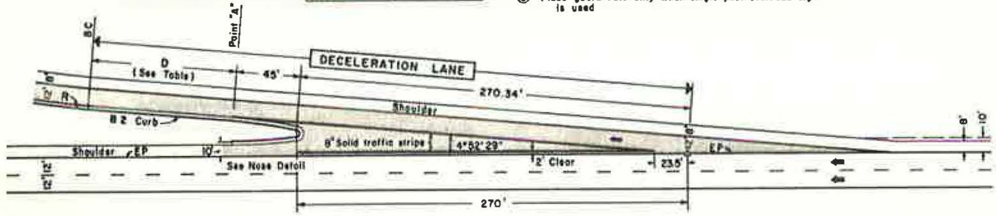
R (feet)	Min D (feet)
Less than 300	250
300 – 500	150
500 – 1000	100
1000 or more	0

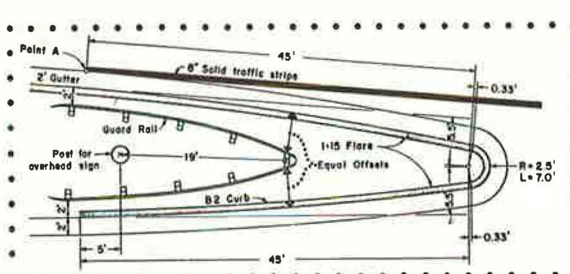
Notes

① Minimum length between Point A and end of ramp is 400' for full stop at end of ramp

② D Distance may be eliminated where weaving condition precedes exit (See Index No. 7-505.7)

③ Place guard rail only when single-post overhead sign is used





NOSE DETAILS

Figure 25. Ramp designs (present practice).

TABLE 16

RAMP ACCIDENT RATE VS RAMP ACCELERATION LANE LENGTH

Speed @ Nose →	0 to 25 MPH					30 to 35 MPH					40 to 50 MPH					TOTALS				
Acceleration Length ↓	NO. RAMPS	ACC	M V	RATE	AVG ACCEL. LENGTH	NO. RAMPS	ACC	M V	RATE	AVG ACCEL LENGTH	NO RAMPS	ACC	M V.	RATE	AVG ACCEL LENGTH	NO. RAMPS	ACC	M V	RATE	AVG ACCEL LENGTH
0 - 100 ft.																				
101 - 200	4	5	9.3	0.54	190						5	24	8.0	3.00	184	9	29	17.3	1.68	187
201 - 300	5	13	8.6	1.51	258						17	73	37.3	1.96	269	22	86	45.9	1.87	267
301 - 400	4	14	12.3	1.14	385	3	7	4.5	1.56	363	8	29	21.2	1.37	367	15	50	38.0	1.32	371
401 - 500	6	6	14.7	0.41	460	3	13	10.7	1.21	480	8	28	21.1	1.33	456	17	47	46.5	1.01	462
501 - 600	9	24	24.1	1.00	570	22	26	43.5	0.60	548	27	41	74.0	0.55	568	58	91	141.6	0.64	561
601 - 700	9	13	15.1	0.86	671	9	26	32.0	0.81	662	18	28	73.8	0.38	658	36	67	120.9	0.55	662
701 - 800	12	19	21.1	0.90	743	5	20	12.2	1.64	736	12	29	39.7	0.73	740	29	68	73.0	0.93	740
801 - 900	2	1	2.2	0.45	875	3	5	9.4	0.53	867	10	4	6.4	0.63	875	15	10	18.0	0.56	873
901 - 1000	4	0	1.9	0	973	2	3	4.7	0.64	955	3	1	11.8	0.08	930	9	4	18.4	0.22	954
1001 - 1100	2	1	1.0	0.83	1040						2	10	28.6	0.38	1060	4	11	29.6	0.37	1050
1101 - 1200						2	5	13.9	0.36	1200	1	1	2.0	0.50	1200	3	6	15.9	0.38	1200
1201 - 1300	2	1	3.0	0.33	1280						2	1	3.0	0.33	1280	2	1	3.0	0.33	1280
1301 - 1400											1	0	3.6	0	1400	1	0	3.6	0	1400
1401 - 1500																				
1501 - 1600																				
1601 - 1700											1	2	5.7	0.35	1660	1	2	5.7	0.35	1660
1701 - 1800											1	3	5.3	0.57	1800	1	3	5.3	0.57	1800
1801 - 1900						1	1	2.1	0.48	1900	1	0	0.5	0	1840	2	1	2.6	0.39	1870
1901 - 2000											4	3	16.0	0.19	1938	4	3	16.0	0.19	1938
2001 - 2100											1	3	4.4	0.68	2080	1	3	4.4	0.68	2080
2101 - 2200											2	1	4.9	0.20	2130	2	1	4.9	0.20	2130
2400											1	6	6.4	0.94	2400	1	6	6.4	0.94	2400
2520											1	2	5.5	0.36	2520	1	2	5.5	0.36	2520
Full Lanes	1	1	0.7	1.43	FULL LANE	1	1	0.7	1.43	FULL LANE	10	25	68.7	0.36	FULL LANE	12	27	70.1	0.39	FULL LANE
TOTALS	60	98	114.0	0.86		51	107	133.7	0.80		134	313	444.9	0.70		245	518	692.6	0.75	

1959-1961 period. These ramps have, therefore, been omitted in the main body of this study because the accident rates due to the short acceleration lengths would bias the sample of diamond ramps. They were included in this portion of the study because the acceleration lane length is the variable being examined.

The safe entering speed was first determined for each on-ramp by driving the ramp several times and observing the entering speed. Three speed groups were used: (a) 0-25 mph at the nose; (b) 30-35 mph at the nose; and (c) 40-50 mph at the nose.

Table 16 is a tabulation of the ramp data by speed group. It arrays the ramps in order of increasing acceleration lane lengths. The average rate shown in the table (0.75) is higher than shown in Table 10 because the 13 extra ramps (with short acceleration lanes) have high rates.

Figures 26 and 27 show the accident rate vs acceleration lane length curves. The curves are free-hand fits in which an attempt was made to give more weight to the large MV values and less weight to the small MV values.

The average on-ramp rate (0.59 Acc/MV) from Table 10 was plotted to show that:

1. Below average accident rates can be expected on ramps with acceleration lanes greater than 750-800 ft.

2. If the acceleration lane is less than 750-800 ft, the ramps with the high entrance speeds can be expected to have higher accident rates than those with low entrance speeds.

Off-Ramp Geometry

Off-ramps have higher accident rates than on-ramps, and the higher rate is primarily due to accidents which occur on the ramp proper rather than in the diverging area. Figure 28 is the result of an attempt to relate various off-ramp characteristics to the off-ramp accident rate. The figure shows that straight ramps (zero central angle and infinite radius) have the lowest rates. Those ramps with long (900 ft or more)

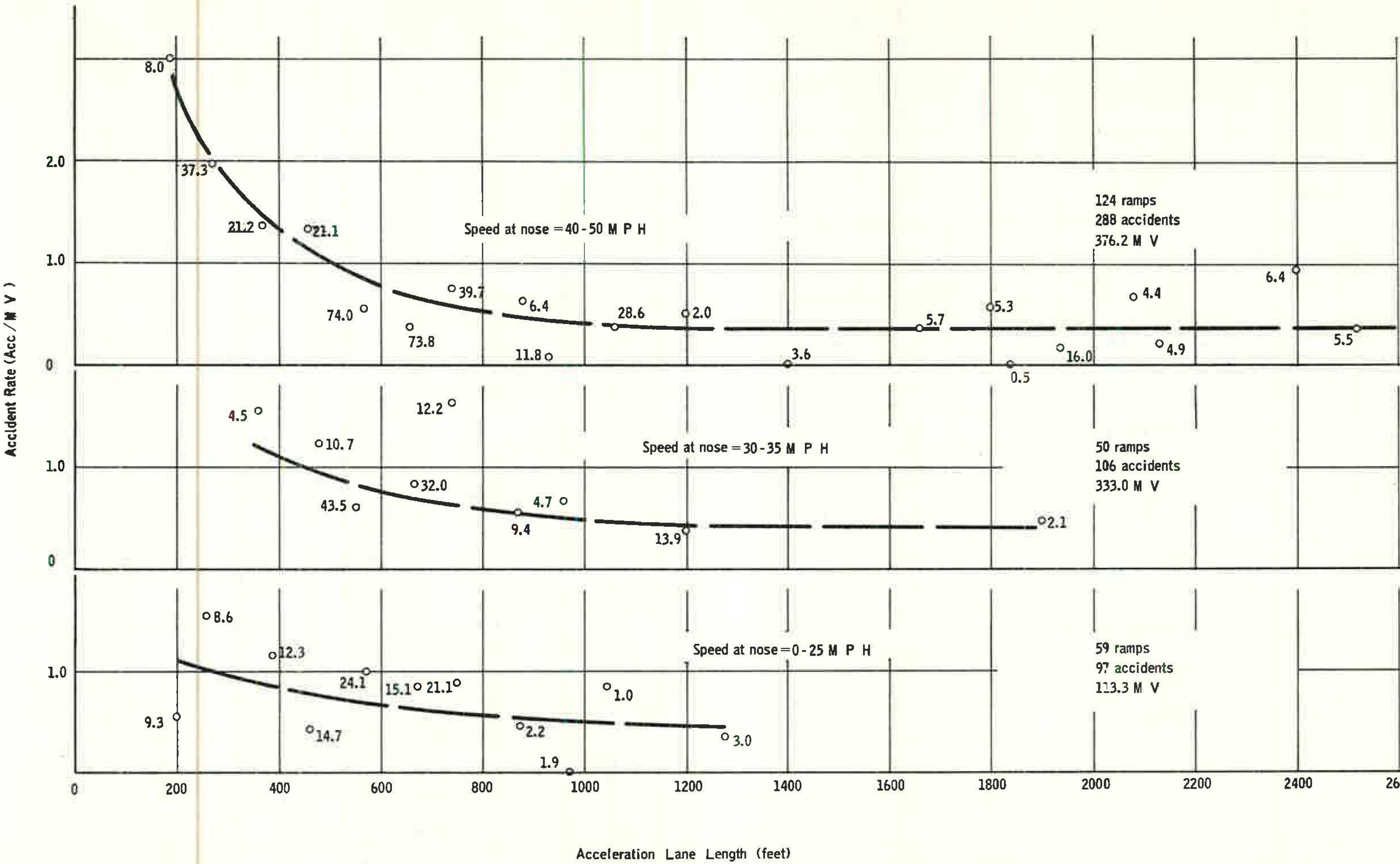


Figure 26. On-ramps: accident rate vs acceleration lane length.

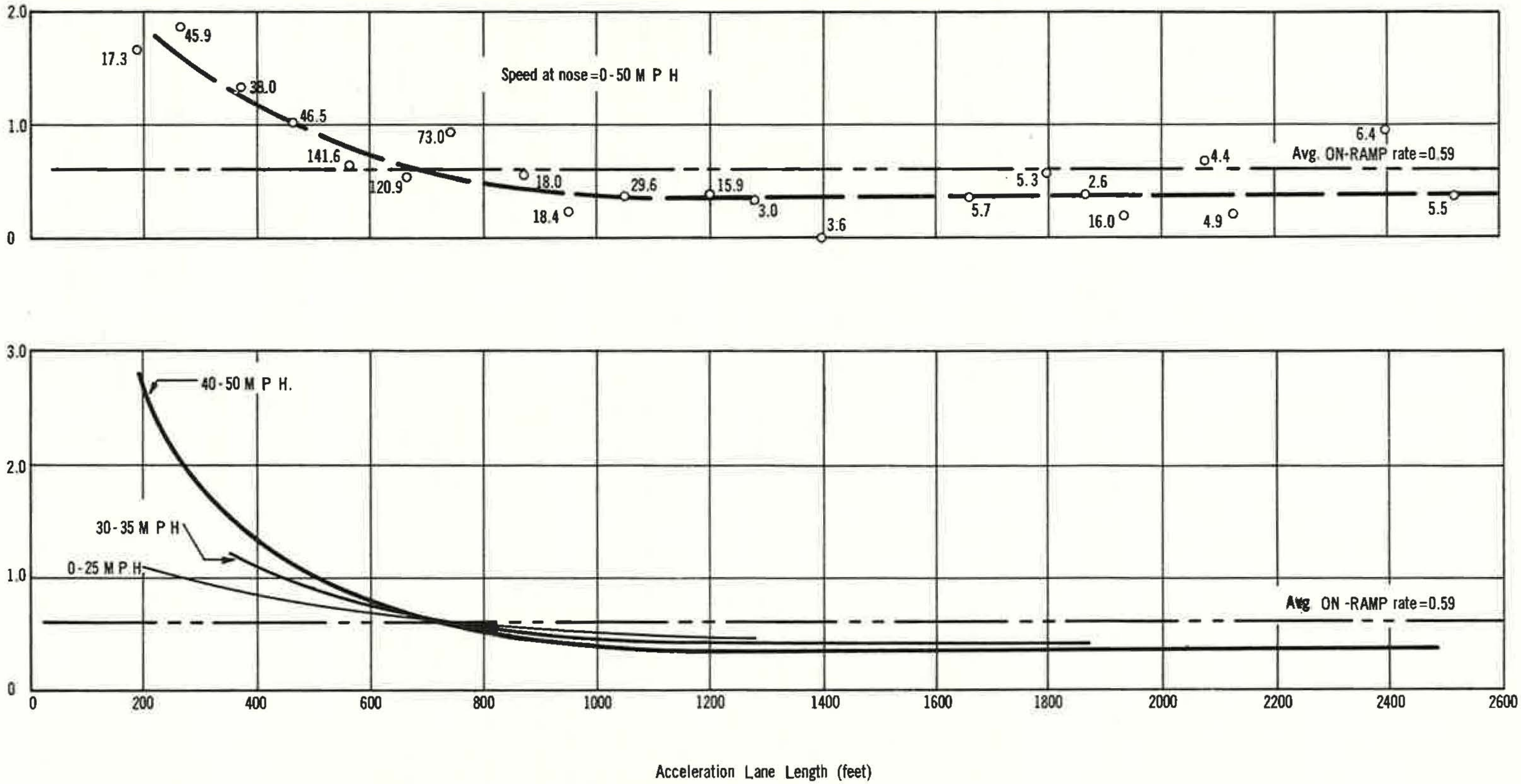


Figure 27. On-ramps: accident rate vs acceleration lane length (233 ramps, 491 accidents, 622.5 MV).

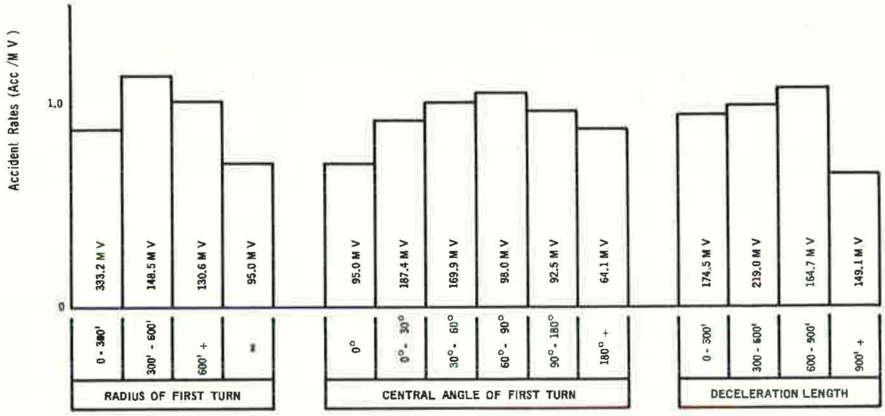


Figure 28. Off-ramps: accident rates for group B ramps as grouped by first curve radius, first curve central angle, and deceleration lane length.

deceleration lengths seem to have lower rates than those with shorter deceleration lengths. Table 15 and Figure 24 show the old deceleration lane standards and Figure 25 shows the new standards.

The distance used as the deceleration length was all the available tangent distance from where the deceleration off-ramp taper became 12 ft wide (Fig. 24) to the beginning of the first ramp curve. If no curve exists on the ramp, such as is the case with some diamond ramps, the distance was measured to the end of the ramp at the crossroad. In the case of cloverleaf loops, the distance between the on-ramp loop nose and the off-ramp loop nose was considered to be available for deceleration. If a collector-distributor road was available, the distance between the nose of the right turning off-ramp at the collector road to the off-ramp loop nose was considered to be available for deceleration.

The short radius, large central angle ramps seem to have lower rates than the ramps with medium range radii and central angles (Fig. 28). This is perhaps a case where the tight turns appear as an obvious hazard to the drivers and they take the necessary precautions, whereas the medium range curves do not appear dangerous and the driver does not compensate.

This analysis is based on a simple, one independent and one dependent variable technique. All of the off-ramps were arrayed in some sequence of an independent variable (radius, delta, etc.) and the bar graphs were constructed by calculating the dependent variable (accident rate) for predetermined groups of the independent variable. An attempt to unite combinations of independent variables produced extremely small samples and resulted in large accident rate fluctuations (Fig. 29). An analysis through the use of multiple regression techniques could prove beneficial in this area. However, larger and more detailed samples would be necessary to obtain reasonable accuracy from the program.

At this point we might, at best, say that the large radii, small central angles, and long deceleration lengths appear to provide the safest ramp designs.

SUMMARY

During a period of approximately 3 years, the 722 study ramps experienced 18 percent (1, 643) of the accidents occurring on the freeways which they served. During this period, the ramps carried over 2 billion vehicles.

Most of the ramps had very few accidents. In fact, of the 722 ramps studied, 232 (32 percent) of them were accident-free. No design differences were noted between the accident-free ramps and those ramps with accidents.

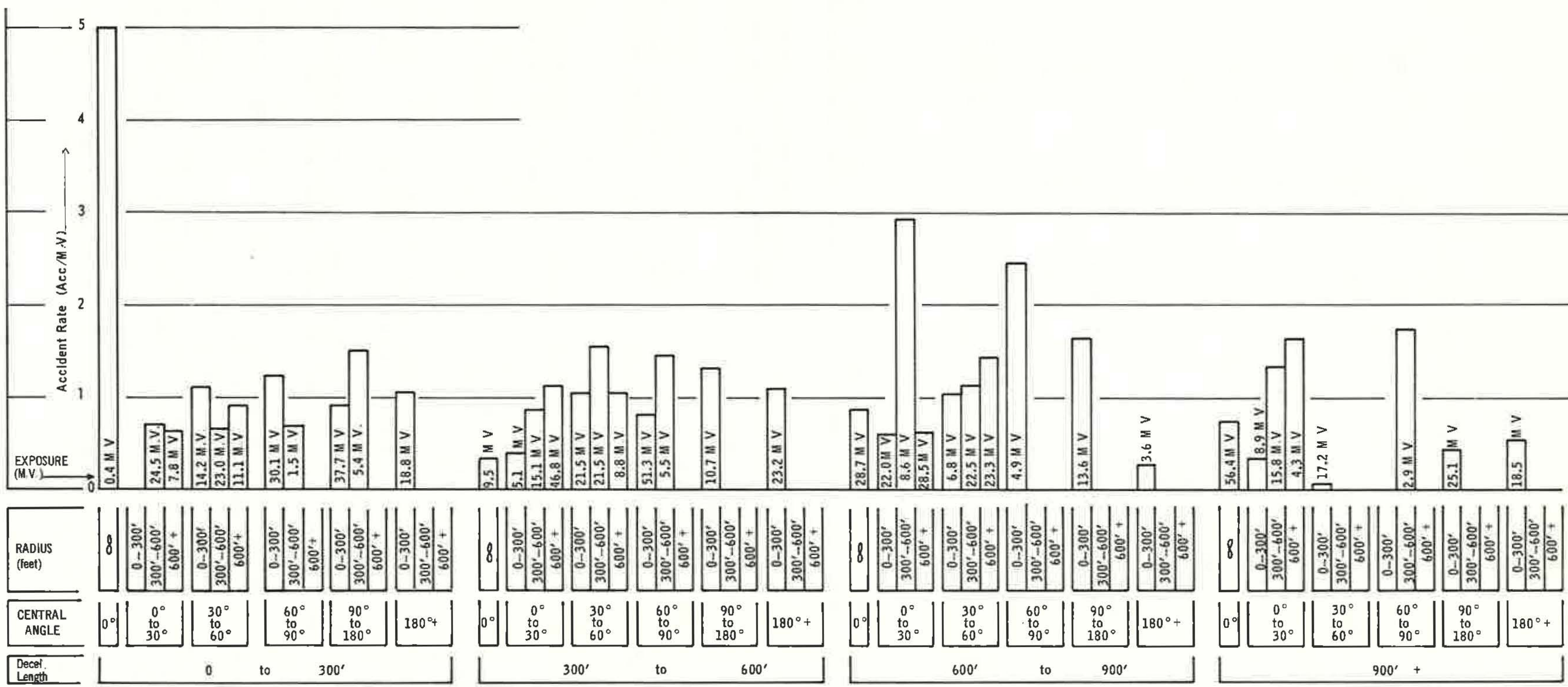


Figure 29. Off-ramps: accident rates for group B grouped by deceleration lane length, central angle and radius of the first curve.

TABLE 17

ACCIDENT RATES (ACC/MV)

Ramp Type	On	Off	On + Off
1. Diamond ramps	0.40	0.67	0.53
2. Trumpet ramps	0.84	0.85	0.85
3. Cloverleaf ramps without collector-distributor roads	0.72	0.95	0.84
4. Cloverleaf ramps with collector-distributor roads[a]	0.45	0.62	0.61[a]
5. Loops without collector-distributor roads	0.78	0.88	0.83
6. Cloverleaf loops with collector-distributor roads[a]	0.38	0.40	0.69[a]
7. Left side ramps	0.93	2.19	1.91
8. Direct connections	0.50	0.91	0.67
9. Buttonhook ramps	0.64	0.96	0.80
10. Scissors ramps	0.88	1.48	1.28
Average	0.59	0.95	0.79

[a]Only the On + Off rate includes the accidents occurring on the collector-distributor roads.

The ramp accident severity ratios are approximately the same as those associated with the freeway main line, i.e., 1.8 percent fatal, 42.9 percent injury and 55.3 percent property damage only.

Table 17 gives the average accident rates, as calculated for the ten basic ramp types.

Off-ramp rates are consistently higher than the on-ramp rates. The off-ramps have more single vehicle accidents, and these accidents produced the primary difference between the on-ramp and off-ramp accident rates.

These average accident rates are also subject to certain variations. If the ramps are associated with an overcrossing, they may be expected to have slightly lower rates, especially the off-ramps. If they are associated with an undercrossing, the rates may be slightly higher.

Accidents on ramps, especially off-ramps, have a greater proportion of single vehicle involvement than accidents on the freeway mainline. In fact, approximately half (51 percent) of the off-ramp accidents are single vehicle accidents (vs 38 percent of freeway mainline accidents). The primary factor in the difference in rates between on-ramps (0.59 Acc/MV) and off-ramps (0.95 Acc/MV) is the single vehicle accident rate (0.18 Acc/MV for on-ramps and 0.48 Acc/MV for off-ramps).

About 64 percent of all freeway fixed objects are located in the ramp areas. About 36 percent of these fixed objects occur adjacent to off-ramps and about 28 percent are adjacent to on-ramps. These fixed objects are involved in 42 percent of the off-ramp accidents and 22 percent of the on-ramp accidents.

Signs generally are placed in the most vulnerable locations (in the gore nose and on the outside edge of curves) in both the on- and off-ramp situations. Piers, abutments and bridge rails are more exposed to the off-ramp vehicle than to the on-ramp vehicle. Light standards have a low accident involvement, and this is probably because they are no longer placed on the outside portion of curves.

Nighttime accident rates are normally higher than daytime rates. However, the increase in nighttime rates for ramps (generally illuminated) was less than the increase on freeways (generally not illuminated). This would indicate that lighting is beneficial. It is difficult, however, to determine exactly how much of this decrease is attributable to the lighting.

An investigation of ramp average daily traffic as related to ramp accident rates showed a decrease in accident rate with an increase in daily traffic. However, it is felt that the decrease is not entirely attributable to the volume as such but rather to the better design standards of the high-volume ramps.

On the average, about 52 percent of the on-ramp accidents occur in the merging area (adjacent to the main line) and about 44 percent of the off-ramp accidents occur in the diverging area.

On the accident per million vehicle basis, it was found that the off-ramp diverging rates are only 23 percent higher than the on-ramp merging rates, whereas the accident rates for the off-ramps proper (from the gore nose to the cross-street terminal) are 65 percent higher than for the on-ramps proper. In other words, accidents on the turning roadways are primarily responsible for the difference.

On-ramps with acceleration lane lengths greater than 800 ft can be expected to have below average accident rates. If the acceleration lane is less than 800 ft, the rate will probably be greater than average, especially if the geometry upstream of the nose is such that a high-speed approach is possible.

The off-ramps with the long (900 ft +) deceleration lane lengths have lower rates than the ramps with shorter deceleration lengths. The short radius, large central angle curved off-ramps seem to have lower rates than the ramps with median range radii and deltas. This is perhaps a case where the tight turns appear as obvious hazards to the drivers and they take the necessary precautions, whereas the medium range curves do not appear dangerous and the drivers do not compensate. The straight ramps have lower rates than any of the curved classifications.

REFERENCES

1. Vostrez, John, and Lundy, Richard A. Comparative Freeway Study. Highway Research Record 99, p. 157, 1965.
2. Johnson, Roger T., and Tamburri, Thomas N. Continuous Freeway Illumination. Calif. Div. of Highways, May 1965.

Appendix A

LOCATION OF GROUP A RAMPS

Sec. No.	Freeway Name	Study Period	Location	On Ramps				Off Ramps				Total Ramps			
				No of Ramps	Acc.	M V	Acc / M V	No of Ramps	Acc	M V	Acc / M V	No of Ramps	Acc.	M. V.	Acc. / M V
1 A	Montgomery	1958–1959–1960	SD-5-SD,ChV,G,NatC San Ysidro Jct. to S.C.L. of National City	22	23	31.4	0.73	21	28	26.0	1.00	43	51	59.4	0.86
2 A	Balboa Bypass	1958–1959–1960	SD-5-S D 1 mile South to 0.65 mile North of Balboa Ave.	2	4	15.6	0.26	3	6	14.0	0.43	5	10	29.6	0.34
3 A	Long Beach	1958–1959–1960	LA-7-LBch,A,Com,Lyn, SGt Pacific Coast Hwy. to Atlantic Ave.	16	16	56.5	0.28	17	27	57.8	0.47	33	43	114.3	0.38
4 A	Pasadena	1958–1959–1960	LA-11-LA 4-Level Structure to Jct. Interstate 5 (Golden State Fwy.)	9	40	63.2	0.63	8	147	62.6	2.36	17	187	125.8	1.49
5 A	Pasadena	1958–1959–1960	LA-11-LA Jct. Interstate 5 (Golden Gate Fwy.) to Ave. 64	0	0	0	0	4	5	15.2	0.33	4	5	15.2	0.33
6 A	Pasadena	1958–1959–1960	LA-11-LA,SPas Ave. 64 to Orange Grove Ave.	1	1	7.5	0.13	5	5	11.8	0.42	6	6	19.3	0.31
7 A	U. S. 99	1958–1959–1960	Tul-99-F Visalia Airport Interchange to 1 mile No. of Goshen	7	10	6.2	1.61	8	10	5.3	1.89	15	20	11.5	1.74
8 A	Petaluma	1958–1959–1960	Son-101-F,C 2.23 mile No. of Marin Co. Line to S.C.L. of Santa Rosa	21	8	13.9	0.58	20	20	12.3	1.63	41	28	26.2	1.07
9 A	Bayshore	1958–1959–1960	SM-101-Var. Bransten Rd. to N.C.L. of South San Francisco	28	57	110.0	0.52	31	77	113.3	0.68	59	134	223.3	0.60
10 A	Bayshore	1958–1959–1960	SM,SF-101-F;SF N.C.L. of South San Francisco to 3rd St. in San Francisco	2	9	12.2	0.74	2	8	10.6	0.75	4	17	22.8	0.75
11 A	Colorado	1958–1959–1960	LA-134-LA,Pas,SPas Eagle Vista Drive to Holly St.	5	4	22.3	0.18	5	6	18.1	0.33	10	10	40.4	0.25
12 A	Castro Valley Link	1958–1959–1960	Ala-238-A,SLn Jct. Interstate 17 (Eastshore Fwy.) to Jct. Interstate 580	4	2	10.3	0.19	5	12	12.2	0.98	9	14	22.5	0.62
13 A	Nimitz	1958–1959–1960	SCl,Ala-680-SJs,A;Fmt Interstate 101/680 Separation to Warm Springs Separation	7	10	11.8	0.85	8	5	9.4	0.53	15	15	21.2	0.71
	Totals			124	184	367.1	0.50	137	356	370.6	0.96	251	540	737.7	0.73

Appendix B

LOCATION OF GROUP B RAMPS

Sec. No	Freeway Name	Study Period	Location	On Ramps				Off Ramps				Total Ramps			
				No of Ramps	Acc	M V	Acc. / M V	No of Ramps	Acc	M V	Acc / M V	No of Ramps	Acc	M.V	Acc / M.V.
1B	Golden State	1959–1960–1961	LA-5-LA, Gndl, LA Glendale Blvd. to Burbank Blvd.	16	29	59.7	0.49	17	29	57.4	0.51	33	58	117.1	0.51
2B	Long Beach	1959–1960–1961	LA-7-Com, A, Lyn, SGt. Atlantic Ave. To Firestone Blvd.	15	38	61.0	0.62	15	43	58.6	0.73	30	81	119.6	0.68
3B	Long Beach	1959–1960–1961	LA-7-Bell, B, Ver Firestone Blvd. to No. Jct. Atlantic Blvd.	6	15	27.3	0.55	7	14	31.0	0.45	13	29	58.3	0.50
4B	Long Beach	1959–1960–1961	LA-7-Bell, B, Ver, Cmrc No. Jct. Atlantic Blvd. to Olympic Blvd.	3	14	33.6	0.42	3	41	28.9	1.42	6	55	62.5	0.88
5B	San Bernardino	1959–1960–1961	LA-10-Cla, Pom, C, W. Cov Citrus St. to San Bernardino County Line	16	30	30.3	0.99	15	38	34.2	1.11	31	68	64.5	1.05
6B	San Bernardino	1959–1960–1961	SBd-10-Mcl, Upl, Ont, D Los Angeles County Line to Live Oak Ave.	15	11	16.3	0.67	16	22	17.4	1.26	31	33	33.7	0.99
7B	San Bernardino	1960–1961	SBd-10-D, Ria, Col Live Oak Ave. to 5th St. in Colton	9	6	8.9	0.67	10	10	10.4	0.96	19	16	19.3	0.83
8B	Warren	1960–1961	Ala-13-Oak Redwood Rd. to Thornhill Rd.	3	0	2.7	0.00	4	3	3.4	0.88	7	3	6.1	0.49
9B	Riverside	1960–1961	SBd-395,15-F, Col, SBd Riverside County Line to Jct. Interstate 10 and 650' So. of Mill St. to Jct. Interstate 15	17	22	24.3	0.91	15	27	23.2	1.16	32	49	47.5	1.03
10B	Riverside	1960–1961	SBd-15-F, Col, SBd Jct. Interstate 10 (San Bernardino Fwy.) to 650' So. of Mill St.	8	5	13.9	0.36	8	37	14.7	2.52	16	42	28.6	1.47
11B	Los Gatos	1960–1961	SCl-17,280-LGts, D, Cmb, SJs; D, SJs Santa Clara Ave. to the Alameda	23	32	40.6	0.79	19	39	39.6	0.98	42	71	80.2	0.89
12B	Central	1960–1961	SF-80,101-SF Jct. Interstate 80 (Bayshore Fwy) to Turk St.	2	10	28.6	0.35	2	30	29.9	1.00	4	40	58.5	0.68
13B	I-94	1960–1961–1962	SD-94-SD West of 25th St. O.C. to E. of Palm Ave.	26	44	61.0	0.72	25	79	64.6	1.22	51	123	125.6	0.98
14B	Bayshore	1959–1960–1961	SM-101-D, MIP, RdwC Santa Clara County Line to Bronsten Rd.	11	25	39.5	0.63	12	34	38.4	0.89	23	59	77.9	0.76
15B	Ventura	1959–1960–1961	LA-101-LA Jct. Interstate 405 (San Diego Fwy) to Loúise Ave.	6	20	25.3	0.79	6	42	24.4	1.72	12	62	49.7	1.25
16B	Roseville	1959–1960–1961	Sac; Pla-160;160,80-B; A,A, Rsv Howe Ave, to Atlantic St.	23	23	41.2	0.56	21	27	37.0	0.73	44	50	78.2	0.64
17B	Escondido	1959–1960–1961	SD-395-SD Approx. 0.1 mile No. of Ash St. to Genesee Ave.	16	69	69.7	0.99	15	63	79.5	0.79	31	132	149.2	0.88
18B	Escondido	1959–1960–1961	SD-395-SD Genesee Ave. to Clairmont Mesa Blvd.	5	13	20.0	0.65	6	33	25.7	1.28	11	46	45.7	1.01
19B	San Diego	1959–1960–1961	LA-405-CIC, LA, A Approx. 0.2 mile No. of Venice Blvd. to Ovada Pl.	12	19	60.7	0.31	13	26	60.3	0.43	25	45	121.0	0.37
Totals Group "B" Ramps				232	425	664.6	0.64	229	637	678.6	0.94	461	1062	1343.2	0.79
Totals Group "A" Ramps				124	184	367.1	0.50	137	356	370.6	0.96	261	540	737.7	0.73
Collector – Distributor Road Accidents													41		
Grand Totals Group "A" and "B" Ramps				356	609	1031.7	0.59	366	993	1049.2	0.95	722	1643	2080.9	0.79