Freeway Traffic Accident Analysis and Safety Study

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In 1958, the Texas Transportation Institute initiated a research project under the sponsorship of the Automotive Safety Foundation to determine the possible correlation between freeway accidents and specific geometric design features on urban freeways and to investigate methods of improving accident reporting. A report on the phase concerned with improving accident reporting procedures was published in the December 1960 issue of Traffic Engineering.

This study considered some 10,000 accident reports on 54 miles of freeways in the five largest Texas cities, covering from 2 to 5 years of data. The reports, obtained from the files of the various cities, were recorded on microfilm to facilitate handling. The collision diagrams were plotted on continuous strip maps of each freeway showing the geometric and profile features to scale.

A study of the continuous collision diagrams for various freeways indicated that certain locations experienced higher accident frequency than other locations. Because certain locations experienced high accident frequency and others having the same apparent physical characteristics experienced low accident frequency, even with due consideration of the respective volumes, it was probable that some physical factor contributed to the high accident frequency. If this relationship could be determined, a reduction in the number of accidents might be realized by improvements in design.

Concentrations of accidents generally involved the following design features: (a) major changes in vertical alignment (crests and sags), (b) freeway ramps, (c) freeway interchange elements (interchange intersections and frontage roads), and (d) fixed objects. This report covers studies of accident concentrations in relation to each of these design characteristics.

Concentration of accidents at crests and sags indicated that the requirement for visibility or sight distance is particularly important. Freeway traffic, regardless of volume, tends to travel in more or less compact groups or platoons. The headway between the vehicles is often very short. For safe operation, the trailing driver must have a view of the traffic, or vehicles, for some distance ahead of him in both his and/or the adjacent lane or lanes. This visibility distance is greater than the distance required by the criteria for stopping sight distance on 2-lane roadways.

Entrance or on-ramps on the 10 freeways experienced much higher accident frequency than the exit or off-ramps. There was indication that the sight relationship afforded both the on-ramp drivers and the freeway through-lane drivers was especially critical. All high accident frequency on-ramp locations involved poor sight relationships.

Off-ramps with large angles of divergence and especially those affording poor visibility experienced higher frequency among off-ramps.

Diamond interchange intersections contributed three-fourths of the 21 percent of all freeway accidents which occurred on the frontage road system.

Most of the frontage roads were continuous and two-thirds were one-way. The frontage road at the points where the ramps joined the frontage roads and the section between the two ramps (included because the frontage roads were continuous) contributed only 2 percent of all freeway accidents. Practically all of the two-way frontage roads were at extremely low volume locations and afforded no accurate comparison with the one-way sections.

Much improvement is needed in the operational control of diamond interchanges. Their complexity coupled with inadequate operational controls probably contributed to the accident frequency at these points.

Twelve percent of the freeway accidents involved fixed objects. Such accidents caused 38 percent of all injuries and 65 percent of all fatalities. A large percentage of fixed-object accidents occurred on the through-lanes and mostly at exit ramps. Medians (curbs and median barrier) were involved in one-third of the fixed-object accidents.

Early in the study it was discovered that the techniques used by enforcement officials in many cities in the investigation and reporting of freeway traffic accidents did not supply information adequate for proper engineering analysis. This inadequacy of reporting techniques seriously affected the progress and accuracy of correlations of accidents with design features.

The procedure developed in the early phases of the project to provide special freeway accident diagrams and the establishment of reference points along the freeway proved to be beneficial in improving the accuracy of reporting. The police departments reported greater ease in accurately locating and reporting freeway accidents.

Although few conclusive relationships were found between accident experience and specific design elements, inadequate sight relationship appeared to be a factor in all high accident frequency locations.

This study has emphasized the necessity of completely planning the study ahead of time, arranging for proper accident reporting, and obtaining necessary volume data during the study period for a most complete and accurate picture. The procedure of "looking back" followed in this study leads to a great deal of frustration brought about by inadequacy and inaccuracy in accident reporting.

●THE FUNCTION of freeways is the safe and efficient movement of large volumes of traffic. The vast expenditures for their construction and the traffic volume which they accommodate demand that the highest possible degree of safety be embodied in their design. Recent research by the Texas Transportation Institute involving the correlation of design and operational characteristics of freeways in Texas (1) emphasized the value of accident analysis and the need for much improvement in securing information on accidents.

The traffic accident rate (accidents per 100 million vehicle-miles) is generally lower on freeways than on lesser types of traffic facilities. However, the fact that some locations on the freeways experience relatively high accident frequency indicates that there may be some geometric design features contributing to these concentrations of accidents.

Numerous studies have been made on two-lane rural highways and on city streets, but only a few recent studies have dealt with the analysis of freeway accidents. These freeway accident studies have attempted to correlate accident occurrence with general

design features such as interchanges, ramps, and curves, and other factors such as weather and light. Some studies have dealt with specific design treatments of components such as medians.

Established knowledge indicates that many accidents may be attributed to driver factors such as lack of skill, inattention, carelessness, or flagrant disregard of restrictions and suggests that the highway engineer should work diligently for the most easily understood design elements, especially on the express traffic facilities designed for the most consistent coordination of safety, speed, and volume. Because loss of life, personal injury, and property damage can be lessened by better design and operation of traffic facilities, research regarding these complex problems is deemed necessary.

To study freeway accidents properly, it is necessary to have precise information concerning the location and manner of occurrence. The techniques used by the enforcement officials of many cities in the investigation and reporting of freeway traffic accidents do not supply such information consistently and adequately for proper engineering analysis. Therefore a need for study of reporting procedures exists rather generally.

If an analysis should show consistently high accident occurrence, particularly of the same type, at locations where the same or similar design features exist, then these features must present some inherent characteristics which adversely affect the psychological or physical behavior of a considerable number of drivers. Similarly, these design features might be related to some of the operational limitations of a significant proportion of vehicles. Where a few locations are experiencing high accident frequency and others having the same apparent physical characteristics are experiencing low accident frequency, even with due consideration for their respective traffic volume, it is probable that some physical factor contributes to the high frequency. Thus, a reduction in the number of accidents might be realized by improvements in design.

RESEARCH OBJECTIVES

In January 1958 the Texas Transportation Institute began a research project, sponsored by the Automotive Safety Foundation, with the primary objective of determining the correlation between accident frequency and specific geometric design features on the urban freeways in Texas.

A secondary but important objective was that of improving accident reporting methods in order to make the investigating officer's job easier and to make the accident reports of more value to the engineer.

SOURCES OF DATA

The research involved examination of microfilmed copies of some 10,000 accident reports on 54 miles of freeways in the five largest Texas cities (Figs. 1 - 7). These were supplied by the police departments of the cities and covered from 2 to 5 years, according to data available, 1954-58. Continuous collision diagrams were prepared by plotting accidents on strip maps of these freeways (Fig. 8). The geometric features of design, profile data, etc., were supplied by the Texas Highway Department and the traffic engineering departments of the various cities. Table 1 gives the mileage, through-lane volume data, accident rates and fatality rates for the various freeways, for the years 1957-1958. Volume data consisted of the average daily traffic at the location of permanent count stations on each of the freeways. Other volume data included ramp volumes and corresponding through-lane volumes taken immediately back of the ramp. Such data were not available for all possible study locations, nor for all years for which accident records were available.

A project advisory committee, composed of key administrative personnel of the five largest Texas cities, the Texas Highway Department, the Department of Public Safety, Bureau of Public Roads and Automotive Safety Foundation contributed valuable advice and assistance throughout these studies.

Figure 1. North-South Expressway, Austin.

Figure 2. Central Expressway, Dallas, Texas.

Figure 3. East-West Freeway, Fort Worth.

Figure 4. North-South Freeway, Fort Worth.

Figure 5. Eastex Freeway, Houston.

Figure 6. Gulf Freeway, Houston.

Figure 7. South, East and North Expressways, San Antonio.

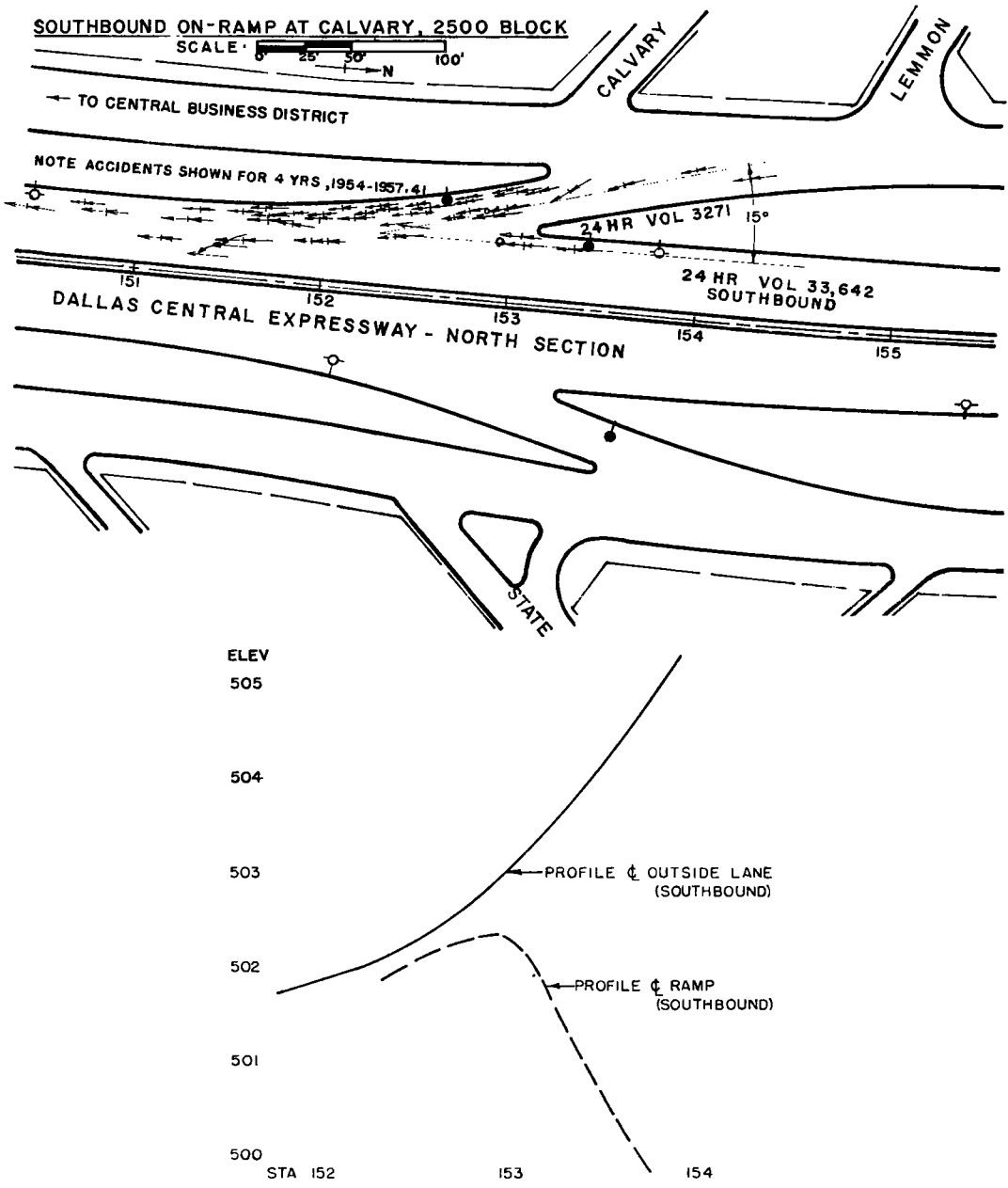


Figure 8. Section of strip map showing collision diagram.

DIAGRAMS AND NOMENCLATURE FOR FREEWAY ACCIDENT REPORTING

The need for development of improved methods of reporting accidents became evident early in the study. A study of accident reports revealed the fact that police personnel were not familiar with the complicated engineering terminology related to the design features. Accident diagrams plotted on the report forms were often so inadequate and terminology so confused that it was impossible to determine on what portion of the freeway the accident occurred. Examples of inadequate reports are shown in Figure 9.

TABLE 1

MILEAGE, ADT VOLUMES, ACCIDENT RATES, AND FATALITY RATES OF FREEWAYS

Freeway	Freeway Code No	Miles of Freeway Studied	ADT (through lanes only)	Accid. in 1957-58 Including Through Lanes, Ramps, and Frontage Roads	Accident Rate per Million Vehicle-Miles	Fatalities in 1957-58	Fatality Rates per 100 Million Vehicle-Miles
Dallas - North	1	8 9	59,000	971	2 533	2	0 522
Dallas - South	2	3 3	29,000	282	4 037	0	0 000
Houston - Eastex	3	7.0	28,400	478	3 294	4	2 756
Houston - Gulf	4	9 2	81,800	1,548	2 818	9	1.638
Fort Worth - East-West	5	5 7	34,000	746	5.273	3	2.121
Fort Worth - North-South	6	6.6	29,000	637	4 559	7	5.010
Austin	7	8 5	22,000	244	1 787	0	0 000
San Antonio - North	8	2 2	35,000	180	3 202	2	3 558
San Antonio - South	9	1 5	23,000	138	5.479	2	7 941
San Antonio - North-East	10	1 2	17,500	50	3 262	2	13 046
Total - Miles, accidents, fatalities		54.1		5,274		31	

Note Rates are based on maximum through-lanes ADT volumes only, as frontage road volumes were not generally available

Effort was made, however, to spot the locations of accidents accurately enough both longitudinally and laterally, to provide correlation of accident location and type as related to specific geometric roadway features such as entrance and exit ramps, speed-change lanes, frontage roads, overpass structures, sight distances, grades, and guardrails.

In an attempt to eliminate at least some of the confusion incurred by accident investigators having to draw complicated diagrams to describe locations of accidents, standard diagrams of several typical freeway sections were developed complete with simple nomenclature. These standard diagrams are shown in Figures 10 and 11. They were furnished to the police departments of each of the participating cities for trial use.

LOCATION OF ACCIDENTS BY REFERENCE POINTS

The general practice of most city police departments to use block numbers to reference accident locations to street intersections is not well suited for freeway accidents. Study of the assembled accident records indicated that the system of referencing freeway accidents did not furnish location information with sufficient accuracy for the engineer to relate the accident occurrence to the design features. The proportion of accidents which could not be accurately plotted, mainly because of inexact location information, ranged from 5 percent for one freeway to 60 percent for another.

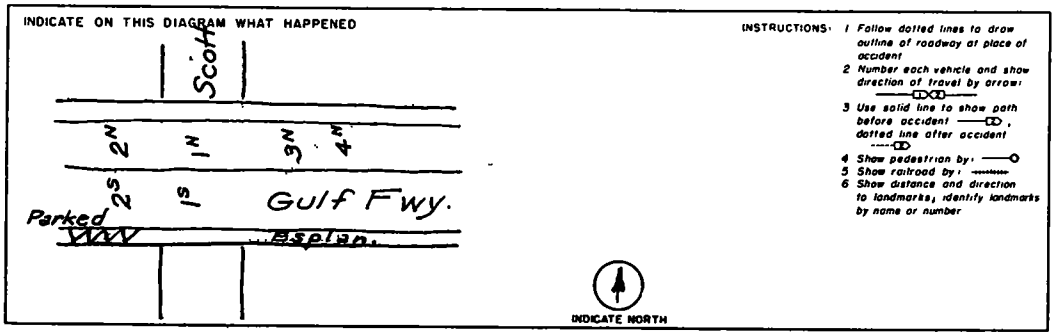
A suggested system of establishing reference points along the freeways from which accidents can be accurately referenced was recommended to the participating cities for trial use. Typical serial numbers established by two of the cities are shown in Figure 12. The system involved the use of a serial number for each reference point and incorporated the block number where applicable, along with the serial number.

STUDY METHOD

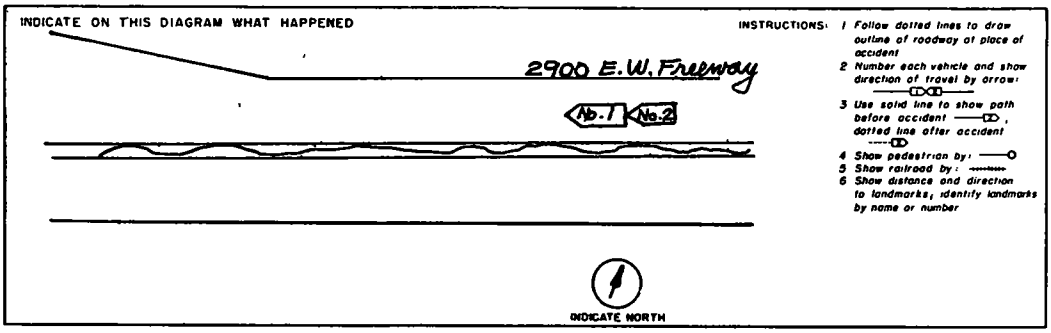
A number of participating cities made trial use of the special freeway accident diagrams and the Texas Highway Department Districts established reference points along the freeways. The combined use of special diagrams and reference points resulted in marked improvement in the ability to locate accidents. It is regrettably noted that few cities continued to use the special diagrams after the trial period. A more detailed report of this phase of the project was published in December 1960 (3).

ANALYSIS OF ACCIDENTS DATA

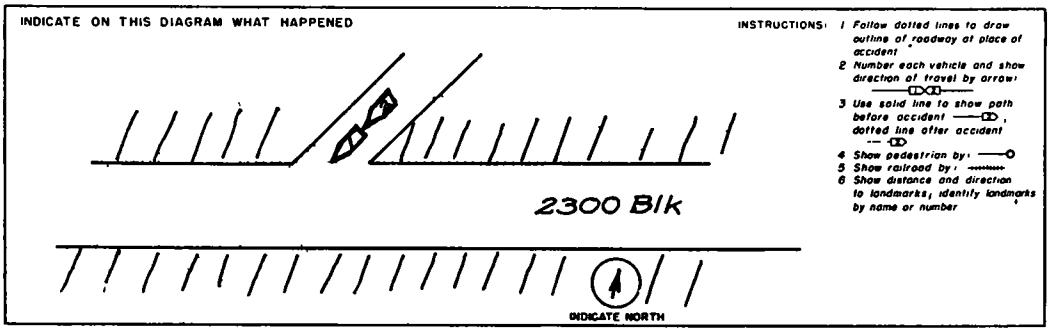
An attempt was made to code all accident information, traffic data and roadway design factors for punched card analysis. This proved to be impractical because of the number and complexity of the variables and the difficulty in locating many accidents accurately enough for this type of analysis. It was found that the loss of "personality" of the individual accident made proper analysis more difficult. Too often it was necessary to estimate certain data to facilitate coding and there was a tendency for these



Through-lane Accident Inadequately Described and Unsatisfactorily Located



Accident Adequately Indicated but Located Only Within the Block Since no Distance is Given to the Presumed Off-Ramp



Accident Indicated but Location Doubtful as to whether on a Ramp Entering the Through-lanes or on a Street Intersecting the Frontage Road

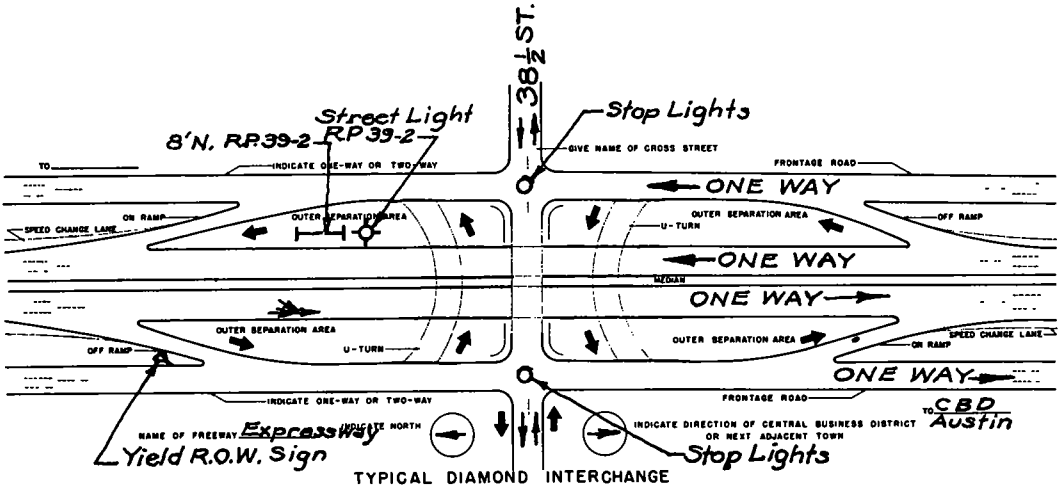
Figure 9. Standard accident report form with collision diagrams unsatisfactory for freeway reporting.

FREEWAY ACCIDENT DIAGRAMS

NO

DATE

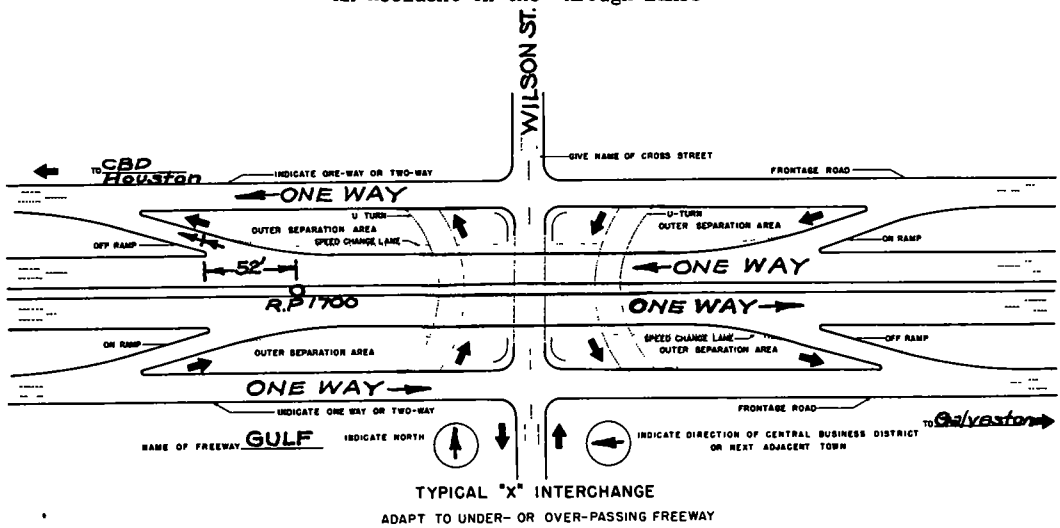
ADD NECESSARY STREETS OR DRIVEWAYS WHICH INTERSECT FRONTAGE ROADS
INDICATE TRAFFIC SIGNALS, STOP SIGNS, YIELD SIGNS & PARKING RESTRICTIONS
LOCATE STREET LIGHT STANDARDS OR OTHER REFERENCE POINTS, IDENTIFY BY NO. GIVE REFERENCE DISTANCES
MARK OUT FEATURES NOT APPLICABLE ADD AS NEEDED
INDICATE BY SKETCH IF ROADWAY CURVES



TYPICAL DIAMOND INTERCHANGE

ADAPT TO UNDER- OR OVER-PASSING FREEWAY

An Accident on the Through-lanes



TYPICAL "X" INTERCHANGE

ADAPT TO UNDER- OR OVER-PASSING FREEWAY

An Accident on an Off-ramp

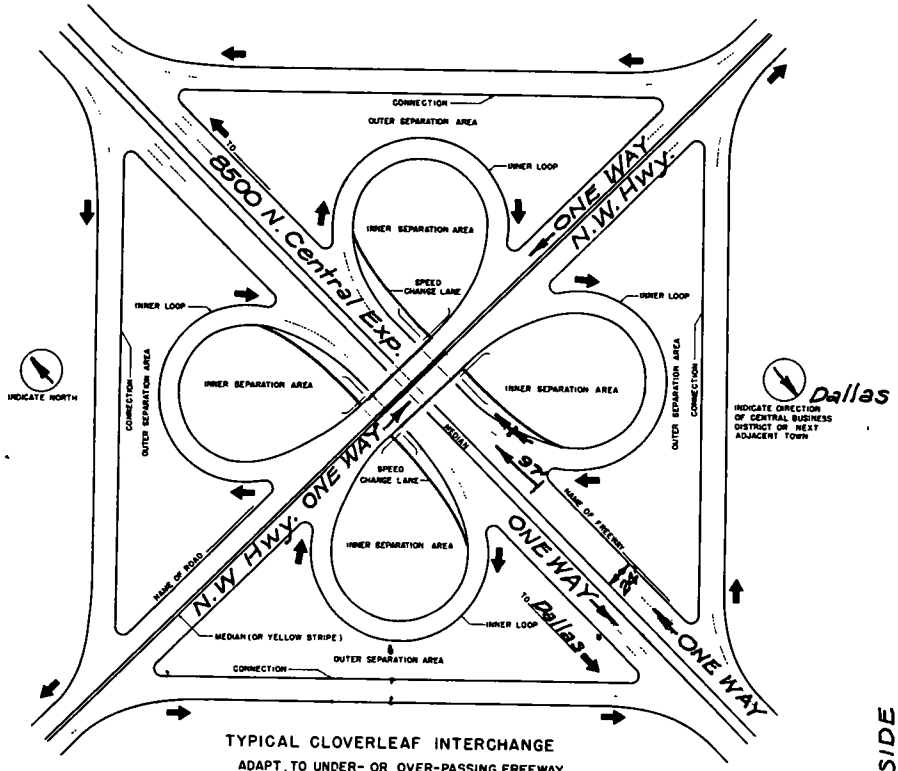
Figure 10. Use of typical freeway diagrams encourages satisfactory location and description of accidents on the freeway.

FREEWAY ACCIDENT DIAGRAMS

NO

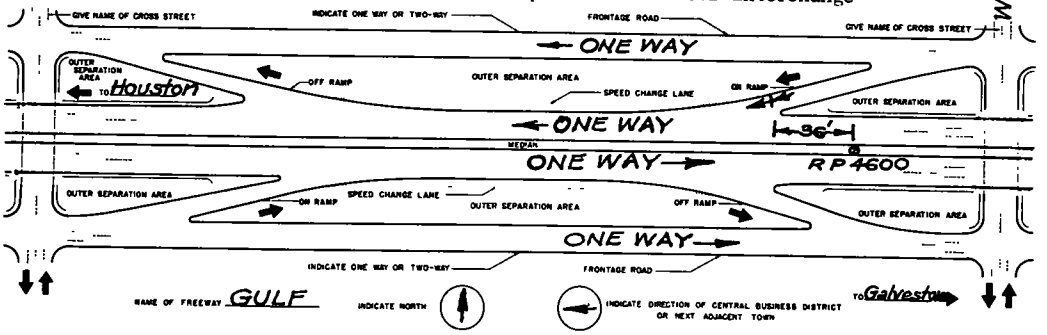
D-TE

ADD NECESSARY STREETS OR DRIVEWAYS WHICH INTERSECT FRONTAGE ROADS
INDICATE TRAFFIC SIGNALS, STOP SIGNS YIELD SIGNS & PARKING RESTRICTIONS
LOCATE STREET LIGHT STANDARDS OR OTHER REFERENCE POINTS IDENTIFY BY NO. GIVE REFERENCE DISTANCES
MARK OUT FEATURES NOT APPLICABLE, ADD AS NEEDED
INDICATE BY SKETCH IF ROADWAY CURVES



TYPICAL CLOVERLEAF INTERCHANGE
ADAPT, TO UNDER- OR OVER-PASSING FREEWAY

An Accident on an On-ramp of a Loop of a Cloverleaf Interchange



TYPICAL INTERMEDIATE AREA- BETWEEN INTERCHANGES
ADAPT TO UNDER- OR OVER-PASSING FREEWAY

An Accident on an On-ramp Approaching an Intermediate Area

Figure 11. Better accident reporting on other freeway sections.

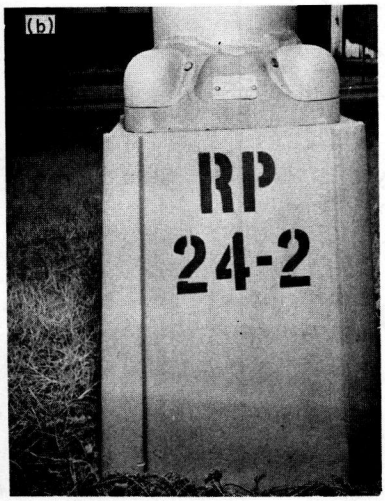


Figure 12. (a) Reference number of median guard fence; and (b) reference number on luminaire standard.

estimated values to then become "fact" when coded and considered only as numbers.

Several comparisons and analyses were made in connection with studies of specific locations on a number of the freeways. Most of these were in cooperation with other studies of traffic operation, ramp design, etc. The results of these special studies have been used in developing the reports of the other studies (1, 2, 4).

After a number of preliminary tabulations and analyses, it was decided, with the help of the advisory committee, to study each design element by determining the accident experience of this element in relation to its design. It was also determined that the study of high accident frequency locations probably would reveal the combinations of elements contributing to high accident experience.

Because of the custom of designing accidents by block numbers, graphs of accident frequency by blocks were prepared to determine the distribution of accidents along the freeway (Fig. 13).

The next step in such an approach necessitated a summary of accidents on all the freeways to indicate the geometric design features of the freeway systems where the greater proportions of accidents occurred. Such a summary, along with the figures for each freeway, is shown in Figure 14 and Table 1. In addition to the percent of all accidents which occurred on the through lanes, ramps, frontage roads and cross streets, the average daily traffic, total accidents and freeway mileage for each freeway are shown. Volume of traffic and number of accidents are shown for the years 1957-58. Table 1 gives the accident and fatality rates for all freeways. Only two years of accident data could be obtained for one of the largest volume and longest freeways, therefore only the two years 1957 and 1958 were used for this summary.

Grouping the frontage roads, the cross streets and the ramps together as interchange elements, the analysis in Figure 14 showed the following distribution: (a) freeway through lanes—53 percent of total accidents; and interchange elements—47 percent of total accidents.

ACCIDENTS ON INTERCHANGE ELEMENTS

Practically all of the interchanges on all 10 freeways included in the study were of the diamond type. Most were regular diamond, with a few reversed diamond or X type. Some were a combination of these two types of ramp arrangement. The one cloverleaf and one fully directional interchange within the study area did not provide enough samples for comparative analysis.

Frontage Roads

Because the Texas freeways included in this study were built on rights-of-way

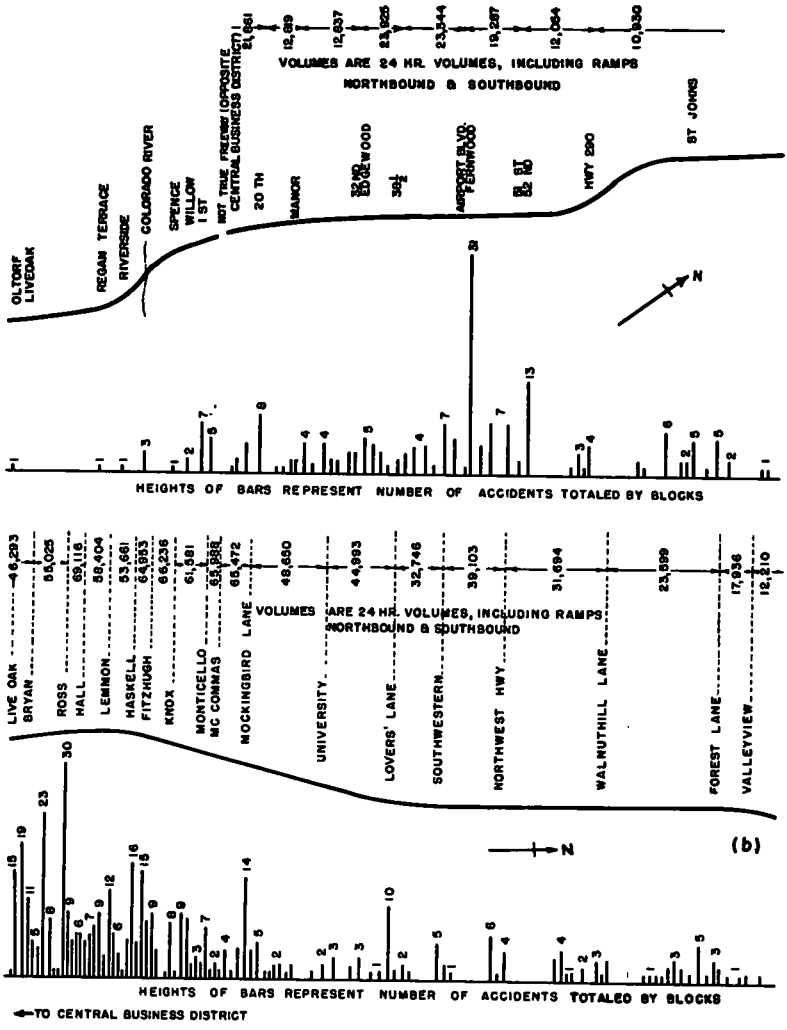


Figure 13. (a) Accident frequency, 1957, North-South Freeway, Austin; and (b) Accident frequency, 1957, North Central Expressway, Dallas.

furnished by local governments, they were constructed with continuous or nearly continuous frontage roads. The interchange elements were considered as the ramps, frontage roads, interchange intersections and cross streets between the two intersections of the diamond interchange.

Accidents on the frontage roads and interchange intersections were 21 percent of all freeway accidents. The interchange intersections accounted for 75 percent of these accidents or 16 percent of all freeway accidents. The frequency of accidents on two-way and one-way frontage roads was closely proportional to their respective mileage and the location of accidents on frontage roads was about the same for both.

Table 2 gives the percentages of accidents at the various locations along the frontage roads.

Volume data were not available for the various locations along the frontage roads; therefore, only summary data are presented. The accident experience on two-way frontage roads could be expected to be higher than on one-way, but because most of the two-way frontage roads were at low volume locations, the data presented are somewhat misleading.

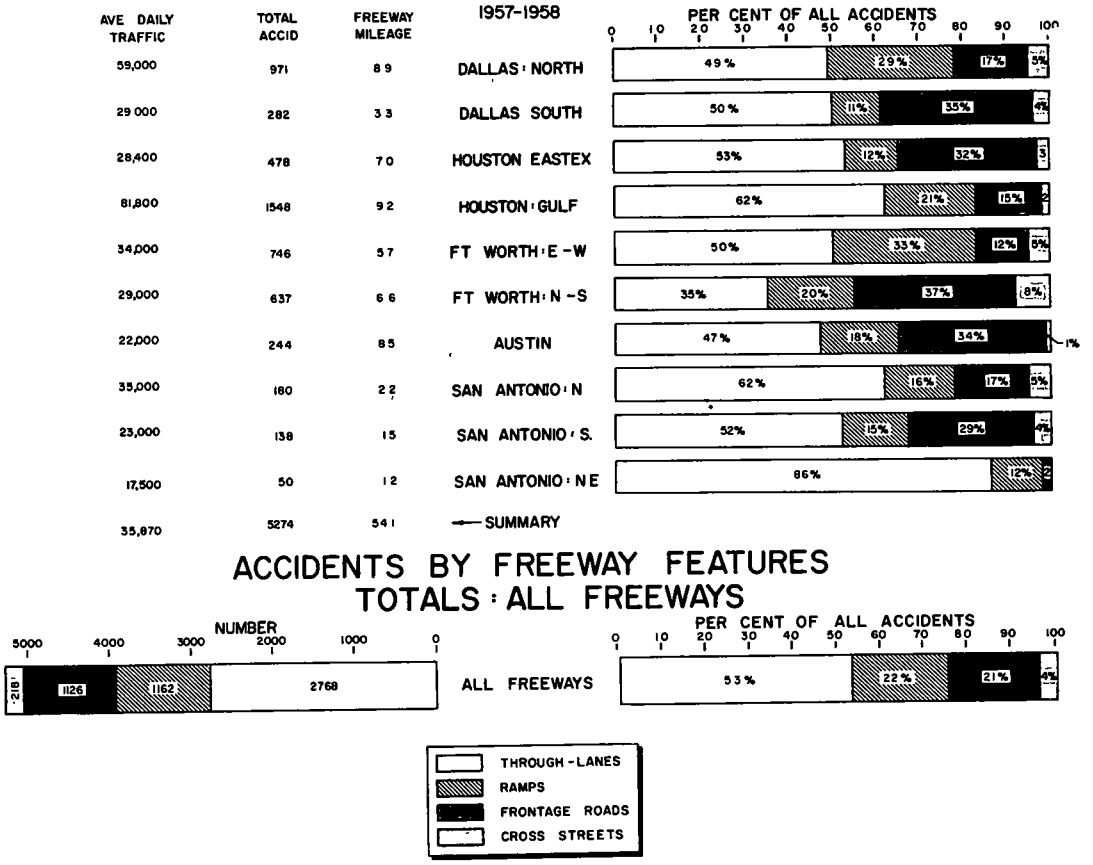


Figure 14. Comparison of accidents by freeways and by freeway features.

One fact worthy of note is the low accident frequency at locations B, C, and D, inasmuch as these would be the only locations not involved if the frontage roads were not continuous. The locations A and E and the intersections, I, would be required for diamond interchanges without continuous frontage roads. Locations B, C, and D contributed only 11 percent of the frontage road accidents. This amounts to only about 2 percent of all freeway accidents.

FREEWAY THROUGH LANES

A study of the through-lane accidents indicated that they were concentrated in the areas of change in vertical profile (crests and sags) and in the vicinity of ramps: crests and sags—35 percent; vicinity of ramps—18 percent; total on through lanes—53 percent of all accidents.

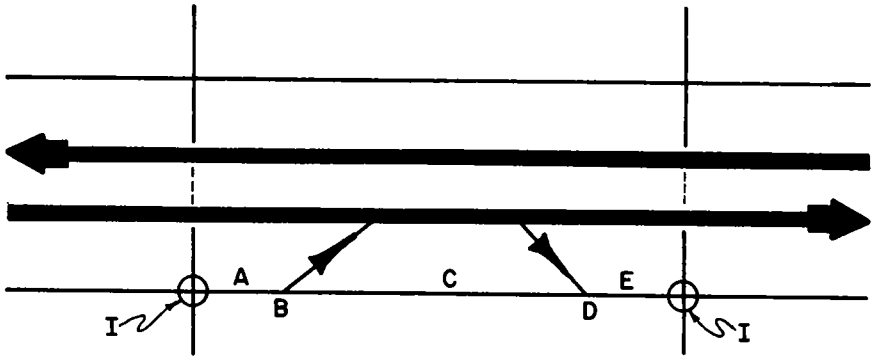
Through-lane accidents were of three basic types—rear end, side swipe, and fixed object, with a scattering of all types of accidents as expected.

Crest-Sag Accidents

In plotting accidents on the freeway strip maps, difficulty was encountered in accurately locating many of the accidents as indicated in the earlier discussion concerning the procedure of developing the accident data. Many accidents occurring on the through

TABLE 2

FRONTAGE ROAD ACCIDENTS (1957-1958)



	% of Frontage Road Mileage[a]	Total Accidents		I		A		B		C		D		E	
		No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)
One-way	67	671	(60)	487	(73)	48	(7)	10	(1)	40	(6)	21	(3)	65	(10)
Two-way	33	455	(40)	368	(81)	16	(4)	7	(2)	28	(6)	16	(3)	20	(4)
Summary		1,126	(100)	855	(76)	64	(6)	17	(2)	68	(6)	37	(3)	85	(7)
				I		A and E		B and D		C					
		1,126	(100)	855	(76)	149	(13)	54	(5)	68	(6)				

[a]Total frontage road mileage: 93.6

lanes were not tied to any reference and therefore could not be accurately located along the freeway. It was possible in most cases to assign these to the general area of occurrence such as the block number or section between interchanges. The long stretches of through lanes between interchanges provided fewer convenient reference points from which to accurately locate the accidents.

An analysis of the accidents on the through lanes on the Central Expressway in Dallas where 94 percent of the accidents could be accurately located to within a few feet of actual point of occurrence, showed that 69 percent of the through-lane accidents occurred on crests and sags. A study of all accidents that could be accurately located on all of the freeway through lanes indicated approximately the same percentage (Fig. 15). Comparison of mileage shows crest and sag areas to be 54 percent of the through-lane mileage (Fig. 16).

A study of the strip maps indicated that the points of grade reversals—that is, accending to descending (crest), or from descending to ascending (sag)—were important in the study of the effect of the profile on accident frequency.

The algebraic difference in grades was used as a common basis for describing the extent of the profile change. In addition, consideration was given to the length of vertical curve, especially where a considerable algebraic difference occurred in combination with a short vertical curve.

Considering the length of roadway under each profile condition, the following rates in terms of accidents per mile were determined for nine freeways: crests—10.7 accidents per mile; sags—12.8 accidents per mile; and tangents—5.1 accidents per mile. The term "tangents" refers to profile sections other than crests and sags.

No steep grades or other unusual grade conditions existed on any of the freeways except at the areas of crests and sags.

COMPARISON OF THROUGH-LANE ACCIDENTS TO CREST-SAG ACCIDENTS ON FREEWAY SYSTEM FOR 1957-58*

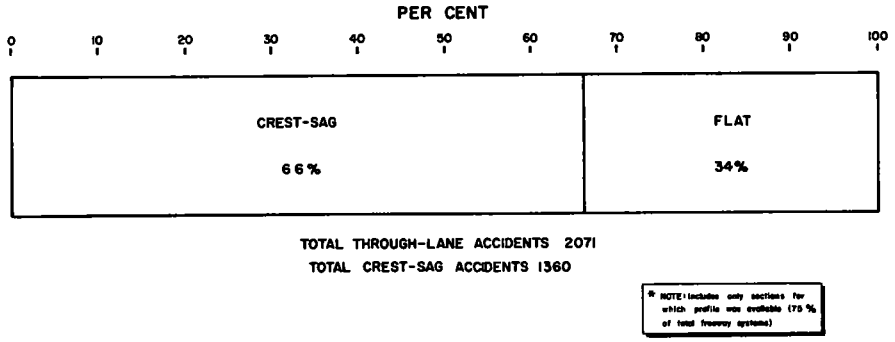


Figure 15. Comparison of through-lane accidents to crest-sag accidents on freeway system.

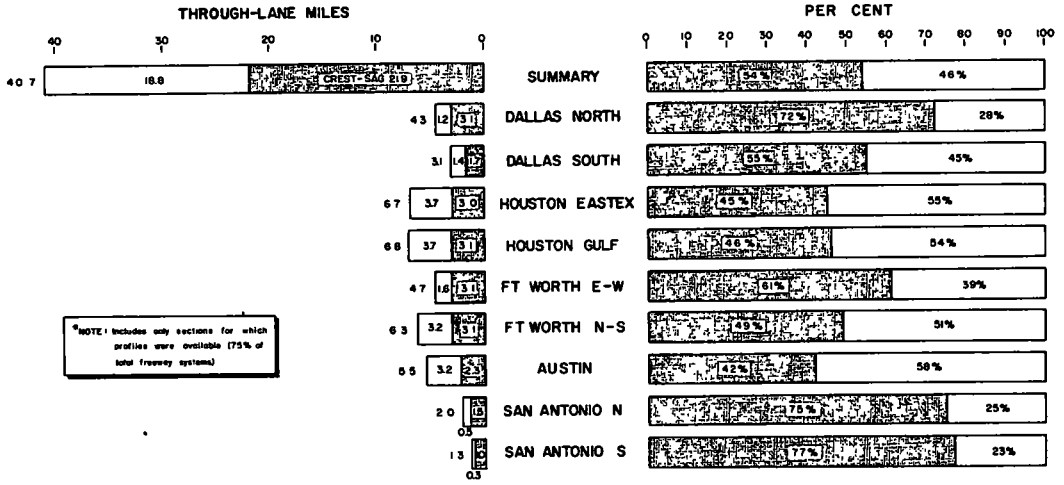


Figure 16. Comparative mileage of through lanes and crest-sag sections (one-way). Note: Includes only sections for which profiles were available (75 percent of total freeway systems).

Table 3 gives the number of crests and sags for all of the freeways studied. Each direction of travel was considered separately. This table also gives the numbers and percentages of accidents by type and the average number of accidents for each location. Considering the accidents per location, there appeared to be no correlation between the algebraic difference in grade and the frequency of accidents.

In considering the effect of sight distance, the numbers of accidents were adjusted to give a rate per 100,000 ADT. This value was then plotted against algebraic difference in grades (Fig. 17a) and against the rate of change of gradient, K (Fig. 17b). Neither of these plots showed any correlation between the number of accidents per 100,000 ADT and the algebraic difference in grades or the rate of change of gradient.

In an attempt to more directly relate effect of sight distance, the accident frequency was related to the algebraic difference, sight distance value, K, and the volume of traffic using the facility. If the sight distance directly contributed to accident frequency, then accident frequency would be directly proportional to algebraic difference and

TABLE 3

TOTAL THROUGH-LANE CREST AND SAG ACCIDENTS BY TYPE AND DIFFERENTIAL GRADE (All Freeways)

Algeb. Diff. in Grade	No. of Locations	Number of Each Type of Accident						Total Accidents	Accid per Location
		R.E.	F.O	S.S	O C	H O.	Pedestrian		
Crests, less than 3%.	2	6	0	0	0	0	0	6	3 00
3 - 4	8	36	4	16	2	2	0	60	7.50
4 - 5	8	47	11	8	4	2	1	73	9.13
5 - 6	16	49	12	24	10	3	1	99	6.19
6 - 7	22	65	23	28	12	4	3	135	6.14
7 - 8	16	30	10	21	2	0	0	63	3.94
8 - 9	28	94	24	16	6	1	1	142	5 07
9 - 10	4	17	5	7	2	1	0	32	5.33
10 - up	20	272	27	36	6	1	3	345	17 25
Summary	124	626	116	155	43	14	9	955	7.70
%		65	12	16	5	1	1		
Sags, less than 3%.	2	8	0	3	2	0	0	13	6.50
3 - 4	4	22	5	7	2	1	0	37	9.25
4 - 5	4	4	1	0	2	1	0	8	2 00
5 - 6	10	27	10	10	8	0	0	55	5.50
6 - 7	8	17	2	8	1	2	0	30	3.76
7 - 8	18	47	12	20	3	1	1	84	4.67
8 - 9	20	70	12	18	4	1	0	105	5.25
9 - 10	6	18	10	4	0	0	0	32	5.33
10 - up	4	31	4	6	0	0	0	41	10.25
Summary	76	244	56	76	22	6	1	405	5.33
%		60	14	19	5	2	0.2		
Tangents	114	476	65	121	28	10	11	711	6 24
%		67	9	17	4	2	1		

volume, and inversely proportional to the sight distance which is dependent on the length of vertical curve for any value of algebraic differences.

$$\text{(number of accidents)} = \frac{ADT}{100,000} - \frac{(A)}{L} \text{ (Factor).}$$

Assumed accident factor = No. of accidents (K/100) x (100,000/ADT).

This value was then plotted against each of the variables in the expression (Fig. 17c). No straight line or curvilinear relationships appeared to exist, which indicated that no apparent relationship existed between the number of accidents and the sight distance as an independent contributing factor. Data on these locations are given in Table 4.

Table 5 gives the occurrence of accidents by the position on the crests and sags. Also shown are the accident rates per mile for the various elements of the crests and sags. This table again does not indicate any direct correlation between the accident occurrence and these profile features except that the accident rate in terms of accidents per mile is greatest for the peak of crests and is least for the downgrade of crests. The rate of accidents per mile on the tangent sections was less than one-half that on crests and sags.

There were numerous possible interactions between contributing factors that would affect the occurrence of accidents on the crests and sags. For example, a ramp in close proximity would materially affect the accident occurrence on the crest or sag.

Lack of adequate visibility of the traffic stream ahead (sight distance) probably accounted for the high percentage of rear-end and side-swipe accidents at these points of differential grades. The rate of rear-end accidents per mile was 1½ times as high on crests and sags as on the other sections of the through lanes. Because most of the ramps joined the freeway on sections outside the areas designated for crests and sags, most of the ramp-influence accidents were counted on the tangent sections. This substantiates the assumption that the lack of proper sight relations ahead of and behind each driver may well have been a strong contributing factor in accident occurrence.

High Accident Frequency Locations

A special study was made of 14 locations on four freeways where a crest or a sag

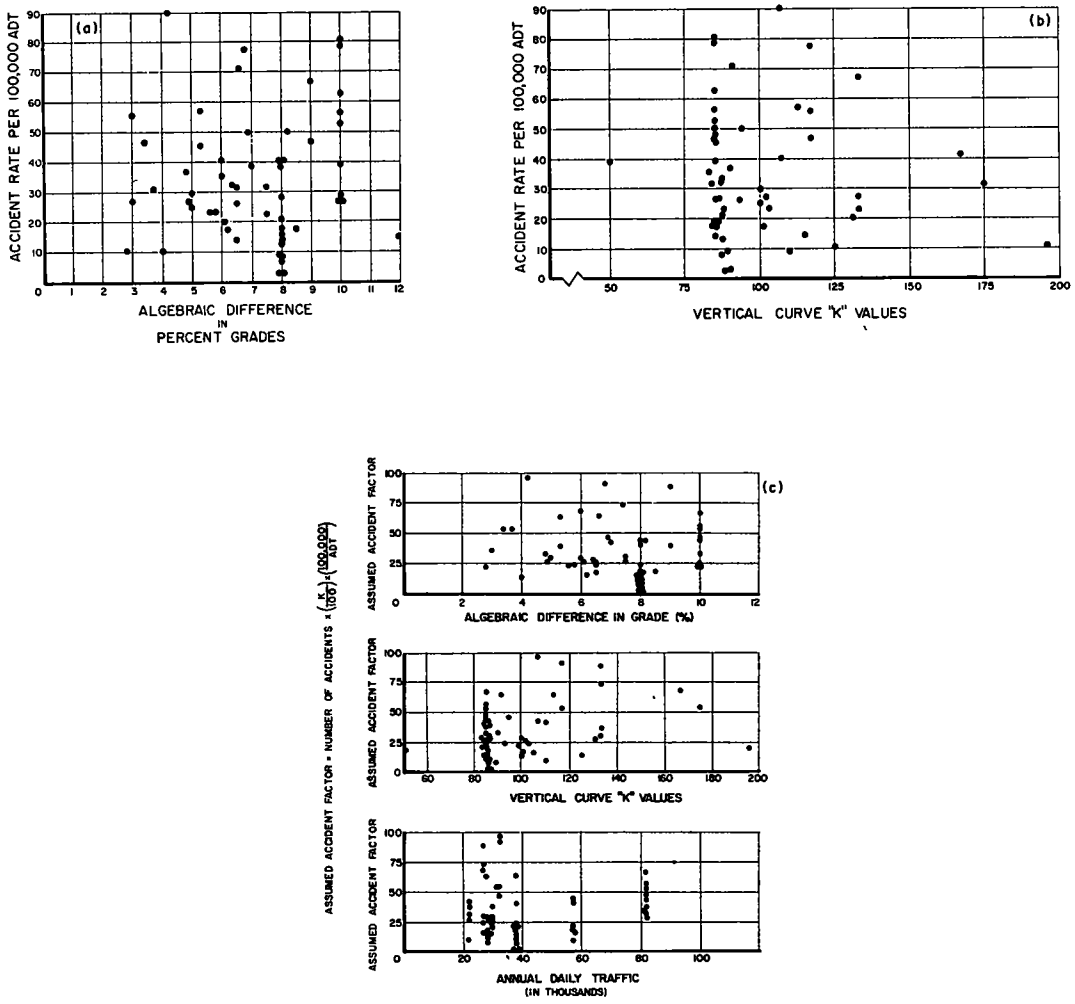


Figure 17. Effect of sight distance on accidents at crest vertical curves.

had 10 or more accidents during 1957 and 1958. The conditions at these 14 locations are given in Table 6. These data are shown in summary in Figure 18.

In addition to actual number and percentages of accidents, tabulation was made of the mileage involved and the volume (ADT) for each of these 14 high accident frequency locations. From these data an exposure factor in million vehicle-miles was calculated for each location; also an accident rate computed by dividing the number of accidents at each location by the corresponding exposure factor.

When based on exposure factor the accident rate for the crests, shows 2.02 per million vehicle-miles, less than the 2.96 rate for the sags. The accident rates by position on grade were 2.33 on upgrade of crest, 1.92 on downgrade of crest and 1.96 on the peak. On sags, 3.57 occurred on downgrade, 2.39 on upgrade, and 2.45 on bottom of sag. The distribution of accidents by position on grade at these high frequency locations was thus much the same as at all crest-sag locations—namely, most on the inclines whether up or down. Especially should it be stressed that the differential grade whether at crest or sag, was high in every high accident frequency case, none less than 5 percent and ranging from 5 to 10 percent.

With respect to horizontal curvature, the respective accident rates were 2.79 for 2 deg or more, 3.48 for 1 deg ± and 2.04 for straight tangent locations. Thus the

influence of horizontal curvature on accident frequency seemed to be negligible or doubtful.

Six (43 percent) of the 14 crest-sag high accident frequency locations were at interchanges where the freeway passed under the cross street (sags). Seven (50 percent) were at freeway overpasses (crests). One was a location at considerable distance from any adjacent cross street. The average accident rate per million vehicle-miles for the underpassing freeway sag locations was 2.96 as compared with only 1.73 for the overpassing freeway crest situations. In either case, the prevailing sight conditions for each particular location, such as determined by retaining walls, abutments and bridge structures, added their influence to the effect of differential grade and other factors on accident frequency.

The rear-end type comprised 70 percent of all accidents on the high frequency crest-sag situations, pointing up the driver tendency to follow too closely, as well as unfavorable sight conditions ahead on these locations with high differentials in grade.

Driver violation in following too closely was charged in 44 percent of the accidents in the high accident frequency crest or sag locations, probably constituting a primary or a contributing causative factor.

RAMPS

The accident strip maps of each freeway clearly indicated concentrations of accidents at ramp locations. Accidents occurring on the ramp proper and on the acceleration and deceleration lanes were classified as ramp accidents. There were a total of 416 ramps on the 10 freeways studied. Of 498 ramp accidents during the year 1957 (Table 7), a high percentage (82 percent) occurred on entrance ramps (Tables 8 and 9). Figure 19 illustrates concentration of accidents at relatively few ramps with about one-half of the on-ramps and three-fourths of the off-ramps having no accidents during the study period.

It was assumed that the concentration of accidents at any particular ramp was related to: (a) greater accident potential or exposure, or (b) the geometric design of the ramp and/or ramp area. "Accident rates based on improper exposure values are misleading and can delay the proper correction of accident hazards. There is also a danger that highways of modern design with large traffic volume will be termed unsafe merely because accident rates are not based on proper exposure data" (5).

To arrive at some common denominator or exposure index to facilitate comparison between locations with different accident experience, the following relationships were considered:

1. The chance for accidents is related to the number of conflicts between the through-lane vehicles and the entering or exiting vehicles.
2. The chance for accidents involving only through-lane vehicles is greater in the vicinity of ramps and is related to the number of merging and diverging maneuvers.
3. The chance for accidents involving only the ramp vehicles is related to the ramp volume.

Ramp accident rates in Tables 7, 8, and 9 were calculated by dividing the number of ramp vehicles by each of the following exposure factors: (a) ramp volume, (b) product of ramp volume (ADT) and freeway volume (ADT), and (c) ratio of ramp volume (ADT) divided by freeway volume (ADT). Reports of operational studies (1) showed that the sight conditions and other design conditions probably contributed to the "false-start" rear-end accidents. After considering these operational studies it was reasoned that the chance for accidents was related to the volume of ramp traffic and to the relationship between the ramp and through-lane volumes. The product of the two volumes (ramp and through-lane) yields the same value for high through-lane volume with low ramp volume as for the combination of high ramp volume and low through-lane volume. It would seem reasonable that the exposure is in someway related more directly to the ramp volume because these vehicles create the merging maneuvers. Therefore the ratio of the two volumes was considered significant.

Kinds of Accidents.—Of 498 ramp accidents on the 10 Texas freeways in 1957,

TABLE

SIGHT DISTANCE FACTORS FOR TEN HIGH A

Location Code No	Freeway Code No	High Rate per 100,000 ADT	High Rate per 100,000 ADT with Respect to Sight Distance	Grades +	Grades -	Algebraic Difference	K	Length of V C	ADT	Number of Accidents in 2 Years
1	4	X	X	5 0	5 0	10 0	85	850	81,800	64
2	4	X	-	5 0	5 0	10 0	85	850	81,800	51
3	4	X	-	5 0	5 0	10 0	85	850	81,800	66
4	5	X	X	3 3	3 5	6 8	117	800	32,300	25
5	5	X	X	2 7	1 5	4 2	107	450	32,300	26
6	3	X	X	1 6	5 0	6 6	91	600	38,000	28
7	6	X	X	5 0	4 0	9 0	133	1,200	26,900	18
8	6	-	X	2 0	1 0	3 0	133	400	26,900	15
9	6	-	X	2 5	3 5	6 0	167	1,000	26,900	11
10	9	-	X	3 5	1 8	5 3	113	600	28,000	16

82 percent were of the rear-end type, 7 percent were side-swipe accidents, 6 percent were fixed-object type of accidents, and the remaining were distributed between out-of-control, angle, and pedestrian accidents (Fig. 20). Of 25 personal injuries, most of them—9 and 11, respectively—occurred in the rear-end and fixed-object types of accidents. Of 4 fatalities, 2 occurred in the out-of-control type of accident and 2 were pedestrian accidents.

Comparison of Accident Rates for On-Ramps and Off-Ramps.—Eighty-two percent of all ramp accidents occurred on on-ramps, whereas only 18 percent occurred on off-ramps. The average number of accidents per on-ramp was 2.03, whereas on off-ramps the average was only 0.40. The average volume product accident rate per on-ramp was 66 per billion compared with 22 per billion per off-ramp. The average accident frequency index per on-ramp was 26.2 as compared with 4.10 for the off-ramps. All of this was despite the fact that the average volume per on-ramp (ADT) was only about 8 percent greater than for the average off-ramp, 2,100 compared with 1950. The accident rates computed on the basis of the number of ramp vehicles without regard to the through-lane volume were much higher for on-ramps: 3.91 per million ramp vehicles on on-ramps as compared to 0.72 for the off-ramps.

In view of the consistency of the results of all these methods of computing accident rates (namely, in showing that the on-ramps have a much higher accident rate than the off-ramps—a finding not in agreement with certain other studies of freeway ramps in other sections of the country), evidently a closer study of the on-ramp design is in order. A later portion of this report presents analysis of a large sample of on-ramps

TABLE 5

THROUGH-LANE CREST AND SAG ACCIDENTS BY POSITION ON GRADE (All Freeways[a])

Position	No of Locations	Number of Each Type of Accident R.E	F.O	S.S.	O.C.	H O	Pedestrian	Total Accid	Miles	Accidents per Mile	Accid. per Location
Upgrade of crest	124	69	11	16	5	3	1	105	11 4	9 2	0 85
Peak of crest	124	58	14	23	6	2	0	103	5 4	19 0	0.83
Downgrade of crest	124	64	12	26	7	2	0	111	13 0	8 5	0 90
Totals—crest	372	191	37	65	18	7	1	319	29 8	10 7	0.86
Downgrade of sag	76	49	9	11	1	0	0	70	6 8	10.3	0 92
Bottom of sag	76	26	7	4	5	0	0	42	3 4	12 4	0 55
Upgrade of sag	76	68	9	17	3	2	1	100	6.4	15 6	1 31
Totals—sag	228	143	25	32	9	2	1	212	16.6	12 8	0.93
Totals—crest and sag	600	334	62	97	27	9	2	531	46 4	11 4	0 89
Tangents								180	35 0	5.1	
Total through lanes								711	81 4	8 7	

[a]Includes only sections for which profile was available (75 percent of total freeway length) and only accidents plottable on indicated portions of profile

CIDENT FREQUENCY CREST LOCATIONS

Accident Rate per 100,000 ADT	Acc $\times \frac{K}{100} \times \frac{100,000}{ADT}$	Distribution of Accidents	Distance in One Direction to Nearest Ramps	Distance in Other Direction to Nearest Ramps	Horizontal Curvature
78 2	66 5	At ends of bridge	1,300'	900'	0°
62 3	53 0	equal	650'	700'	0°
80 6	56 0	equal	600'	950'	0°
77 5	90 7	equal	none	600'	0°
90 0	96 3	at peak and beginning	350' and 650'	exit entrance 1,300'	1 5° 1,000° tangent then 3°
71 0	64 6	on 5% grade	1,100'	900'	0°
67 0	89 1	equal	250'	250'	1°
55 8	74 2	equal	700'	700'	0°
40 9	68 3	at ramp	0	none	0°
57 1	64 5	on long 1 8% downgrade	1,000'	1,400'	0°

with high accident frequency and compares them with a similar number of on-ramps with low accident frequency.

Of the 412 accidents on on-ramps, 376 (91.3 percent were of the rear-end type. This is due in part to the dividing of the attention of the entering drivers between oncoming through-lane traffic and vehicles preceding them on the ramp. Several "false-start" accidents occurring on certain ramps have been by chance recorded in motion pictures during the filming of many hours of freeway operation. The false-start accident occurs when a driver preparing to enter the through lanes of the freeway comes to a stop, often quickly and at the very edge of the outside through lanes. At the last minute he has decided to reject a particular gap in the freeway traffic stream. The following driver on the ramp, probably watching in turn for his entering opportunity, assumes the driver ahead is going on in and he takes his attention from the vehicle ahead and a rear-end collision results. The driver of the leading vehicle on the ramp has the sole decision to enter the freeway, to slow, or to stop. Because this decision is possible right up to the time that the leading vehicle enters the outside through lane, it is important that the trailing driver maintain a safe distance behind the leading vehicle and keep the leading vehicle in his line of sight as long as the choice of slowing or stopping is possible. The design of many on-ramp approaches required the driver to look back at a very acute angle in order to evaluate the gap into which he was to move. This diversion of attention violates the principle of safe driving practices which requires the driver to keep a sharp lookout in the direction his vehicle is moving.

Analysis of data and critical examination of on-ramps indicated that the problem is "what the driver sees" as he approaches the freeway rather than simply a matter of sight distance in its common usage. Relative elevations of a ramp and freeway through lanes, grade profiles, horizontal curvature of ramp and through freeway, and the location of structures and other sight restrictions may all be important considerations.

Study of the High Accident Frequency of On-Ramps

A special study (6) of the relationships between ramp accidents and specific geometric design elements of on-ramps was conducted by selecting a group of the highest accident frequency on-ramps and a group of the lowest frequency on-ramps for direct comparison.

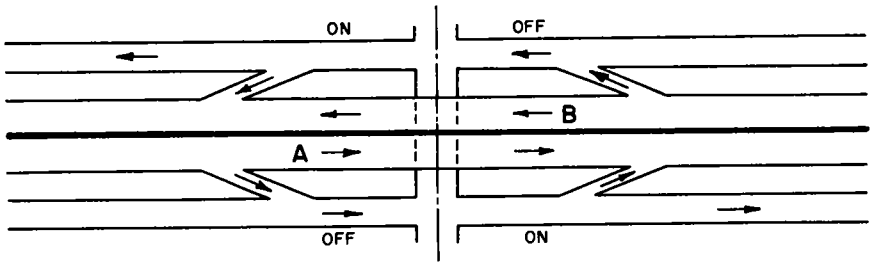
One factor considered in this analysis of selected ramps was the accident frequency on the through lanes in the vicinity of the entrance ramp junctions. Twenty-three percent of all through-lane accidents was found to be in these areas.

Inasmuch as many of the accidents could be plotted by block number only, the through-lane sections considered with each ramp were made to coincide with block lengths. The number of accidents in each of these through-lane sections was adjusted to account for the variable length of the sections. A typical study location is shown in Figure 21.

After considering several different exposure and frequency factors, the following Accident Frequency Index was chosen as a basis for comparing one ramp with another:

TABLE 6

PROXIMITY OF RAMPS TO CREST OR SAG HIGH ACCIDENT FREQUENCY LOCATIONS
(10 or More Accidents on Crest or Sag in 2 Years: 1957-1958)



Location No.	Direction	Algebraic Difference (%)	Length of Crest or Sag (ft)	Length of Crest or Sag (mi)	Distance to Nearest Ramp (ft)		No. of Accidents, 2 Years, 1957-1958
			(a) Crests				
1	A	8	2,500	0.47	1,500 off	1,200 off	11
	B				1,850 on	1,500 on	
2	A	8	1,200	0.23	700 off	550 on	24
	B				560 off	720 on	
3	A	7	1,200	0.23	500 off	500 off	18
	B				500 on	500 on	
4	A	5	800	0.15	90 on	550 off	15
	B				500 on	130 off	
5	A	10	1,100	0.21	975 off	600 on	12
	B				600 off	950 on	
6	A	6	1,100	0.21	640 off	440 on	12
	B				1,100 off	700 on	
7	A	8	1,900	0.36	720 off	770 off	12
	B				860 on	500 on	
8	A	6.4	1,150	0.22	500 off	500 on	14
	B				600 off	600 on	
			(b) Sags				
9	A	6.7	1,400	0.26	530 on	700 on	22
	B				680 off	580 off	
10	A	8.4	1,200	0.23	600 off	600 on	27
	B				580 off	550 on	
11	A	8	1,050	0.20	850 off	560 on	16
	B				570 off	580 on	
12	A	7.5	1,150	0.22	620 off	730 off	25
	B				670 on	620 on	
13	A	8	1,100	0.21	650 on	625 off	15
	B				675 on	625 off	
14	A	5	900	0.17	500 off	575 on	14
	B				525 off	575 on	

SUMMARY

NUMBER OF ACCIDENTS 237

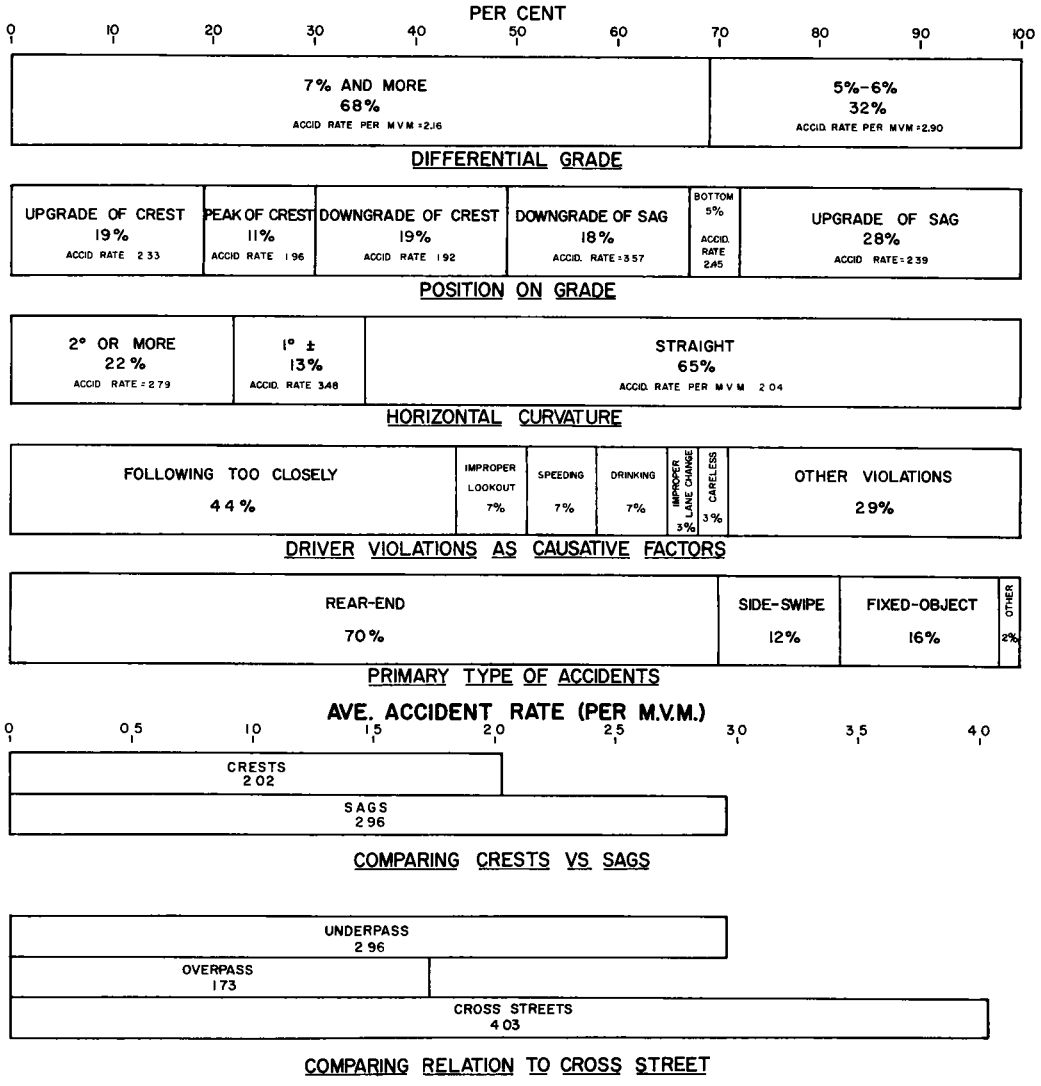


Figure 18. Factors involved in high accident frequency (10 or more in two years, 1957-58): 14 crest or sag locations on 4 freeways.

$$\text{Accident Frequency Index (AFI)} = \frac{VPF+AEF}{(VPF)(AEF)} A_R + \frac{A_{L_1}}{L_1} + \frac{A_{L_2}}{L_2} + \frac{A_{L^*}}{L}$$

VPF = Volume Product Factor—product of ramp and through-lane volumes.
AEF = Accident Exposure Factor—ratio of the two volumes.
A_R = Ramp Accidents
A_{L_1} and A_{L_2} = Through-lane accidents within L_1 and L_2, respectively (Fig. 16).
A_L = Accidents (which could be) located only by block number.
*L_1, L_2, and L = See Figure 16.

TABLE 7

FREEWAY RAMP ACCIDENTS FOR YEAR 1957

(a) All Ramps

Freeway Code No [a]	No of Ramps	No of Ramp Accidents	Percent of All Accidents	Average Number of Accident per Ramp	Most Accid. of Any Ramp
1	78	113	26	1.45	18
2	26	13	10	0 50	3
3	47	24	10	0 51	7
4	64	154	21	2 41	19
5	51	90	26	1 76	31
6	59	56	19	0.95	9
7	50	25	15	0 50	6
8	17	8	11	0.47	4
9	14	14	26	1 00	3
10	10	1	5	0 10	1
Summary	416	498	20	1 20	31

(b) Ramps for Which Ramp Volume and Through-Lane Volume Were Available

Freeway Code No [a]	No of Ramps	No of Ramp Accidents	ADT Volume per Ramp	Ave. Accid Frequency Index	Vol Prod Factor per Ramp (M)	Ave. Volume Product Accid Rate/(M)	Total Ramp Vehicles (M)	Accid Rate per (M) Ramp Veh
1	78	113	1,805	15 7	39 04	0.031	51.5	2.19
2	20	13	1,420	3 0	15.51	0.028	10.4	1 25
4	40	119	3,660	34.7	129 34	0.024	53.4	2.23
5	29	70	1,865	19 8	32.40	0 100	19 7	3.55
6	35	52	1,765	5.7	17.24	0 069	22 8	2 28
7	32	18	1,334	3.1	13.13	0.032	15 6	1.15
Summary	234	385	2,026	15 2	44 84	0.044	173 4	2.22

[a] See Table 1

TABLE 8

FREEWAY RAMP ACCIDENTS FOR YEAR 1957

(a) All On-Ramps

Freeway Code No.	No of Ramps	No. of Ramp Accidents	Percent of all Ramp Accidents	Average Number of Accid per Ramp	Most Accid on Any Ramp
1	39	108	96	2 77	18
2	12	7	54	0 58	3
3	22	16	67	0 73	7
4	34	130	84	3 53	19
5	25	81	90	3 24	31
6	30	33	59	1.10	9
7	21	20	80	0 95	6
8	8	5	63	0.63	4
9	7	11	79	1.57	3
10	5	1	100	0.20	1
Summary	203	412	82	2 03	31

(b) On-Ramps for Which Ramp Volume and Through-Lane Volume Were Available

Freeway Code No.	No. of Ramps	No. of Ramp Accidents	ADT Volume per Ramp	Ave Accid. Frequency Index	Vol Prod Factor per Ramp (M)	Ave. Volume Product Accid. Rate/(M)	Total Ramp Vehicles (M)	Accid Rate per (M) Ramp Veh.
1	39	108	1,820	29 6	38 41	0 058	25 9	4.17
2	10	7	1,790	2.8	21.00	0 019	6.6	1 06
4	22	104	3,640	55.2	119.44	0.039	29 2	3.56
5	15	65	1,933	33 6	33.46	0.171	10.6	6 13
6	19	31	1,694	5.3	16.09	0 059	11 7	2.65
7	12	15	1,311	5 0	11 38	0.062	5.8	2.59
Summary	117	330	2,100	26.2	45.13	0.066	89 8	3 75

Complete ramp and corresponding freeway through-lane volume data were available for 69 ramp locations varying from one to four years of data. This resulted in an aggregate of 253 "ramp-year" samples for study. These 253 samples were then categorized into two groups according to high and low accident frequency. From this listing a total of 25 on-ramps having low frequency and 25 high frequency on-ramps were selected to determine if there were any independent geometric features related to accident frequency.

Simple plots were made for each geometric feature for both the high frequency and low frequency ramps. These are shown in Figures 22 through 34. The cumulative

TABLE 9

FREEWAY RAMP ACCIDENTS FOR YEAR 1957

(a) All Off-Ramps

Freeway Code No	No of Ramps	No of Ramp Accidents	Percent of All Ramp Accidents	Average Number of Accid per Ramp	Most Accidents on Any Ramp
1	39	5	4	0 13	1
2	14	6	46	0.43	3
3	25	8	33	0 32	5
4	30	24	16	0.80	4
5	26	9	10	0 35	2
6	29	23	41	0 80	4
7	29	5	20	0 17	2
8	9	3	38	0 33	1
9	7	3	21	0 43	1
10	5	0	0	0 00	0
Summary	213	86	18	0.40	5

(b) Off-Ramps for Which Ramp Volume and Through-Lane Volume Were Available

Freeway Code No	No of Ramps	No of Ramp Accidents	ADT Volume per Ramp	Ave Accid Frequency Index	Vol. Prod Factor per Ramp (M)	Ave Volume Product Accid Rate/(M)	Total Ramp Vehicles (M)	Accid Rate per (M) Ramp Veh.
1	39	5	1,790	1 7	39 67	0 005	25 6	0.20
2	10	6	1,050	3 1	10 00	0 036	3 8	1 58
4	18	15	3,680	9 5	141 44	0 006	24 2	0 62
5	14	5	1,790	5 1	31 27	0 025	9 1	0 55
6	16	21	1,848	6 3	18 60	0 081	11.1	1.89
7	20	3	1,347	1 9	14 17	0 014	9 8	0.31
Summary	117	55	1,950	4 1	44 55	0.022	83 6	0 67

frequency curves indicate the number of on-ramps in each of the two groups at or below any particular value of the element being evaluated.

The geometric features evaluated were:

Ramp Spacing (Fig. 22). —The cumulative frequency curves which compare the spacing to adjacent ramps indicate no effect of ramp spacing on the frequency of accidents at any ramp.

In other research (7), the accident frequency was related to average spacing between ramps. This approach was applied to each of the 10 freeways in this study. Compari-

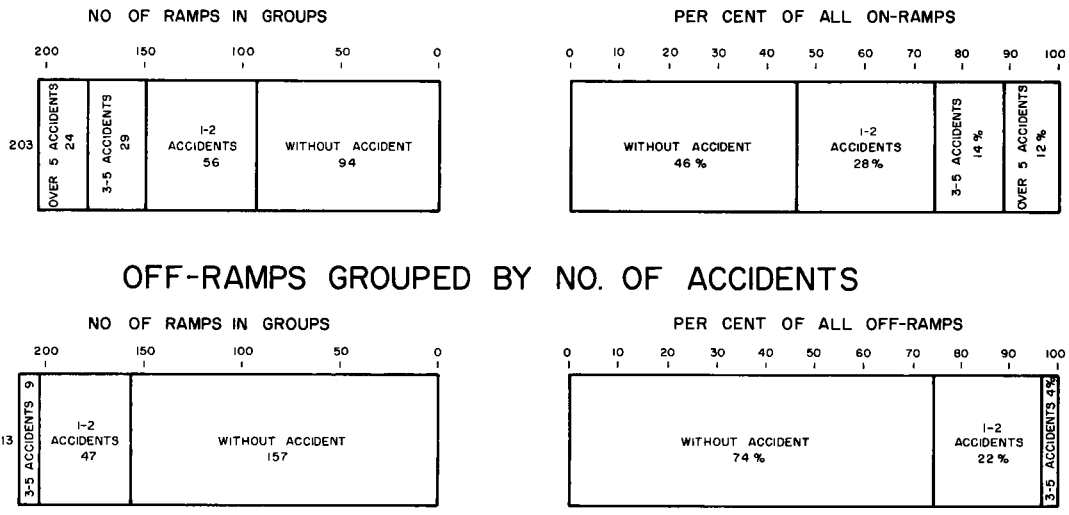


Figure 19. On-ramps grouped by number of accidents.

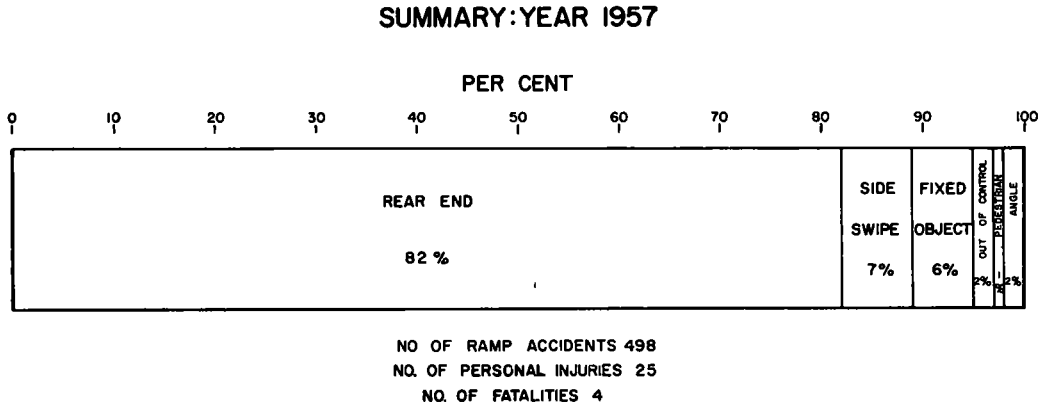


Figure 20. Comparison of ramp accidents by type and by severity.

son of the results of this investigation with the continuous collision diagrams showed the results to be very misleading. A few very long or very short spacings between successive ramps unduly influenced the correlations. The heavier concentrations of accidents at certain ramps appeared to be unrelated to the spacing between successive ramps except that some of the ramps with minimum spacing indicated an influence of this factor.

Length of Ramp (Fig. 23). —The selected high and low frequency ramps showed no correlation between accidents and the length of the ramp.

A grouping of all ramps, both on and off, according to length and the accident frequencies (volume product accident rate) were compared (Fig. 24). There was no indication that ramp length alone was directly related to the frequency of accidents.

Type of Speed-Change Lane (Fig. 25). —On-ramps were classified according to the design of their terminals with the through freeway lanes. Figure 21 shows the number of high and low frequency ramps with each type of speed-change lane. Ramps with long taper design and those with auxiliary lane design (continuous between on-ramp and adjacent off-ramp) are indicated to be more prevalent in the low accident group. It should be noted, however, that the samples of ramps with either long taper or long acceleration lane were too small to be reliable for comparison.

To obtain a greater sample of ramps in each speed-change lane category, all ramps for which volume data were available were compared. Ramps with acceleration lanes and those with auxiliary lanes showed lower volume product accident rate as indicated in Figures 26 and 27 and Table 10.

Junction of Ramp with Through Lanes Related to Vertical Alignment of Freeway (Fig. 28). —The location of the ramp junction for each of the 25 high-frequency and 25 low-frequency on-ramps is shown in Figure 28 in relation to the vertical alignment of the through freeway lanes. There was no strong correlation indicated by this plot.

Distance to Nearest Structure (Fig. 29). —In Figure 29 the distances ahead and back to the nearest structure are evaluated. This cumulative frequency curve shows no indication that this factor by itself was directly related to the accident frequency.

Difference in Elevation and Relative Gradient Between the Ramp and Freeway (Fig. 30). —The fifty selected on-ramps were plotted according to the difference in elevation between the ramp and freeway 200 ft in back of the ramp junction. The relative gradient between the ramp and freeway is also shown. These cumulative frequency curves showed nothing significant about this single factor.

Ramp Width (Fig. 31). —Studies of on-ramp traffic operation (2) have shown that ramps wide enough to permit two-lane operation experienced sluggish and inefficient operation. The widths of the ramps at the ramp nose and 100 ft back from the nose are compared in Figure 31 for the high and low accident frequency ramps. Effect of ramp width is not indicated in these cumulative frequency curves.

Horizontal Curvature of Ramp and Freeway (Fig. 32). —The horizontal curvature of the ramp and of the freeway is shown in Figure 32. The curvature of the high frequency group and of the low frequency group was quite comparable and provided no indication that this factor alone contributed to accident frequency.

Angle Between Ramp and Freeway (Fig. 33). —Operation studies (1) indicated that traffic on-ramps approaching the freeway at very low angles operated with fewer stops and otherwise much smoother flow. The 50 selected ramps illustrated in Figure 33 failed to show any effect of this single factor. None of the ramps studied, however, had what would be termed a "flat" angle of approach; they all aimed the ramp vehicle along a path which encouraged direct entry into the freeway.

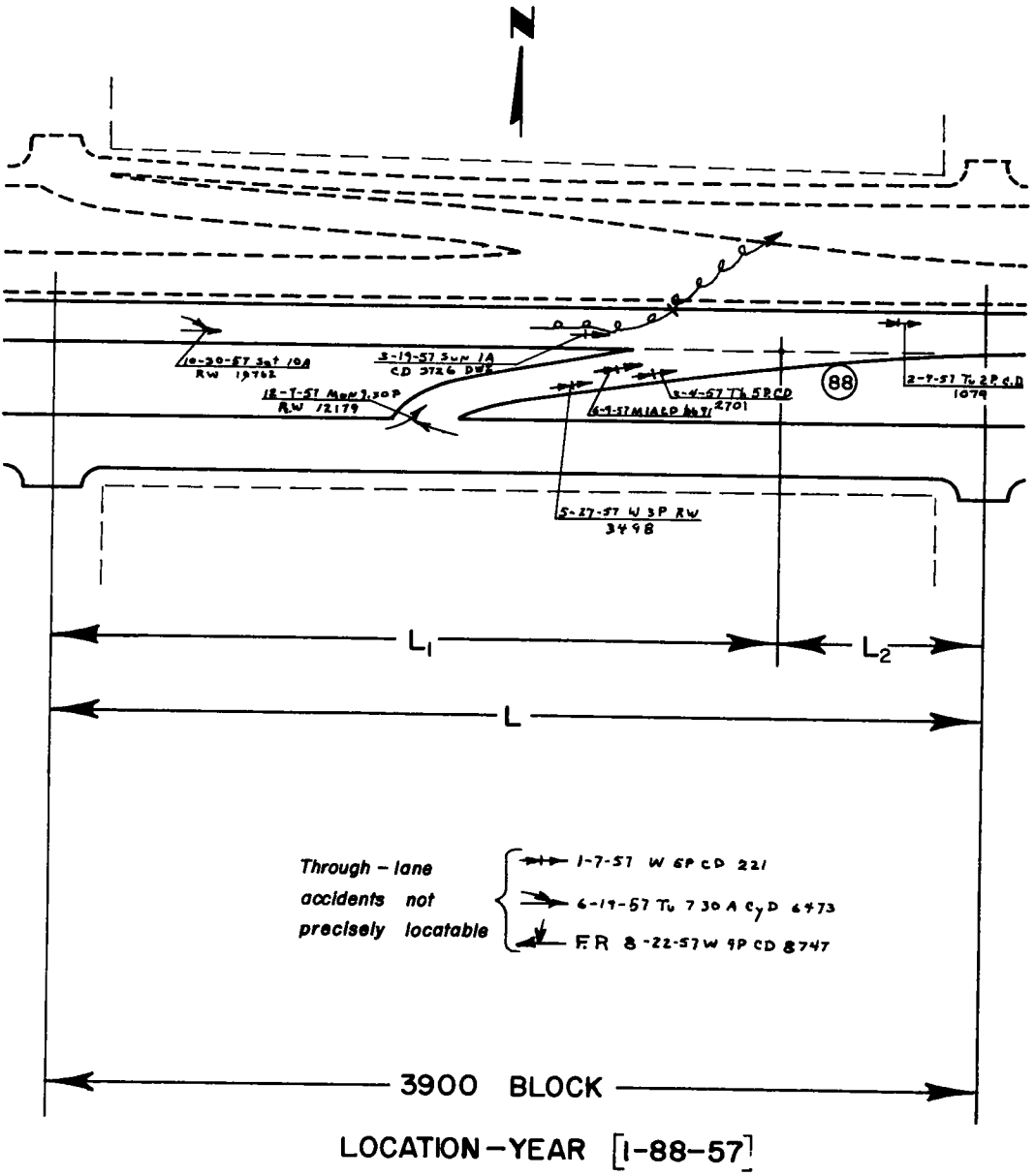
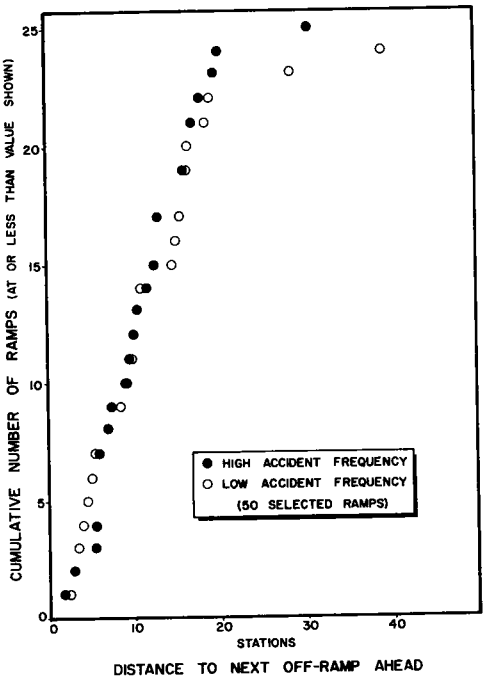
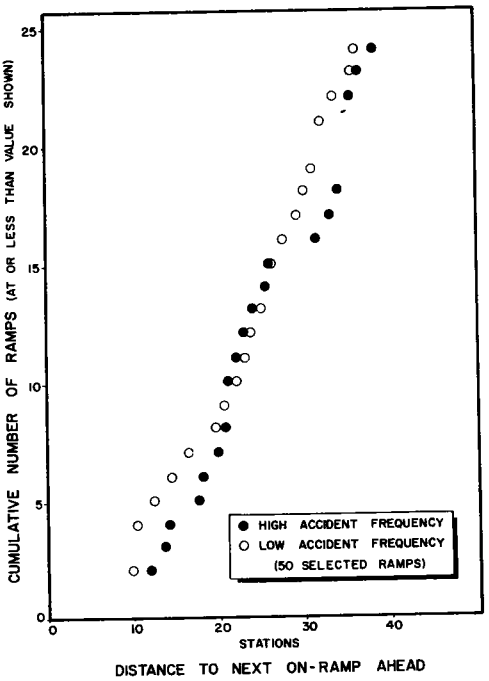
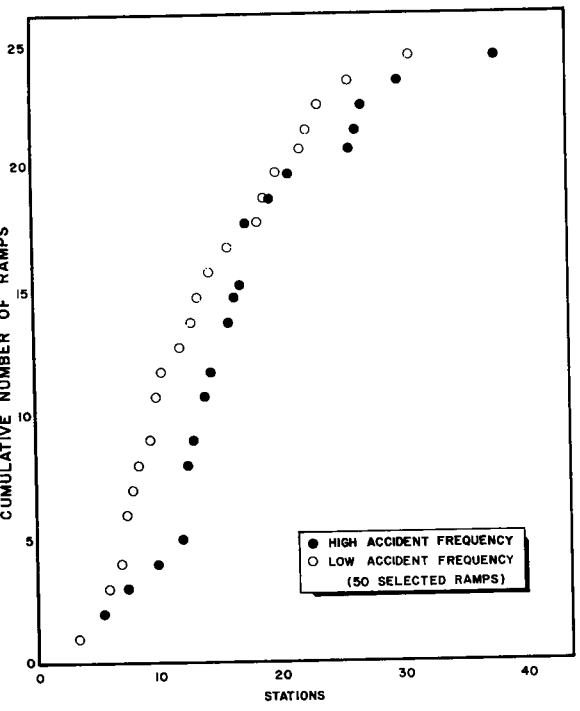


Figure 21. Typical study location.







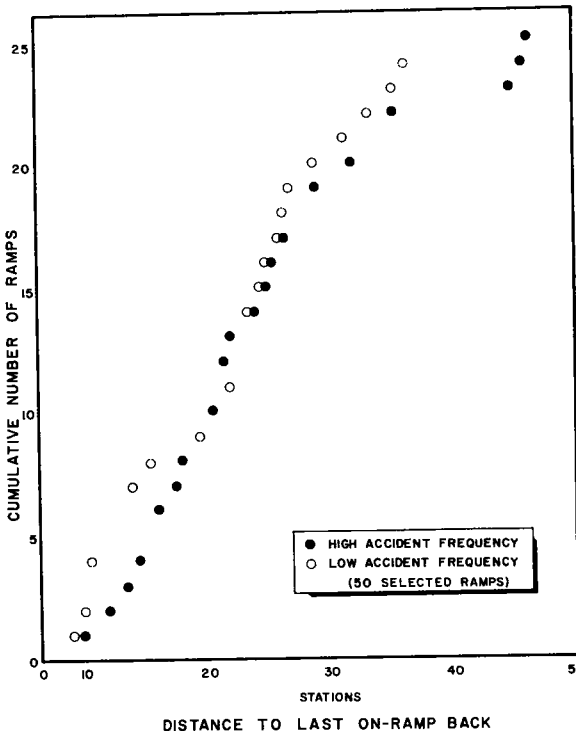


Figure 22. Ramp spacing.

Volume (Fig. 34).—The freeway volumes at the ramp sites were greater for the high accident on-ramps than for the low frequency ramps as shown in Figure 34. The accident frequency index incorporated several volume and volume-combination factors as well as accident frequency, and served as the basis for selecting the high and low accident frequency categories. The low accident frequency group had accident frequency indices ranging from 0 to 4, while the high frequency group had indices ranging from 70 to 397.

There is no question that the relationships between through-lane and ramp volumes are vital in analyzing the relative safety of various design elements. The accident frequency index (AFI) developed and used in this study is probably not the best for relating the volume and accident characteristics. Additional studies are needed and are recommended to develop a reliable and easily applied index of accident frequency.

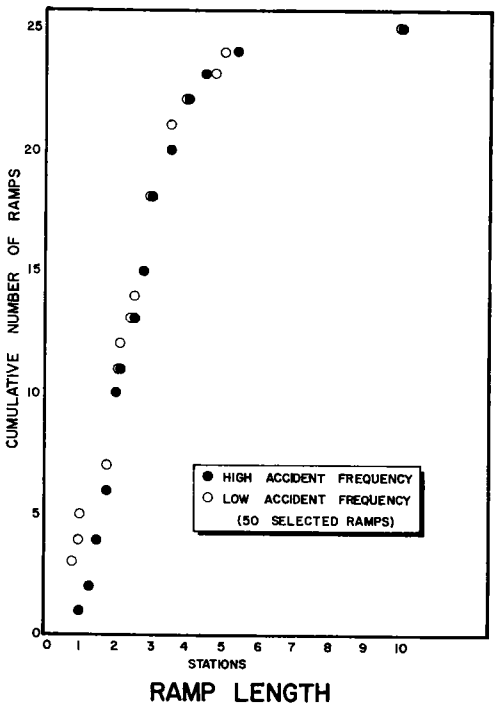


Figure 23.

Summary of On-Ramp Study

From these plots, no relationships were felt to be strong enough to indicate that a single design element by itself contributed greatly to the accident experience. The complexity of the entering maneuver, coupled with the fact that few if any ramps had identical combinations of geometric elements, invalidated any relationship of a single element with accident experience. Several attempts to determine multiple correlations showed that no particular combinations of design elements were consistent in either the high or low frequency categories.

The closest combination of elements appeared to be these:

High Accident Frequency Ramps.—(a) freeway under structure back, (b) distance back to structure less than about 750 ft, (c) freeway upgrade at the junction of ramp with freeway, and (d) direct entry.

Low Accident Frequency Ramps.—(a) long acceleration or auxiliary lane, (b) distance back to structure greater than about 750 ft, and (c) freeway downgrade at the junction of ramp with freeway.

The sight relationship afforded both ramp and freeway drivers is of primary importance. The highest accident frequency ramps studied incorporated a combination of factors which reduced the effective sight condition afforded either the ramp driver, freeway driver or both (Figs. 35-38).

Off-Ramp Study

Off-ramps had much lower accident frequencies than on-ramps. This was true regardless of the accident frequency rate or index used for comparison.

Off-Ramp Speed-Change Lane Design.—Data for all off-ramps and for those with available volume data are presented in the same manner as for on-ramps (Table 9 and Figures 26 and 27). In examination of Figure 26 where each type of speed-change lane is shown, the auxiliary lanes appear to be no better than the direct off-ramp design. However, as in the case with on-ramps, off-ramps with speed-change lane design showed a lower volume product accident rate than all ramps without speed-change lane design as indicated in Figure 27. The accident frequency on off-ramps was very low. For this reason, the reliability of the comparisons between ramps of various designs is questionable.

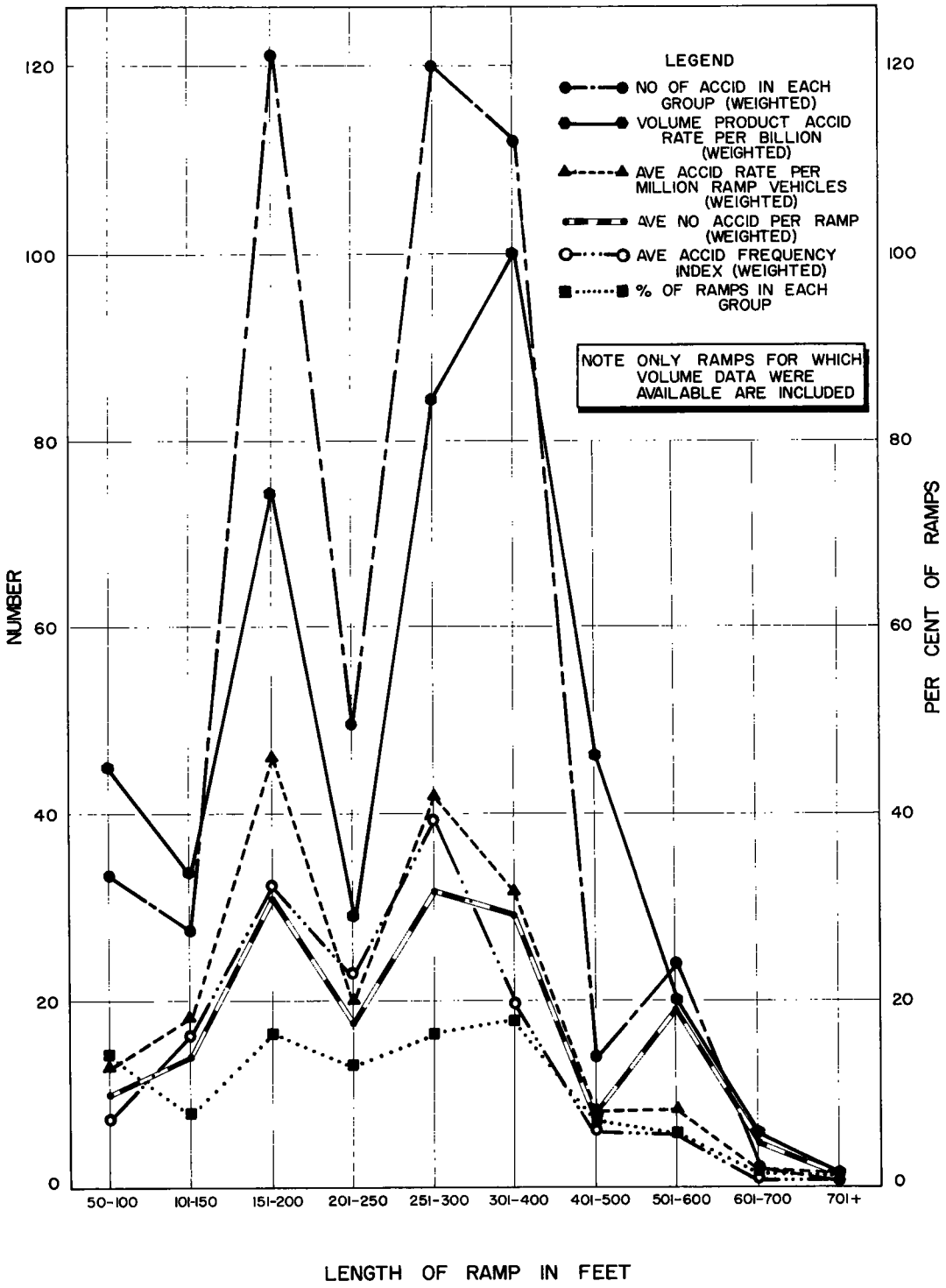
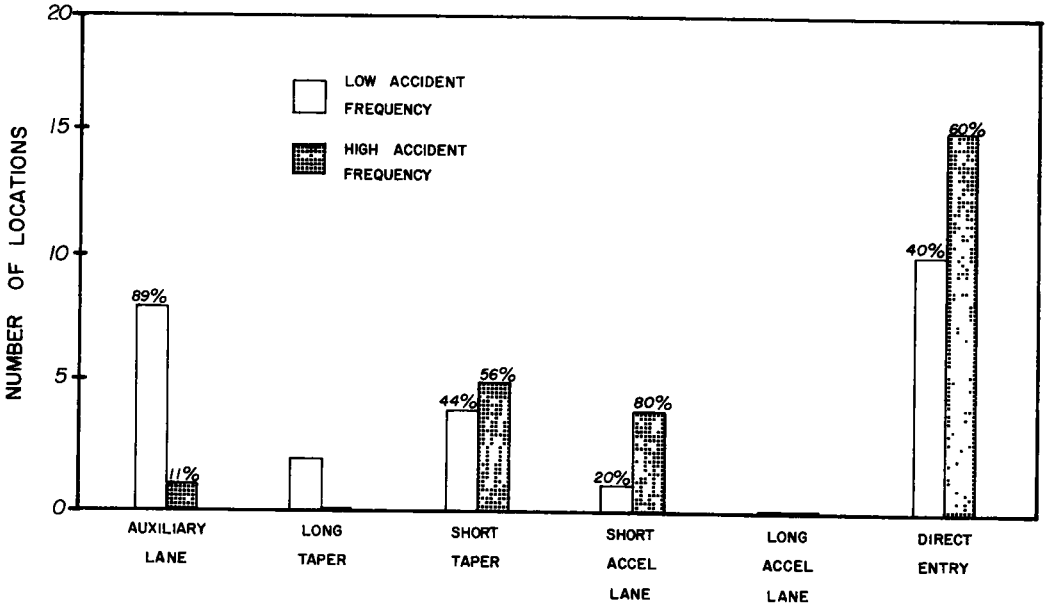


Figure 24. Comparison of ramp accidents by length of ramp.



1. Long taper: distance from ramp nose to end of taper of right curb curb line of ramp $>$ 400 feet.
2. Short taper: distance from ramp nose to end of taper of right curb line of ramp is $>$ 200 feet and $<$ 400 feet.
3. Short acceleration lane: full width of lane; $<$ 300 feet.
4. Long acceleration lane: full width of lane; $>$ 300 feet.
5. Auxiliary lane: an additional lane ahead of ramp extending to the next off-ramp ahead.
6. Direct entry: distance from ramp nose to end of taper of right curb of ramp $\leq$ 200 feet.

Figure 25.

Comments already made on on-ramps regarding length and spacing between ramps apply in general to off-ramps also. No special study was made of high accident frequency off-ramps, except such as will be reported under "Fixed-Object Accidents."

FIXED-OBJECT ACCIDENTS

Proportion and Severity of Fixed-Object Accidents

Fixed-object accidents accounted for 12 percent of the total freeway accidents and were generally among the more severe accidents (Fig. 39). Therefore, a separate study was made of all accidents involving fixed objects.

It is interesting to note that the fixed-object accident rate per million vehicle-miles was lowest on the two freeways having highest volume and greatest length, averaging 0.250 for these compared to 0.720 for the other eight freeways.

Distribution of Fixed-Object Accidents on General Features of Freeway

Fixed-object accidents were more frequent along the through lanes than on other features of the freeway (Fig. 40). Two-thirds of all fixed-object accidents occurred on the through lanes. Perhaps higher speeds attainable on through lanes were a factor, because speeding was often charged as a violation by one or more drivers involved in fixed-object accidents.

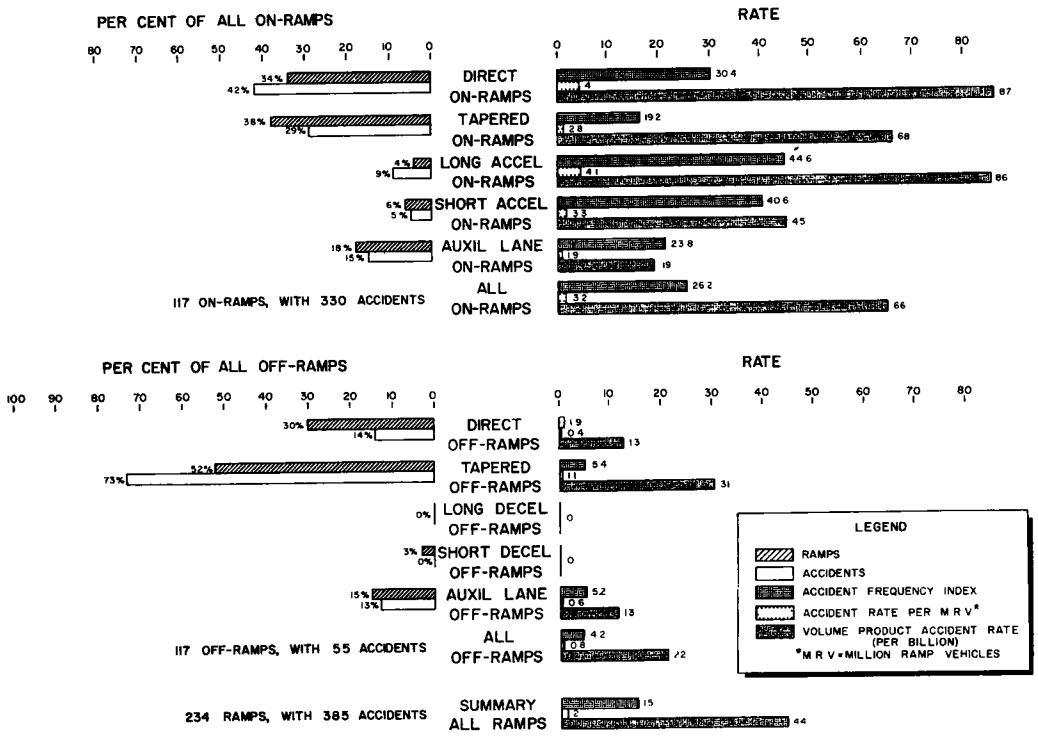


Figure 26. Comparison of ramp accidents by design of ramp terminal, all freeways, 1957.

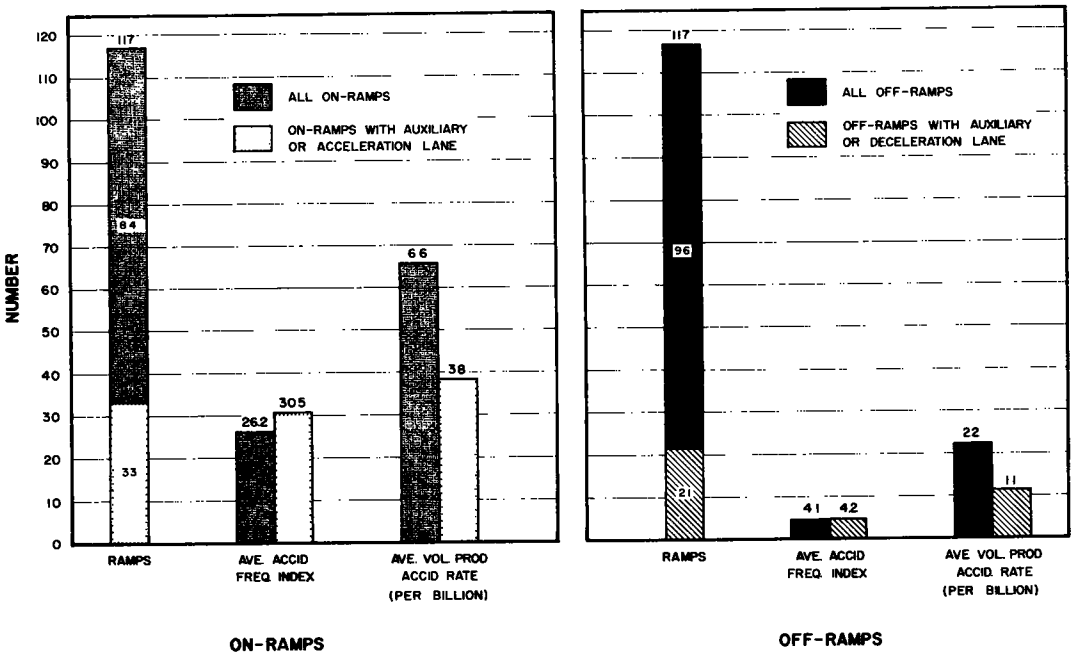


Figure 27. Ramps with speed-change lane compared with all on-ramps and with all off-ramps for six freeways with available volume data, 1957.

TABLE 10

FREEWAY RAMP ACCIDENTS FOR YEAR 1957

(a) On-Ramps with Acceleration or Auxiliary Lane

Freeway Code No	No of Ramps	Percent of All On-Ramps	No. of Ramp Accidents	Percent of On-Ramp Accidents	Average Number of Accid per Ramp
1	4	10	3	3	0 75
2	8	67	4	57	0.50
3	15	68	11	69	0.73
4	17	50	88	66	5 18
5	5	20	9	11	1 80
6	5	17	1	3	0.20
7	9	43	6	30	0.67
8	2	25	0	0	0.00
9	2	29	1	9	0.50
10	3	60	0	0	0.00
Summary	70	30	123	33	1.77

(b) On-Ramps with Acceleration or Auxiliary Lane for Which Ramp Volume and Through-Lane Volume Were Available

Freeway Code No	No. of Ramps	No of Ramp Accidents	Average Number of Accid per Ramp	Ave. Accident Frequency Index	Ave. Volume Product Accident Rate/(M)
1	4	3	0.75	2.5	0.013
2	8	4	0.50	3 0	0 016
4	14	75	5 36	64 4	0.040
5	4	8	2 00	15.3	0.058
7	3	6	2.00	3.7	0.090
Summary	33	96	2.91	30.5	0.038

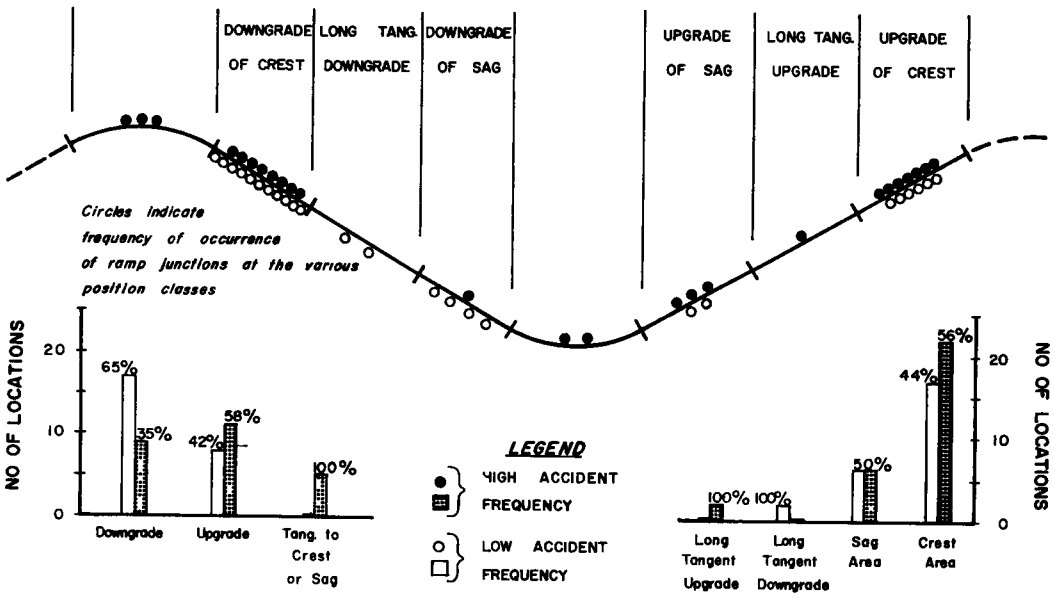
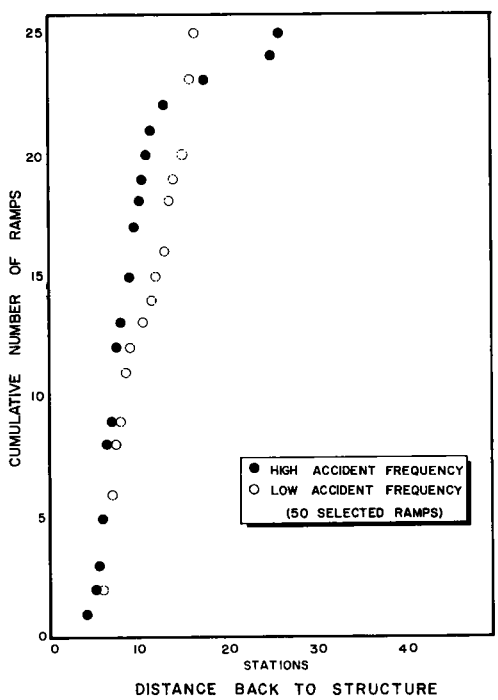


Figure 28. Junction of ramp with through lanes related to vertical alignment of freeway.



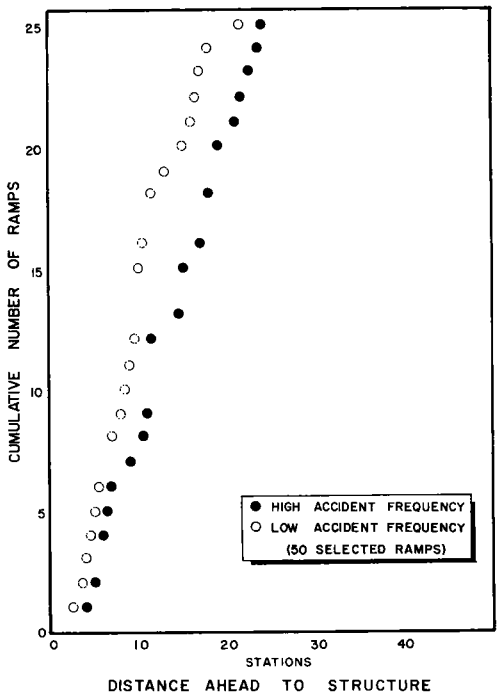
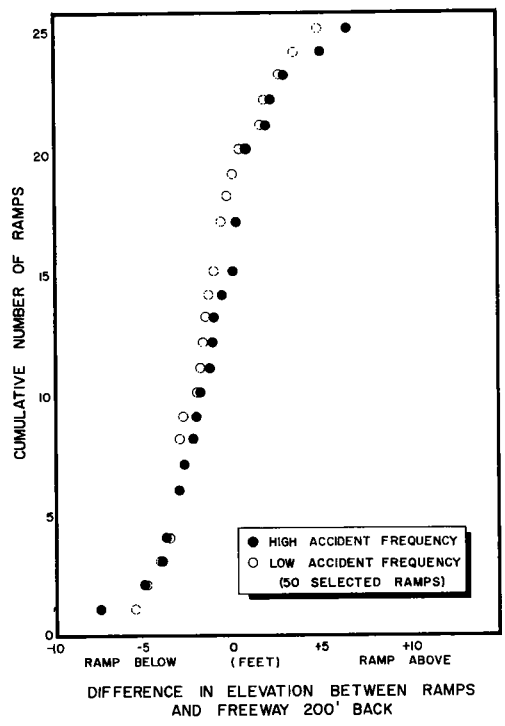


Figure 29. Relationship of ramp to structure.



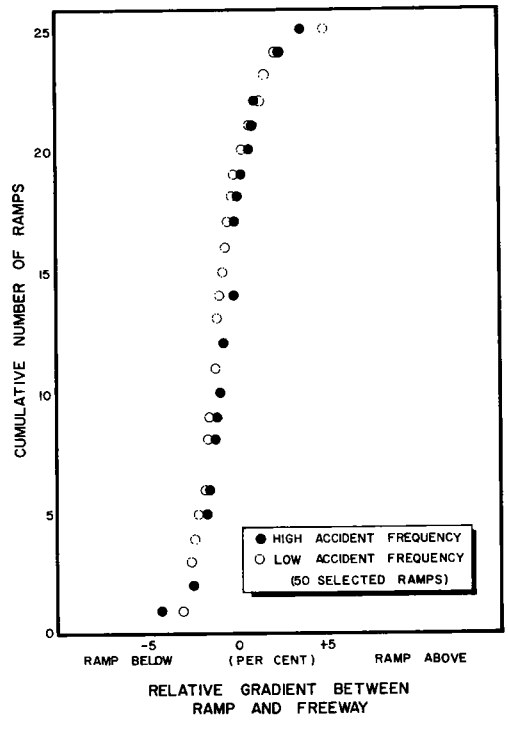
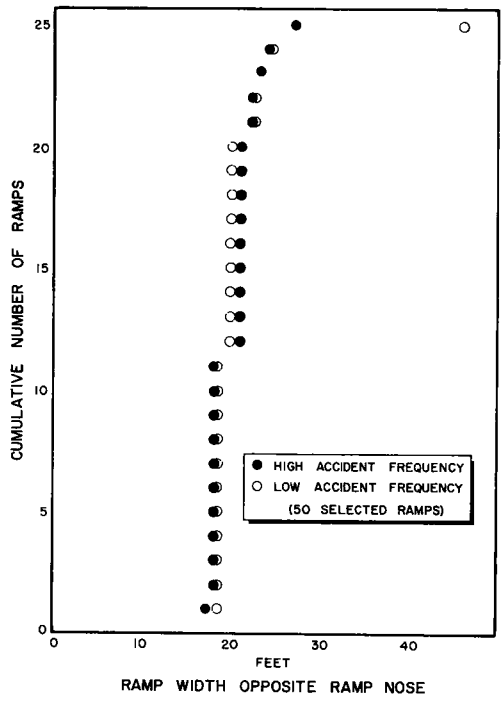


Figure 30.



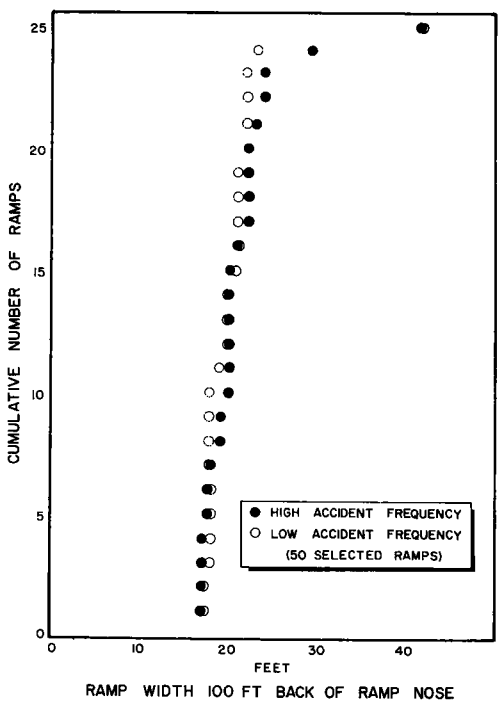
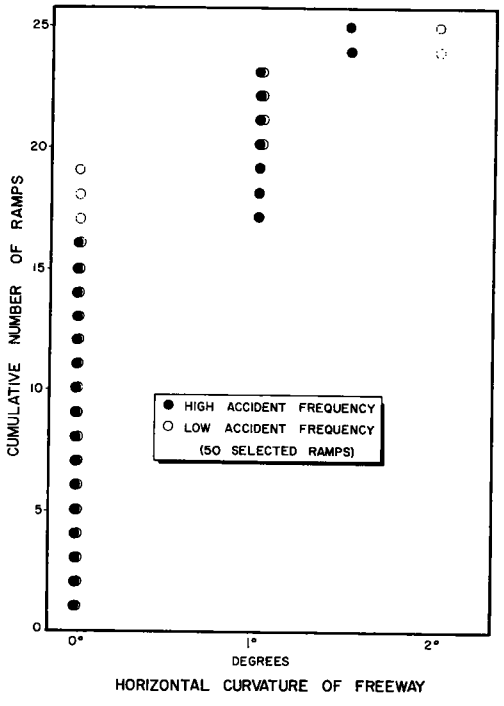


Figure 31. Ramp width.



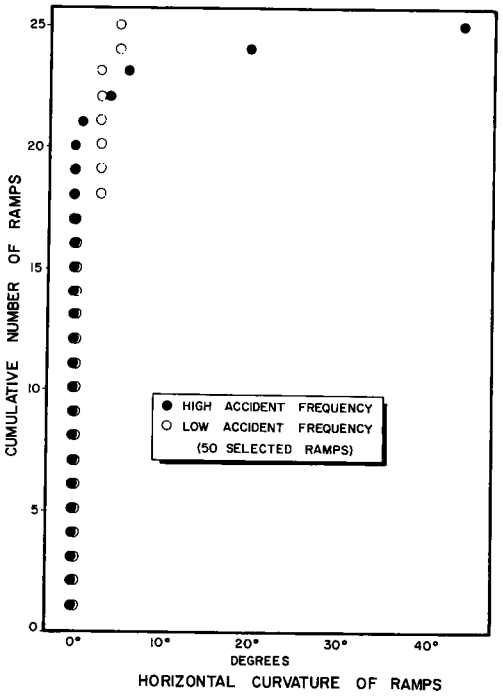


Figure 32. Horizontal curvature.

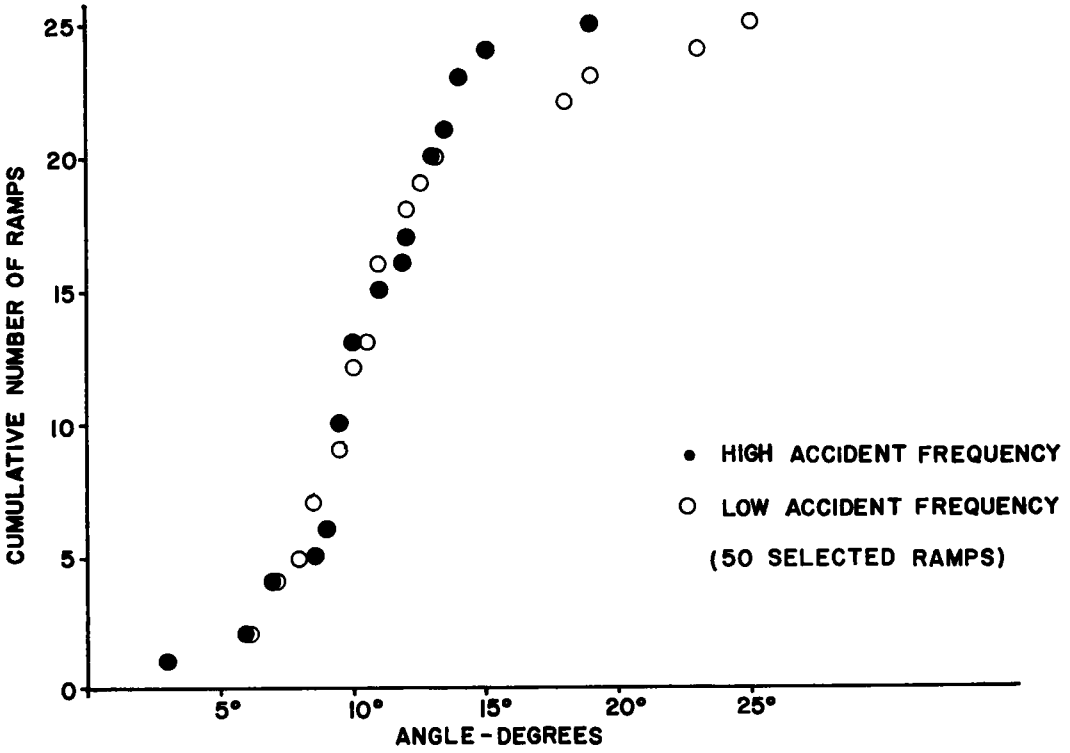


Figure 33. Angle between ramp and freeway.

A search was made along each strip map to determine if any specific fixed object, specific type of fixed object or specific location showed high accident frequency. There were 12 locations where the same fixed object had been struck two or more times in the 2-yr period. Three-fourths of these were located at off-ramps.

Fixed-object accidents on all ramps accounted for 13 percent of all fixed-object accidents. Most of these (70 percent) were on exit ramps (Fig. 41). A study of the strip maps showed that about 56 percent occurred at the freeway end (or entrance) of the off-ramp, 13 percent in the middle of the ramp, 22 percent at the exit end, and 9 percent at an unknown location on ramp. There appeared to be no correlation as to the specific design of the ramp itself. However, the frequency of fixed-object accidents was somewhat higher in those instances where the off-ramp was located beyond and relatively near a freeway overpass.

There was no correlation for the fixed-object accidents on entrance ramps.

The fixed object was the primary contributing factor in all of the off-ramp fixed-object accidents, whereas the fixed object was secondary in one-third of the entrance or on-ramp accidents. The fixed object was considered secondary if the vehicle was in collision with another vehicle prior to striking the fixed object on the ramp.

Types of Fixed Objects and Frequency of Collision

The types of fixed objects most frequently struck were median curbs and median guardrails, other curbs, sign posts, and luminaire standards as indicated in Figure 42.

The Median and Fixed-Object Accidents

The median was involved in 34 percent of the 630 total fixed-object accidents. Of the 214 median accidents, 22 percent struck a median guard fence. Where no guard

fence was present, 40 percent crossed the median, nearly one-half of them striking a car in the opposing lanes, resulting in 42 injuries and 3 fatalities. A "before" and "after" study of a median guard fence has been previously reported (4). Figure 43 and Table 11 show the change in median design and the accident experience during the four years of that study. The average daily traffic at one of the highest volume locations on this freeway increased from 69,000 to 81,000 during the time. Although the total accident rate per 100 million vehicle-miles increased (195.94 before to 232.93 after), the rate of the severe accidents decreased slightly (personal injury 26.33 before to 24.34 after and fatal 2.63 before to 2.01 after).

The median accident rate was only slightly reduced from 13.56 before to 11.71 after. By contrast, the severity of the median accidents was materially reduced. There were 4 fatal median accidents before compared with none after, and 28 personal injury accidents involving the median before compared with 11 after.

Study of 172 fixed-object accidents involving the medians in the study of the 10 freeways revealed few placed along the medians where a concentration of fixed-object accidents was noted (Fig. 44).

Frequency of fixed-object median accidents seemed to have little, if any, relationship to the variations in horizontal curvature or profile grade of the freeway, except possibly where grades of 3 percent or more were concerned.

Lateral Curbs

Analysis of 148 fixed-object accidents involving lateral curbs showed no positive influence of horizontal curvature or profile grade of the freeway through lanes (Fig. 45).

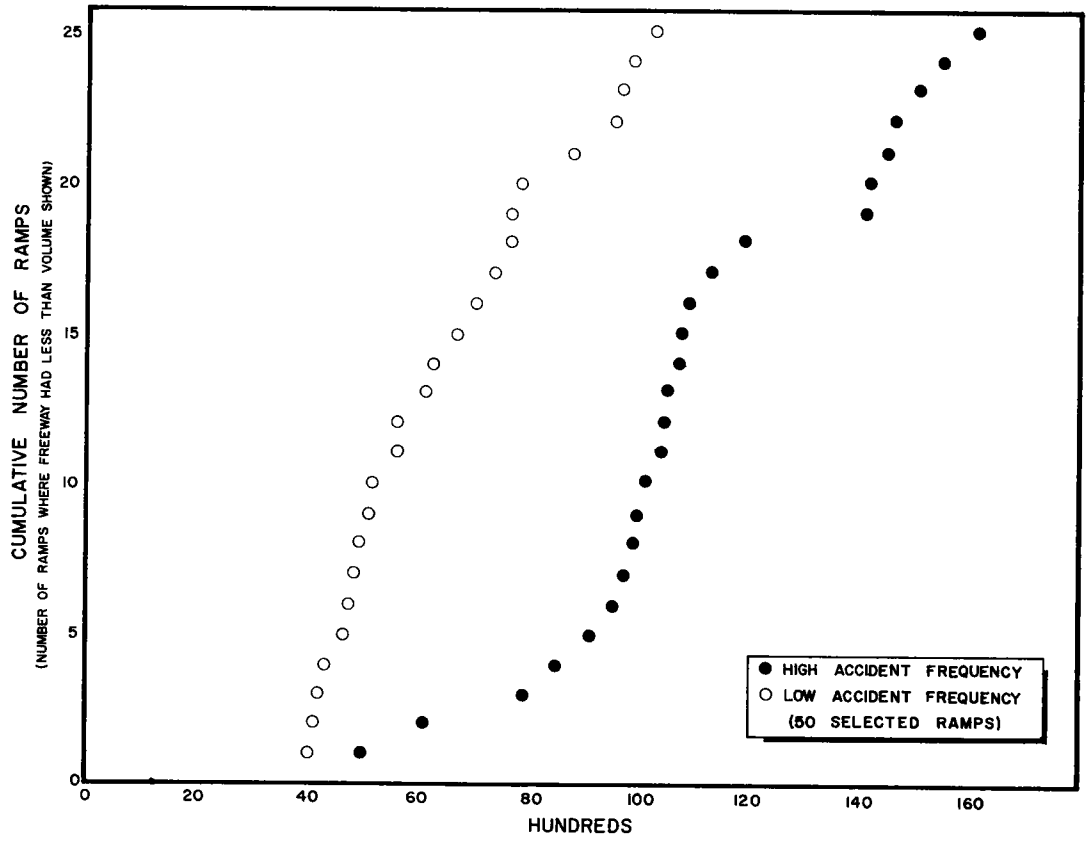


Figure 34. Average daily traffic per through lane (beyond ramp).

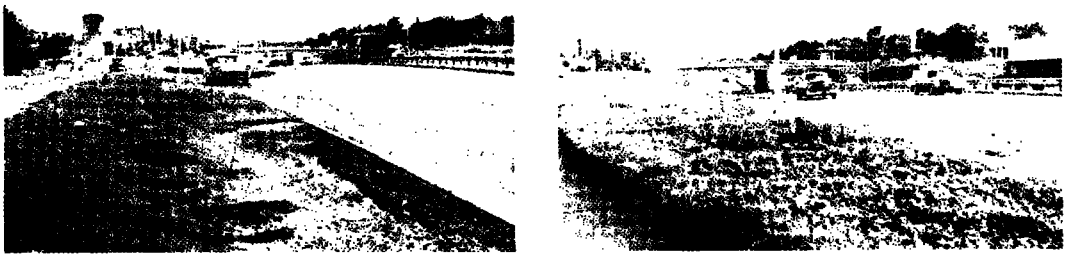


Figure 35. On-ramp outbound from Fitzhugh Avenue, North Central Expressway, Dallas: Left—looking back from end of ramp terminal opening, and right—driver's view of freeway looking back from ramp.

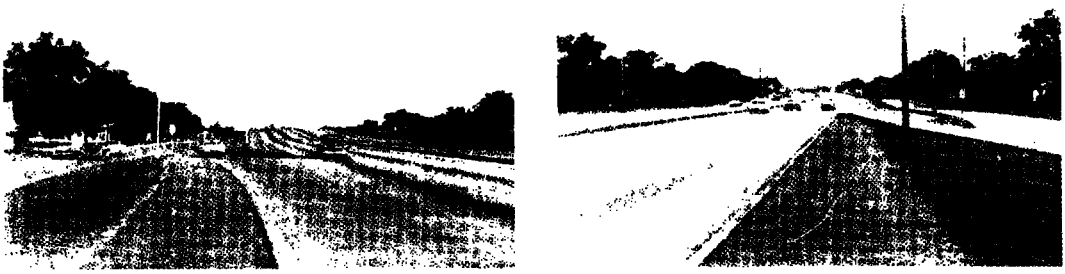


Figure 36. On-ramp inbound from Metropolitan Drive, South Central Expressway, Dallas: Left—view from auxiliary lane, and right—view from freeway.

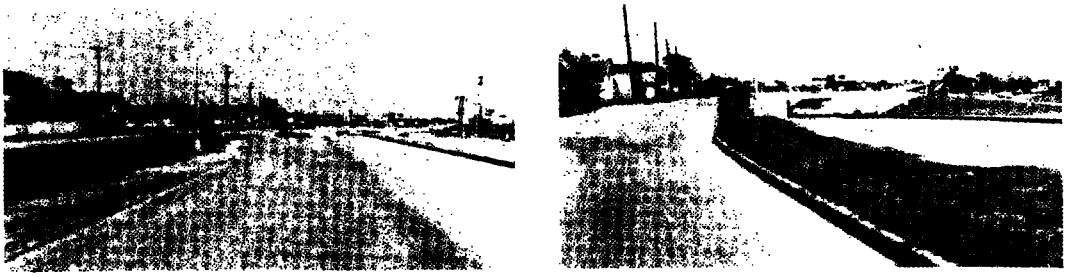


Figure 37. On-ramp outbound from Horne Street, East-West Freeway, Fort Worth: Left—view from auxiliary lane, and right—driver's view of freeway looking back from ramp.

Figure 38. On-ramp outbound from University Drive, East-West Freeway, Fort Worth: Left—driver's view of freeway looking back from ramp, and right—view from freeway.

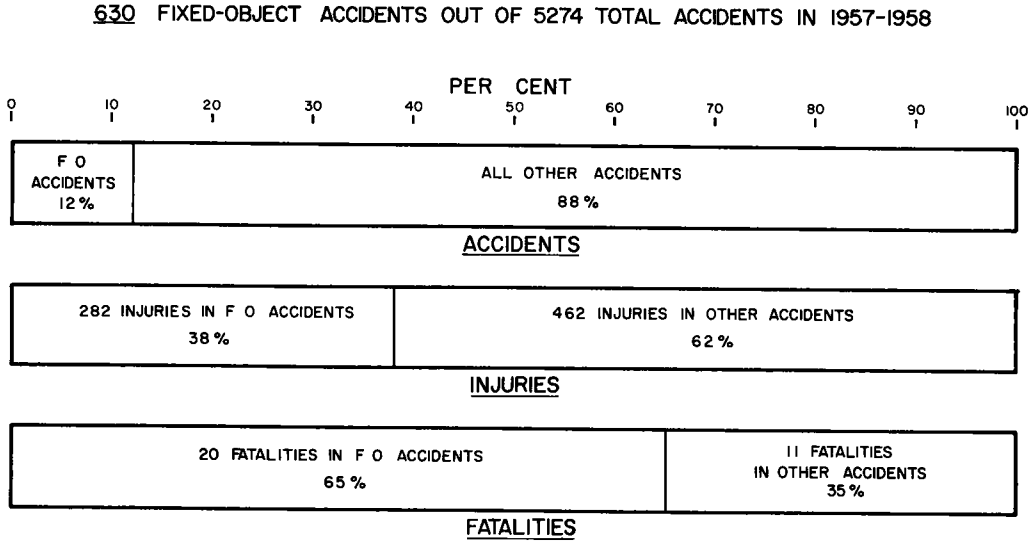


Figure 39. Comparison of number and severity of fixed-object accidents to all accidents.

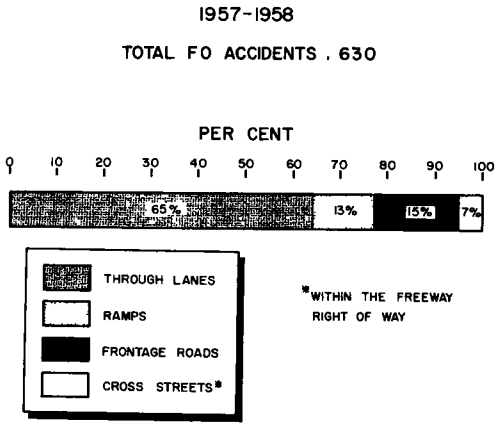


Figure 40. Comparison of fixed-object accidents by freeway features: all freeways.

Review of Diagrams

A review was made of accident diagrams at the 12 locations where the same fixed object or the same design element of the freeway was struck two or more times in the 2-yr period. Four examples of such diagrams are given in Figures 46, 47, 48, 49. The review of the 12 diagrams showed the following:

1. Most fixed-object accidents occurred where there was a significant change in direction of the normal vehicular path. On four of the nine off-ramps included in the 12 special locations, the angle of ramp divergence from the through lanes was large—21 to 33 deg.

The profile grade of each of these four ramps was downgrade about 4 percent. In addition, two off-ramps in this group of nine had rather steep upgrade slopes (4 percent).

2. In four of the off-ramps involved, the profile of the outside freeway lane

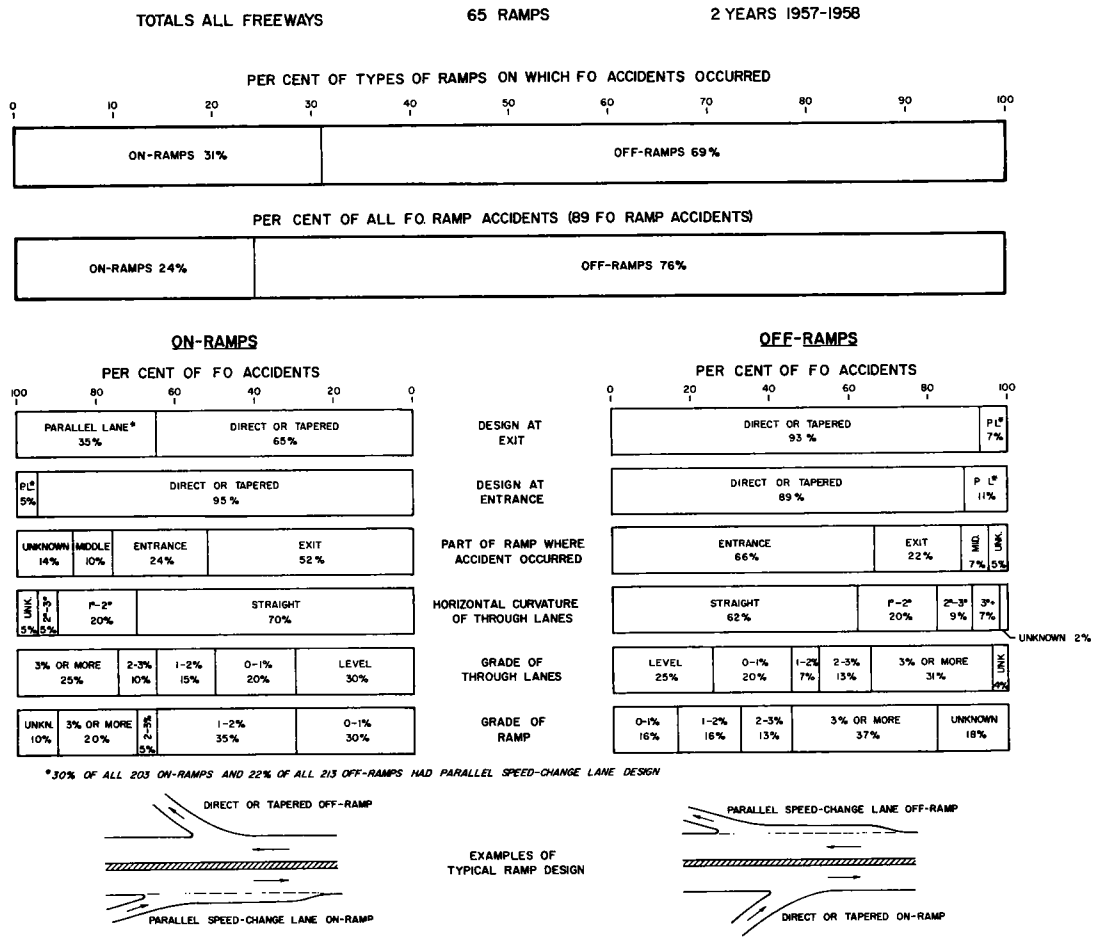


Figure 41. Design features related to fixed-object ramp accidents.

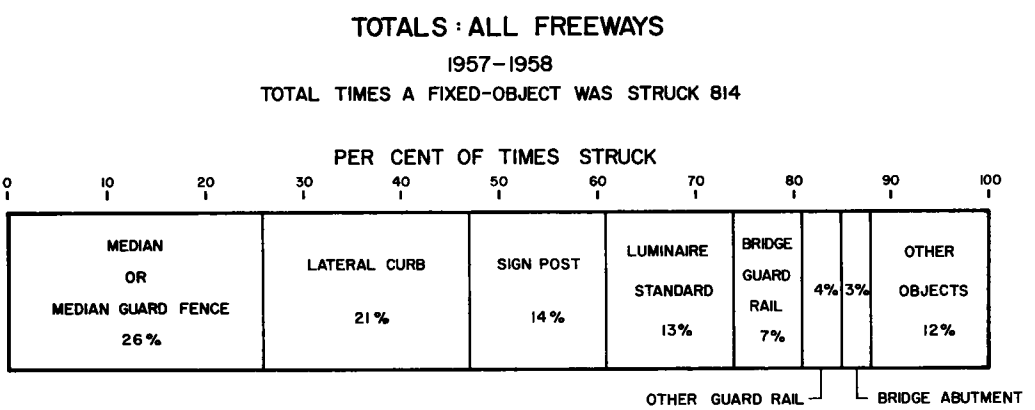


Figure 42. Type of fixed object struck.

TABLE 11

ACCIDENT DATA, GULF FREEWAY, HOUSTON (1954 to 1958)

Type of Accident	Property Damage	Personal Injury	Fatal	Total
Main-lane freeway (no/100 mil veh-mi):				
Before	166.98	26.33	2.63	195.94
After	206.58	24.34	2.01	232.93
Median (no.):				
Before	15	28	4	47
After	34	11	0	45
Median (no./100 mil veh-mi):				
Before	-	-	-	13.56
After	-	-	-	11.71

approaching the ramp was downgrade followed by a steeper downgrade on the ramp. The combination of continuing downgrades and of the change in direction of vehicular path was thought to accentuate difficulty of sight distance, and of control and maneuverability of the vehicle. Three combinations of consecutive upgrades on through lane and ramp were also noted in these locations where the same fixed object was struck repeatedly.

3. Seventy percent of the repeatedly-struck, fixed-object accidents occurred at night, whereas only 26 percent of the average daily traffic occurred during this period (Table 12). Figure 50, indicating the general fixed-object accident frequency related to hours of the day and thus approximately to hours of daylight and darkness, confirms this data.

(Although 82 percent of all fixed-object accidents occurring at night were under streetlight conditions, the general conclusion may be drawn from the foregoing data

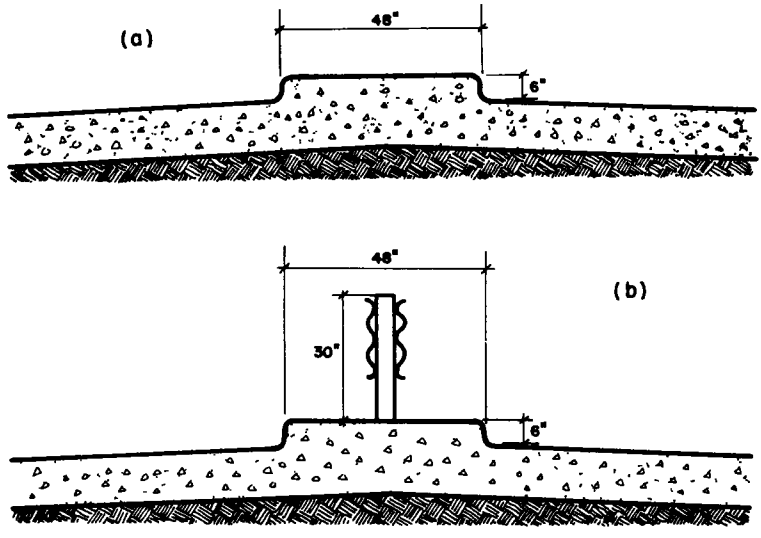


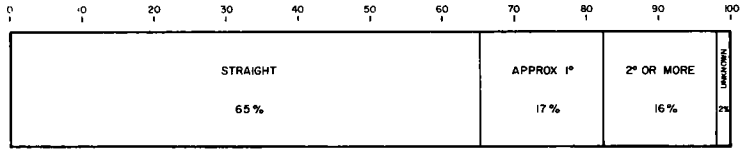
Figure 43. Median sections, Gulf Freeway, Houston: (a) section before construction of barrier fence, and (b) section after construction of barrier fence.

TOTALS ALL FREEWAYS 172 FO ACCIDENTS 2 YEARS 1957-1958

(MEDIAN OR MEDIAN FENCE WAS PRIMARY OBJECT STRUCK)

(ONLY 12% OF FREEWAY MEDIAN HAD FENCE)

PER CENT BY HORIZONTAL CURVATURE OF FREEWAY



PER CENT BY PROFILE GRADE OF FREEWAY

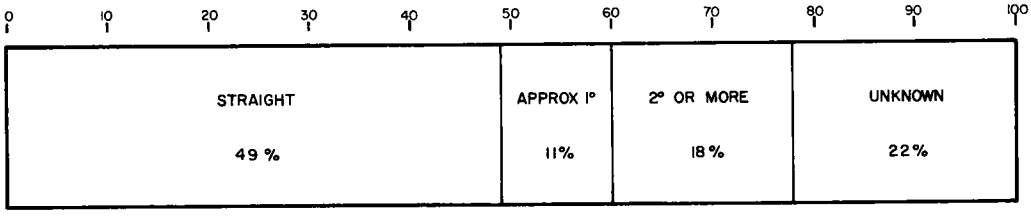
LEVEL	1-2% GRADE	2-3% GRADE	3% GRADE OR MORE	UNKNOWN
34%	12%	16%	24%	14%

Figure 44. Fixed-object accidents involving the median or median fence.

TOTALS ALL FREEWAYS 148 FO ACCIDENTS YEARS 1957-1958

(CURB WAS PRIMARY OBJECT STRUCK)

PER CENT BY HORIZONTAL CURVATURE OF FREEWAY



PER CENT BY PROFILE GRADE OF FREEWAY

LEVEL	1-2% GRADE	2%-3% GRADE	3% GRADE, OR MORE	UNKNOWN
30%	14%	17%	23%	16%

PER CENT BY FREEWAY FEATURE

RAMP CURB	THROUGH-LANES CURB	FRONTAGE ROAD CURB	CROSS STREET CURB
38%	27%	25%	10%

Figure 45. Fixed-object accidents involving lateral curbs.

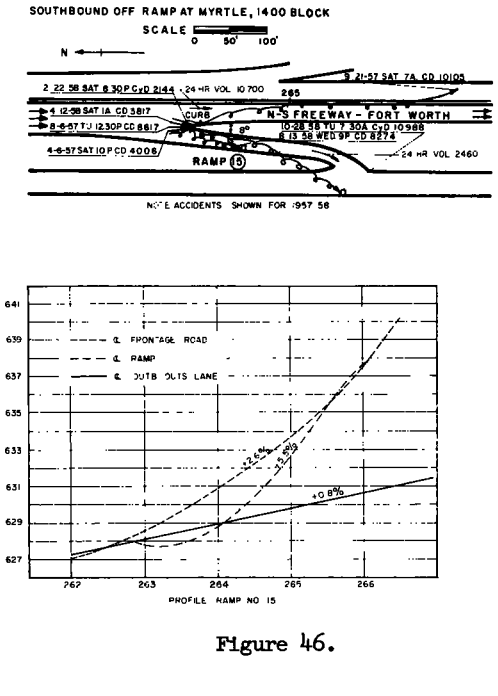


Figure 46.

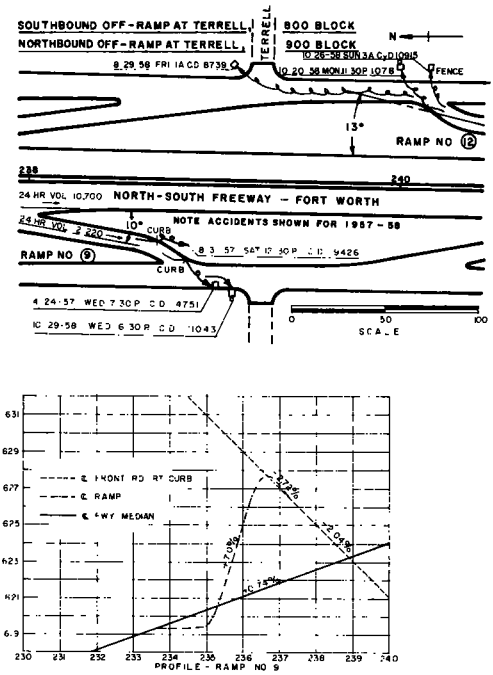


Figure 47.

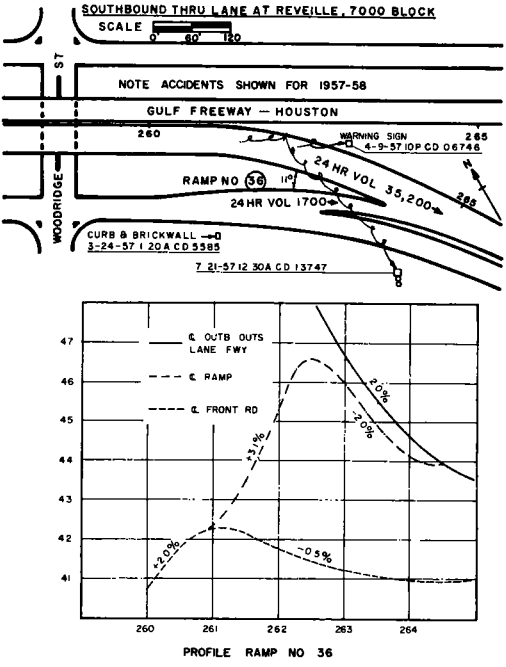


Figure 48.

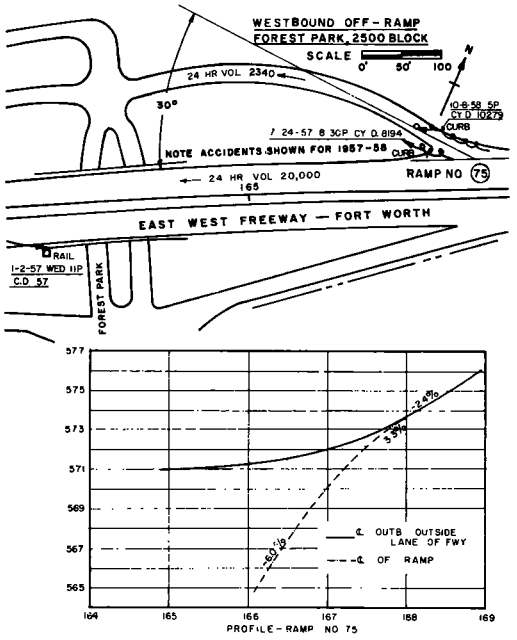


Figure 49.

TABLE 12

FIXED-OBJECT ACCIDENTS AT TWELVE HIGH FREQUENCY LOCATIONS
(Total: 54 Accidents)

Item	Time			
	Day		Night	
	7 AM - 12 N	12 N - 7 PM	7 PM - 12 M	12 M - 7 AM
No. of accidents	6 (11%)	10 (19%)	21 (39%)	17 (31%)
No. by weather:				
Clear and dry	6	10	19	16
Raining and wet	0	0	2	1
DWI	0	0	1	2
Fixed object, secondary*	1	0	0	0
Percent of ADT	30	44	17	9

*In studying all fixed-object accidents on all the freeways for the years 1957-1958, it was noted that the fixed object determined the primary collision type in 90 percent of the cases.

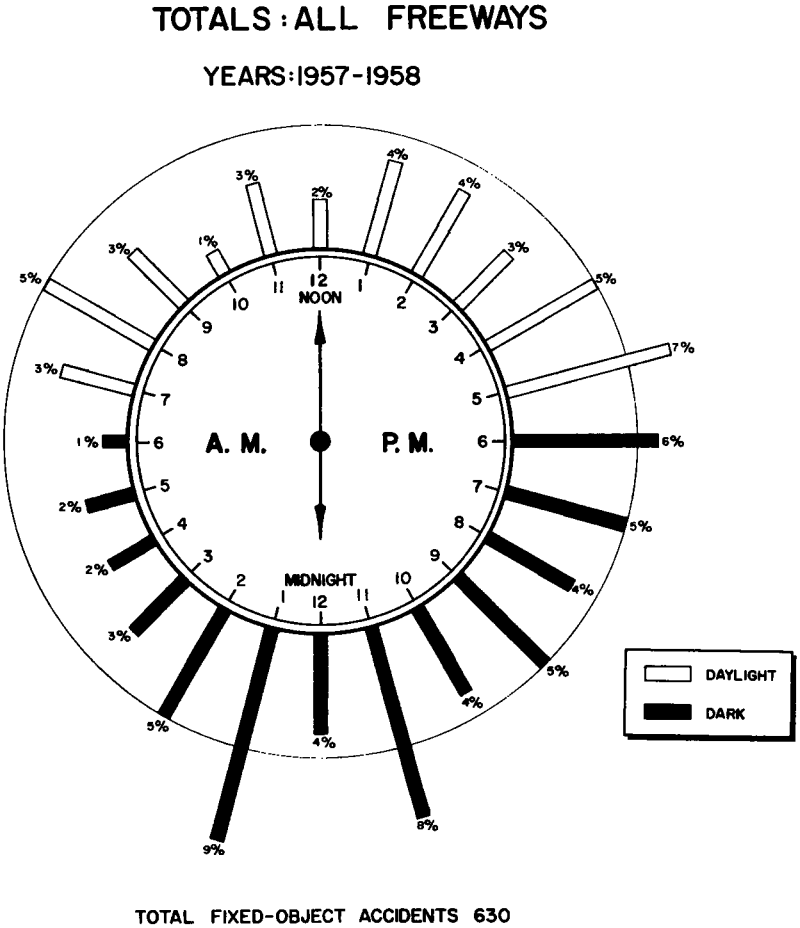


Figure 50. Hour of day for fixed-object accidents.

YEARS: 1957-1958 SUMMARY ALL FREEWAYS TOTAL F.O ACCIDENTS 630

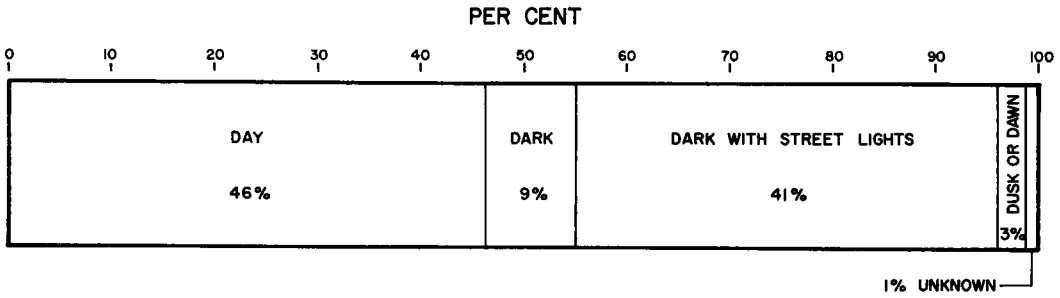


Figure 51. Light conditions in fixed-object accidents.

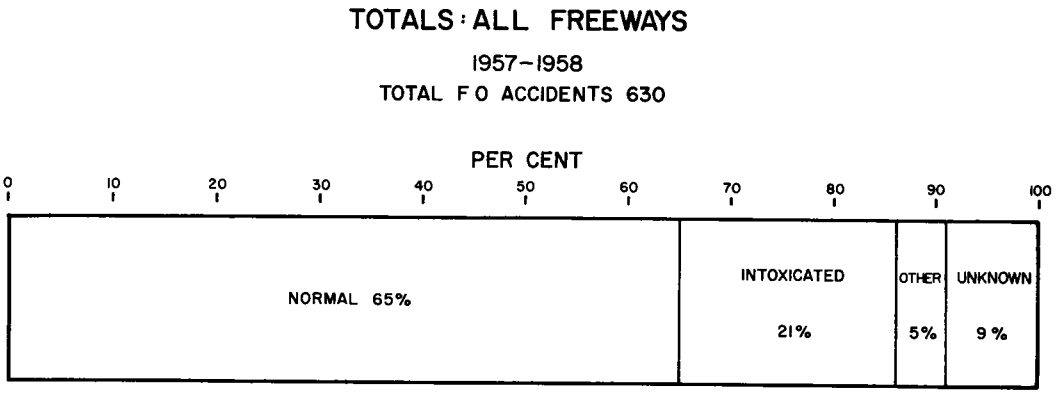


Figure 52. Driver condition (as determined from the report of the investigating officer) in fixed-object accidents.

that there is an over-all problem of night visibility. Figure 51, showing the light conditions in all fixed-object accidents substantiates this conclusion.)

4. It is believed that driver condition enters into the picture much more significantly than is indicated by Figure 52 based on data from the report forms of all fixed-object accidents. Note from Table 12 that 31 percent of the fixed-object accidents in the 12 special locations occurred between midnight and 7 a.m., when drivers are prone to be tired, sleepy, and in some cases experiencing the after-effects of the earlier social hours.

5. There is no apparent influence from rainy weather or road surface conditions indicated by fixed-object accidents at the 12 special locations nor by the data from all fixed-object accidents as shown in Figure 53.

To strengthen the opinion previously expressed that driver condition and behavior were often important contributing factors in fixed-object accidents, along with design features or elements, Figures 54, 55, and 56 are presented. Speeding and drinking were significantly specified in these data taken from the police officers' reports. Saturday and Sunday may be noted as days of the week when fixed-object accident frequency was somewhat higher. These are days when drinking and speeding or other reckless driving are commonly known to be more prevalent. Resulting lack of control of the vehicle is obviously a strong factor in fixed-object accidents.

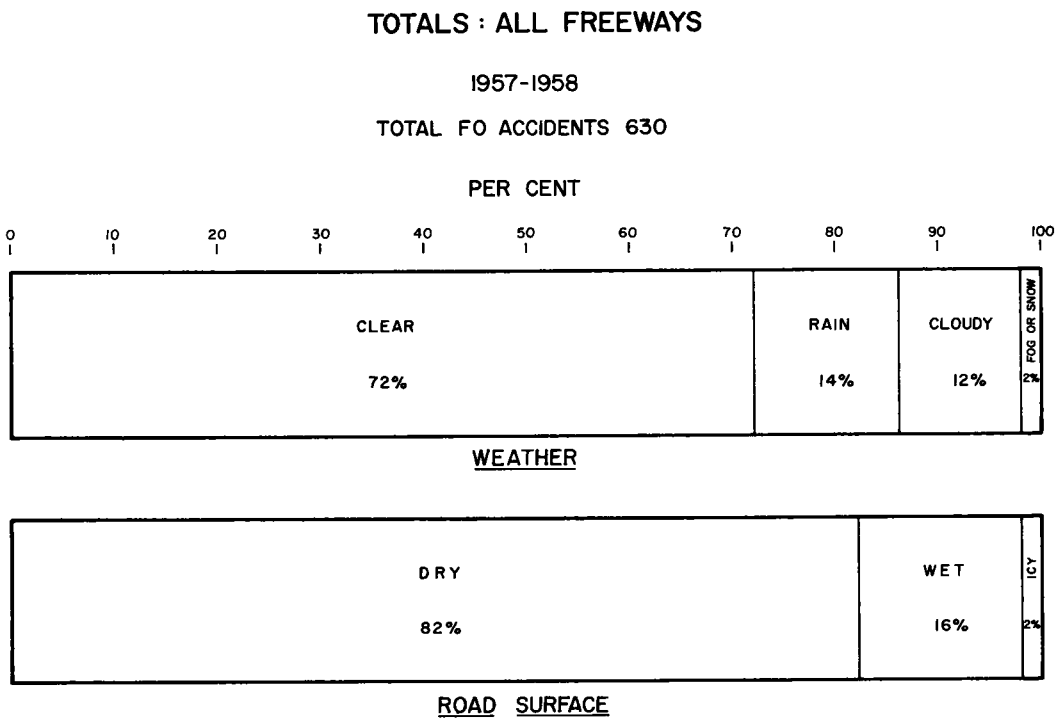


Figure 53. Condition of weather and road surface in fixed-object accidents.

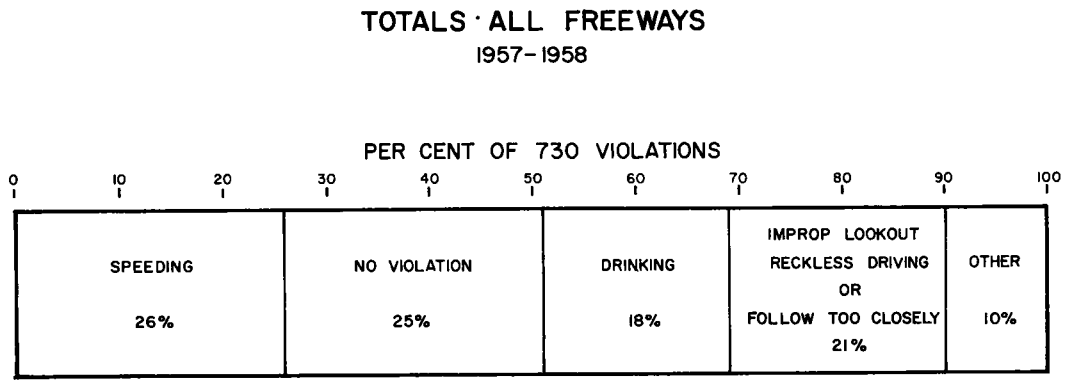


Figure 54. Drivers' violations (as determined from the report of the investigating officer) in fixed-object accidents.

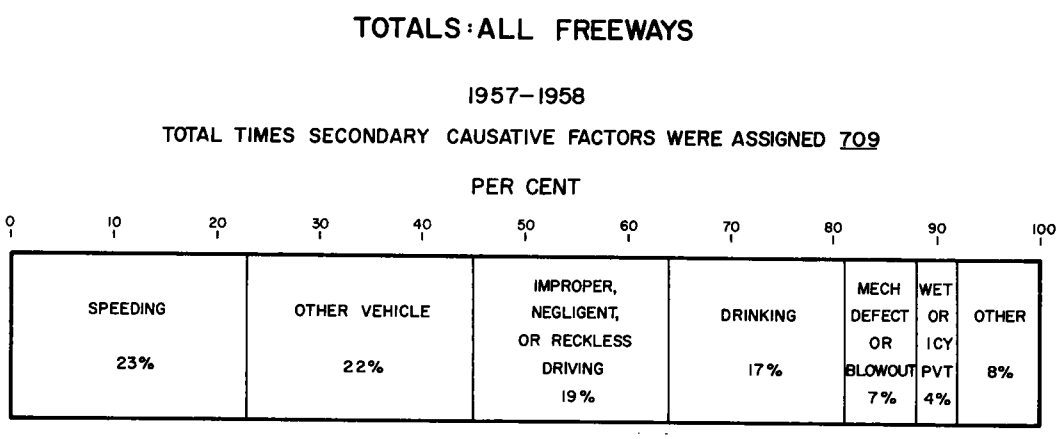


Figure 55. Secondary causative factors in fixed-object accidents.

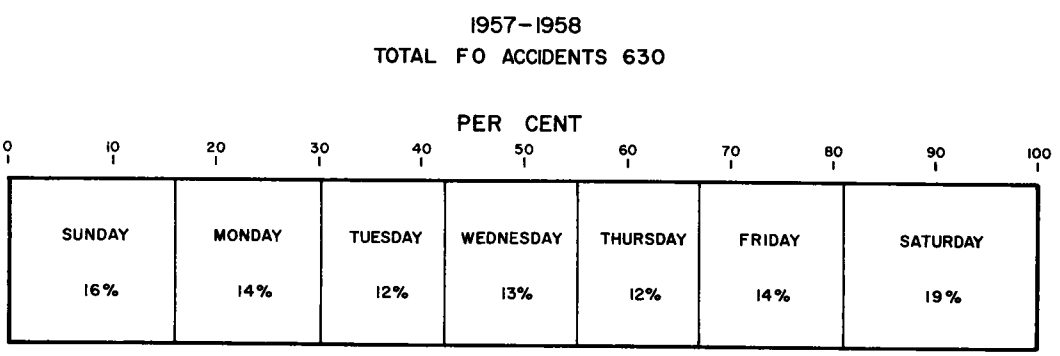


Figure 56. Fixed-object accidents by day of week.

SUMMARY AND RECOMMENDATIONS

1. Further study of accidents as related to design and operation of freeways is recommended.

2. There is a need for improving freeway traffic accident reporting in order to evaluate the relative safety of the geometric design of the various freeway elements. Typical freeway diagrams and established reference points proved in these studies to be useful in improving the accuracy of reporting accidents. Preparations for having adequate accident data must be made considerably in advance of analysis studies.

3. Sight distance or sight relationships are of great importance in the safety of freeway facilities. The vertical alignment must provide adequate visibility for the high-speed traffic traveling under high-density conditions on the freeway through lanes. Good visibility must be provided at points of ingress and egress. This visibility requirement applies to both through-lane traffic and ramp traffic. Standards of measurement of sight distance that are especially applicable to freeways are needed for best advantage in relating conditions and design features.

4. The designs of entrance and exit ramps should provide good sight relationships to encourage smooth flow at proper operating speeds without stopping, for the merging streams of on-ramp traffic with the through-lane traffic, and for the diverging streams of off-ramp vehicles.

5. Night visibility and driver condition are significant factors in fixed-object accidents.

6. Further study to determine the most satisfactory accident exposure factor to be used in calculating ramp accident rates is recommended.

These comprehensive studies of freeway accidents substantiate the evidence of previous studies that full control of access materially reduces accidents, injuries and fatalities. It is felt that the relief of the existing network provided by the freeway results in a reduction of accidents on that system and that the over-all safety afforded by the freeway should include the improved safety of the existing facilities. Further comprehensive accident studies are needed in order to compare accident experience on existing networks of streets and highways prior to the construction of a freeway with the accident experience on this system including the freeway.

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Appreciation is extended to Frank M. Smith, Jr., who, as a graduate student in Civil Engineering at the A. and M. College of Texas, made significant contributions in the special correlation study of selected on-ramp locations.

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