Objective Criteria for Guardrail Installation

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•THE PRIMARY reason for installing guardrail on embankments and adjacent to fixed objects is to reduce the combined effect of severity and frequency of ran-off-road type accidents. Guardrail reduces accident severity only for those conditions where the overall severity of striking the guardrail is less than the overall severity of going down the embankment or striking the fixed object. Guardrail reduces accident frequency only if it provides increased delineation at high frequency ran-off-road accident locations. Generally, however, it would be expected that installing guardrail adjacent to fixed objects would increase the accident frequency because the guardrail would be a larger obstacle.

Warrants for guardrail installation are presently subjective in nature, requiring judgment of the relative effect of certain factors for each installation. This required judgment may vary greatly from one design engineer to another, precluding the possibility of minimizing the consequence of running off the road. The purpose of this study, therefore, was to develop a more objective basis for installing guardrail on embankments and adjacent to fixed objects.

Guardrail standard in California during this study was W-section corrugated beam guardrail (Fig. 1). Before January 1, 1960, the guardrail standard was spring-mounted curved metal plate guardrail (Fig. 2). Based on a recent full-scale dynamic impact test series (1), the 1965 guardrail standard has been revised to a 27-in. overall beam height and 6-ft, 3-in. center-to-center post spacing. The testing demonstrated that, at 58 mph and a 25-deg impact angle, a passenger vehicle could vault the rail (1965 standard).

No distinction was made between the two existing types of guardrail in collecting data for this investigation because of the difficulty in locating each type throughout the state. The curved metal plate guardrail is the more prevalent of the two because it was installed and is still maintained on all highways built before 1960.

It was assumed for this investigation that all three guardrail types have the same accident severity potential. The basis of this assumption is that each successive change in the guardrail standard has increased the rigidity (more severe for vehicles striking and deflecting in normal path) and at the same time has decreased the penetrability (less likely for a striking vehicle to vault the rail and suffer the greater severity of the condition protected by the guardrail).

THEORETICAL MODEL

To establish objective warrants for guardrail placement, it is necessary to compare guardrail safety with embankment or fixed object safety in relation to two variables: (a) accident severity and (b) accident frequency. In other words, at any one embankment or fixed object location there is a threshold of severity and frequency of accidents above which guardrail placement would increase the relative safety. To establish an objective basis for guardrail placement, therefore, it was necessary to develop a mathematical relationship to evaluate accident severity and accident frequency, and to compare the relative safety of guardrail with that of embankments and fixed objects.

Severity Index

To evaluate severity, weighted severity values were assigned to the three accident severity classes: fatal, injury, and property-damage-only (PDO). Economic accident

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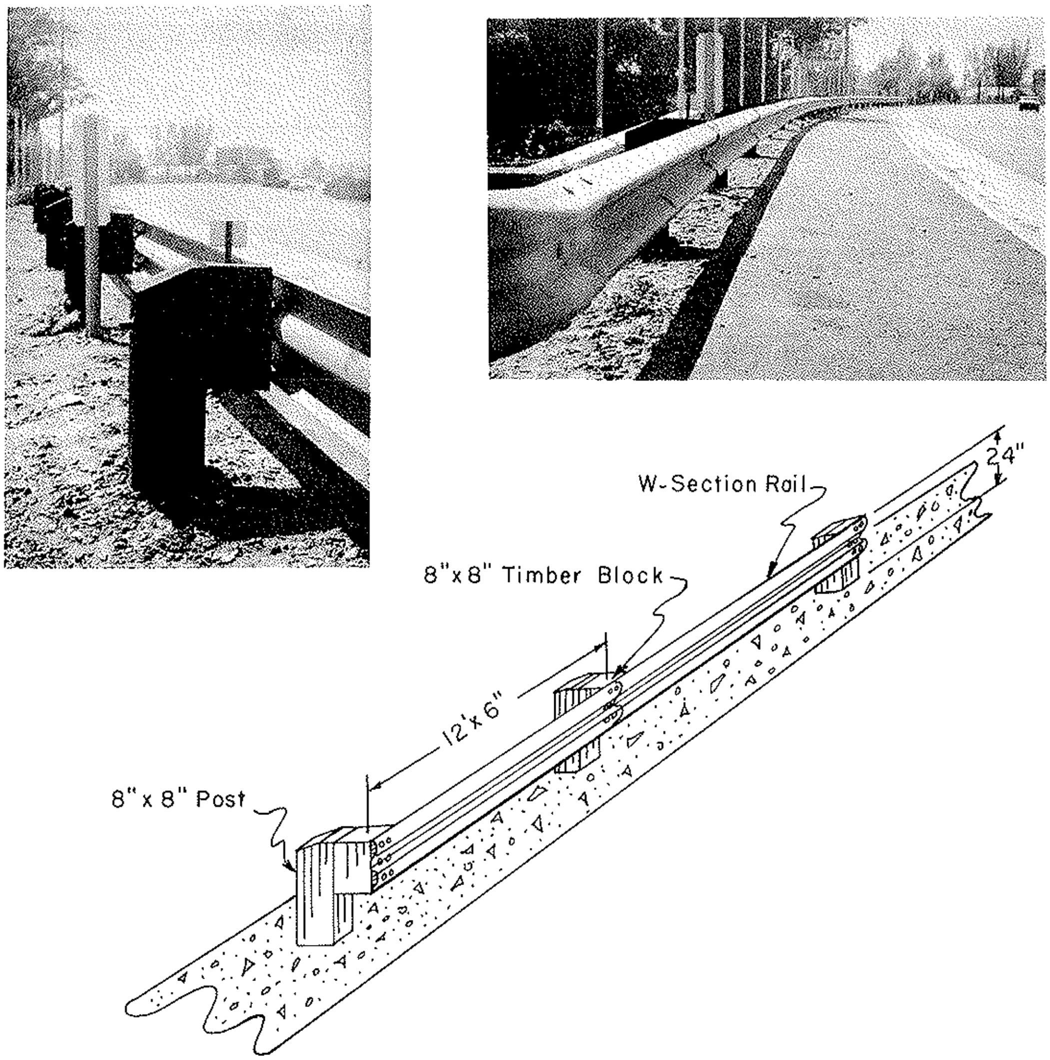


Figure 1. 1965 California guardrail standard (W-section corrugated beam guardrail).

values are the most convenient basis for evaluating the three classes of accidents. Many different philosophies have related the economic values of traffic accidents. However, rather than be conjectural, it was decided to use the direct costs of single vehicle accidents to obtain the relative severity weights of the three accident classes.

A study made by the Illinois Division of Highways (2) was used to obtain direct accident costs. These costs were adjusted for California single vehicle reported accident data (see Appendix). Table 1 gives the direct costs and relative severity weights of California single vehicle accidents.

Moderate changes in the relative weights of the fatal and injury accidents have a relatively small effect on the severity index (SI). However, a consideration of human suffering and loss of future earnings would increase the severity weights of the fatal and injury accidents considerably and would have a substantial influence on the SI. The use of these increased weights was investigated and was found to affect the use of guardrail for embankments but not for fixed objects.

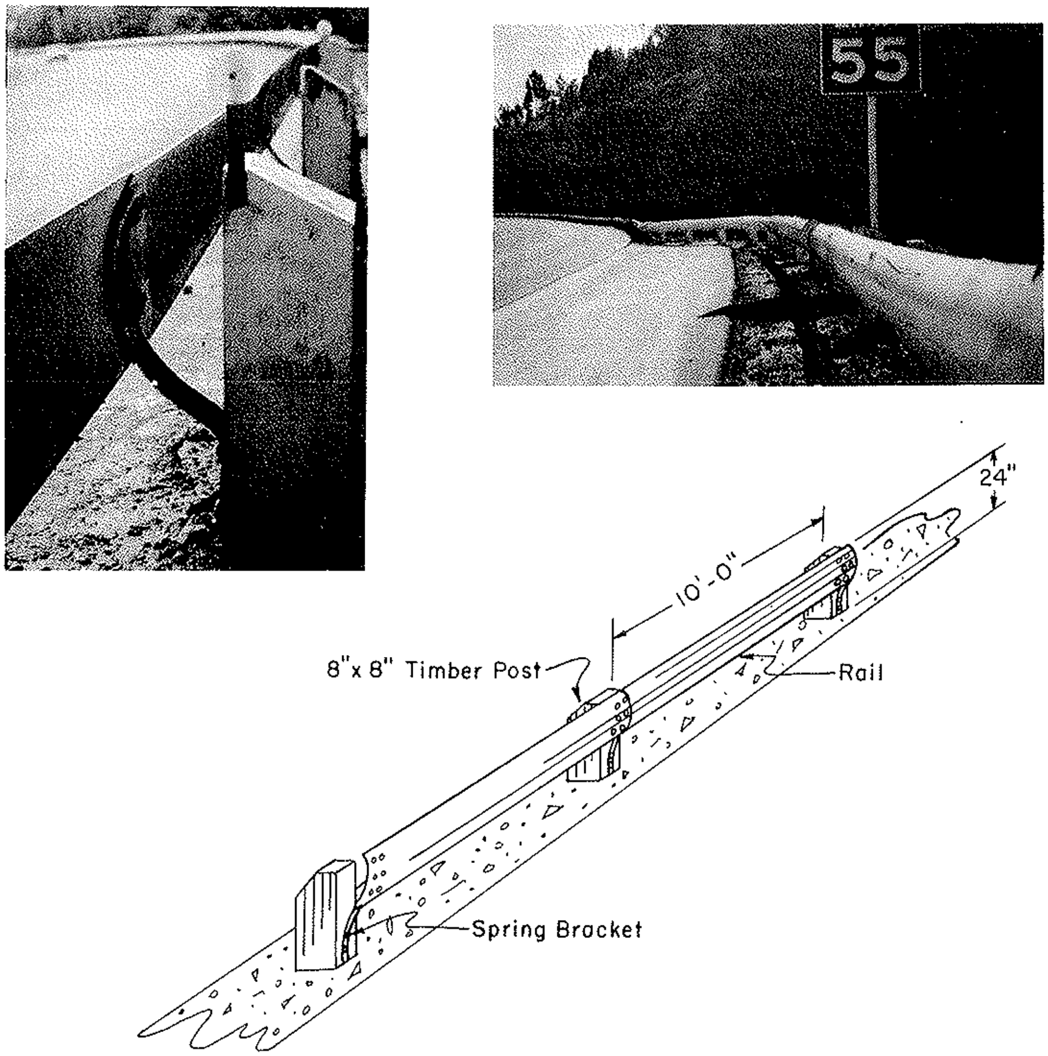


Figure 2. Spring-mounted curved metal plate guardrail.

TABLE 1

CALIFORNIA SINGLE VEHICLE DIRECT ACCIDENT COSTS AND RATIOS BY SEVERITY CLASS

Accident Type	Direct Cost ($)	Relative Severity Weight
Fatal	5,100	25
Injury	1,200	6
PDO	200	1

The severity index chosen for comparison purposes is an average per involvement severity value for all accidents for a given condition; it is of the following form:

$$SI = \frac{25F + 6I + P}{N}$$

where

F = no. of fatal accidents for condition,
I = no. of injury accidents for condition,
P = no. of PDO accidents for condition, and
N = total no. of accidents for condition.

Probability Index

The severity index alone is not sufficient for comparing the relative safety of two different conditions. For instance, two locations with the same vehicular exposure may have the same SI even though one location has twice as many accidents. It is necessary for comparison purposes, therefore, to consider also the number of accidents that occurred in relation to the number of vehicles exposed to the condition.

The accident frequency represents the probability that an accident will happen for a given set of conditions. The probability index (PI) is of the following form:

$$PI = \frac{N}{V}$$

where

N = no. of accidents for condition, and
V = no. of vehicles exposed to the condition during accident study period.

This equation assumes that accident frequency is related to the number of vehicles xposed to the condition, but the accident rate is independent of traffic volume (time ate of exposure). It is recognized that accident rate may vary with traffic volumes. However, for comparison purposes, if the volume distributions are similar for locations for each of the conditions compared, the probability indices will not be affected by the "volume vs accident rate relationship."

Collision Index

The true measure for comparing the relative safety of guardrail with embankments or fixed objects is the product of the SI and the PI, which was named the collision index (CI):

$$CI = SI \times PI = \frac{25\,F + 6I + P}{N} \times \frac{N}{V}$$

$$CI = \frac{25\,F + 6I + P}{V}$$

To obtain a better understanding of the meaning of this equation, the severity values may be considered as equivalent PDO accidents. In other words, each injury accident is equivalent to 6 PDO's and each fatal accident is equivalent to 25 PDO's. If this equivalence is assumed, a more conceptual form of the equation would be:

$$CI = \frac{\text{equivalent PDO accidents}}{\text{exposure volume}}$$

DETERMINATION OF GUARDRAIL NEED FOR EMBANKMENT CONDITIONS

The primary reason for placing guardrail on embankments is to increase the relative safety of ran-off-road type accidents at embankment locations. This includes increasing the safety to vehicle occupants and to people and property off the roadbed. An investigation concerning the protection of people and property off the roadbed was previously reported (3). The present study, therefore, was concerned only with investigating guardrail need to increase the safety to ran-off-road vehicle occupants.

Warrants for installing embankment guardrail are presently subjective in nature, requiring judgment concerning the relative effects of such factors as embankment height and slope, alignment, roadbed width, accident history, speed and volume of traffic, visibility, and climatic conditions. This required judgment may vary greatly from one design engineer to another, precluding the maximization of ran-off-road accident safety at embankment locations.

This part of the study, therefore, was aimed at an objective determination of the combinations of roadway geometry and embankment conditions which require guardrail placement to maximize the overall safety of ran-off-road accidents at embankment locations.

Design of Study

The determination of the probability index for ran-off-road accidents was beyond the scope of this study. This determination would involve evaluating the frequency of accidents, for embankment and for guardrail, related to the following roadway and environmental variables: horizontal alignment, vertical alignment, superelevation, roadway width, shoulder width, type of roadway, number of lanes, traffic volume, vehicle speeds, and climatic conditions.

The analysis would entail collecting many years of accident data for many miles of roadway to obtain a stable sample for the great number of combinations of roadway and environmental variables which relate to off-the-road accidents.

Because the PI was not measurable, it was necessary to estimate how the guardrail PI relates to the embankment PI. The only discernible reason why guardrail would reduce accident frequency is its delineation quality on horizontal curves. However, this delineation can be accomplished with guide markers or a continuous device less severe than guardrail. Also, it was assumed that guardrail would not increase accident frequency unless the roadside maneuver area was greatly reduced by its presenc With these assumptions in mind, it was estimated that guardrail placement would not significantly affect ran-off-road accident frequency, and the comparison of guardrail vs embankments was made on a severity basis alone.

The embankment severity index can be directly evaluated by using multiple regression techniques to relate the severity of a down-the-embankment accident to the embankment conditions at the site of the accident. The guardrail SI can be directly evaluated by obtaining a large sample of embankment guardrail single vehicle accidents, classified by severity.

The variables considered for analysis as affecting the severity of down-the-embankment accidents were as follows: (a) height of embankment (including natural hillside height), (b) slope of embankment, (c) size of embankment surface material, (d) firmness of embankment material, (e) slope of "original ground" at the toe of the embankment, (f) water at the toe of the embankment, (g) fixed objects on slope, and (h) speed of vehicle. After examining these variables, a selection was made of the following four variables for use in a multiple regression analysis: height of embankment (including natural hillside height), slope of embankment, size of embankment material, and slope of the original ground at toe of embankment.

Not using the other four variables could possibly reduce the degree of correlation; however, these variables were not used for the following reasons.

1. The firmness of the embankment material is difficult to evaluate because it is variable over time.
2. Fixed objects contribute considerably to severity, but this factor should be considered separately from embankment conditions.
3. Water at the toe of the slope should also be considered separately.
4. Speed definitely contributes to severity but unfortunately is not a predictable quantity for any single vehicle involved in an accident. Generally, however, if larger accident samples are used, it is expected that the distribution and range in speeds

for accidents within each embankment category will be similar. If this is true, speed would not affect the relative severity between embankment categories.

Conduct of Study

Reports of all 1963 single vehicle down-the-embankment accidents were obtained. Each of 1, 368 accident reports was read, and those involving fixed objects or bodies of water were eliminated. The number of accidents involving the embankment only was 1, 046. A field inspection was made of the site of each of these accidents, and the desired embankment variables were recorded. In the field, the necessary data at 47 sites were not obtainable because of recent construction; therefore, 999 usable records remained.

Reports of all 1963 and 1964 single vehicle embankment guardrail accidents were obtained. Each accident report was read to verify that embankment guardrail was involved. Table 2 gives the severity breakdown of these accidents.

TABLE 2

1963-1964 SINGLE VEHICLE STRUCK
EMBANKMENT GUARDRAIL ACCIDENTS

Fatal	Injury	PDO	Total	SI (1-6-25)
14	147	170	331	4. 24

Analysis of Data

The basic form of the linear multiple regression equations is

$$\text{Embankment SI} = b_1 + b_2h + b_3s + b_4m + b_5t$$

where

h = height of embankment,
s = slope of embankment (inverse decimal equivalent),
m = size of embankment material, and
t = slope of original ground at toe of embankment.

In the computer analysis, transformations were also used to investigate semi-log and log-log fits. In the initial computer analysis it was discovered that two variables, the slope material and the slope of original ground at the toe of embankment, had no significant correlation with the SI.

The form of the accident data used in the final computer analysis is indicated in Table 3. The data were grouped and categorized to improve the reliability of the SI in each category of embankment height and slope. The category limits were chosen so that the distribution of heights within each category was as symmetrical as possible.

The SI data entered in the computer analysis were the category mean SI's and not the SI's for each accident because the regression equation was intended to predict an average SI of all accidents for a given embankment condition rather than predict the SI for a single accident for that condition.

Several sets of severity ratios were considered in the computer analysis to investigate the effect of different severity weights on the prediction equation.

Results of Analysis

The regression equations developed in the computer analysis are given in Table 4. The correlation coefficient and standard error are also given for each equation. In comparing the goodness of fit for the various equations, a direct comparison can be made between correlation coefficients but not between standard errors because the magnitude of the standard error is dependent on the magnitude of the severity ratios.

TABLE 3

1963 SINGLE VEHICLE EMBANKMENT ACCIDENTS

EMBANKMENT CATEGORY			NUMBER OF ACCIDENTS				SI
Embankment Height Range	Category Height	Embankment Slope	Fatal	Injury	PDO	Total	(1-6-25)
1-5	3	.200(5:1)	0	2	9	11	1.91
	3	.250(4:1)	0	2	7	9	2.11
	3	.333(3:1)	0	4	6	10	3.00
	3	.500(2:1)	0	22	20	42	3.62
	3	.667(1½:1)	0	10	7	17	3.94
	3	1.000	0	1	3	4	2.25
6-10	8	.200	0	2	2	4	3.50
	8	.250	1	4	3	8	6.50
	8	.333	0	5	5	10	3.50
	8	.500	1	34	31	66	3.94
	8	.667	2	42	27	71	4.63
	8	1.000	1	19	5	25	5.76
11-20	15	.250	1	1	3	5	6.80
	15	.333	0	6	3	9	4.33
	15	.500	5	75	44	124	4.98
	15	.667	3	73	41	117	4.73
	15	1.000	1	14	9	24	4.88
21-30	25	.250	0	1	1	2	3.50
	25	.333	0	0	2	2	1.00
	25	.500	1	33	22	56	4.38
	25	.667	8	42	28	78	6.17
	25	1.000	1	21	5	27	5.78
31-40	35	.500	1	22	5	28	5.80
	35	.667	1	20	8	29	5.65
	35	1.000	1	5	4	10	5.90
41-50	45	.500	0	3	3	6	3.50
	45	.667	2	18	7	27	6.12
	45	1.000	0	10	1	11	5.55
51-70	60	.500	0	8	4	12	4.33
	60	.667	3	25	6	34	6.80
	60	1.000	2	3	2	7	10.00
71-100	85	.500	1	6	3	10	6.40
	85	.667	0	20	3	23	5.37
	85	1.000	1	4	2	7	7.28
101-150	125	.500	0	1	1	2	3.50
	125	.667	0	16	3	19	5.22
	125	1.000	1	7	1	9	7.68
151-200	175	.500	0	2	0	2	6.00
	175	.667	1	7	3	11	6.36
	175	1.000	3	8	0	11	11.20
201-500	350	.667	1	6	1	8	7.75
	350	1.000	5	7	0	12	13.90

With a regression equation established, it is possible to predict at what embankment conditions guardrail will reduce the SI. This is accomplished by substituting the guardrail SI for the embankment SI in the regression equation. Figure 3 shows a plot of the resulting two-dimensional equations for the three fits using the 1-6-25 ratios. Figure 4 plots the resulting two-dimensional linear equations using the various sets of severity ratios. The guardrail need is determined by checking if an embankment condition plots above or below the regression line. Guardrail will reduce the SI for all embankment conditions which plot above the line.

Figure 4 shows that there is some difference in the amount of guardrail needed, depending on the severity ratios used. However, the use of any of the equations would permit considerably less guardrail than the present California standard which permits guardrail for heights above 10 feet or slopes steeper than 4:1.

Figure 5 shows a conceptual form of the severity criteria. The curve was derived from the best fit (log-log form with R = 0.80 and S. E. = 0.91) curve for the chosen ratios of 1-6-25. The curve predicts, on the average, a family of embankment conditions which have an SI equal to the SI for guardrail. Because of the limitations of the

TABLE 4
MULTIPLE REGRESSION EQUATIONS

SEVERITY RATIOS	EQUATION TYPE	REGRESSION EQUATION	STANDARD ERROR	MULTIPLE CORRELATION COEFFICIENT
1-4-17	Linear	$SI = 1.988 + 0.012h + 1.933s$	0.656	0.791
	Semi-Log	$SI = 2.250 + 1.433\mathrm{Log}(h) + 2.061\,\mathrm{Log}(s)$	0.705	0.753
	Log-Log	$\mathrm{Log}(SI) = 0.413 + 0.149\mathrm{Log}(h) + 0.278\,\mathrm{Log}(s)$	0.440	0.794
1-5-25	Linear	$SI = 2.189 + 0.017h + 2.851s$	0.970	0.788
	Semi-Log	$SI = 2.679 + 2.020\mathrm{Log}(h) + 3.064\mathrm{Log}(s)$	1.071	0.734
	Log-Log	$\mathrm{Log}(SI) = 0.505 + 0.164\mathrm{Log}(h) + 0.329\mathrm{Log}(s)$	1.070	0.785
1-6-25	Linear	$SI = 2.649 + 0.018h + 3.075s$	0.966	0.804
	Semi-Log	$SI = 3.146 + 2.185\mathrm{Log}(h) + 3.316\mathrm{Log}(s)$	1.032	0.772
	Log-Log	$\mathrm{Log}(SI) = 0.566 + 0.160\mathrm{Log}(h) + 0.324\mathrm{Log}(s)$	0.913	0.804
1-6-28	Linear	$SI = 2.565 + 0.0190h + 3.341s$	1.108	0.785
	Semi-Log	$SI = 3.151 + 2.326\mathrm{Log}(h) + 3.566\mathrm{Log}(s)$	1.190	0.747
	Log-Log	$\mathrm{Log}(SI) = 0.572 + 0.164\mathrm{Log}(h) + 0.336\mathrm{Log}(s)$	1.272	0.790
1-10-100	Linear	$SI = 2.787 + 0.068h + 9.578s$	4.163	0.750
	Semi-Log	$SI = 3.618 + 7.625\mathrm{Log}(h) + 9.773\mathrm{Log}(s)$	4.690	0.667
	Log-Log	$\mathrm{Log}(SI) = 0.806 + 0.235\mathrm{Log}(h) + 0.467\mathrm{Log}(s)$	18.841	0.738

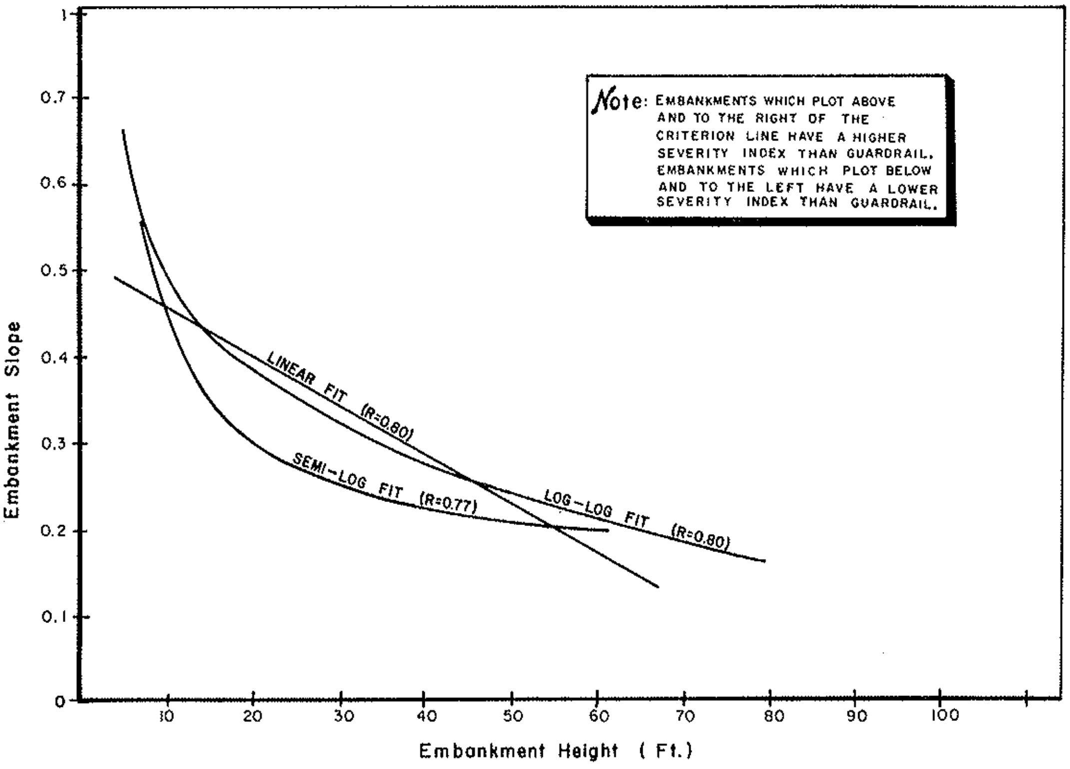
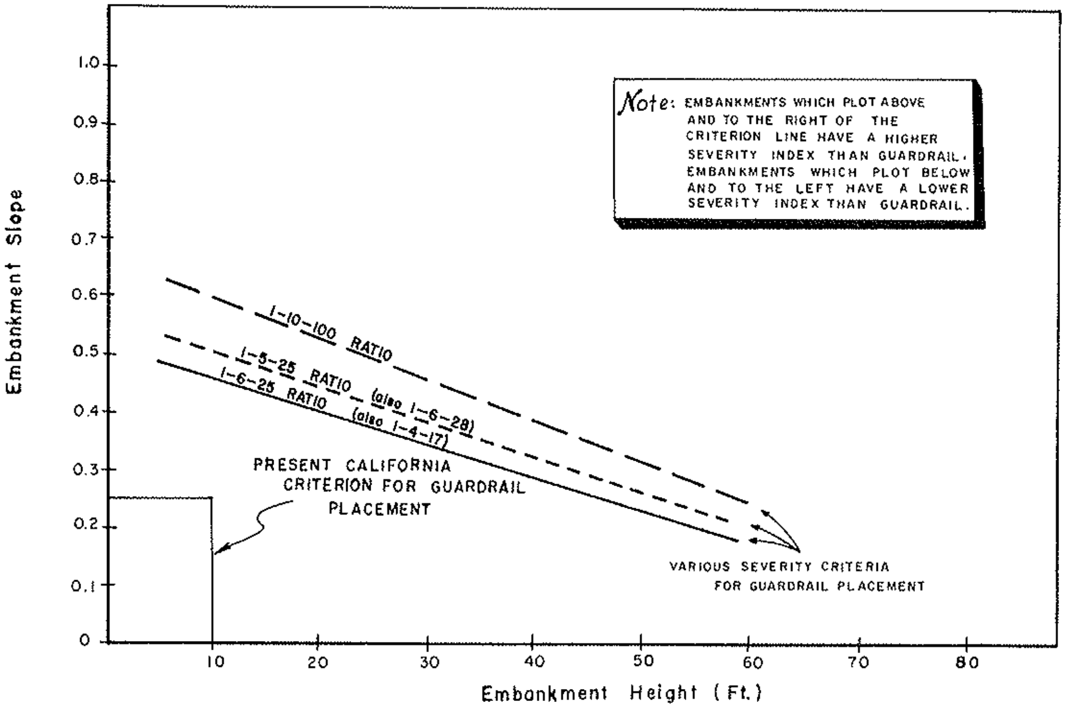
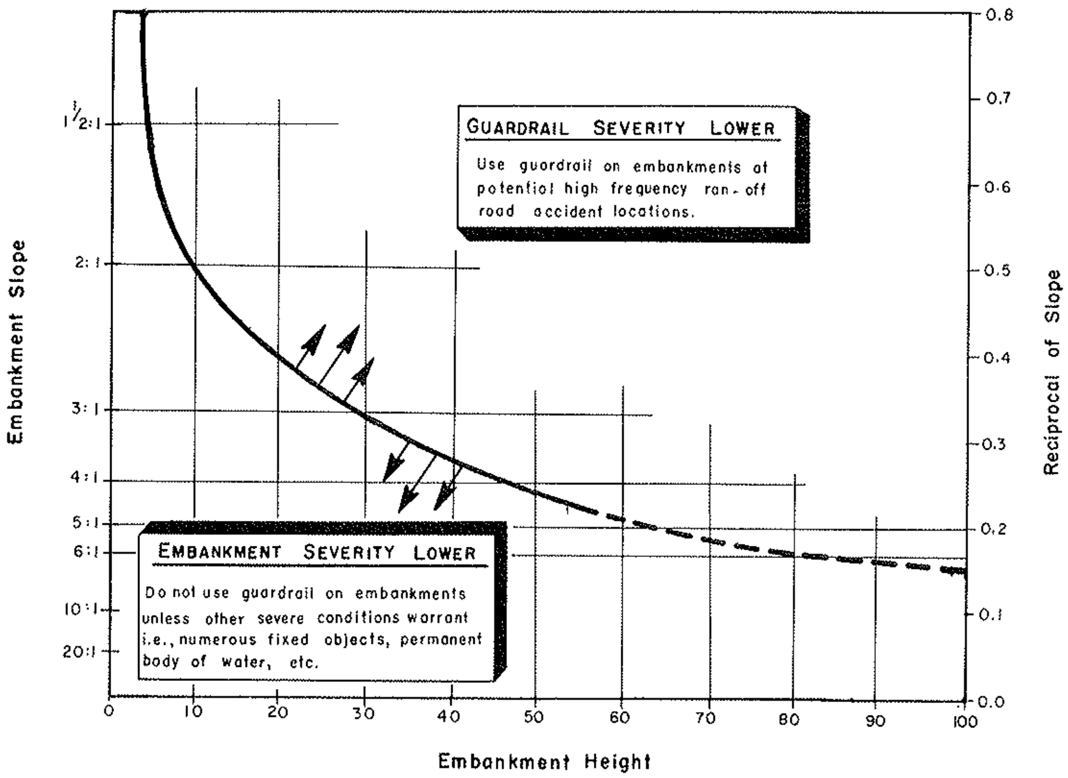


Figure 3. Three types of equations investigated in the regression analysis for the severity ratios of 1-6-25.



Note: EMBANKMENTS WHICH PLOT ABOVE AND TO THE RIGHT OF THE CRITERION LINE HAVE A HIGHER SEVERITY INDEX THAN GUARDRAIL. EMBANKMENTS WHICH PLOT BELOW AND TO THE LEFT HAVE A LOWER SEVERITY INDEX THAN GUARDRAIL.

Figure 4. Linear regression equations developed using various severity ratio sets.



GUARDRAIL SEVERITY LOWER

Use guardrail on embankments at potential high frequency run-off road accident locations.

EMBANKMENT SEVERITY LOWER

Do not use guardrail on embankments unless other severe conditions warrant i.e., numerous fixed objects, permanent body of water, etc.

Figure 5. Severity comparison of embankments vs guardrail.

TABLE 5

1963-1964 ACCIDENT RATES FOR STATE HIGHWAYS

Location	Total Accidents/ Million Vehicle-Miles	Fatal + Injury Acc. / MVM	Fatalities/ 100 MVM
Freeways	1.46	0.64	2.71
Other	3.68	1.42	7.55

data, the portion of the curve for the higher embankment heights and flatter embankment slopes has been indicated as an extrapolation.

Figure 5 is not completely objective, because the guardrail need is determined only on a reduced severity basis. Because guardrail can be a costly item, it would be economically feasible to install it only at potentially high frequency ran-off-road accident locations (i.e., on the outside of horizontal curves and on higher volume roadways).

If an embankment condition plots in the lower area of the chart, guardrail should not be installed on that embankment unless other severe conditions warrant it (i.e., numerous fixed objects on the slope or at the toe and permanent water at the toe of slope).

It should be kept in mind that at locations where the guardrail need is determined, guardrail placement is not the only method to minimize the SI. For lower embankment heights (say less than 20 ft) with steep slopes (steeper than 2:1), it may be more economical to flatten the slope.

DETERMINATION OF GUARDRAIL NEED ADJACENT TO FREEWAY FIXED OBJECTS

It has been established that freeways are much safer than all other highways (4). Table 5 indicates that state freeways have significantly lower rates than all other state highways for total accidents, fatal plus injury accidents, and number of fatalities.

However, by examining relative SI's, which represent the average per involvement severity, it becomes apparent that freeways have a higher per involvement severity than all other highways (Table 6).

It might appear that the per involvement severity of freeways should be lower than all other highways because of the minimization of three severe accident types: head-on, right-angle, and pedestrian accidents. The minimization of these types of accidents and the overall safety of freeways evolves from the elimination of conflicting traffic. However, this elimination of conflict necessitates grade separations and introduces a new contributor to the severity picture: fixed objects. Grade separations require structures, complex signing, and interchange illumination which account for the majority of the fixed objects on freeways.

The fact that fixed object accidents constitute 25 percent of all freeway accidents and 31 percent of freeway fatal accidents shows that fixed objects contribute to the higher overall severity of freeways (5).

TABLE 6

RELATIVE SEVERITY INDICES, 1963-1964

Location	Fatal Accidents		Injury Accidents		PDO Accidents		Total Accidents	
	No.	SI	No.	SI	No.	SI	No.	SI
Freeways	847	25	23,192	6	31,700	1	55,739	3.45
Other	2,696	25	59,820	6	98,999	1	161,515	3.25

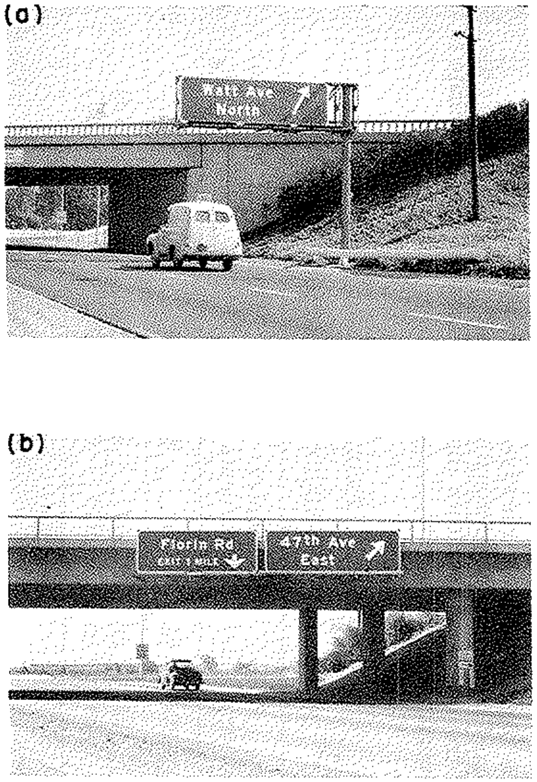


Figure 6. (a) Possible location for structure-mounted sign; (b) structure-mounted sign.

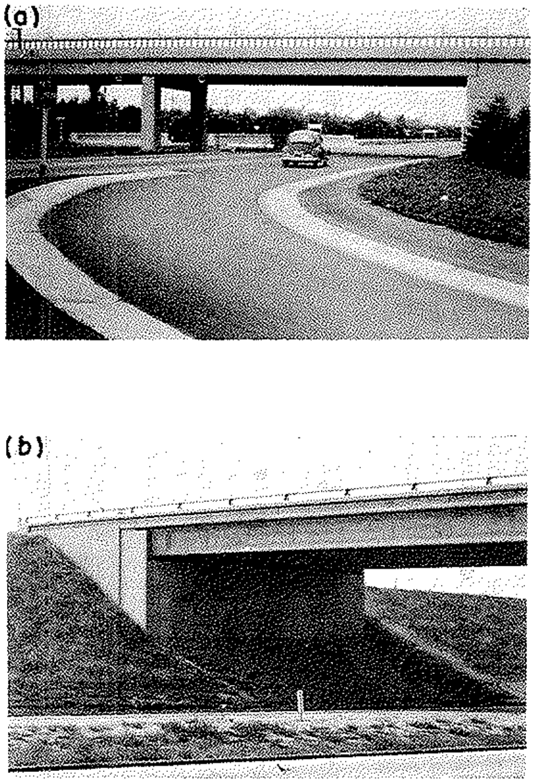


Figure 7. (a) Possible location for enclosing side abutment in fill cone; (b) side abutment enclosed in fill cone or cut slope.

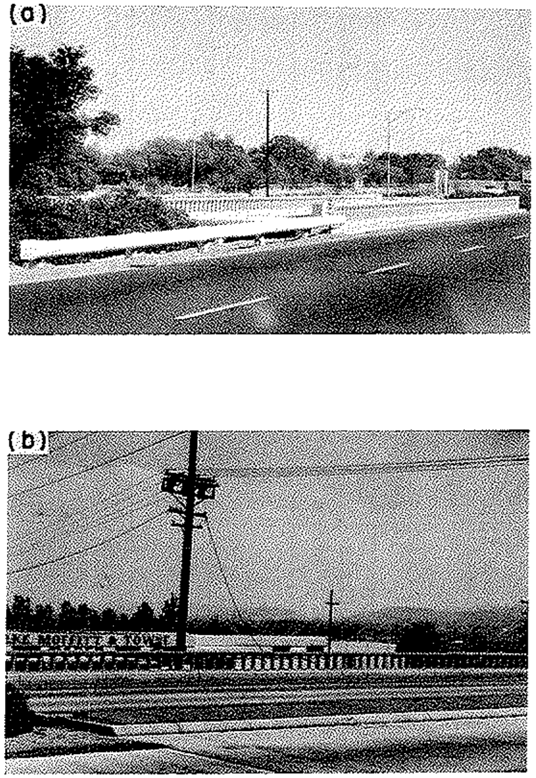


Figure 8. (a) Separate bridges with interior bridge rails; (b) bridge structure with no interior bridge rails.

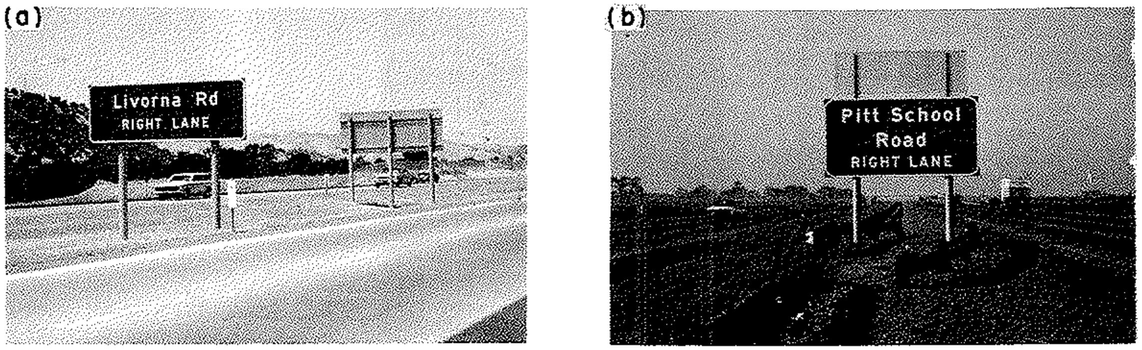


Figure 9. (a) Possible location for back-to-back signs; (b) back-to-back signs.

Figure 10. Combined sign and lightpole.

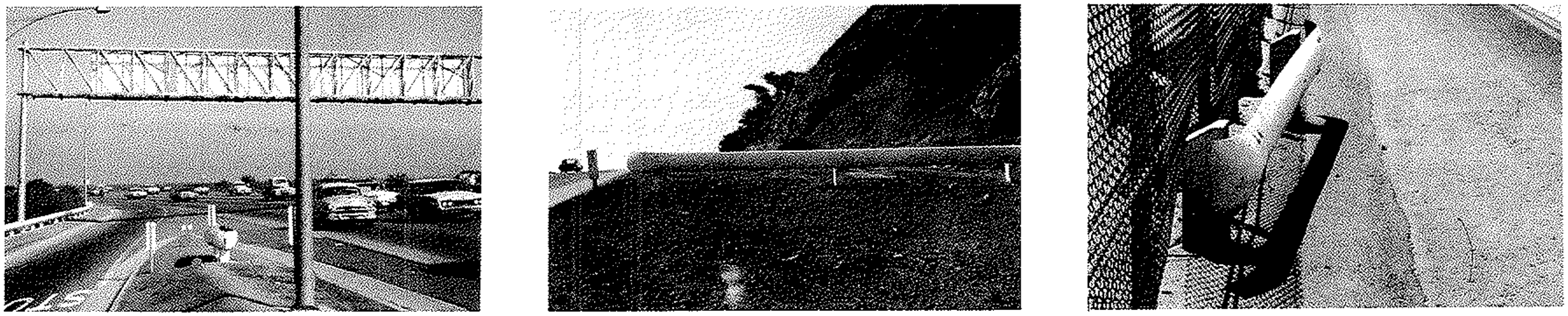


Figure 11. Indiscriminate use of guardrail.

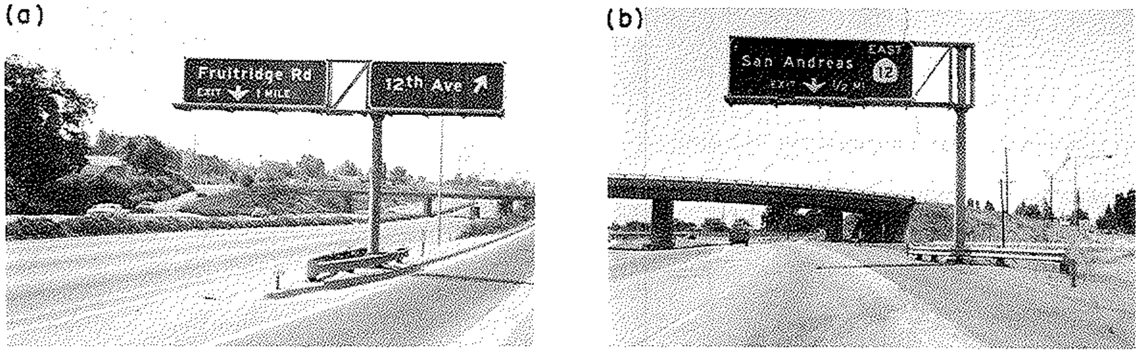


Figure 12. (a) Gore sign could be replaced by overhead sign adjacent to right shoulder at beginning of ramp taper and a structure-mounted sign for next exit; (b) overhead sign adjacent to shoulder.

Figure 13. Signpost placed immediately beyond bridge rail.

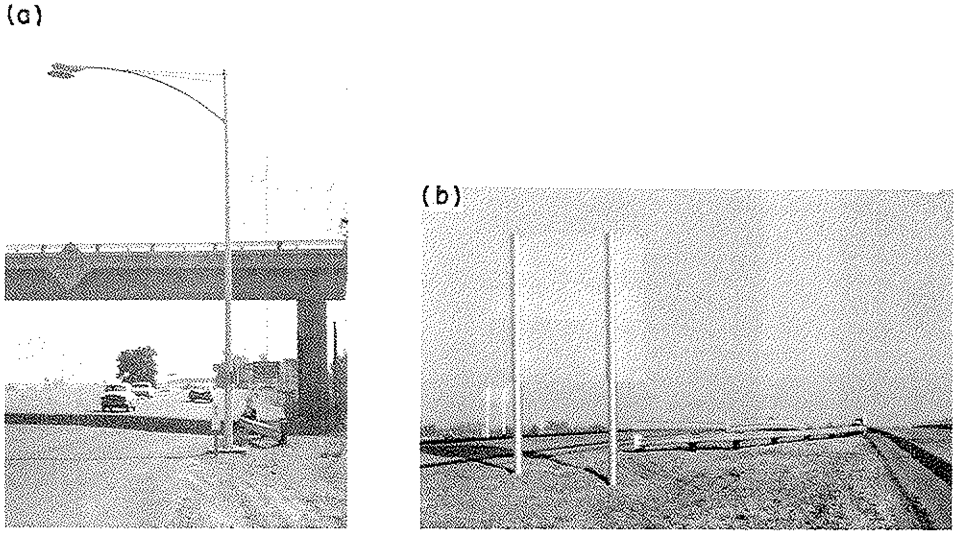


Figure 14. (a) Possible location for placing lightpoles behind pier guardrail; (b) possible location for placing signpost ind bridge guardrail flare.

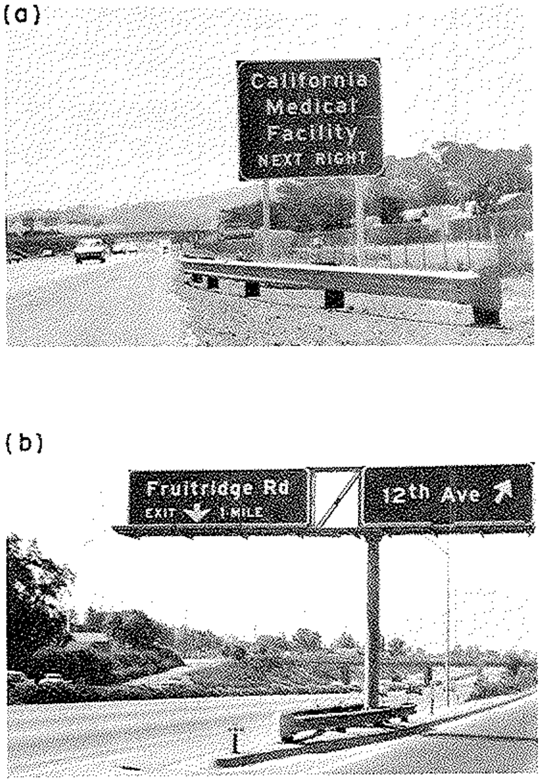


Figure 15. (a) Fixed object (wood signpost) less hazardous than guardrail protection; (b) fixed object more hazardous than guardrail protection.

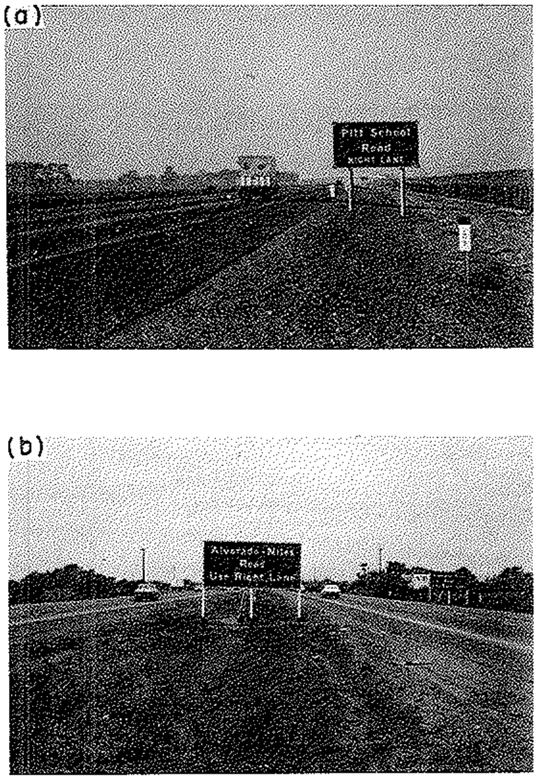


Figure 16. (a) Sign with steel posts which could have been placed on timber posts; (b) sign on timber posts.

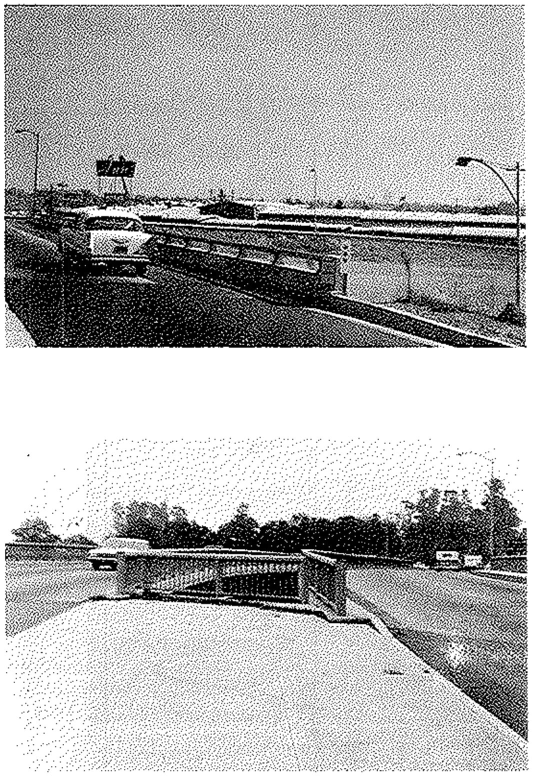


Figure 17. Bridge rails.

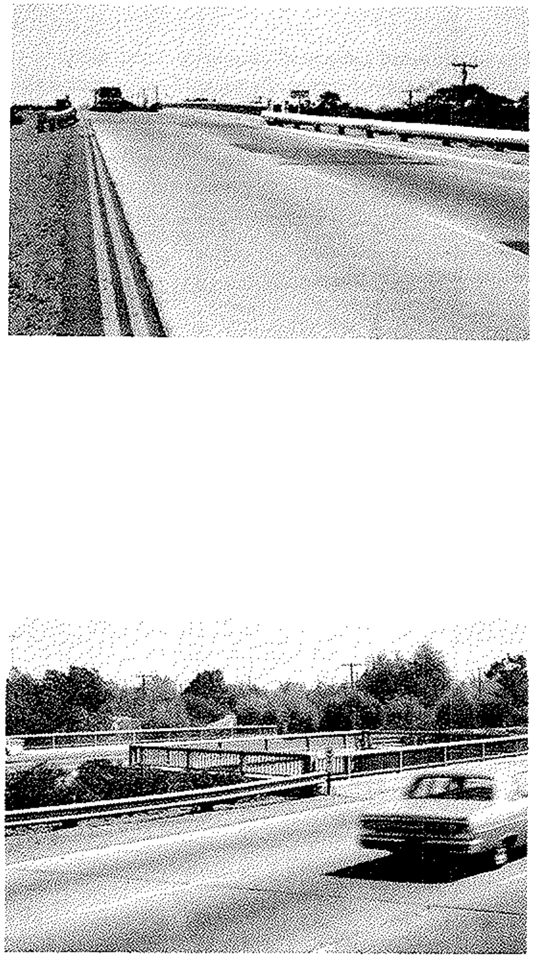


Figure 18. Guardrail flare at bridge rails.

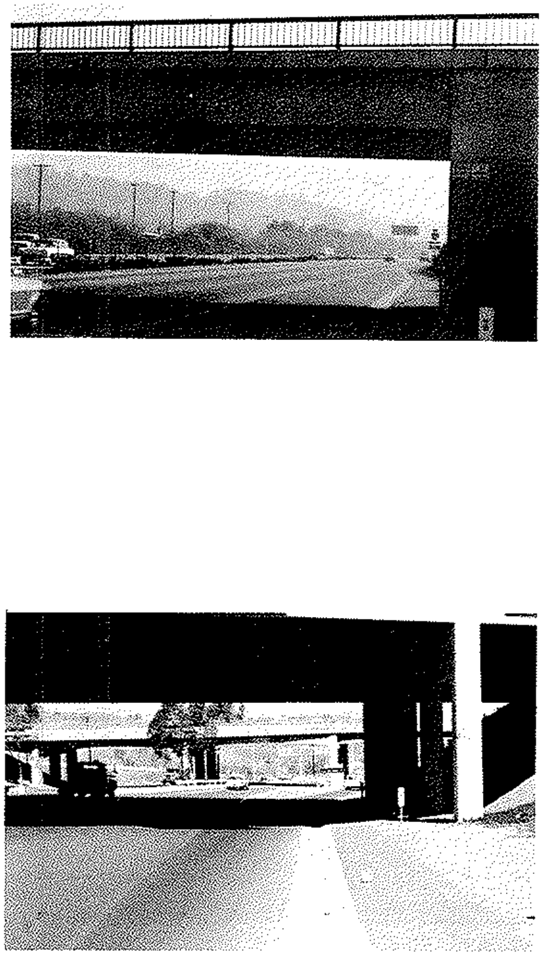


Figure 19. Abutments and piers.

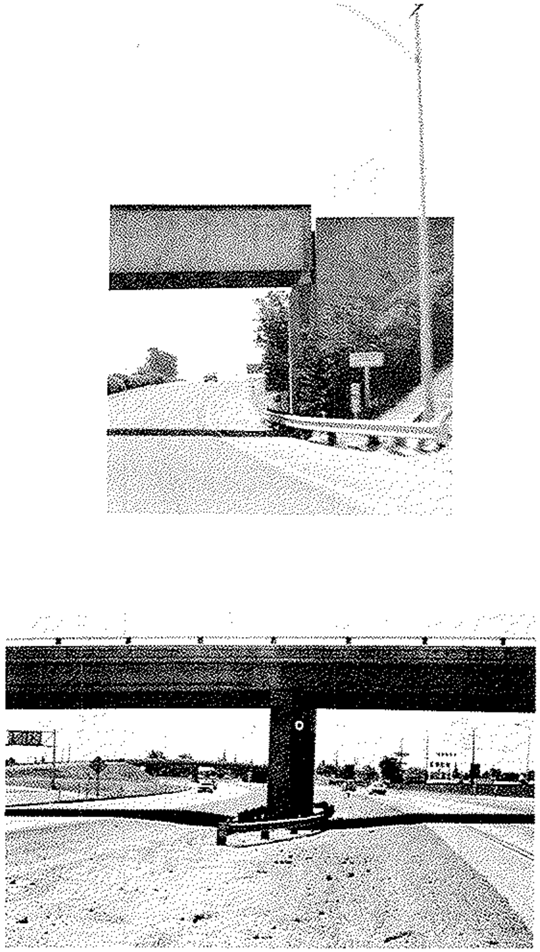


Figure 20. Guardrail flare at abutments and piers.

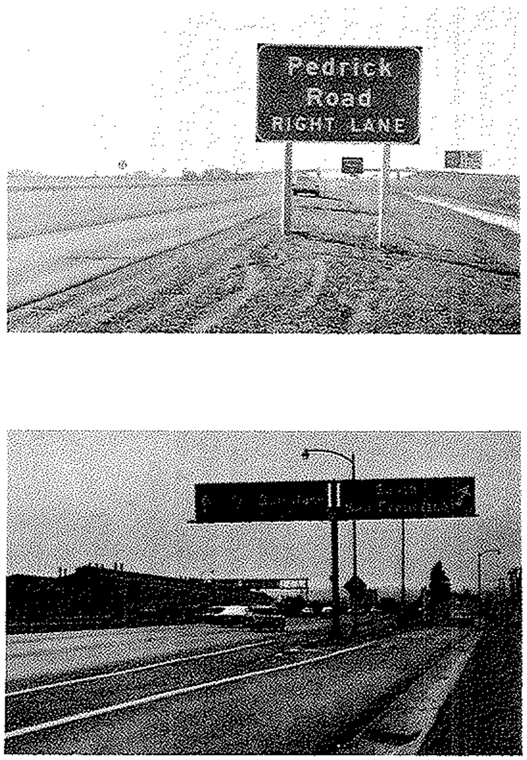


Figure 21. Steel signposts.

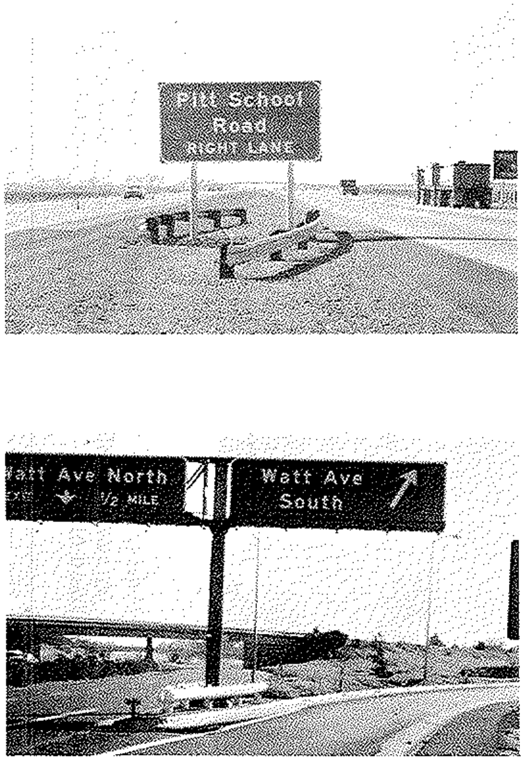


Figure 22. Guardrail at steel signposts.

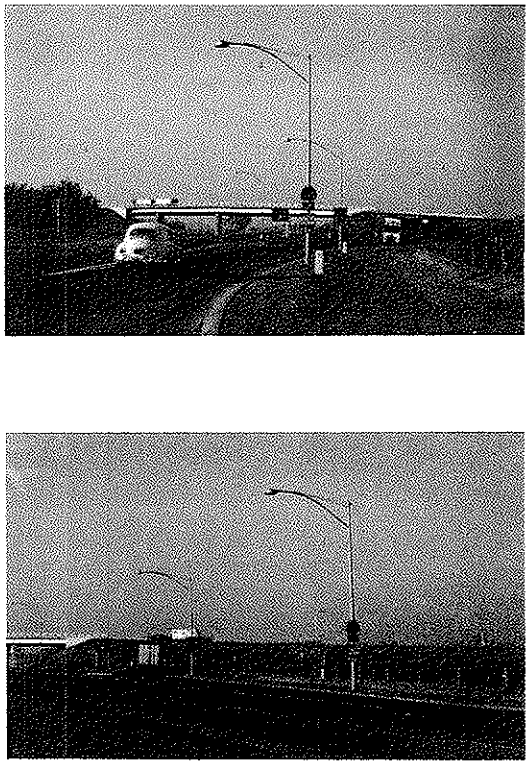


Figure 23. Lightpoles.

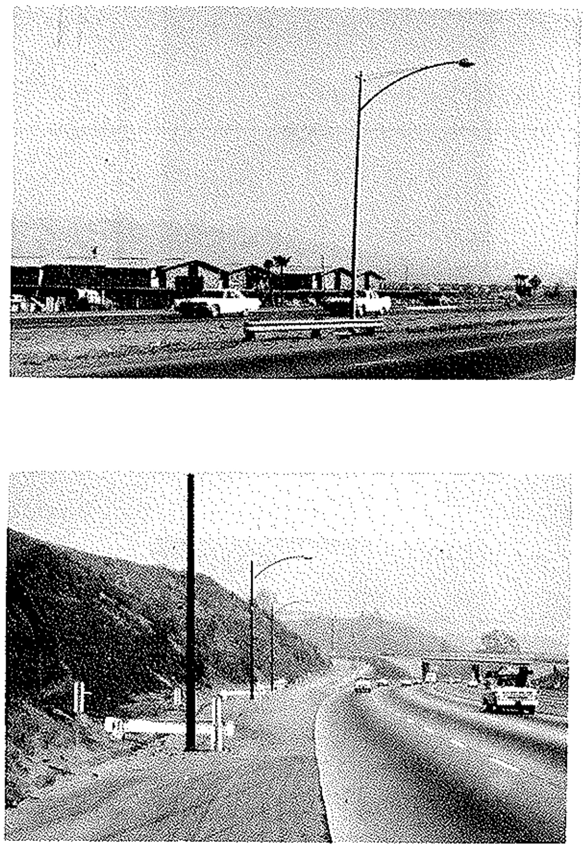


Figure 24. Guardrail at lightpoles.

It is therefore possible to increase the overall safety of freeways by reducing the number of fixed objects, by reducing the exposure to fixed objects, and by reducing the consequence of striking fixed objects. The following are suggestions for accomplishing these three objectives.

1. Methods to reduce the number of fixed objects: (a) place overhead signs on overcrossing structures where appropriate (Fig. 6); (b) enclose overcrossing abutment in cut slope or fill cone (Fig. 7); (c) avoid construction of separate bridges with interior bridge rails whenever possible (Fig. 8); (d) place electroliers on overcrossing structures where possible; (e) place signs back to back in median (Fig. 9); (f) investigate use of advance information signs for possible reduction in number; (g) combine signs and lightpoles (Fig. 10); and (h) avoid indiscriminate use of guardrail (Fig. 11).
2. Methods to reduce exposure to fixed objects: (a) place large overhead directional signs adjacent to the right shoulder in lieu of the more vulnerable gore position (Fig. 12); (b) place signs and lightpoles on top of or immediately beyond bridge rails where convenient (Fig. 13); (c) place signs and lightpoles behind bridge rail and abutment guardrail flares where convenient (Fig. 14); and (d) place signs and lightpoles adjacent to right shoulder instead of in the median (reduced exposure to total traffic).
3. Methods to increase safety of fixed object accidents: (a) place guardrail in front of those objects having a higher collision index than the guardrail (Fig. 15); (b) employ wood posts for smaller directional signs (Fig. 16); (c) design less rigid and less penetrable bridge rails; (d) design a more contiguous bridge-rail-guardrail system; and (e) place fixed objects at greatest possible distance from the edge of the traveled way.

This part of the investigation was concerned with determining what affect adjacent protective guardrail has in reducing the CI of various fixed objects. The fixed objects studied were bridge rails, abutments (and piers), steel signposts, and lightpoles. Present freeway design standards provide for guardrail flares for all bridge rails and guardrail protection for abutments, piers, and overhead steel signposts within 12 ft of the traveled way.

The fixed objects studied, with and without guardrail protection, are shown in Figures 17 through 24.

Design of Study

It was necessary for this investigation to make certain assumptions to simplify comparisons and to obtain relatively large samples within each fixed object category. The following simplifications were used.

1. Guardrail accidents were tabulated without regard to guardrail type.
2. Accidents involving bridge-rail ends were tabulated without regard to bridge-rail design.
3. Accidents involving abutments, piers, and columns were all tabulated in the same category.
4. Accidents involving lightpoles were tabulated without regard to the light standard design.
5. Accidents involving steel signposts were tabulated without regard to size or design.
6. Roadway geometry and lateral placement of fixed objects were not considered as variables.
7. Fixed objects off the outside shoulder were assumed to be exposed to one-half the total two-way volume.
8. Fixed objects in the median were considered to be exposed to the total two-way volume unless site conditions made exposure possible from one direction of travel only.
9. As discussed earlier, it was assumed that accident frequency is independent of traffic volume (time rate of exposure). That is, accident rate is constant regardless of traffic volume. The effect of this assumption (if erroneous) on the results of the study was examined. Because the distribution of exposure volumes for fixed objects closely matched the distribution of exposure volumes for guardrail within each comparison group, the effect of large variations in accident rate with moderate variations in the traffic volume would have a negligible effect on the comparison of the fixed object and guardrail.

Conduct of Study

Computer tabulations of 1963-1964 main-line single vehicle freeway fixed object accidents were obtained. These tabulations were verified by reading the original accident reports. The accident totals by fixed object category are given in Table 7.

To obtain a relative exposure count, a field inventory of fixed objects on 1,100 freeway miles was made. This represents 95 percent of 1,157 freeway miles existing on January 1, 1963. The number of each type of fixed object was tabulated between points of major volume changes on each route and the corresponding volume applied to each fixed object using the 1965 annual traffic census data. The exposure totals are given in Table 8.

The fixed object accident categories were mutually exclusive with respect to fixed object type. However, if a vehicle struck both the guardrail and the fixed object, the accident was classified as a guardrail accident because the overall severity of the accident was composed of the severity of striking the guardrail and the severity of the guardrail failure (striking the fixed object).

Results of Analysis

Table 9 combines Tables 7 and 8 to indicate the relative SI's, PI's, and CI's of the various fixed object categories. It is evident that overall fixed object safety can be

TABLE 7

1963-1964 SINGLE VEHICLE FREEWAY FIXED OBJECT ACCIDENTS

Type of Fixed Object	No. of Accidents			
	Fatal	Injury	PDO	Total
Bridge-rail ends	19	79	25	123
Guardrail and bridge-rail ends	16	191	199	406
Abutments and piers	51	183	59	293
Guardrail at abutments and piers	8	36	28	72
Lightpoles	26	401	305	732
Guardrail at lightpoles	1	23	13	37
Steel signposts adjacent to shoulder	11	112	146	269
Guardrail at steel signposts adjacent to shoulder	1	36	31	68
Steel signposts in gore area	7	27	17	51
Guardrail at steel signposts in gore area	15	220	116	351
Timber signposts	3	165	624	792

TABLE 8

FIXED OBJECT ACCIDENTS

Type of Fixed Object	No. Counted	2-Yr Exposure (billion vehicles)
Bridge-rail ends	755	14. 35
Guardrail at bridge-rail ends	1, 612	40. 76
Abutments and piers	1, 750	34. 17
Guardrail at abutments and piers	568	13. 20
Lightpoles	8, 338	179. 84
Guardrail at lightpoles	99	2. 20
Steel signposts adjacent to shoulder	1, 464	24. 53
Guardrail at steel signposts adjacent to shoulder	616	15. 65
Steel signposts in gore area	57	1. 01
Guardrail at steel signposts in gore area	968	20. 25

increased by placing guardrail adjacent to bridge rail ends, abutments (and piers), and steel signposts. Guardrail should not be placed adjacent to lightpoles.

Table 9 also indicates that steel signposts should not be placed in the off-ramp gore area, because even with guardrail these sign installations are not as safe as steel signposts adjacent to the shoulder.

Table 9 also gives the SI for timber signposts. Inasmuch as the signpost material should not affect the PI, it appears that overall signpost safety could be improved by placing all the smaller signs on timber posts.

The analysis used in Table 9 was performed using severity ratios that ranged from 1-4-17 to 1-10-100. The conclusions of the analysis were independent of the severity ratios used.

The following additional comments apply to the CI analysis.

1. All objects which had the higher CI also had the higher SI.

TABLE 9

ANALYSIS OF FIXED OBJECT COLLISION INDEX

FIXED OBJECT TYPE	NUMBER OF ACCIDENTS				EXPOSURE VOLUME (Billion Vehicles)	SEVERITY INDEX (SI)	PROBABILITY INDEX [a] (PI)	COLLISION INDEX (CI)
	Fatal	Injury	PDO	Total				
Bridge-rail Ends	19	79	25	123	14.35	7.9	8.6	67.9
Guardrail @ Bridge-rail Ends	16	191	199	406	40.76	4.3	10.0	43.0
Abutments & Piers	51	183	59	293	34.17	8.3	8.6	71.4
Guardrail @ Abutments & Piers	8	36	28	72	13.20	6.2	5.5	34.1
Light Poles	26	401	305	732	179.84	4.6	4.1	18.9
Guardrail @ Light Poles	1	23	13	37	2.20	4.8	16.8	80.6
Steel Signposts Adjacent to Shoulder	11	112	146	269	24.53	4.1	11.0	45.1
Guardrail @ Steel Sign Posts Adjacent to Shoulder	1	36	31	68	15.65	4.0	4.3	17.2
Steel Sign Posts In Gore Area	7	27	17	51	1.01	7.0	50.5	353.5
Guardrail @ Steel Sign Posts In Gore Area	15	220	116	351	20.25	5.2	17.4	90.5
TOTAL	155	1308	939	2402	345.96	5.3	7.0	37.1
Timber Sign Posts	3	165	624	792	NA	2.1	NA	NA

[a] PI expressed as accidents per billion vehicles

2. For abutments and for both roadside and gore-mounted signs, the data indicate that the addition of guardrail reduced the PI considerably. Actually, an increase could be expected for the following two reasons. First, the guardrail has a greater impact area than the fixed object. However, Figures 20 and 22 show that the impact area at abutments and signs is not substantially increased with the addition of guardrail. For the two fixed object types (bridge ends and lightpoles) which experience an increased PI with the addition of guardrail, the guardrail impact area is considerably greater than that of the fixed object. Second, the fixed objects are generally at a greater distance from the edge of the traveled way than the guardrail. The decrease in accident frequency with guardrail at abutments and signs could be due to the following: (a) guardrail increases the delineation at the fixed object, and (b) the reporting level of accidents at the guardrail could be lower than that of the fixed objects, because of glancing blows to the guardrail in which the vehicle continued without stopping; however, if this inequality existed and the statistics were corrected accordingly, the CI of the guardrail would be increased only slightly because PDO accidents do not greatly affect the CI.

3. The SI for striking guardrail at fixed objects varies considerably with the different fixed objects, ranging from 4. 0 for guardrail at signposts adjacent to the shoulder to 6. 2 for guardrail at abutments and piers. This occurs, even though the guardrail installations are substantially the same, because the guardrail accidents included accidents where vehicles had struck both the guardrail and the fixed object. It is expected that the severity of the secondary collision would be greater in the case of abutments and piers.

TABLE 10

EXPECTED REDUCTION IN REPORTED ACCIDENTS BY PLACING GUARDRAIL ACCORDING TO COLLISION INDEX ANALYSIS

Fixed Object	Fatal	Expected Number of Accidents[a]			SI
		Injury	PDO	Total	
Guardrail at bridge-rail ends	22(35)	258(270)	269(224)	549(529)	4. 3(5. 1)
Guardrail at abuts. and piers	29(59)	130(219)	101(87)	260(365)	6. 2(7. 9)
Lightpoles	26(27)	407(424)	308(318)	741(769)	4. 6(4. 8)
Guardrail at steel signposts adjacent to shoulder	3(12)	92(148)	78(177)	173(337)	4. 0(4. 1)
Guardrail at steel signposts in gore area	16(22)	232(247)	121(133)	369(402)	5. 2(5. 4)
Total after change	96	1119	877	2092	4. 8
Previous accident totals	155	1308	939	2402	5. 3
Expected reduction in accidents for 2-yr period	59	189	62	310	8. 6

[a] Figures in parentheses indicate the original total accidents for the fixed object and guardrail at the same fixed object.

Analysis of Possible Accident Reduction

If guardrail adjacent to all lightpoles were removed, and if guardrail were installed adjacent to all bridge-rail ends, abutments (and piers) and signposts, a reduction in the 1963-1964 accidents would be expected as indicated in Table 10.

The method employed to arrive at the figures in Table 10 treated each of the five comparison groups separately. Using the PI and ratio of fatal-injury-PDO accidents of the lower CI condition and the exposure of the higher CI condition, the expected number of accidents (by severity) was determined at the locations where the higher CI condition was changed. These accidents were added to the accidents for the lower CI condition to obtain the total accidents expected.

For example, in the case of bridge-rail ends, the exposure of 14. 35 billion vehicles was multiplied by the PI (10. 0) of guardrail at bridge-rail ends giving 143 accidents which would have occurred if these bridge-rail ends had been protected by guardrail. (Actually, there were 123 accidents at bridge-rail ends.) The 143 accidents added to the 406 which actually occurred at guardrails at bridge-rail ends gives the 549 accidents listed in Table 10 for guardrail at bridge-rail ends. The 549 accidents are now subdivided into the fatal-injury-PDO categories in the same ratio as the original 406.

The accident reduction accomplished by this change in guardrail placement specifications would save approximately $270, 000 in direct accidents costs per year. The additional guardrail needed (using 100 ft per installation at $4. 00 per ft) would cost approximately $1, 600, 000 to install. This illustrates that in approximately six years the savings in accident costs would pay for the additional guardrail installation.

Also important is the fact that the SI of those accidents that could be eliminated is a high 8. 9.

RECOMMENDATIONS

1. Embankment guardrail need should be determined on the basis of Fig. 5, and modified by considerations of cost, alignment, grade, traffic volume, climate, and accident experience.

2. Guardrail should be placed adjacent to: (a) bridge-rail approach ends, (b) bridge piers and abutments, and (c) steel signposts. The guardrail increases the relative safety (decreases the product of accident frequency and severity) at these fixed objects.
3. Guardrail should not be placed adjacent to lightpoles. The guardrail decreases relative safety (increases accident frequency, whereas the severity remains approximately unchanged).
4. Steel signposts in the off-ramp gore area should be avoided. Similar signposts placed adjacent to the right shoulder are safer.
5. Dimensional lumber signposts should be used in lieu of steel signposts whenever possible.
6. A review of present material and dimensional requirements of signposts should be made with the objective of providing posts of the minimum strength consistent with structural requirements to reduce the severity of accidents involving signposts.
7. A subsequent investigation should be undertaken with the purpose of evaluating the effects of highway geometry and traffic on the frequency of ran-off-road accidents. With this information, a more objective basis for embankment guardrail placement can be developed.

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Appendix

COMPUTATION OF DIRECT ACCIDENT COSTS FOR CALIFORNIA SINGLE VEHICLE REPORTED ACCIDENTS USING THE ILLINOIS COST ANALYSIS (2)

TABLE 11

DIRECT COSTS PER VEHICLE INVOLVEMENT OF URBAN AND RURAL REPORTED ACCIDENTS IN ILLINOIS BY SEVERITY OF ACCIDENT—1958

Severity of Accident	Cost per Accident Involvement ($)	
	Rural	Urban
Fatal	5,628	4,215
Injury	1,421	910
PDO	272	144

TABLE 12

NUMBER OF URBAN AND RURAL SINGLE VEHICLE REPORTED ACCIDENTS ON CALIFORNIA STATE HIGHWAYS CLASSIFIED BY SEVERITY OF ACCIDENT—1964

Severity of Accident	Number of Accidents				
	Rural	%	Urban	%	Total
Fatal	608	63.5	350	36.5	958
Injury	7,880	54.2	6,668	45.8	14,548
PDO	8,628	48.2	9,142	51.4	17,770

TABLE 13

COMPUTATION OF COST PER SINGLE VEHICLE REPORTED ACCIDENTS ON CALIFORNIA STATE HIGHWAYS CLASSIFIED BY SEVERITY OF ACCIDENT—1964

Severity of Accident	Computation	Cost ($)
Fatal	5,628(0.635) + 4,215(0.365)	5,100
Injury	1,421(0.542) + 910(0.458)	1,200
PDO	272(0.486) + 144(0.514)	200