Studies of Roadside Hazards for Projecting Fatal Crash Sites

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This paper presents a survey of road curvature, superelevation, gradient, and number and distance from the roadway of roadside hazards conducted in Georgia at 300 sites of fatal crashes into fixed objects and at 300 comparison sites 1.6 km (1 mile) from the accident site. More than 26 percent of fatal crash sites and only 8 percent of comparison sites had road curvature greater than 6 deg combined with downhill gradient of -2 percent or less at or approaching the sites. Fifty percent of fatal crash sites and only 23 percent of comparison sites were at or near curves greater than 6 deg irrespective of gradient. A state study found that only 22 percent of roadways throughout the state had curvatures of more than 5.5 deg. Nonlocal roads accounted for 83 percent of the fatal crashes into fixed objects but comprised only 33 percent of the roads in the state. In 98 percent of the cases objects struck were within 15 m (50 ft) of the pavement edge. Top priority should be given to modification of roadside hazards on and near curves greater than 6 deg, particularly those on nonlocal roads where the downhill grades are -2 percent or less.

Most U.S. roads are bordered by natural and man-made unyielding structures (trees, rocks, poles, guardrails) that are hazardous roadside objects. When vehicles collide with these objects, the occupants are either maimed or killed. The magnitude of the danger is difficult to assess because most single-vehicle collisions are categorized as noncollision rather than as fixed object. In 1974, the National Safety Council listed 13 500 deaths in the noncollision category and only 3600 deaths in the fixed-object category (1). A few states have modified their reporting categories to reflect accurately the toll caused by roadside object collisions. In 1974, Pennsylvania reported 766 occupant fatalities in single-vehicle crashes. Of that amount, 689 or 90 percent of the accidents were caused by collisions with fixed objects (2). Undoubtedly, the vast majority of occupant fatalities in single-vehicle accidents, which average more than 17 000 per year in the United States, result from collisions with unyielding structures along the roadside.

The technology is readily available for either removing roadside hazards or modifying them or the immediate environment so that the energy of errant vehicles can be managed to protect occupants from intolerable energy transfers (3, 4, 5, 6, 7). However, these hazards are so numerous that immediate removal or modification is infeasible, and some method is needed to identify those that should have priority treatment. The results of this study provide criteria for identifying road locations where fatalities caused by collisions with roadside hazards are likely to occur. The numbers and types of hazards in defined areas contiguous to the crash sites are also identified.

METHOD

The study was designed to identify and compare roadway characteristics at two sites. The site where one or more vehicle occupants died when the vehicle struck a roadside object was termed the crash site. A site located 1.6 km (1 mile) upstream, which the vehicle had likely passed before reaching the crash site, was termed the comparison site. The differences noted between the roadway characteristics of these sites can be used to identify other sites where fatalities are likely to occur. Comparison of characteristics of crash and comparison sites with characteristics of other Georgia roadways provides additional criteria for selecting sites for modification.

During a 14-month period ending in April 1975, virtually all locations where fatal collisions into roadside objects had occurred in the 108 contiguous counties in north and central Georgia were studied (Figure 1). This area includes a variety of land usage (rural, suburban, urban), roadway types, and topography. The Georgia State Patrol routinely mailed fatal accident reports to the research team. Those accidents in which the fixed object had not been struck or had not been a significant factor in the fatality were excluded.

Engineering measurements were made by a three-person team in a 0.3-km (0.2-mile) section at each site. Measurements were referenced from an object most likely to receive impact or cause vehicle occupant death. Crash sites were determined by locating a point along the roadway edge immediately adjacent to a selected object. The comparison site was located 1.6 km (1 mile) upstream from the crash site (Figure 2). The choice of turns at T- or Y-intersections was randomly selected in the

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location of comparison sites.

Curvature, superelevation, and gradient were measured both upstream and downstream from crash and comparison sites. Measurements began 15 m (50 ft) from each site and continued every 30 m (100 ft). Curvature and superelevation measurements ceased at 137 m (450 ft); gradient measurements ceased at 152 m (500 ft).

Figure 1. Area studied (shaded).

Distance was measured by using a 30-m (100-ft) cloth tape. Horizontal curvatures were measured by applying the middle ordinate method described by Baker (8) that consists of measuring the curve on the edge of the roadway and by converting the middle ordinates to degrees of curvature at the centerline of the roadway. Superelevation and gradients were measured at the center of the road on the side where the driver approached the crash location. These measurements were made with a specially designed instrument consisting of a 1.2-m (4-ft) carpenter's level having an adjusted calibrated leg. Curvature, superelevation, and gradient data for Interstate highways were taken from plan and profile sheets.

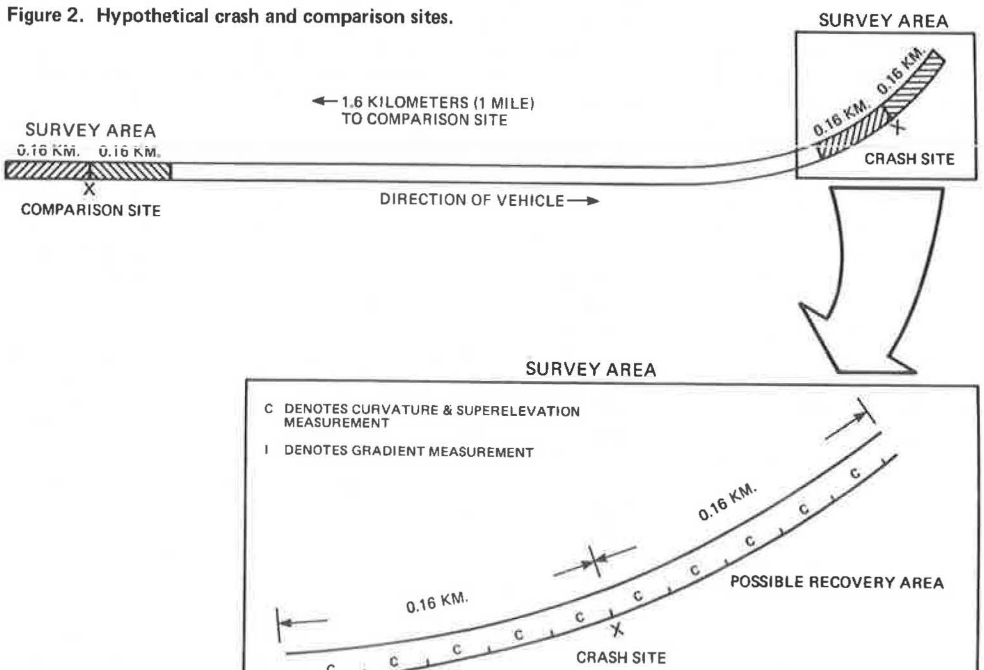
In the survey area, various fixed objects were inventoried in 3-m (10-ft) segments of a 9-m (30-ft) border along the pavement edge. Other road characteristics, which included type of road, number of lanes, and widths of pavement and shoulder, were also recorded.

The Georgia Department of Transportation supplied curvature length data derived from a 25 percent sample of the 41 216-km (25 600-mile) public road network. The department also provided distances by functional class for the complete 161 325-km (100 202-mile) system. The data served as a basis for estimating the amount and type of Georgia roadway that would require hazard modification by using this study's criteria.

RESULTS

The largest difference between crash and comparison sites was road curvature. More than 80 percent of the crash sites had curvature within 152 m (500 ft) whereas only 55 percent of comparison sites had curvature within this range (Figure 3). The road curvature within 152 m (500 ft) of the sites was greater than 6 deg for more than 50 percent of the crash sites but less than 24 percent of the comparison sites. The difference in distributions of curvature between crash and comparison sites would not normally occur by chance fluctuations in sampling (χ^2 = 80.1, d.f. = 7, $p < 0.001$). Only 22 percent of the 25 per-

Figure 2. Hypothetical crash and comparison sites.



cent sample of all Georgia roads had curvature greater than 5.5 deg.

The severest degree of curvature was usually found near to or upstream from the crash site. Figure 4 shows the percentage of road curvature greater than 6 deg at intervals upstream and downstream from crash and comparison sites. The largest differences occur in the area from -107 m (-350 ft) upstream to 15 m (50 ft) downstream. More than 69 percent of the vehicles crashing on or near curves left the outside of the curve, that is, the right side of a left-bending curve or the left side of a right-bending curve (Figure 5).

Although the results for superelevation are not shown, they closely parallel those for curvature. The cases where high curvature and low or nonexistent superelevation occurred were too few to separate the two variables as factors for identifying sites where fatal crashes into fixed objects would occur.

Roadways approaching crash sites exhibited more downhill gradient than those approaching comparison sites. Figure 6 shows the average road gradients at 30-m (100-ft) intervals within 152 m (500 ft) of crash and comparison sites. Average gradients decreased at each interval before crash sites but not before comparison sites. Extreme uphill gradient was more common beyond crash sites than beyond comparison sites, suggesting that

Figure 3. Maximum road curvature by distance from crash and comparison sites.

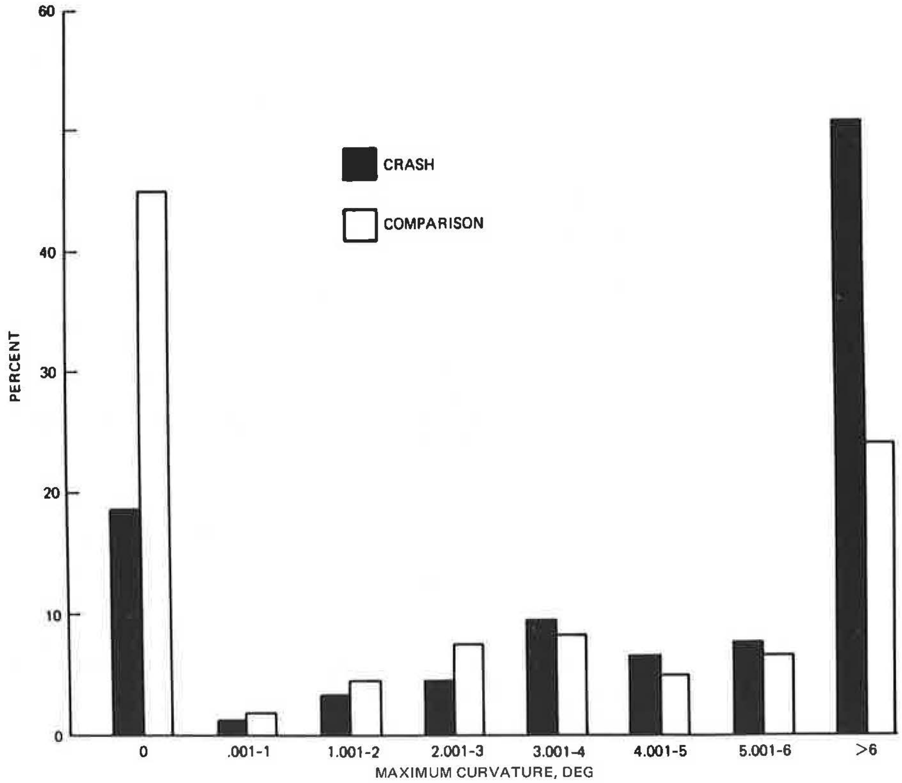


Figure 4. Road curvature > 6 deg by distance from crash and comparison sites.

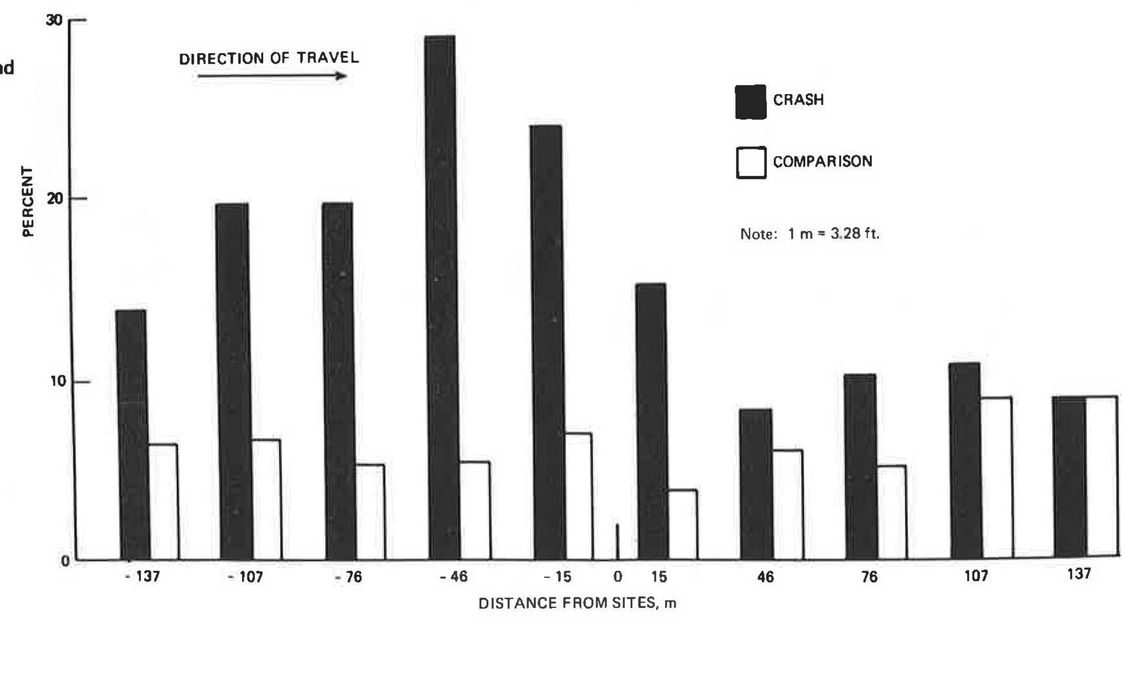


Table 1. Analysis of variance for gradient ±152 m from crash and comparison sites.

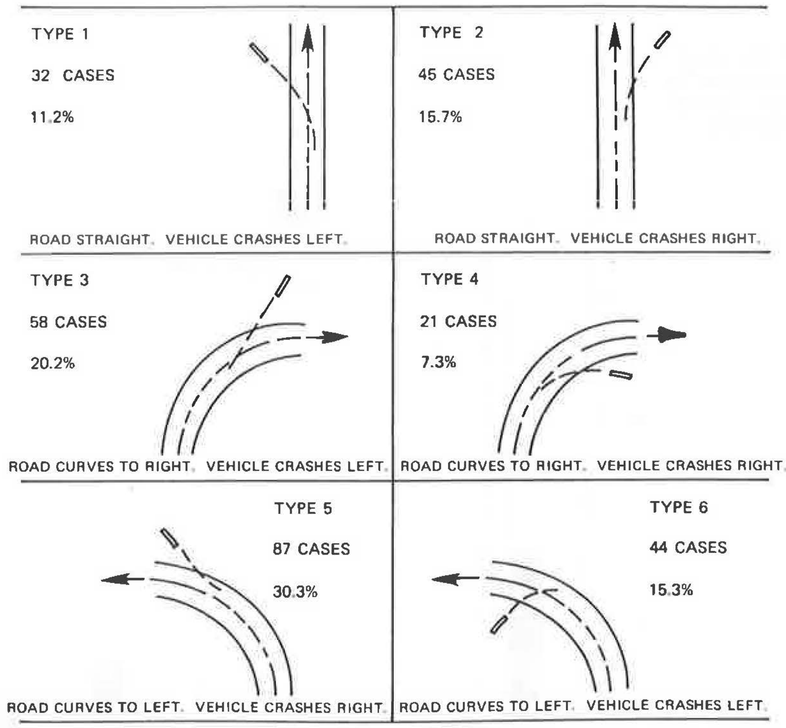
Source of Variation	Degrees of Freedom	Mean Squares	Variance Ratio, F	Significance
Differences of crash and comparison sites	1.0	40.873	4.905	p < 0.05
Differences among measuring points	20.0	11.294	1.355	
Residual	6.490	8.333		

Note: 1 m = 3.28 ft.

crash sites were closer to points where downhill gradient ended and uphill gradient began. The analysis of variance in Table 1 indicates that the average differences in gradient between crash and comparison sites would not have occurred as a result of random fluctuation in sampling ($p < 0.05$).

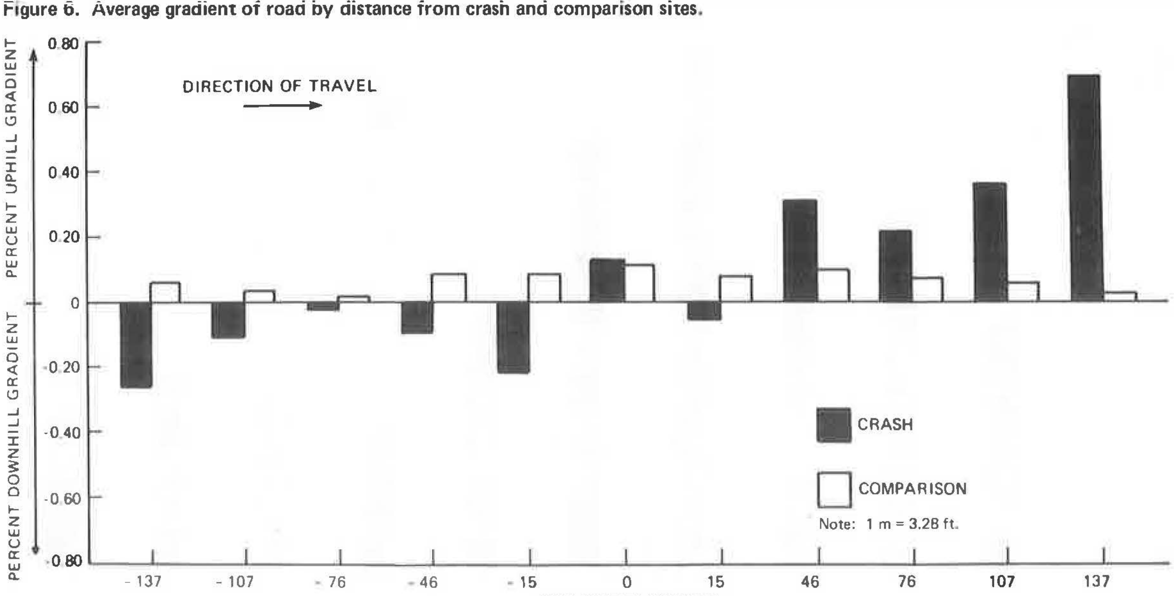
Crash and comparison sites were not characterized substantially more by extreme downhill gradients than by moderate downhill gradients. Figure 7 shows the minimum gradients observed at 152 m (500 ft) upstream from crash and comparison sites. The frequent minimum gra-

Figure 5. Fatal crashes into roadside objects by type of curvature.



Note: Excludes 13 cases where curves had more than 1 type of bend or information was missing.

Figure 6. Average gradient of road by distance from crash and comparison sites.



dient approaching sites was -2 percent or less for crash sites and greater than -2 percent for comparison sites.

The combined factors of maximum road curvature and minimum gradient did substantially discriminate between crash and comparison sites (Figure 8). Maximum curvature greater than 6 deg combined with minimum gradient of -2 percent or less occurred at 26 percent of the crash sites and only 8 percent of the comparison sites.

Since crash and comparison sites were on the same or similar roads, there was no difference between number of lanes or pavement width. Thus, the average differences in these factors were not significant ($p > 0.04$). There was also no significant difference in width of road shoulder between crash and comparison sites ($p > 0.05$).

The roadways were classified functionally for each crash location by using the classifications of the Georgia Department of Transportation (Figure 9). Only 17 percent of crash sites were on local roads, which make up 67 percent of the roads in the state. Based on its percentage of all roads, each type of nonlocal road had a greater percentage of fatal crashes than would be expected.

Potential hazards near the roadside differed little between crash and comparison sites (Table 2). Of the objects that apparently took the brunt of impact, about 90 percent were within 11 m (35 ft) from the pavement edge

Figure 7. Minimum gradient of road by distance upstream from crash and comparison sites.

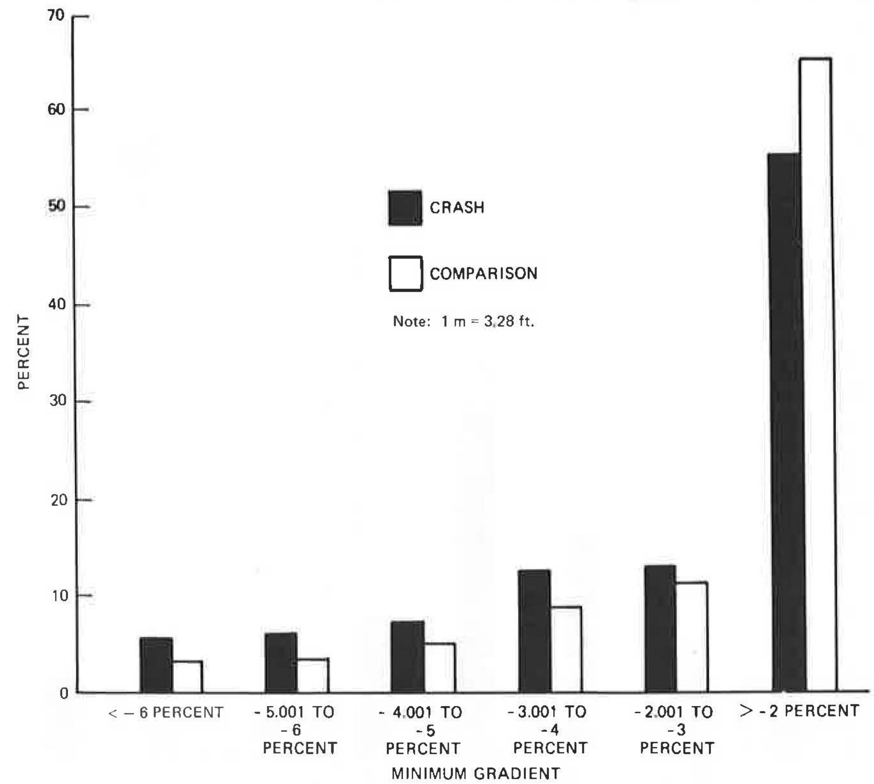
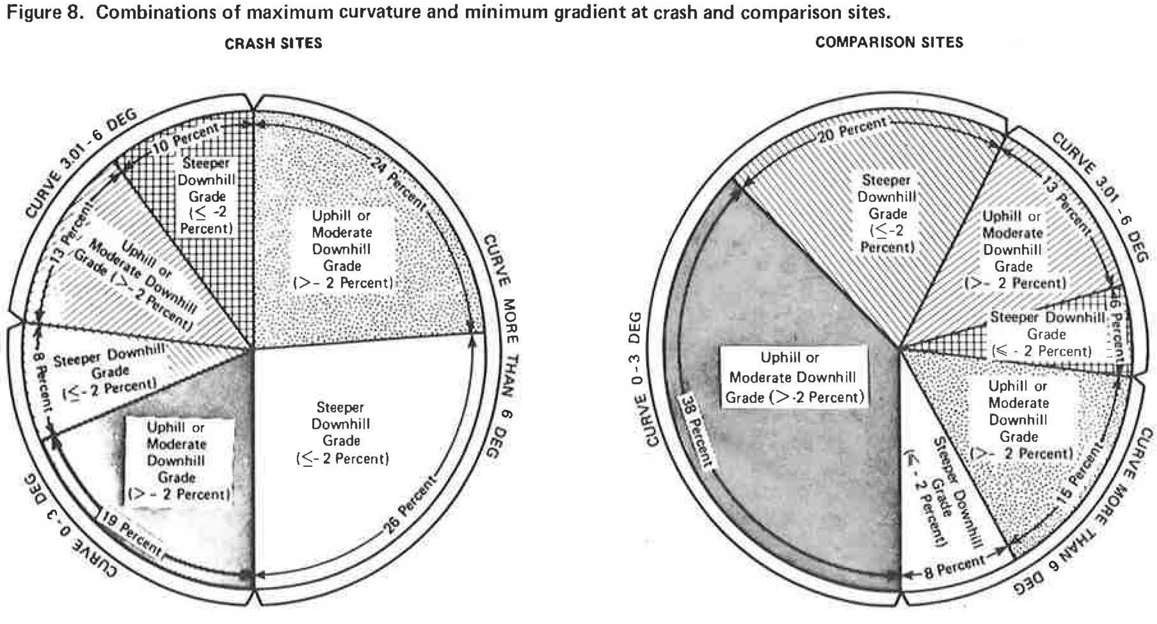


Figure 8. Combinations of maximum curvature and minimum gradient at crash and comparison sites.



(Figure 10) and 98 percent were within 15 m (50 ft). The objects struck and the percentage of fatal crashes involving them are as follows:

Objects	Percent	Objects	Percent
Trees	39	Guardrails	7
Embankments and ditches	23	Signs	5
Utility poles	14	Bridge abutments	3
		Other	19.3

Table 3 gives the average number of objects in a path on each side and upstream of the crash site. There were about 6 narrow potential hazards and 5 m (15 ft) of elongated potential hazards.

RECOMMENDATIONS

The results of this study indicate that roads or roadside objects exhibiting hazardous characteristics should be modified or where applicable removed. The following discussion summarizes this study's findings and recommendations.

Roads exhibiting the following characteristics are

Figure 9. Relation of crash sites and all Georgia roads by functional classification.

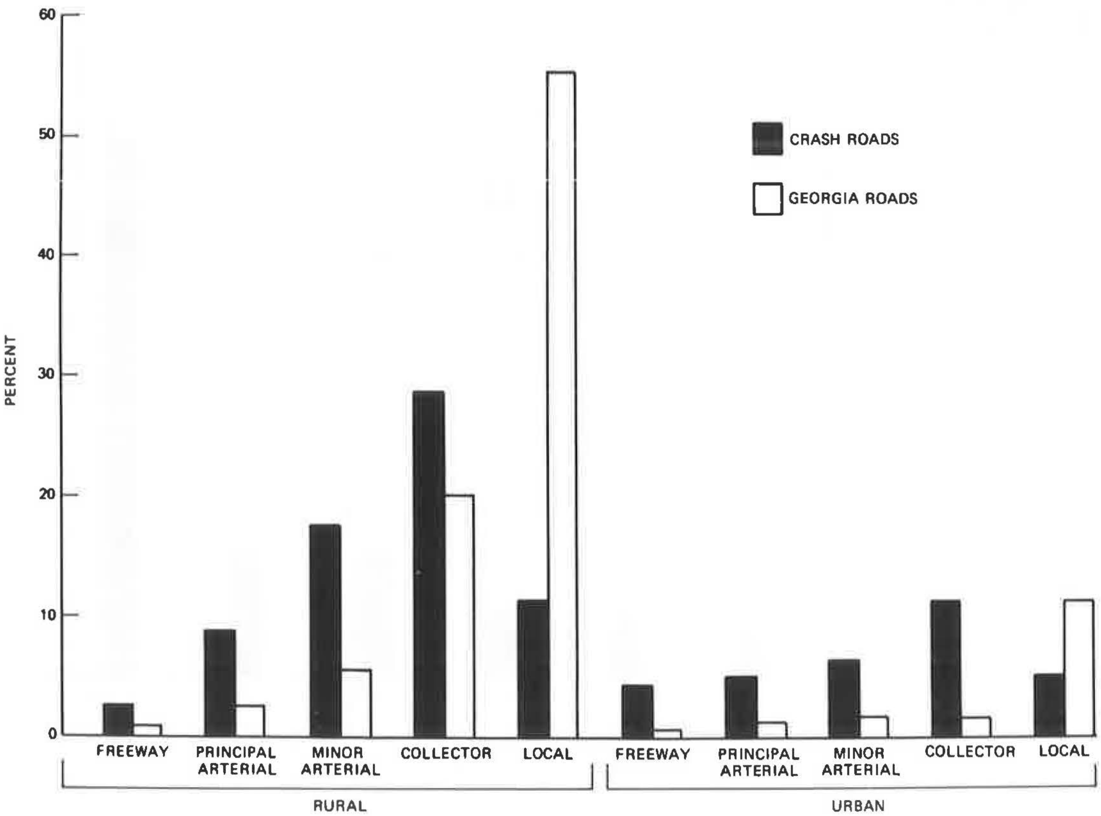


Table 2. Average number of narrow potential hazards and length of elongated potential hazards 9 m from pavement edge and 161 m from site.

Potential Hazards	Upstream From Site								Downstream From Site							
	Crash Sites				Comparison Sites				Crash Sites				Comparison Sites			
	0 to 3 m	3 to 6 m	6 to 9 m	Total	0 to 3 m	3 to 6 m	6 to 9 m	Total	0 to 3 m	3 to 6 m	6 to 9 m	Total	0 to 3 m	3 to 6 m	6 to 9 m	Total
Narrow, number																
Trees	0.7	2.7	3.9	7.3[a]	0.7	1.8	3.0	5.5	1.0	3.1	4.9[a]	9.0[a]	0.5	2.8	3.4	6.7
Utility poles	0.6	0.4	0.3	1.3	0.6	0.5	0.3	1.4	0.6	0.4	0.2	1.2	0.8	0.4	0.2	1.4
Traffic sign/signal posts	0.7	0.2	0.1	1.0	0.6	0.2	0.1	0.9	0.6	0.2	0.1	0.9	0.7	0.2	–[b]	0.9
Street luminary poles	0.1	–[b]	–[b]	0.1	–[b]	–[b]	–[b]	0.1	–[b]	–[b]	–[b]	–[b]	–[b]	–[b]	–[b]	0.1
Other	1.3	2.0	1.7	5.0	1.6	2.0	1.0	4.6	1.4	1.7	1.5	4.6	1.8	1.2	1.1	4.1
Total	3.4	5.3	6.0	14.7[a]	3.5	4.5	4.4	12.5	3.6	5.4	6.7	15.7	3.8	4.6	4.7	13.2
Elongated, m																
Guardrails	3.3	3.4	0.5	7.2	3.2	1.2	–[b]	4.4	4.9	3.0	–[b]	7.9	2.4	3.0	–[b]	4.4
Curbs	9.7	1.7	0.5	11.9	11.2	1.6	0.1	12.9	9.8	1.9	0.1	11.8	11.7	2.4	0.3	14.4
Embankments	11.1	19.1	4.8	35.0	8.6	16.6	3.8	29.0	9.7	18.7	5.2	33.6	8.3	20.7	4.3	33.3
Banks/cuts	4.5	9.9	4.7	19.1	4.7	9.5	4.2	18.4	5.0	11.9	5.9	22.8	5.7	12.6	3.6	21.9
Ditches	13.1	18.1	4.4	35.6	14.9	13.4	3.0	31.3	15.8	15.6	3.7	35.1	12.6	18.3	4.7	35.6
Median barriers	0.5	0.7	0.0	1.2	1.2	0.1	–[b]	1.3	0.5	–[b]	0.5	1.0	0.9	0.1	0.1	1.1
Total	42.2	52.9	14.9	110.0	43.8	42.4	11.1	97.3	45.7	51.1	15.4	112.2	41.6	57.1	13.0	110.7

Note: 1 m = 3.28 ft.

[a]Significantly different ($p < 0.05$, two-tailed) from comparison sites.

[b]<0.05 but not 0.00.

listed according to degree of hazard and modification priority.

1. Curvature greater than 6 deg combined with a

Figure 10. Distance of objects from roadside at crash sites.

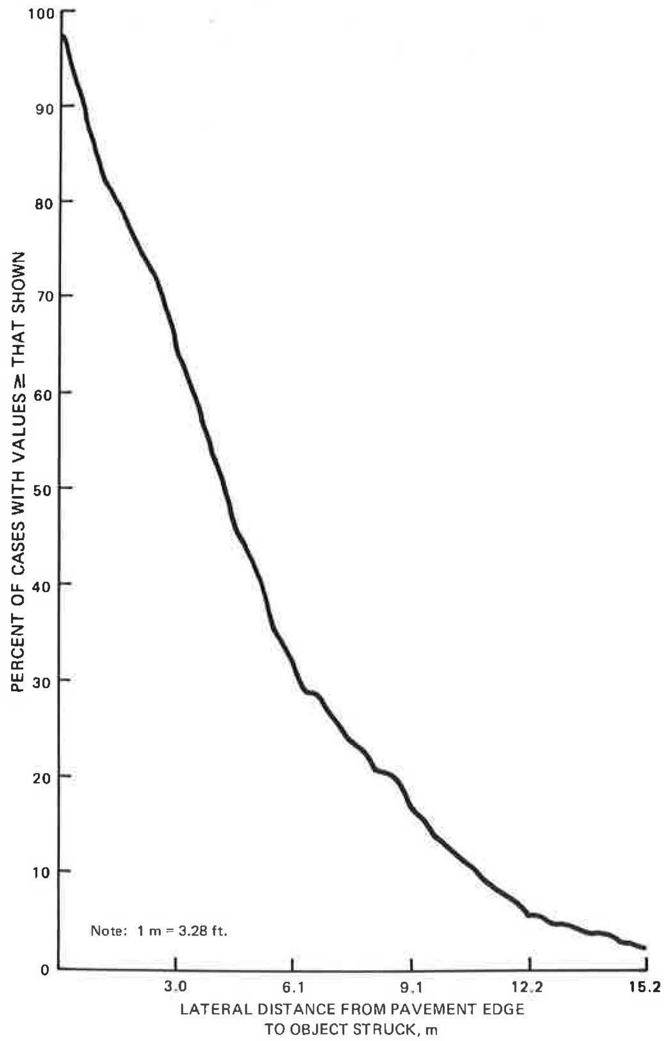


Table 3. Average number of narrow potential hazards and length of elongated potential hazards 4.6 m to each side and 27 m upstream from crash site.

	Vehicle Path Beyond Crash Site (m)			
Potential Hazards	0 to 9	9 to 18	18 to 27	Total
Narrow, number				
Trees	1.2	1.3	1.4	3.9
Utility poles	0.1	—[a]	0.1	0.1[b]
Traffic sign/signal posts	0.1	—[a]	—[a]	0.1
Street luminary poles	0.0	—[a]	0.0	—[a]
Other	0.6	0.5	0.3	1.4
Total	2.0	1.8	1.8	5.5
Elongated, m				
Guardrails	0.5	0.2	0.2	0.9
Curbs	0.2	0.1	0.1	0.4
Embankments	0.6	0.3	0.4	1.3
Banks/cuts	0.3	0.4	0.4	1.1
Ditches	0.5	0.4	0.2	1.1
Median barriers	0.0	0.0	0.0	0.0
Total	2.1	1.4	1.3	4.8

Note: 1 m = 3.28 ft.
[a] 0.05 but not 0.00. [b]Total not equal to sum because of rounding.

downhill gradient of -2 percent or less prior to or in curves,

2. Curvature greater than 6 deg,
3. Curvature greater than 3 deg combined with downhill gradient of -2 percent or less, and
4. Curvature greater than 3 deg.

Fatal crash locations can further be narrowed to nonlocal roads. Although the available state road data did not allow degree of curvature and gradient to be assessed by type of roadway, it is clear that fatal crashes into roadside objects occurred mostly on nonlocal roads. The obvious approach to reducing the number of roadside hazards is to identify the types of roads in a given state that have a history of noncollision and fixed-object fatalities and to apply the noted curvature and gradient criteria to likely crash sites. Although the number and types of hazards on a road may differ because of climate, land use, and other factors, the involvement of curves and gradient in likelihood of impacting hazards is undoubtedly similar in all areas.

A number of researchers have attempted to relate road characteristics to crashes with some success (9, 10, 11, 12, 13). However, a clear set of factors used to identify likely crash locations caused by roadside hazards has not emerged prior to this study. Previous studies have included nonhomogeneous sets of crashes, have failed to distinguish injury severity, or have used arbitrarily defined road segments. By studying only fatal crashes into fixed objects and by referencing the roadway characteristics to specific crash sites this study presents a clear profile of hazardous locations.

The modifications at a particular location depend on a number of factors: number and types of hazards, width of right-of-way, cooperation of utility companies and others who erect and maintain objects on or off the right-of-way, and costs of alternative means of modification. In some cases it may be possible to reduce or eliminate curvature and gradient and modify or remove hazards. In other cases only modification or removal of the hazards may be feasible.

In the absence of fixed objects, attention must be given to roadway characteristics that might contribute to vehicle rollover. These characteristics include ditches, culverts, curbs, or embankments. If fixed objects are modified or removed but roadside characteristics contributing to rollover remain, a subset of the fatalities will continue to occur. In every case, the goal should be a clear recovery area for vehicles that leave the road; if objects cannot be entirely cleared, energy management principles should be applied to eliminate the lethal transfer of crash forces to vehicle occupants (3, 4, 5, 6, 7).

The data also provide guidelines for the types of fixed objects and other roadside characteristics that can be expected and their distribution at the locations to be modified. Most fatal crashes occur in curves or within a few hundred meters beyond maximum curvature. Apparently, the driver loses vehicle control while he or she is in or coming out of a curve and not while anticipating the difficulty with a curve. In the cases studied the majority of fatalities would not have occurred had a 15-m (50-ft) roadside area 137 m (450 ft) before and after the maximum curvature been clear of fixed objects and characteristics contributing to rollover. Of the objects struck 98 percent were within 15 m (50 ft) of the pavement edge.

The average roadside area, 161 by 9 m (528 by 30 ft), had nine trees, one utility pole, one traffic sign or signal post, and five other such relatively narrow objects at crash locations. The average length of elongated objects was as follows:

Objects	Length (m)	Objects	Length (m)
Guardrails	7	Banks and cuts	19
Curbs	12	Ditches	36
Embankments	35	Median barriers	1

Guardrails and median barriers may be protective or hazardous depending on their designed ability to gently absorb or redirect the energy of a moving vehicle as well as their proper construction and installation (3, 4, 5, 6, 7).

Since almost 70 percent of fatal crashes occurred on the outside of the curves, that side of the road should take precedence in ameliorative efforts when resources do not allow such efforts on both sides of the road at every available site. It is not known how often a vehicle ran off the inside curve to avoid objects on the outside of the curve. However, to ensure maximum benefit both sides of the road must be modified.

Relatively few objects were found in a 9 by 27-m (30 by 90-ft) path that the vehicles would likely have traveled had they not struck a lethal object. The potential for large reductions in human damage by small efforts in modifying roadside hazards is clear. Failure to act promptly in ameliorative efforts could provide grounds for legal liability (14).

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