fact is supported by other data (8,9) that show that 29 percent of Georgia's fatal accidents involve fixed objects whereas the comparable figure in New Mexico is less than 11 percent. The fatal-accident data indicate that, for vehicles that have left the roadway, crashes in Georgia are more likely to involve fixed objects whereas those in New Mexico are much more likely to involve overturning. The difference is attributable not only to the number of spot fixed objects but also to the extent and height of embankments.

Although the findings of this study offer some guidance for the selection of hazardous locations in New Mexico, the significant differences found between Georgia and New Mexico suggest that other roadway, traffic, and environmental factors need to be considered in the development of a priority scheme for nationwide application. A project is under way to coalesce the results of these studies into a model for establishing priorities for improving locations where there is a potential for overturning crashes. There may have to be different criteria among the states for assessing the level of hazards.

ACKNOWLEDGMENT

The work reported in this paper was supported by the Insurance Institute for Highway Safety. The opinions, findings, and conclusions expressed are ours and do not necessarily reflect the views of the Insurance Institute for Highway Safety.

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Study of Fatal Rollover Crashes in Georgia

PAUL H. WRIGHT AND PAUL ZADOR

Engineering surveys were performed at 214 locations in Georgia where single-vehicle fatal rollover crashes occurred over a one-year study period. Similar surveys were made at comparison locations 1.6 km (1 mile) upstream from the crash locations. The most prominent roadway feature associated with fatal rollover crashes in Georgia was horizontal curvature, particularly along left curves. It was found that fatal rollover crash locations can be discriminated from comparison locations by curvature greater than 6°, the same value suggested in the fixed-object studies. Steep gradients were also found to be strongly and significantly associated with rollover crash locations. The pattern of distribution of longitudinal slopes observed in earlier studies of fixed-object crashes, in which negative slopes tended to occur upstream and positive slopes downstream, was also apparent at rollover crash locations. Rollover sites were characterized by significantly larger changes in lateral slope at the shoulder edge than were found at comparison sites. The rollover sites were also more likely than the comparison sites to have embankments along the roadside but less likely to have trees and certain other spot fixed objects. Similarly, the rollover crash sites had longer embankments, banks, and ditches than were found at fixed-object crash sites. On the other hand, more trees, poles, and signs were found at the fixed-object crash sites than at the rollover crash sites.

Vehicle rollover is one of the leading causes of death in single-vehicle crashes. According to an estimate obtained from the U.S. Department of Transportation Fatal Accident Reporting System (FARS), in 1978 and 1979, 46 percent of the passenger cars in fatal single-vehicle crashes rolled over. Little research has been performed on possible contributions of the roadway to the occurrence and severity of such crashes.

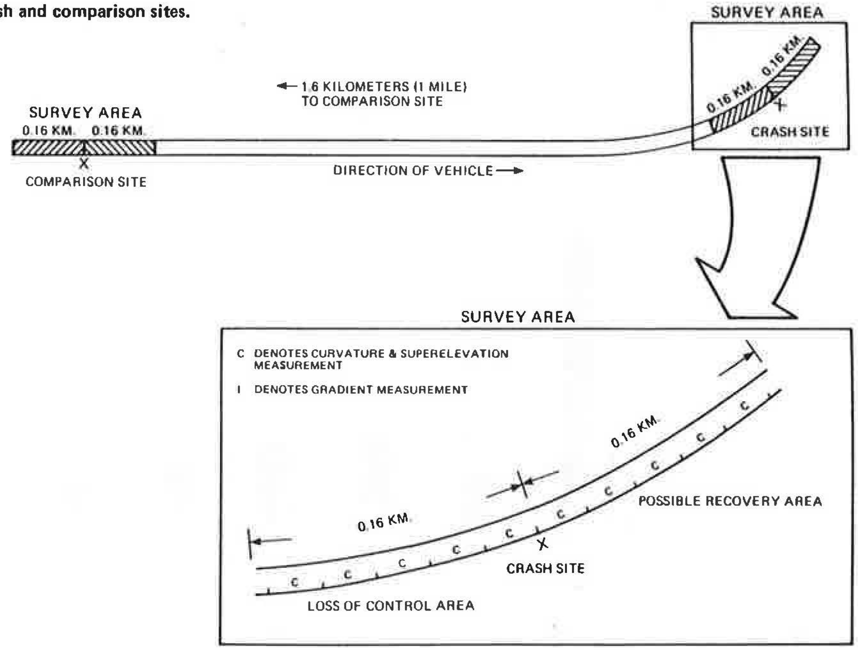
The objective of the study described in this paper was to identify distinctive roadway characteristics at locations in Georgia where fatal rollover crashes occurred and to develop guidelines for the reduction or elimination of such crashes by modifying roadway and/or roadside features. A companion study, described in the paper by Hall and Zador in this Record, was undertaken in New Mexico.

The study described here is the third in a series relating single-vehicle crashes in Georgia to roadway and/or roadside characteristics. The first two studies (1,2) involved crashes of vehicles into fixed objects. One project focused on 300 fatal fixed-object crashes in 108 counties in Georgia during a 14-month period ending in April 1975 (1). The second project was a study of a general population of fixed-object crashes, including 7 fatal, 112 nonfatal injury, and 181 property-damage-only crashes, in a three-county area in north Georgia during a five-month period in 1977 and 1978 (2). These two studies, and the one described here, were based on surveys of geometric design features and an inventory of roadside obstacles at both crash and noncrash sites.

BACKGROUND

FARS provided general statistics on the circumstances and conditions associated with fatal rollover crashes. These statistics revealed that, for fatal single-vehicle rollover crashes throughout the United States in 1978, 43.5 percent occurred along roadways with curved alignment, 34.3 percent oc-

Figure 1. Hypothetical crash and comparison sites.



curred along roadways with gradient, 87.5 percent occurred along two-lane roadways, 86.1 percent occurred where the roadway surface was reported to be dry, and 9.5 percent occurred where inclement weather or adverse atmospheric conditions were identified.

METHOD

This study was designed to compare roadway characteristics at two groups of sites: sites where one or more vehicle occupants died in a rollover crash and sites 1.6 km (1 mile) away that the vehicle was likely to have passed prior to reaching the site of the fatal crash. Differences between the two groups of sites can be used to identify roadway and/or roadside features where fatal rollover crashes are more likely to occur. Virtually all of the locations of fatal single-vehicle rollover crashes that occurred in Georgia during a 12-month period ending in July 1979 were included in this study.

The study area included a variety of land uses (rural, suburban, and urban), roadway types, and topography. Police reports of fatal rollover crashes were routinely mailed to the research team by the Georgia State Patrol. A total of 223 crashes were identified, but 9 were eliminated because of difficulties in locating or collecting data at the sites.

Engineering surveys were made, usually by three-person teams, at 214 fatal crash locations and at 214 comparison locations. The surveys were confined to a 0.3-km (0.2-mile) section at each of the locations. The measurements were referenced to the point at which the rollover of the vehicle commenced. A point along the roadway edge immediately adjacent to the reference rollover point was identified as the "crash site". As Figure 1 shows, a point 1.6 km upstream (i.e., away from the crash site, in the direction from which the vehicle traveled) was designated as the "comparison site". In locating comparison sites, turn choices at T- or Y-intersections were made randomly (by flip of a coin).

Measurements of curvature and superelevation were made beginning 15 m (50 ft) from the crash and comparison sites and at 30-m (100-ft) intervals for 137 m (450 ft) both upstream and downstream from these sites. The gradient was measured every 30 m for 152 m (500 ft) both upstream and downstream from the sites.

A 30-m cloth tape was used for measuring distances. Horizontal curvatures were measured by the middle ordinate method. The curve measurements were usually taken on the edge of the roadway. The middle ordinates were converted to degrees of curvature of the centerline of the roadway. Superelevation and gradients were measured at the center of the side of the road used by the driver in approaching the crash location. Those measurements were made with a specially designed instrument consisting of a 1.2-m (4-ft) carpenter's level with an adjusted calibrated leg. On Interstate highways, curvature, superelevation, and gradient data were taken from plan and profile sheets.

At a subsample of 48 locations, side slopes and other elements of the cross section were carefully measured with a cloth tape, hand level, and level rod. This subsample was chosen to include a pair of crash and comparison sites for which either or both locations had sharp curvature and steep negative gradient. The subsample included all cases for which the curvature exceeded 6° and the gradient was negative and steeper than 2 percent at both the crash and comparison locations. The subsample also included half of the cases where these criteria were satisfied at either the crash or comparison location and all of the remaining cases where the curvature exceeded 4° and the gradient was negative and greater than 1 percent at both locations.

Inventories were taken of various types of fixed objects in 3-m (10-ft) segments of a 9-m (30 ft) border for 161 m (0.1 mile) in each direction from the crash and comparison sites. In addition, type of road, number of lanes, and widths of pavement and shoulder were recorded.

Pavement skid resistance was measured at approximately half of the crash and comparison sites by pulling a 32-kg (71-lb) lead block, mounted on small rubber shoes, along the roadway and measuring the resistance by means of a spring scale.

The data-collection procedures used in this study were essentially the same as those used in the

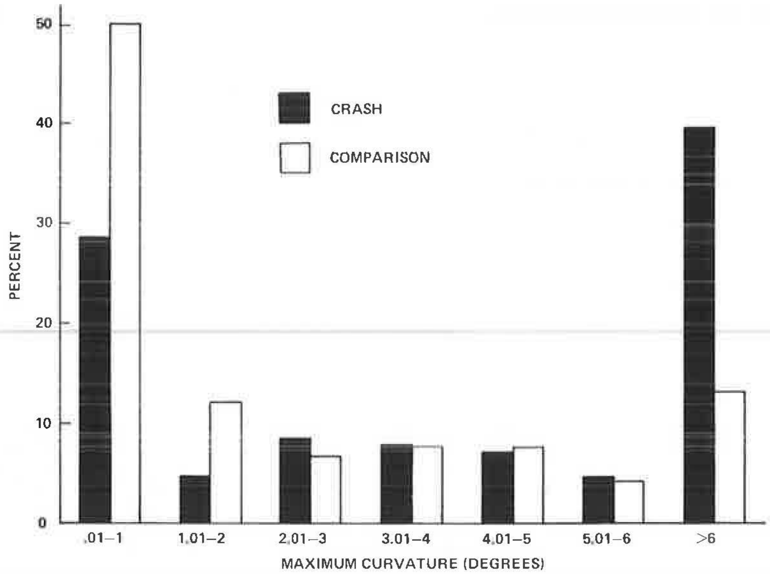


Figure 2. Distribution of maximum road curvature at sites of fatal rollover crashes and at comparison sites.

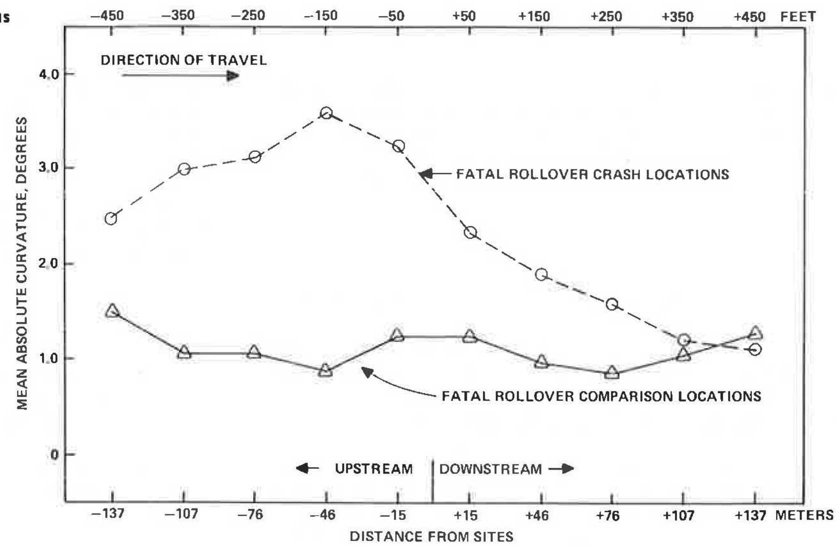


Figure 3. Mean degree of curvature observed at various section positions at crash and comparison sites.

earlier studies of single-vehicle collisions with roadside obstacles (1,2).

RESULTS

Curvature

The largest difference between the crash and comparison sites was in road curvature. Approximately 40 percent of the crash sites had a maximum curvature greater than 6° whereas only 13 percent of the comparison sites had a maximum curvature greater than 6° (see Figure 2). At half of the comparison sites, but at only 28 percent of the crash sites, the roadway was straight or had negligible curvature (degree of curve $\leq 1°$). The difference in distribution of curvature between the crash and comparison locations shown in Figure 2 could not commonly occur from chance fluctuations in sampling ($X^2 = 218.5$, df = 6, $p < 0.001$).

The curvature usually occurred near the crash site or upstream. The largest differences in curvature occurred in the area from 107 m (350 ft) upstream to 15 m (50 ft) downstream from the sites. The maximum curvature tended to occur at a point located 46 m (150 ft) upstream from the crash site, as Figure 3 shows. This is reasonable, since horizontal curvature places heavier demands on drivers and increases the likelihood of a driver losing control of a vehicle.

The pattern of distribution of mean curvatures with station location was similar to that found in the earlier study of fatal fixed-object crashes (see Figure 4). The mean curvature values for the fixed-object crash locations were generally higher than for the rollover crash locations, and Student's t-test indicated that the differences were significant at the 5 percent level for four locations: 46 m upstream and 76, 107, and 137 m downstream (150 ft upstream and 250, 350, and 450 ft downstream).

Table 1 gives a distribution of the fatal rollover and fixed-object crashes by general type of alignment and direction of vehicle departure from the roadway. The distribution shows a marked tendency for vehicles in rollover crashes to leave the roadway along left-turning curves and, among these curves, vehicles leaving the roadway on the outside (or right side) are overrepresented. Among crashes in which the vehicle left a straight road section on the left side, there were more off-the-

Figure 4. Mean degree of curvature observed at various section positions at sites of fixed-object crashes and rollover crashes.

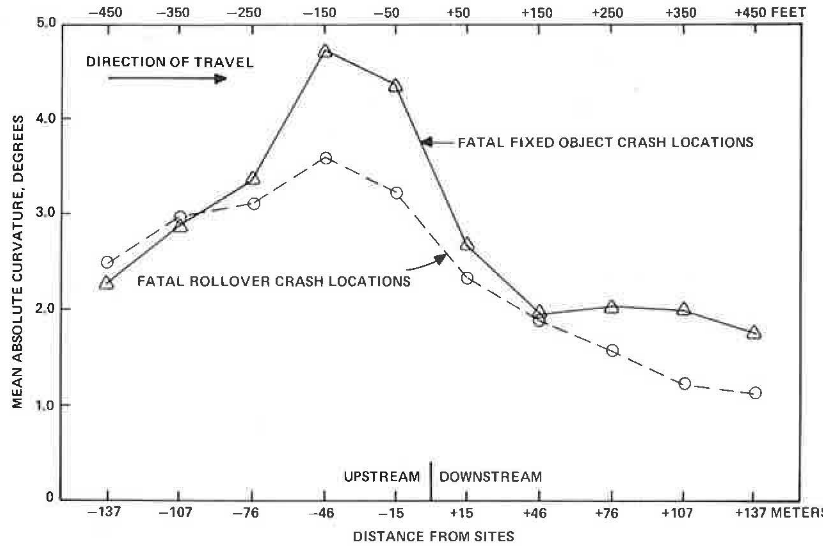


Table 1. Distribution of fatal crashes by type of alignment and direction of vehicle departure from roadway.

Roadway Alignment	Side of Road on Which Vehicle Crashed	Percentage of Crashes Observed: Fixed-Object Study	Rollover Study
Straight	Left	11.2	16.9
	Right	15.7	15.5
Curve to right	Left	20.2	8.9
	Right	7.3	7.0
Curve to left	Left	15.3	15.0
	Right	30.3	23.5
Not specified	On road	-	13.2

road rollovers than fixed-object crashes. For vehicles that crashed along the left side of right-turning curves and the right side of left-turning curves, a greater percentage of fixed-object crashes than rollover crashes was found.

Lateral Slope

The mean lateral slopes of the traveled lanes are shown in Figure 5 for each position at the crash and comparison locations. The data shown represent both superelevation values (for curved roadways) and crown values (for straight roadways). The slightly higher mean values noted in the upstream area reflect the superelevation commonly provided for the curves that tend to occur in the areas approaching the crash sites; these differences were statistically significant ($p < 0.085$). The lateral slopes tended to be greater at the locations of fixed-object crashes than at the locations of rollover crashes, but in only two instances--at 107 and 137 m (350 and 450 ft) downstream--were the differences significant.

Gradient

Figure 6 shows the pattern of variation of mean gradients for crash and comparison locations. The apparent differences in mean gradients were tested for each of the 11 positions by using t-tests. None of the differences was found to be significant at the 5 percent level.

The finding of steeper downhill slopes at comparison sites than at crash sites prompted further analysis of these data. Table 2 gives the percentages of rollover crash sites that have various combinations of average curvature and gradient in a 91-m (300-ft) section immediately upstream from these sites. The comparable percentage distribution for the opposite sides of these road sections is also given. The opposite-side percentages were obtained by reversing "left" and "right" for curvature and "uphill" and "downhill" for gradient. For each curvature range, there were more downhill crashes than crashes on the opposite side of the road. Since a crash could have taken place on either side of the roadway, these results show that crashes were more common on downhill than on uphill road segments with the same curvature.

Differences in the gradients at locations of fatal fixed-object and rollover crashes were not significantly different. The patterns of distribution of gradients at the two classes of locations were remarkably similar; there were more negative slopes upstream of the sites and positive slopes downstream (see Figure 7).

Roadside

Measurements of eight key lateral dimensions or slopes along the roadside were made at 48 locations selected from the original set of 214 (50 locations were selected, but field survey teams were unable to perform surveys at 2 of them). In the vicinity of each crash and comparison site, the following measurements of the cross-sectional dimensions and slopes were made at stations 30 m (100 ft) upstream and downstream: shoulder width, shoulder slope, inside slope, back slope, depth of ditch, lateral distance from edge of shoulder to bottom of embankment, extent of drop-off at the pavement edge, and height of curb.

Twenty-four t-tests were made to compare each of the eight variables at each position in the crash vicinity with the corresponding variable and position at the comparison location. Mean values of these slopes and dimensions are given in Table 3. On the basis of two-tailed t-tests, significant differences ($p < 0.10$) were noted for five of the tests:

1. The height of curb 30 m upstream was higher at the comparison location than at the crash location.

2. The shoulder slope at the comparison site was steeper than at the crash site.

3. The inside slope at the crash site was steeper than at the comparison site.

4. The shoulder slope 30 m downstream was steeper at the comparison location than at the crash location.

5. The inside slope 30 m downstream was steeper at the crash location than at the comparison location.

Of special interest in these findings about the roadside is the change in lateral slope at the edge of the shoulder. At the crash site, the mean change in lateral slope was 32.9 percent (37.5 - 4.6). At the comparison site, the mean change in slope was

Figure 5. Mean lateral slope observed at various section positions.

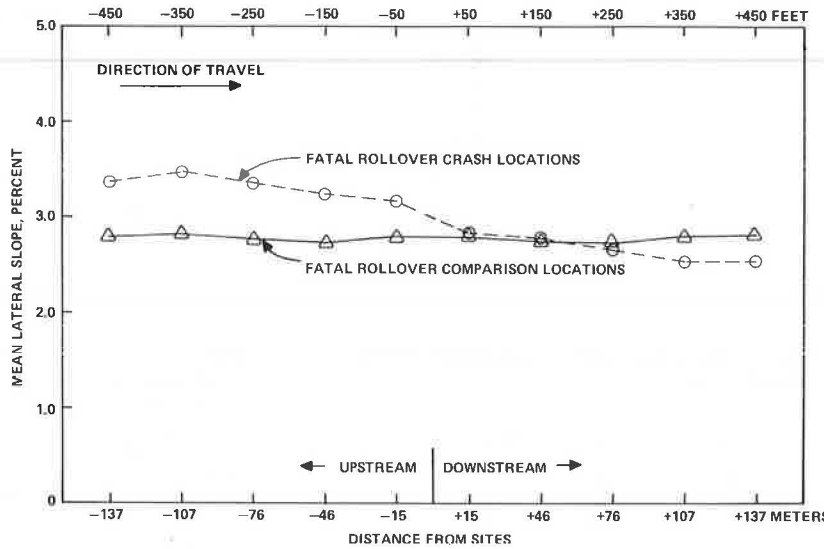


Figure 6. Mean gradient observed at various section positions at sites of rollover crashes and at comparison sites.

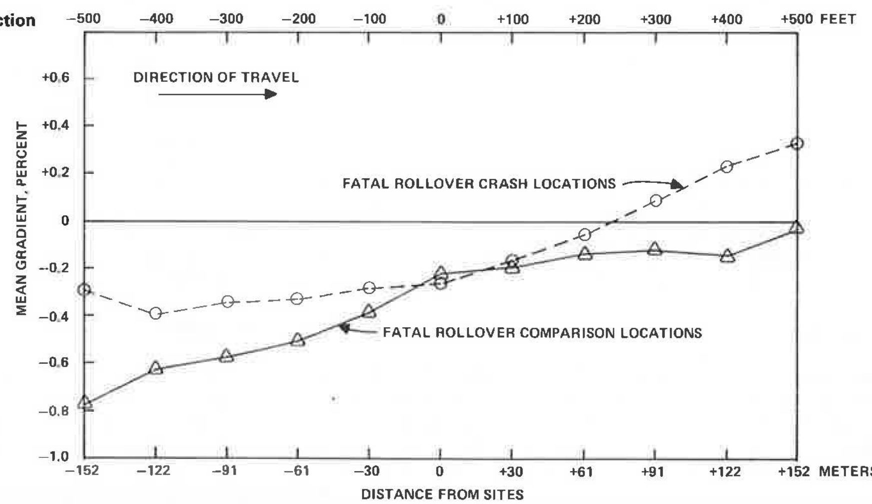


Table 2. Comparison of crash sites and opposite sides of road for various combinations of gradient and curvature.

	Upgrade (>+1.0%)			Nearly Level (≤+1.0% to ≥-1.0%)			Downgrade (<-1.0%)		
Curvature	Crash (%)	Opposite (%)	Ratio	Crash (%)	Opposite (%)	Ratio	Crash (%)	Opposite (%)	Ratio
Sharp right (≤-3.01°)	3.7	10.7	0.35	5.1	7.5	0.69	3.3	8.9	0.37
Gradual right (<-3.00° to <-0.1°)	2.8	6.1	0.46	2.8	7.9	0.35	3.3	2.8	1.17
Nearly tangent (≥-0.1° to ≤+0.1°)	7.9	10.7	0.74	16.4	16.4	1.00	10.7	7.9	1.35
Gradual left (>0.1° to ≤+3.00°)	2.8	3.3	0.86	7.9	2.8	2.83	6.1	2.8	2.17
Sharp left (≥+3.01°)	8.9	3.3	2.71	7.5	5.1	1.45	10.7	3.7	2.88

Figure 7. Mean gradient observed at various section positions at sites of fixed-object crashes and rollover crashes.

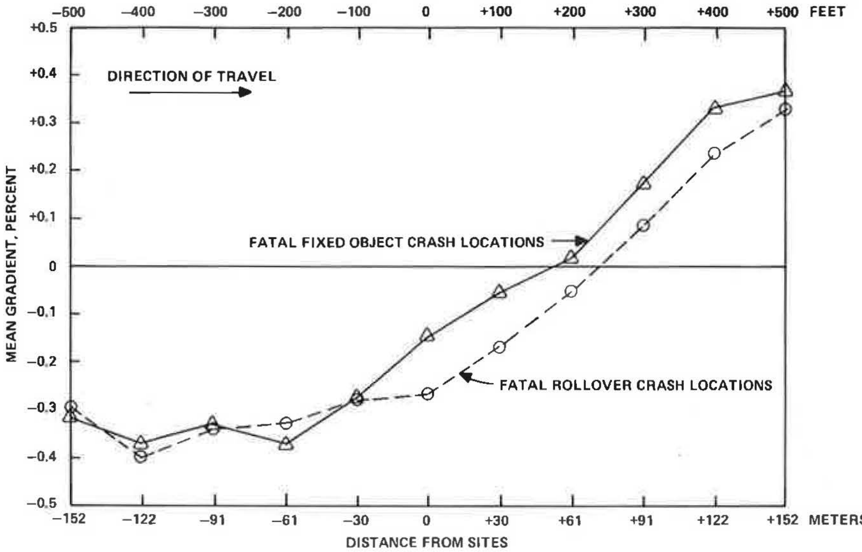


Table 3. Mean dimensions of roadside cross section at various locations.

Variable	30 m Upstream	At Site	30 m Downstream
Shoulder width (m)			
Crash	1.9	1.9	1.9
Comparison	1.7	1.8	1.7
Shoulder slope (%)			
Crash	5.2	4.6[a]	4.1[a]
Comparison	5.5	6.9[a]	6.6[a]
Inside slope (%)			
Crash	30.7	37.5[a]	38.9[a]
Comparison	28.2	28.9[a]	29.2[a]
Back slope (%)			
Crash	26.3	21.7	17.8
Comparison	21.5	13.5	20.1
Ditch depth (m)			
Crash	0.37	0.37	0.38
Comparison	0.36	0.36	0.35
Lateral embankment length (m)			
Crash	3.8	3.2	4.4
Comparison	3.3	3.9	3.6
Curb height (cm)			
Crash	0.70[a]	1.16	1.24
Comparison	2.48[a]	3.10	1.58
Drop-off at shoulder (cm)			
Crash	3.92	4.57	3.16
Comparison	2.95	3.31	4.17

Note: 1 m = 3.28 ft.
[a]Significantly different ($p < 0.10$, two-tailed).

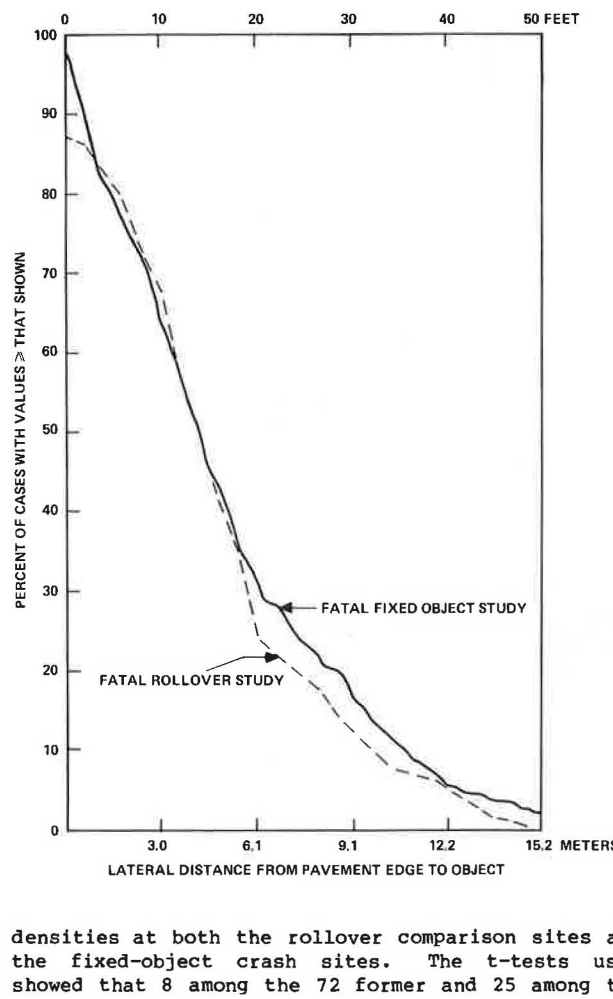
only 22.0 percent (38.9 - 6.9). Similar results were obtained in comparing the mean changes in slopes 30 m downstream.

As Figure 8 shows, about 90 percent of rollover crashes were precipitated at points within 9.1 m (30 ft) of the pavement edge. The distribution of lateral displacement of such points was similar to that for lateral distances to objectives struck in the fixed-object study. The average angle of departure was 9.6°, a value that compares favorably with encroachment angles reported by other researchers (3,4).

Roadside Objects

Tables 4 and 5 give the average numbers of "spot" obstacles and the lengths of elongated obstacles in 0.16-km (0.1-mile) sections upstream and downstream from rollover sites (crash and comparison) as well as at sites of fixed-object crashes. Hazard densities at the rollover crash sites were compared with

Figure 8. Distributions of lateral distance to crash point for studies of fatal fixed-object crashes and rollover crashes.



densities at both the rollover comparison sites and the fixed-object crash sites. The t-tests used showed that 8 among the 72 former and 25 among the 72 latter differences were statistically significant ($p < 0.10$); these differences are indicated in Table 4. The relatively few and small differences between single-vehicle crash and comparison sites in regard to hazard densities confirm the field observation that the placement and frequency of roadside

Table 4. Average number of spot potential hazards 161 m upstream and downstream of crash and comparison sites by distance from pavement.

	Rollover Crash Sites				Rollover Comparison Sites				Fixed-Object Crash Sites			
Hazard	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total
Upstream												
Trees	0.2	3.3	7.3	10.8	0.4	2.4	4.1	6.9	0.7[a]	2.7	3.9[a]	7.3
Utility poles	0.2	0.2	0.3	0.7	0.2	0.3	0.2	0.7	0.6[a]	0.4[a]	0.3	1.3
Traffic-signal posts	0.5	0.1	0.2	0.8	1.9	0.2	0.1	2.2	0.7	0.2[a]	0.1	1.0
Street luminary poles	--[b]	--[b]	--[b]	--	--[b]	--[b]	--[b]	--	0.1	--[b]	--[b]	0.1
Other narrow objects	0.8	0.7	0.3	1.8	0.5[a]	1.2	0.3	2.0	1.3	2.0	1.7	5.0
Total	1.7	4.3	8.1	14.1	3.0	4.1	4.7	11.8	3.4	5.3	6.0	14.7
Downstream												
Trees	0.6	1.5	4.5	6.6	0.3	1.7	3.7	5.7	1.0[a]	3.1[a]	4.9[a]	9.0
Utility poles	0.1	0.1	0.3	0.5	0.2	0.2	0.3	0.7	0.6[a]	0.4[a]	0.2	1.2
Traffic-signal posts	0.5	0.3	0.1	0.9	0.4	0.2	0.1	0.7	0.6	0.2	0.1	0.9
Street luminary poles	--[b]	--[b]	--[b]	--	--[b]	--[b]	--[b]	--	--[b]	--[b]	--[b]	--
Other narrow objects	0.6	2.4	0.4	3.4	0.5	0.5	0.2	1.2	1.4	1.7	1.5	4.6
Total	1.8	4.3	5.3	11.4	1.4	2.6	4.3	8.3	3.6	5.4	6.7	15.7

Note: 1 m = 3.28 ft. [a]<0.05 but not 0.00. [b]Significantly different from rollover crash site data ($p < 0.10$).

Table 5. Average number of elongated potential hazards 161 m upstream and downstream of crash and comparison sites by distance from pavement.

	Rollover Crash Sites				Rollover Comparison Sites				Fixed-Object Crash Sites			
Hazard	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total
Upstream												
Curbs	4.3	2.8	0.1	7.2	8.4	2.5	0.1	11.0	9.3[a]	1.7	0.6	11.6
Embankments	17.6	50.4	11.7	79.7	8.4[a]	37.9[a]	13.8	60.1	11.1[a]	19.2[a]	4.9	35.2
Banks and cuts	1.7	17.7	11.2	30.6	1.0	10.9[a]	13.9	25.8	4.6[a]	10.0[a]	4.6[a]	19.2
Ditches	11.5	42.1	12.9	66.5	16.5	42.5	14.1	73.1	13.0	18.3[a]	4.4[a]	35.7
Guardrails	4.3	3.7	0.2	8.2	2.7	3.0	0.2	5.9	3.3	3.5	0.4	7.2
Other	2.6	4.3	8.2	15.1	3.6	4.8	7.3	15.7	--	--	--	--
Total	42.0	121.0	44.3	207.3	40.6	101.6	49.4	191.6	41.3	52.7	14.9	108.9
Downstream												
Curbs	6.2	1.3	0.7	8.2	7.2	3.4	0.0	10.6	9.4	1.9	0.1	11.4
Embankments	15.9	43.9	14.0	73.8	10.4[a]	40.6	14.8	65.8	9.9[a]	18.7[a]	5.2[a]	33.8
Banks and cuts	0.1	11.7	9.7	21.5	2.5[a]	15.1	18.2[a]	35.8	5.0[a]	11.4	6.0[a]	22.4
Ditches	9.0	47.3	11.7	68.0	13.1	42.9	15.4	71.4	15.5[a]	15.7[a]	3.8[a]	35.0
Guardrails	4.0	2.9	0.2	7.1	2.2	3.2	1.3	6.7	5.0	3.1	a	8.1
Other	4.9	4.9	10.5	20.3	1.6	6.1	6.0	13.7	--	--	--	--
Total	40.1	112.0	46.8	198.9	37.0	111.3	55.7	204.0	44.8	50.8	15.1	110.7

Note: 1 m = 3.28 ft. [a]Significantly different from rollover crash site data ($p < 0.10$. [b]< 0.05 but not 0.00.

Figure 9. Average lengths of embankments, banks, and ditches combined in 161-m sections upstream and downstream from sites.

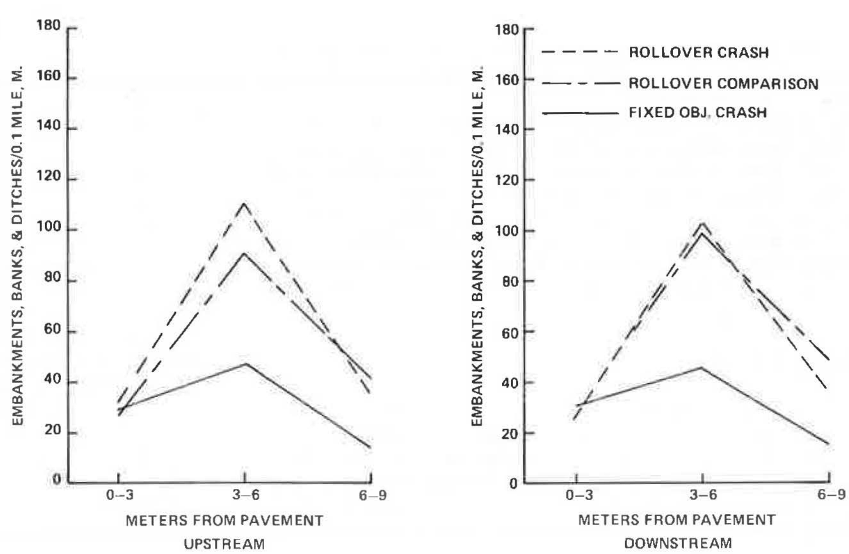
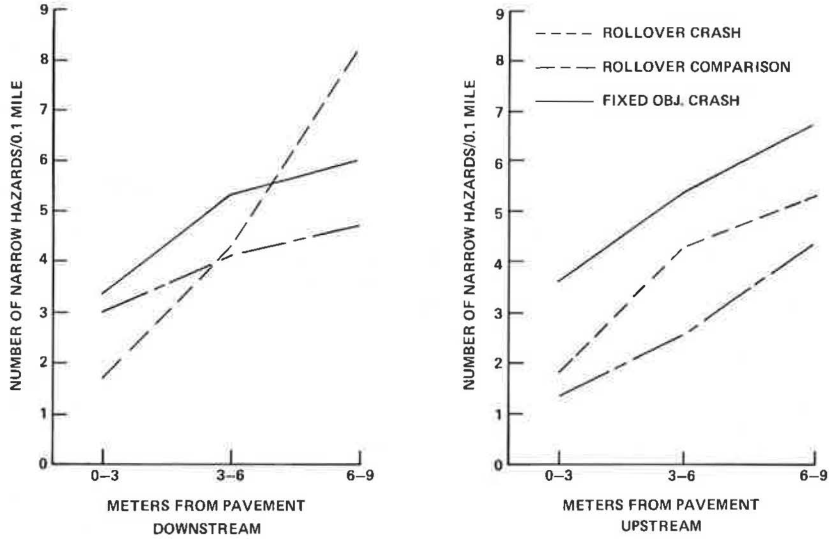


Figure 10. Average number of spot fixed objects combined in 161-m sections upstream and downstream from sites.



hazards vary relatively little along highways.

Figure 9 shows the average lengths of embankments, banks, and ditches combined in the 161-m (530-ft) sections upstream and downstream from the sites. Sharp peaks are noted within 3-6 m (10-20 ft) from the pavement edge for both the rollover crash and comparison sites; fewer of these hazards were noted at the fixed-object crash locations. The presence of the peak at the comparison location suggests that correlations in these values may exist between the rollover crash and comparison locations, as noted above. If this is the case, the role of these hazards is underestimated by the comparison of the hazards at the two locations.

Figure 10 shows the average counts of spot fixed objects combined in the 161-m sections upstream and downstream from the sites. There were twice as many spot fixed objects per section within 3 m (10 ft) of the pavement edge at the fixed-object crash sites as at the rollover crash sites. On the other hand, elongated hazards, notably embankments and ditches, were found to be nearly twice as long at the rollover crash sites as at the fixed-object crash sites.

Differences in the densities of street lights and traffic signs at rollover and fixed-object crash locations were not found to be significant. Similarly, the average lengths of guardrails, curbs, and median barriers were not significantly different.

The pavement widths at the rollover crash locations were significantly narrower ($p < 0.01$) than at the fixed-object sites, but the shoulders were significantly wider ($p < 0.001$) at the rollover sites. A greater density of driveways was found at the fixed-object sites. Differences in the number of pavement lanes and the number of intersections per section were not significant.

Approximate measures of pavement skid resistance made at 130 crash sites and 115 comparison sites were compared and found not to be significantly different ($p = 0.32$).

The roadway at each survey site was functionally classified by the field research team. A broad distribution of the roadways at the crash locations, along with a similar breakdown for all Georgia roads in rural and urban areas, is given below:

Roadway Class	Georgia Roads (%)	Crash Sites (%)
Freeway and principal arterial	5.3	31.0
Minor arterial	7.7	31.5
Collector	23.2	15.5
Local	63.8	22.0

The data suggest that there was an overrepresentation of principal and minor arterial roadways in the crash population and an underrepresentation of local roads. This phenomenon, which was also noted in the case of fixed-object crash studies (1,2), reflects the heavier traffic flows on nonlocal roads. As expected, the distribution of functional roadway classes at comparison locations was almost identical to that at crash locations.

SUMMARY AND CONCLUSIONS

Engineering surveys were performed at 214 locations in Georgia where single-vehicle fatal rollover crashes occurred over a study period of one year. Similar surveys were made at comparison locations 1.6 km upstream from the crash locations. The field survey procedures were similar to those used in two earlier studies of fixed-object crashes (1,2). It was found that single-vehicle fatal rollover crashes are more likely to occur

1. Along nonlocal (especially principal and minor arterial) roads than along local roads,
2. Along curved sections turning to the left than along straight sections or right curves,
3. Along downhill slopes than along level or uphill sections,
4. Along the outside of curves (especially left-turning curves) than along the inside, and/or
5. In the area downstream from a curve than in the area upstream.

The most prominent roadway feature associated with fatal rollover crashes in Georgia was horizontal curvature. The results indicate that locations of fatal rollover crashes can be discriminated from comparison locations by curvature greater than 6°, the same value suggested in the fixed-object studies.

Steep gradients were also found to be strongly and significantly associated with rollover crash locations. The pattern of distribution of longitudinal slopes observed in the fixed-object crash studies, in which negative slopes tended to occur upstream and positive slopes downstream, was also apparent at rollover crash locations.

Sites of rollover crashes were characterized by significantly larger changes in lateral slope at the shoulder edge than were found at comparison sites. The crash sites were also more likely to have embankments along the roadside than the comparison sites but less likely to have trees and certain other spot fixed objects.

In addition, the rollover crash sites had longer embankments, banks, and ditches than were found at fixed-object crash sites. On the other hand, more trees, poles, and signs were found at the fixed-object sites than at the rollover crash sites.

These findings may be summarized in a scenario that fits many of the rollover crashes investigated: The vehicle enters a left curve going downhill at or above a critical speed, the driver loses control of the vehicle, and the vehicle overturns near or beyond the end of the curve where the downslope flattens out.

ASSESSMENT AND RECOMMENDATIONS

Differences in rollover crash rates are explicable in part by the design features of the roadway, the configuration of the roadway surfaces, and the type and density of roadside obstacles. Undesirable geometric design features, especially excessive left-turning curves and downslopes, can increase the demands on the driver-vehicle system and contribute to loss of vehicle control and possible encroachment onto the roadside.

Once a driver has lost control of a vehicle, the outcome is determined, to a large degree, by the roadway environment: the dimensions and slopes of the cross section, the nature and density of roadside obstacles, and the configuration of the roadside surface.

Researchers are seeking to further refine road-improvement priorities for both rollover and fixed-object crashes and to account for regional differences in crash rates attributable to such factors as population, topography, and climate. Pending the completion of such work, the roadside hazard modification scheme (1,2) based on horizontal curvature and gradient should be suitable for identifying and establishing priorities for the correction of locations that have a potential for rollover crashes, in Georgia as well as in other states that have similar topography, demography, and climate.

The modifications undertaken at a specific location depend on several factors: number and type of hazards, width of right-of-way, cooperation of utility companies, and costs of alternative means of modification. In some instances, it may be possible to reduce or eliminate curvature and gradient as well as to modify the roadside. In other cases, only resloping of the roadside and removal or screening of hazardous obstacles would be appropriate. Where roadside encroachments are likely to occur, it is important for the roadside to be free of not only fixed-object hazards but also ditches, steep embankments, and other features that would increase the likelihood of vehicle rollovers.

ACKNOWLEDGMENT

We are indebted to Larry Miller, Willet Cohran, and Judy Vaughn of the Georgia Department of Public Safety, who furnished the crash reports, and to Otis Hammock, Vernon Harvey, and Delores Maloof of the Georgia Department of Transportation, who provided information on the state road network. We also wish to gratefully acknowledge the contributions of Judith Zimmerman, formerly with the Insurance Institute for Highway Safety, who supervised the project during the data-collection phase. Significant contributions were also made by graduate students Howard Stein and Amir Tavakoli.

This paper was supported by the Insurance Institute for Highway Safety. The opinions, findings, and conclusions expressed in this paper are ours and do not necessarily reflect the views of the Insurance Institute for Highway Safety.

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Discussion

John C. Glennon

I would first like to commend the authors of both of the preceding papers--Hall, Zador, and Wright--on their dedication and very worthwhile efforts. I believe these two studies provide some dramatic insights concerning highway safety. I use the word insight because these studies have really just scratched the surface of a more universal safety problem--the association between roadside design and highway curves. I also use the word insight as a caution against drawing any very specific conclusions from a limited sample of a recognizably small portion of the total accident population.

The most significant conclusion of these studies, and perhaps the only firm one, is that fatal overturning crashes (10 percent of all fatal accidents) are highly associated with highway curves. This conclusion seems allied to some conclusions of past research and more particularly to preliminary results of an ongoing Federal Highway Administration research project, "Effectiveness of Design Criteria for Geometric Elements". Some preliminary data from this ongoing research, in which I am a consultant to Jack E. Leisch and Associates, indicate the following:

1. Curves show an overrepresentation of roadside accidents.
2. Left curves (as seen by the colliding driver) are overrepresented in curve accidents.
3. Roadside design may be the factor that is most related to the safety of highway curves.
4. Roadsides tend to be more hazardous on curves.

Perhaps even without these two studies, we should have expected to find a predominance of overturning accidents on curves. In hindsight, I can think of three reasons for this phenomenon:

1. The proportion of run-off-the-road accidents is two to three times higher on curves than on tangents.

2. Overturning tends to be related to the side skidding and vehicle rotation that are common to curve accidents.

3. The dynamics of overturning are enhanced by the usually greater cross-slope breaks at both the edge of the pavement and the edge of the shoulder on curves.

To suggest the development of realistic prediction models or design criteria from the results of these two studies may be overoptimistic. However, the results do suggest some possible new orientations. For example, the 4:1 side slope that is commonly regarded as minimally acceptable, based on full-scale tests and simulations performed on tangent sections, may in fact be unacceptable on highway curves. In addition, the reexamination of guardrail warrants suggested by Hall and Zador may have some merit. It must be remembered, however, that their study only considers fatal overturning crashes, which constitute a small portion of all roadside accidents. Decisions on guardrail placement must, of course, consider the net effect on all roadside encroachments.

On another, more minor matter, the reader should be cautioned about basing any overt conclusions on the comparisons between Georgia and New Mexico data. The differences documented in these papers probably reflect little more than the basic differences in the two state's practices, terrains, and relative traffic exposures to various highway design configurations.

Although the fact is not new, these studies strongly reemphasize the basic safety problem of highway curves. As everyone knows, curves cannot be eliminated and flattening them is usually too expensive (and, except for extremely sharp curves, may only be marginally effective). If major improvements are to be made in safety on highway curves, therefore, these studies and the ongoing research in which I am participating seem to suggest that we look toward minimizing the consequences of run-off-the-road accidents. All indications are that, if there is to be a major emphasis in general roadside safety improvement efforts, it ought to be directed toward highway curves.

Authors' Closure

We would like to thank Glennon for his comments on these two papers. We believe that there is more importance to the results of these studies than that cited by Glennon. A study of all fatal overturning crashes in two states for a one-year period may be a limited sample, but national data clearly indicate that these types of crashes are responsible for a significant portion of highway fatalities. Furthermore, these two studies are the most recent of a series of studies of off-road crashes undertaken by the research group using common methodology. Combined, these projects have involved nearly 1000 on-site engineering surveys at crash locations plus an equal number at comparison locations.

Our data do not support Glennon's statement that roadsides are more hazardous on curves. The disproportionate share of crashes that occur at these locations seems to be more closely related to roadway alignment than to roadside design. As the paper by Wright and Zador states, undesirable geometric design features can increase the demands on the driver-vehicle system and contribute to loss of vehicle control and possible roadside encroachment. Once a driver has lost control of a vehicle, the type and severity of a crash are largely determined by the roadside environment: the dimensions and slopes of the cross section, the nature and density of roadside obstacles, and the configuration of the roadside surface.

There are several techniques the engineer can apply to reduce the frequency and severity of rollover crashes. These techniques, which include improved signing and delineation, roadway realignment, roadside barriers, and flatter side slopes, are not guaranteed to eliminate either roadside encroachments or fatal rollover crashes. We recognize, of course, that vehicles can depart from tangent roadways and overturn on very flat side slopes and that guardrail impacts can result in fatalities. We believe our data support the finding that, although it is impossible to eliminate fatal rollover crashes, the engineer can take action at a limited and identifiable number of locations to reduce the frequency of fatal roadside crashes.

Abridgment

Evaluation of Driveway-Related Accidents in Texas

RAMEY O. ROGNESS AND STEPHEN H. RICHARDS

The results of an extensive study of driveway-related accidents that occurred in Texas between 1975 and 1977 are presented. The study was conducted as part of a larger study to determine the extent and nature of driveway operational and safety problems on Texas streets and highways. The state of Texas computerized master accident file was the primary source of data for the evaluation. The findings of the study indicate that driveway-related accidents constitute a significant portion of the state's total traffic-accident experience. In fact, 16 percent of all traffic accidents in Texas during the three study years were driveway related. This percentage and the overall accident characteristics are consistent with results of previous research. The study results also indirectly suggest that better design and operation of driveways could reduce the number of driveway-related accidents and thus improve traffic safety.

An evaluation of safety and operational problems experienced at urban driveways in Texas was recently conducted (1). Improved guidelines for urban driveway location, design, and operation were developed based on the findings of this evaluation (2). As part of the research, an extensive study of driveway-related accidents that occurred in Texas between 1975 and 1977 was conducted.

The study primarily evaluated driveway-related accidents on city streets and county roads ("off-system" facilities) in Texas. A limited comparative study of driveway-related accidents on state-maintained highways was also performed. The study evaluated the driveway safety problem in terms of the number of accidents, severity, characteristics, and, to some extent, causative factors.

STUDY RESULTS

The accident study revealed that driveway-related