Survey of Single-Vehicle Fatal Rollover Crash Sites in New Mexico

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The results of a study of roadway and roadside characteristics at the sites of 151 fatal overturning crashes in New Mexico are discussed. Comparisons were made with data from nearby locations on the same roads and with data from a similar study of 214 sites in Georgia. The New Mexico crash sites were characterized by sharper curvature and curves to the left, steeper downgrades and embankments, and greater embankment depths than the nearby comparison sites. The Georgia sites exhibited significantly sharper curvature, flatter grades, more spot fixed objects, and steeper but shallower embankments than the New Mexico sites. Guardrail use was significantly higher in Georgia. In New Mexico, the roadsides at a majority of the sites of fatal overturning crashes do not satisfy current guardrail warrants, and it is recommended that these warrants be reexamined. The difference in the values of alignment characteristics between the two states suggests that priority schemes for selecting hazardous locations cannot currently rely on uniform, nationwide criteria.

In 1979, there were 8911 fatalities in single-vehicle rollover crashes; these accounted for 21 percent of nationwide vehicle occupant fatalities. Previous research (1) has shown that the problem is especially critical in western states. The 1979 U.S. Department of Transportation Fatal Accident Reporting System data indicate that more than 40 percent of occupant fatalities in Montana, New Mexico, and Wyoming involved single-vehicle rollover crashes whereas less than 15 percent of occupant fatalities in Illinois, New Jersey, and Pennsylvania involved this type of crash.

Despite the importance of rollover crashes, there is no indication that their highway-related aspects have been studied. The lack of previous study is probably attributable in part to traditional beliefs that hold that single-vehicle crashes are the fault of the driver rather than the roadway. As a consequence, engineers have remained complacent with respect to their responsibilities for this type of crash and have justified their inaction on the assumption that appropriate remedial action is beyond their control.

The research described in this report was designed to examine this questionable premise. Specifically, the research sought to evaluate the hypothesis that the roadway and roadside characteristics at the sites where rollover crashes occurred were more adverse than for the road system in general. Separate but similar studies were conducted in Georgia (see the paper by Wright and Zador in this Record) and New Mexico. This study describes the methodology and findings of the study of rollover crashes in New Mexico and compares the findings of the New Mexico and Georgia studies.

METHOD

The study discussed in this paper was designed to compare roadway and roadside characteristics at the sites of fatal rollover crashes in New Mexico with similar characteristics for a matched set of comparison sites. The field-study procedure was similar to that used in a previous study of fixed-object crashes (2), which selected a set of comparison sites located 1.6 km in advance of the crash site. The crash vehicle and driver would generally have passed the comparison site within 1-2 min of reaching the site of the fatal crash.

The locations studied were the sites of all fatal single-vehicle rollover crashes in New Mexico for the one-year period ending July 31, 1979. The study did not include eight fatal overturning crashes that involved motorcycles, six crashes in which a second vehicle was involved, or three dirt-road crash sites that could not be located. Studies were conducted at the sites of 151 fatal rollover crashes, which represented more than 25 percent of New Mexico's fatal crashes during the study period.

The sites were located in the field through reference to data provided in the reports of the investigating officers. Although these reports varied in quality and the sites were not studied until 4-8 weeks after the crashes, the damage associated with the crashes usually made it possible to identify study sites. When there was doubt concerning the crash site, assistance was obtained from the investigating officer.

A three-person field crew was used to make an engineering survey in the vicinity of each crash and comparison site. Measurements were made of curvature, superelevation, and gradient; roadside spot objects were enumerated; and elongated objects were measured. The alignment measurements were made by using techniques described in a previous report (3). Other characteristics of the sites, including road and shoulder widths, roadside slopes, pavement friction, speed limit, and number of intersections and driveways, were also recorded. At the crash sites, measurements were made of the lateral and longitudinal distances traveled off the roadway by the overturning vehicle.

RESULTS OF THE NEW MEXICO STUDY

One of the most obvious differences between the crash and comparison sites was found to be horizontal alignment. At both sites, 10 curvature measurements were made at approximately 30-m intervals, from 137 m before to 137 m beyond the site. Figure 1 shows the average curvature at 10 positions at both the crash and comparison sites. The average curvature at the crash site was significantly higher than at the comparison site for each position from 137 m before through 76 m beyond the site (unless otherwise noted, all statistical comparisons were performed by using t-tests with $\alpha = 0.05$). The average curvature of 1.7° for all crash sites was significantly higher than the average curvature of 0.7° at the comparison sites. In the area that was most critical to the approaching driver, from 137 m before through 15 m beyond the crash site, the average curvature of 1.9° was also significantly higher than that at the comparison site (0.7°).

The relatively low average values of curvature are misleading. Approximately 36 percent of the comparison sites, versus 54 percent of the crash sites, had a maximum curvature of more than 0.5°. Analysis of curvature at these nontangent locations found that the average curvature at the crash sites was 3.1°, significantly higher than the average value of 2.0° at the comparison sites. The difference at the nontangent locations was even more significant (3.5° versus 1.9°) in the area from 137 m through 15 m beyond the site.

Only 10 percent of the comparison sites had a maximum curvature of 6° or more, whereas at crash

Figure 1. Average degree of curvature for crash and comparison sites.

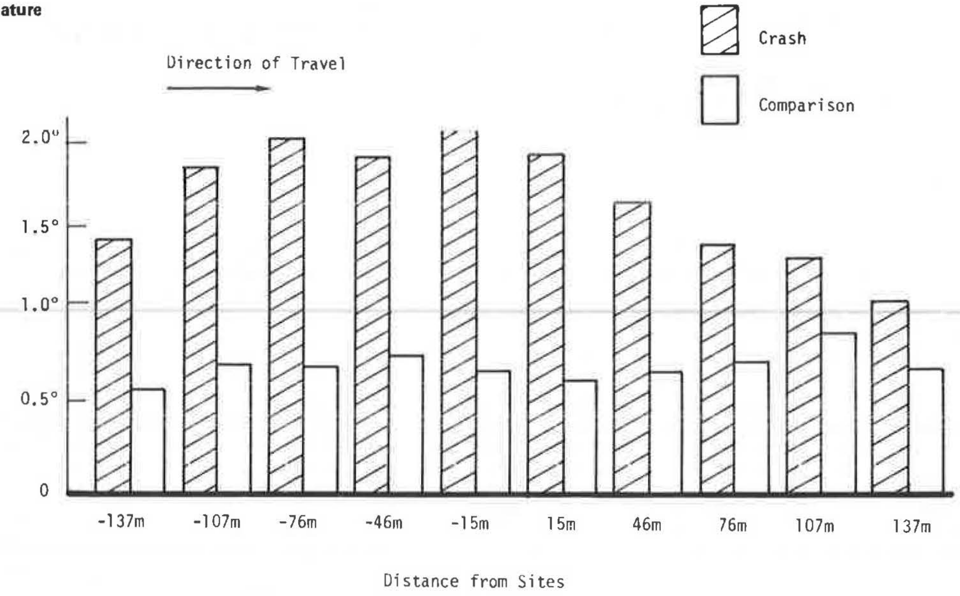
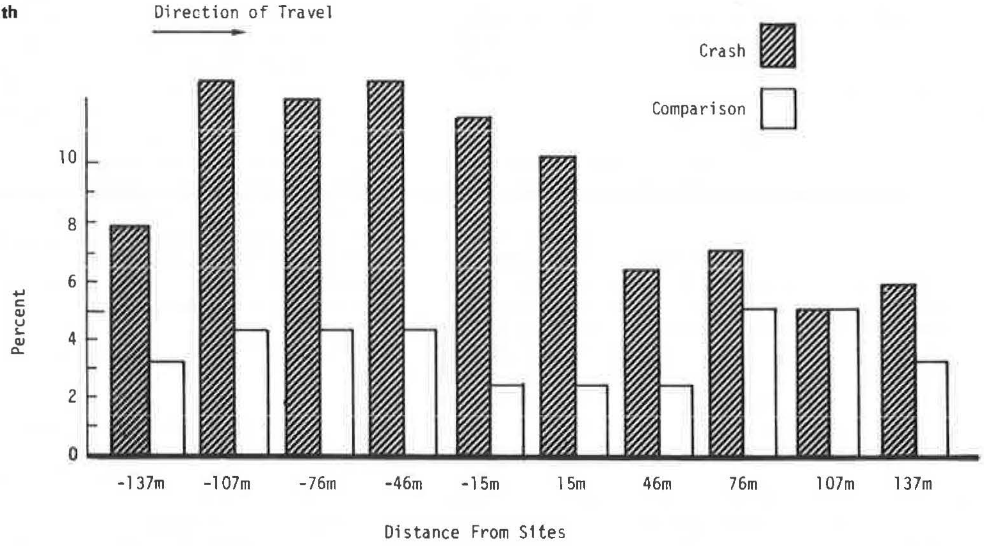


Figure 2. Percentage of sites with curvature greater than 6°.



sites the comparable figure was 21 percent. The difference in horizontal curvature between crash and comparison sites is also suggested in Figure 2, which shows the percentage of sites where curvature was greater than 6° at the 10 measurement positions. There is clearly a difference between the sites in the area immediately before the crash position.

Roadway curvature was also analyzed with respect to the direction of curvature. By using the sign convention of "+" for curves to the left and "-" for curves to the right, it was found that the average maximum curvature was +0.2° at the comparison sites and +1.4° at the crash sites. Although both average values indicate curves to the left, only the value for the crash site was significantly different from zero. The average mean curvature at the comparison sites (+0.03°) did not differ significantly from zero, whereas the corresponding value at the crash site (+0.79°) did. The significant overrepresentation of left-hand curves at crash sites is indicated by the data given below, which compare the direction and sharpness of curvature:

	Percentage of Sites	
Curvature	Crash	Comparison
>5° right	8	5
0.5°-5° right	9	17
Tangent	46	64
0.5-5° left	22	8
>5° left	15	6

An analysis of the pavement superelevation at crash and comparison sites yielded results consistent with those found for curvature. Due to the higher average curvature at crash sites, average and maximum superelevations at these locations were significantly higher than those at comparison sites.

In the vicinity of both the crash and comparison sites, 11 measurements of roadway gradient were taken at approximately 30-m intervals, from 152 m before to 152 m beyond the site. The analysis of average gradients found that they were significantly steeper at the crash sites (-0.92 percent) than at the comparison sites (-0.33 percent). Figure 3 shows the average gradient at each of the 11 measurement positions. For each position from 61 m

Figure 3. Average roadway gradient for crash and comparison sites.

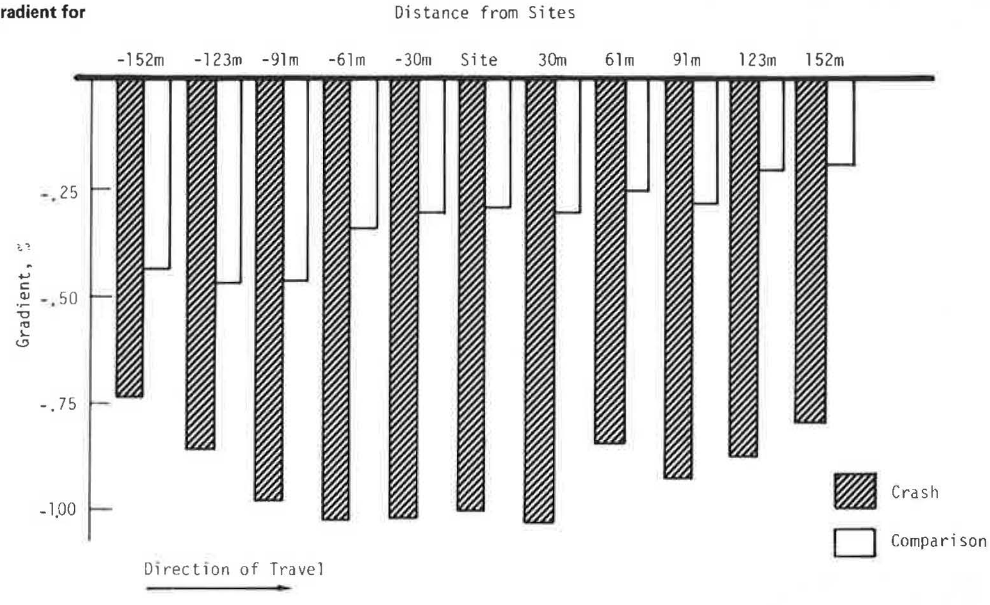


Table 1. Comparison of maximum curvature and minimum gradient at crash and comparison sites.

	Percentage of Sites					
	Gradient < -2 Percent		Gradient -0.55 to -2 Percent		Gradient > -0.55 Percent	
Curvature	Crash	Comparison	Crash	Comparison	Crash	Comparison
>5° right	4.6	4.0	2.0	0	1.3	0.7
0.5°-5° right	4.6	5.3	3.3	7.3	0.7	4.6
Tangent	9.3	11.2	21.9	24.5	15.2	27.8
0.5-5° left	8.6	2.6	4.6	0.7	9.3	2.7
>5° left	12.6	6.0	1.3	1.3	0.7	1.3

before through 152 m beyond the site, the downgrade at the crash sites was significantly steeper than at the comparison sites.

Logic suggests that the average roadway gradient should be zero, and it was therefore surprising that the gradients at the comparison sites were negative. However, 21 of the crash sites (14 percent) were on lengthy downgrades, where the grade was continuously negative for at least 1.6 km before the crash site. These cases, in which both the crash and comparison sites were on the same downgrade, influence the total results shown in Figure 3. When these cases are removed from the analysis, the average gradient at the remaining comparison sites was +0.01 percent, which differs significantly from the average crash-site gradient of -0.65 percent.

Curvature and gradient data show that roadway geometrics were significantly worse at the sites of fatal overturning crashes than at comparison sites. When the condition described by the combined effect of curvature and gradient is examined, the results again indicate that crash sites were characterized by poorer geometric conditions. Table 1 indicates that the crash sites exhibited a higher incidence of the combination of sharp curvature and downgrades than did the comparison sites. The safest condition in the table--tangent roadways on grades more positive than -0.55 percent--accounted for nearly 28 percent of the comparison sites versus only 15 percent of the crash sites. The most adverse condition in the table--curvature in excess of 5° and grades less than -2 percent--was found at 17 percent of the crash sites versus only 10 percent of the comparison sites. Table 1 also indicates the dominance of left-hand curves at crash sites. Analysis showed that the principal factors in distinguishing between crash and comparison sites were the degree and the direction of curvature.

A general observation from the field studies was that a comparatively small object was the most probable immediate cause of overturning. These objects included curbs, edge drop-offs, ditches, and soft soil. However, since a fixed-object collision is one alternative to overturning for a vehicle that has left the roadway, a survey was made of fixed objects within 9 m of the side of the roadway on which the vehicle overturned. Separate surveys were conducted for 161 m before and beyond the crash and comparison sites. Spot fixed objects were counted, and the lengths of elongated fixed objects were measured. Banks and embankments were included if their slopes exceeded 4:1. The results of the fixed-object surveys before and beyond the sites are given in Tables 2 and 3.

There were approximately five spot fixed objects in the 0.16-km area before the crash and comparison sites and an equal number in the area beyond the sites. No significant difference was found between the number of spot fixed objects at the two types of sites. The comparatively low number of spot fixed objects at both sites reflects the generally clear nature of New Mexico roadsides and the fact that 90 percent of the crash sites were in rural areas.

The principal type of elongated fixed object at both crash and comparison sites was the embankment, which accounted for 55 percent of the length of elongated objects at crash sites and 45 percent of the corresponding length at comparison sites. Significant differences in the length of embankments were found between the two types of sites in the

Table 2. Average number of spot fixed objects 161 m before and beyond crash and comparison sites by distance from the roadway.

Type of Fixed Object	Number of Objects							
	Crash Sites				Comparison Sites			
	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total
Before Site								
Luminaire poles	0	0	–[a]	–[a]	–[a]	–[a]	0	–[a]
Utility poles	–[a]	0.1	0.1	0.2	0.1	0.1	0.1	0.3
Traffic signs	0.1	0.1	–[a]	0.2	0.1	0.1	–[a]	0.2
Trees	0.1	0.6	1.5	2.2	0.1	0.4	1.2	1.7
Other	0.8	0.9	0.7	2.4	0.3	1.5	0.9	2.7
Total	1.0	1.7	2.3	5.0	0.6	2.1	2.2	4.9
Beyond Site								
Luminaire poles	0	–[a]	–[a]	–[a]	–[a]	–[a]	0	–[a]
Utility poles	–[a]	–[a]	0.1	0.1	–[a]	0.1	0.1	0.2
Traffic signs	0.2	0.1	–[a]	0.3	0.2	0.1	–[a]	0.3
Trees	0.1	1.2	1.0	2.3	0.2	0.7	0.9	1.8
Other	0.7	0.4	0.4	1.5	0.4	1.4	1.0	2.8
Total	1.0	1.7	1.5	4.2	0.8	2.3	2.0	5.1

[a] Less than 0.05 but greater than zero.

Table 3. Average length of elongated fixed objects 161 m before and beyond crash and comparison sites by distance from the roadway.

Type of Fixed Object	Length of Objects (m)							
	Crash Sites				Comparison Sites			
	0-3 m	3-6 m	6-9 m	Total	0-3 m	3-6 m	6-9 m	Total
Before Site								
Banks	2.2	12.0	13.9	28.1	0.9	6.5	12.8	20.2
Curbs	6.0	0.3	0.2	6.5	9.2	0.8	1.0	11.0
Ditches	11.5	19.1	15.1	45.7	18.6	21.3	17.6	57.5
Embankments	43.8	43.3	32.6[a]	119.7	37.0	41.2	20.4	98.6
Guardrail	0.7	0.3	0.2	1.2	1.9	0.1	0	2.0
Median barriers	0.6	0.9	1.1	2.6	0	0	0	0
Other	5.0	6.3	11.3	22.6	3.6	7.6	13.0	24.2
Beyond Site								
Banks	2.5	10.5	12.3	25.3	3.6	10.8	15.0	29.4
Curbs	5.9	0.8	0.5	7.2	6.8	0.7	0.9	8.4
Ditches	13.8	15.8	15.7	45.3	21.5	18.4	17.6	57.5
Embankments	50.5[a]	52.8[a]	36.0[a]	139.3[a]	35.2	36.9	20.3	92.4
Guardrail	2.4	0.3	0.6	3.3	1.9	0	0	1.9
Median barriers	0	0	0	0	0	0.1	–[b]	0.1
Other	7.9[a]	6.9	11.7	26.5	2.2	6.4	13.5	22.1

[a] Significantly higher than comparison site at $\alpha = 0.05$.
[b] Less than 0.05 but greater than zero.

0.16-km area beyond the sites. For the crash sites, guardrails were more common in the area beyond and less common in the area before the crash sites, although neither difference was significant. The category "other" for elongated fixed objects (e.g., bridge rails) within 3 m of the roadway in the 0.16-km section beyond the site had a significantly greater length at crash sites.

The findings related to embankments led to a more detailed study of embankment characteristics at one-third of the study sites. The sites for detailed study were chosen on the basis of their alignment characteristics. The set consisted of all rural sites on paved roads where the average curvature exceeded 2.5° or the average gradient was less than -2 percent at either the crash or comparison site. Cross-sectional measurements, including data sufficient to calculate shoulder width and slope, front and back slope, and embankment length and depth, were made at crash and comparison sites and 30 m before and beyond these sites (see Figure 4). Analyses of these data, given in Table 4, indicate that at crash sites the front slope and the depth of the embankment or ditch were significantly greater than at comparison sites. At a point 30 m beyond the crash site, the front slope and embankment length and depth were all significantly greater than for the corresponding location at the comparison site. For the comparatively few locations that had a back slope, the mean value was significantly higher at the crash site than at the comparison site.

Although the front slopes were significantly steeper at crash sites than at comparison sites, only 18 percent of crash sites had slopes in excess of 3:1. This slope is part of the normally accepted criteria for the installation of guardrails (4), under the hypothesis that impact with a guardrail would be more severe to vehicle occupants than the consequences of driving down a relatively flat slope.

Other parameters that were measured at the crash and comparison sites were the number of lanes, intersections, and driveways; pavement and shoulder widths; pavement friction; and posted speed limits. There were no significant differences in these characteristics between the crash and comparison sites.

Information from the reports of investigating officers and measurements at the sites were used to determine other characteristics of the crashes. Based on officers' sketches of the crash sites, it was determined that 24 percent of the vehicles actually overturned on the opposite side of the road from where they initially departed. Figure 5 shows the method of departure involved in these crashes. The longitudinal and lateral distances traveled off the roadway were also evaluated. Longitudinal distances varied from 0 to 141 m, and the mean value was 24 m. The 85th percentile longitudinal distance was 50 m. Lateral distances ranged from 0 to 91 m and averaged 5.3 m. It was found that 85 percent of the vehicles overturned within 8.2 m of the roadway, a value that is comparable to the often-quoted "9-m clear roadside".

The principal vehicle types involved in fatal overturning crashes were passenger cars (50 percent) and pickup trucks (37 percent). The involvement of pickup trucks is unusually high, since they account for only 18-20 percent of vehicle registrations and kilometers of travel in New Mexico.

COMPARISON OF NEW MEXICO AND GEORGIA DATA

During the same time that this study was being conducted in New Mexico, an identical study was performed in Georgia (see the paper by Wright and Zador in this Record). The Georgia study investigated the sites of 214 fatal overturning crashes, approximately 17 percent of the fatal crashes in that state during the 12-month study period. By using t-tests, comparisons were made between the data from the two states.

Table 5 summarizes the average values of the alignment characteristics at the New Mexico and Georgia sites. With respect to the crash sites, the Georgia data had significantly higher values of maximum and average curvature, maximum superelevation, and maximum gradient. Average crash-site gradients in both states were negative, but the New Mexico gradients were significantly steeper. There were also some significant differences with respect to the comparison sites, where the maximum values of

Figure 4. Locations of cross-sectional measurements.

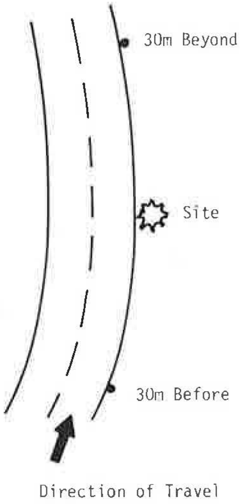


Table 4. Average cross-sectional characteristics at crash and comparison sites with embankments.

Characteristic	30 m Before	Site	30 m Beyond	Mean[a]
Shoulder width (m)				
Crash	2.5	2.1	1.9	2.2
Comparison	2.3	2.2	2.2	2.2
Shoulder slope (%)				
Crash	4.8	5.2	5.4	5.1
Comparison	5.2	5.2	5.4	5.3
Front slope (%)				
Crash	16.1	22.7[b]	24.9[b]	21.0
Comparison	15.1	14.8	17.6	16.5
Back slope (%)				
Crash	48.4	46.0	48.9	47.5[b]
Comparison	27.3	29.4	26.9	25.7
Embankment depth (m)				
Crash	1.1	1.5[b]	1.7[b]	1.4[b]
Comparison	0.9	0.9	0.9	0.9
Embankment length (m)				
Crash	12.6	12.7	12.9[b]	12.4
Comparison	10.6	11.4	10.2	10.8

[a] Average of three measurements at each site.
[b] Significantly higher than comparison site at $\alpha = 0.05$.

Figure 5. Vehicle departures from the roadway in overturning crashes: percentage of departures versus alignment at crash site.

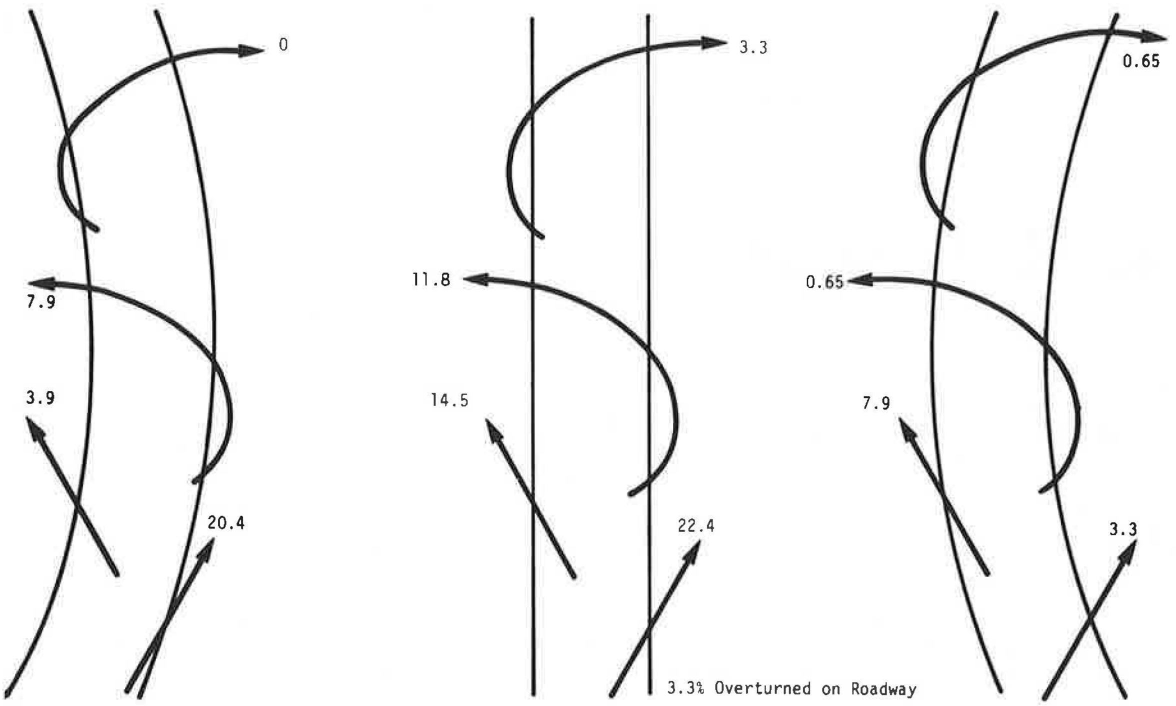


Table 5. Average alignment characteristics for New Mexico and Georgia sites.

	Crash Sites		Comparison Sites	
Characteristic	New Mexico	Georgia	New Mexico	Georgia
Curvature (°)				
Maximum	3.7	6.3[a]	1.9	3.2[a]
Minimum	0.2	0.2	0.1	0.1
Avg	1.7	2.3[a]	0.7	1.1
Critical-area avg[b]	1.9	2.9[a]	0.7	1.0
Superelevation (%)				
Maximum	4.1	5.0[a]	3.2	4.4[a]
Minimum	0.2	0.1	0.5	0.6
Avg	2.3	2.7	1.9	2.6[a]
Gradient (%)				
Maximum	0.4	1.9[a]	0.8	1.8[a]
Minimum	−2.2	−2.0	−1.5	−2.2[a]
Avg	−0.9	−0.2[a]	−0.3	−0.3
Critical-area avg[c]	−1.0	−0.3[a]	−0.4	−0.4

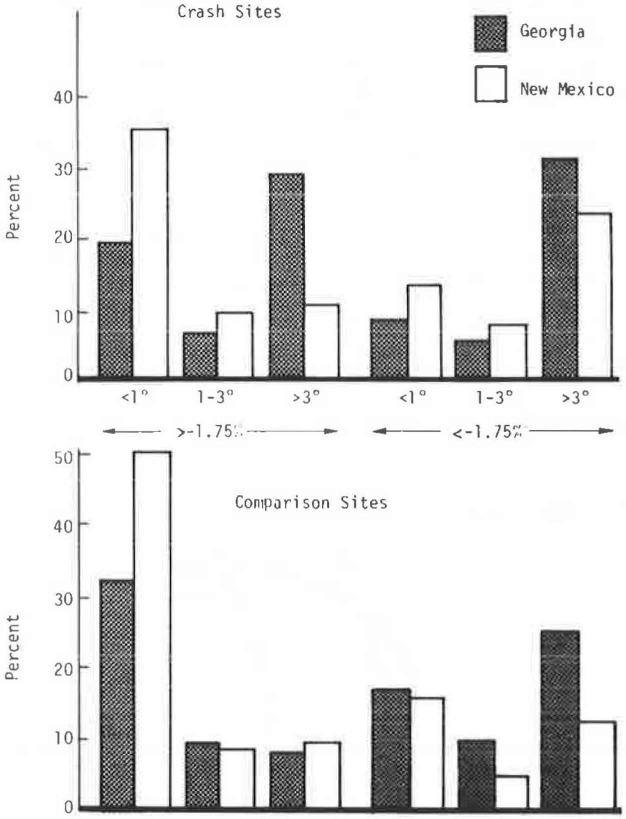
[a] Significant difference between New Mexico and Georgia at $\alpha = 0.05$.
[b] Average curvature from 137 m before site to 15 m beyond site.
[c] Average gradient from 122 m before site to 30 m beyond site.

Table 6. Georgia/New Mexico ratio of average number of spot fixed objects by distance from the roadway.

Type of Fixed Object	Crash Sites 0-3 m	Crash Sites 3-6 m	Crash Sites 6-9 m	Comparison Sites 0-3 m	Comparison Sites 3-6 m	Comparison Sites 6-9 m
Before Site						
Utility poles	7.4	2.4	4.0[a]	3.1	3.2[a]	2.5[a]
Traffic signs	5.8[a]	2.4[a]	3.8[a]	3.8[a]	1.8	5.6[a]
Trees	1.8	5.9[a]	4.9[a]	2.5	5.8[a]	3.6[a]
All spot objects	1.8	2.8	3.4	2.4	1.5	2.2
Beyond Site						
Utility poles	1.7	3.3[a]	3.4[a]	4.0	2.8[a]	5.6[a]
Traffic signs	3.0[a]	5.5[a]	2.3	2.5[a]	3.0[a]	4.7[a]
Trees	5.1	1.2	4.5[a]	1.4	2.3	3.9[a]
All spot objects	1.8	2.6	3.4	1.6	1.1	2.2

[a] Average number of objects significantly higher in Georgia at $\alpha = 0.05$.

Figure 6. Comparison of maximum curvature and minimum gradient at Georgia and New Mexico sites.



curvature, superelevation, and gradient were all higher in Georgia.

Only one of the Georgia crash sites, versus 21 of the New Mexico crash sites, was on a lengthy downgrade that extended for at least 1.6 km in the direction of the comparison site. When data for these sites were removed from the analysis, the gradient results for the two states stayed virtually identical. The average New Mexico curvature and superelevation values were not significantly influenced by the deletion of these data, whereas all of the gradient characteristics (maximum, minimum, and average) increased by approximately 0.3 percent. The significant differences identified in Table 5 were still present when comparisons were made between New Mexico and Georgia sites that were not on lengthy downgrades.

Six conditions of combined horizontal and vertical alignment were used to compare the data from Georgia and New Mexico. The results are shown in Figure 6. Chi-square testing showed that the condition classification, for both crash and comparison sites, was not independent of the state. The predominant characteristic that differentiated the two states was the extreme values of curvature. The New Mexico sites were overrepresented with respect to low curvature and were underrepresented with respect to high values of horizontal curvature. The states were quite similar for sites with curvature between 1° and 3°.

A general comparison of spot fixed objects along the roadside indicated that Georgia had 2.8 times as many objects at crash sites and 1.8 times as many objects at comparison sites. On the other hand, the length of continuous fixed objects was approximately 10 percent greater in New Mexico.

The average number of spot objects was compared--by object type, site type, distance from the pavement, and location (before or beyond the site)--between New Mexico and Georgia. Table 6 gives the Georgia/New Mexico ratio of average number of spot fixed objects. The categories of luminaire poles and other fixed objects are not included in the table because there was no significant difference in the two categories. The most substantial difference between the two states was for the category of trees, which constituted 49 and 68 percent of the crash-site spot fixed objects in New Mexico and Georgia, respectively.

A different pattern was found when a comparison was made between New Mexico and Georgia data for the length of continuous fixed objects. At both crash and comparison sites, Georgia had significantly more guardrails and ditches and significantly fewer embankments. The length ratios are given in Table 7. The differences were primarily attributable to the differences between the states rather than to the distinction between crash and comparison sites.

A detailed comparison of the roadside data from a portion of the New Mexico and Georgia sites revealed significant differences between the two states at both crash and comparison sites. When the sites were classified with respect to their roadside characteristics, it was found that 79 percent of the New Mexico crash sites had embankments versus only 52 percent of the Georgia crash sites. Values for specific cross-sectional features are compared in Table 8. The average percentages for front slopes

Table 7. Georgia/New Mexico ratio of average number of elongated fixed objects by distance from the roadway.

Type of Fixed Object	Crash Sites 0-3 m	Crash Sites 3-6 m	Crash Sites 6-9 m	Comparison Sites 0-3 m	Comparison Sites 3-6 m	Comparison Sites 6-9 m
Before Site						
Bank	0.76	1.5	0.80	1.0	1.7	1.1
Ditch	1.0	2.2[a]	0.86	0.89	2.0[a]	0.80
Embankment	0.40[b]	1.2	0.36[b]	0.24[b]	0.92	0.68
Guardrail	6.4[a]	10.8[a]	1.2	1.4	36.1[a]	–[c]
All continuous objects	0.60	1.5	0.61	0.59	1.3	0.76
Beyond Site						
Bank	0.05[b]	1.1	0.79	0.68	1.4	1.2
Ditch	0.65	3.0[a]	0.75	0.61	2.3[a]	0.87
Embankment	0.31[b]	0.83	0.39[b]	0.29[b]	1.1	0.73
Guardrail	1.7	8.8[a]	0.41	1.2	–[a,c]	–[c]
All continuous objects	0.48	1.3	0.62	0.53	1.52	0.82

[a] Average length in Georgia significantly greater than in New Mexico at $\alpha = 0.05$.
[b] Average length in New Mexico significantly greater than in Georgia at $\alpha = 0.05$.
[c] Average guardrail length in New Mexico = 0.00 m.

Table 8. Average cross-sectional characteristics of Georgia and New Mexico sites with embankments.

Characteristic	Georgia Sites Crash	Georgia Sites Comparison	New Mexico Sites Crash	New Mexico Sites Comparison
Shoulder width (m)	1.9	1.7	2.2	2.2[a]
Shoulder slope (%)	4.8	6.3	5.1	5.8
Front slope (%)	33.4[b]	26.6[b]	21.0	16.5
Back slope (%)	36.1	31.9	39.4	25.4
Embankment depth (m)	0.6	0.5	1.4[a]	0.9[a]
Embankment length (m)	7.2	7.3	12.4[a]	10.8[a]

[a] Average value in New Mexico significantly higher at $\alpha = 0.05$.
[b] Average value in Georgia significantly higher at $\alpha = 0.05$.

Table 9. Other general characteristics of Georgia and New Mexico sites.

Characteristic	Georgia Sites Crash	Georgia Sites Comparison	New Mexico Sites Crash	New Mexico Sites Comparison
Number of lanes	2.3	2.5	2.7[a]	2.7[a]
Pavement width (m)	7.0	7.4	9.7[a]	10.0[a]
Number of intersections	0.4[b]	0.4[b]	0.2	0.2
Number of driveways	1.3[b]	1.5[b]	0.5	0.7
Longitudinal distance (m)	33.8[b]		24.0	
Lateral distance (m)	5.7		5.3	
Downgrade distance (m)	0.16		0.64[a]	

[a] Average value in New Mexico significantly higher at $\alpha = 0.05$.
[b] Average value in Georgia significantly higher at $\alpha = 0.05$.

at both crash and comparison sites were significantly higher in Georgia. However, embankment length and depth were significantly greater in New Mexico. Average shoulder widths for sites that had shoulders were higher in New Mexico, although the difference was significant only at the comparison sites. Data from the two states were used to plot values for front slope versus embankment depth. Whereas the New Mexico data showed a consistently lower limit for the slope of 10.5 percent per meter of depth, there was no discernable relation between these parameters for the Georgia data.

Other characteristics of the crash and comparison sites are summarized in Table 9. The number of lanes was significantly higher in New Mexico at both crash and comparison sites. The number of intersections and driveways was significantly higher at both types of sites in Georgia. The average longitudinal distance traveled off the roadway by overturning vehicles was significantly greater in Georgia, although there was no significant difference in the lateral distance.

DISCUSSION OF RESULTS

The roadway and roadside data at the sites of fatal overturning crashes in New Mexico clearly show that the conditions at these sites were more adverse than at a systematically chosen set of comparison sites. The most dramatic difference was with respect to roadway curvature. Although it is not possible to specify an exact value of curvature that separates safe and hazardous conditions, values of maximum curvature in excess of 5° occurred at crash sites at twice the expected rate. Curves to the left were more frequent and sharper at crash sites. Roadway gradients at the sites of fatal overturning crashes were shown to be significantly steeper downgrades than at comparison sites. The difference was especially apparent for downgrades of less than -2 percent, which were 40 percent more common at crash sites. Although curvature was more significant than gradient in distinguishing between crash and comparison sites, left curves on steep downgrades were twice as frequent at the crash sites.

These alignment characteristics can serve as preliminary screening criteria for the determination of roadway locations that need correction. They appear to be the principal roadway factors that contribute to a vehicle running off the road. However, roadside features were found to influence the probability of overturning for a run-off-the-road vehicle. Although front-slope values, which averaged approximately 4:1 in the area immediately downstream from the crash sites, might not be judged critical by current engineering standards, the evidence clearly indicates that vehicles that departed the traveled way had serious difficulty in traversing such a slope. Current standards for guardrail use do not specify the use of guardrails on embankments that are less than 1.2 m in height, despite the fact that more than half of the fatal overturning crashes occurred where embankment heights were less than this value; other data (5) also indicate that approximately 60 percent of the run-off-the-road crashes involve low embankments and shallow ditches. Analysis of the New Mexico data suggests that, according to current standards (4), guardrails are warranted at less than 15 percent of the sites of fatal overturning crashes. This finding attacks the merits of guardrail warrants, especially in view of the relative severity of overturning and guardrail crashes. Although the current guardrail standards do not assume that slopes of 3:1 or embankments less than 1.2 m high are traversible, they do assume that the occupants of a vehicle that is under control will experience less injury in negotiating a side slope or an embankment than in colliding with a guardrail. The theoretical analyses (6) and field studies (7) on which this assumption is based should be reexamined.

Fatal overturning crashes accounted for a lower percentage of all crashes in Georgia than in New Mexico. The more extensive use of guardrails in Georgia is one factor that partly explains this difference. It is recognized that there may be other traffic and demographic factors that contribute to the variation in frequency of overturning crashes between the states. However, the Georgia data show significantly more adverse horizontal alignment conditions than those found in New Mexico. On the other hand, downgrades were significantly more common at New Mexico sites.

The roadsides in Georgia had significantly more spot fixed objects than those in New Mexico. This 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.

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Study of Fatal Rollover Crashes in Georgia

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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-