GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 2/22/80

Project Title: Fatal Rollover and Crash Site Study

Project No: E-20-606

Project Director: Paul H. Wright

Sponsor: Insurance Institute for Highway Safety

Agreement Period: From 7/1/80 Until 9/30/80

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Sponsor Contact Person (s):

Technical Matters

Contractual Matters (thru OCA)

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Defense Priority Rating: N/A

Assigned to: Civil Engineering (School/~~Laboratory~~)

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- Other ________

B-87-194

GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: March 11, 1981

Project Title: Fatal Rollover and Crash Site Study

Project No: E-20-606

Project Director: Paul H. Wright

Sponsor: Insurance Institute for Highway Safety

Effective Termination Date: 1/31/81

Clearance of Accounting Charges: 1/31/81

Grant/Contract Closeout Actions Remaining:

- X Final Invoice ~~and Closing Documents~~
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ____________

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CA-4 (1/79)

E-20-606

A STUDY OF FATAL ROLLOVER CRASHES IN GEORGIA

November 1980

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A STUDY OF FATAL ROLLOVER CRASHES IN GEORGIA

Crashes involving vehicle rollover are one of the leading causes of death in single-vehicle crashes. In 1978 and 1979, for example, 46 percent of the passenger cars in single vehicle fatal 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 present study 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 accompanying paper (1) 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 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 (2). The second project was a study of a general population of fixed-object crashes including 7 fatal, 112 non-fatal injury, and 181 property damage only crashes in a three county area in North Georgia during a 5-month period in 1977-1978 (3). 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 non-crash sites.

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

*Estimate obtained from U.S. Department of Transportation's Fatal Accident Reporting System (FARS).

Background

The Fatal Accident Reporting System (FARS) provided general statistics on the circumstances and conditions associated with fatal rollover crashes. Statistics revealed that for fatal single-vehicle rollover crashes throughout the U.S. in 1978:

-- 43.5 percent occurred along roadways with curved alignment;

-- 34.3 percent occurred 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 sites where one or more vehicle occupant(s) died when the vehicle rolled over with roadway characteristics at sites one mile away where the vehicle was likely to have passed prior to reaching the fatal site. 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 single-vehicle fatal rollover crashes that occurred in Georgia during a 12-month period ending in July 1979 were included in this study.

This study area included a variety of land usages (rural, suburban, 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 nine 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 kilometer (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 illustrates, a point 1.6 km (1 mile) 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 meters (50 feet) from the crash and comparison sites and at 30 meter (100 foot) intervals for 137 meters (450 feet) both upstream and downstream from these sites. The gradient was measured every 30 meters (100 feet) for 152 meters (500 feet) both upstream and downstream from the sites.

A 30 meter (100 foot) 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 four-foot carpenter's level with an adjusted calibrated leg. On Interstate highways, curvature, superelevation and gradient data were taken from plan and profile sheets.

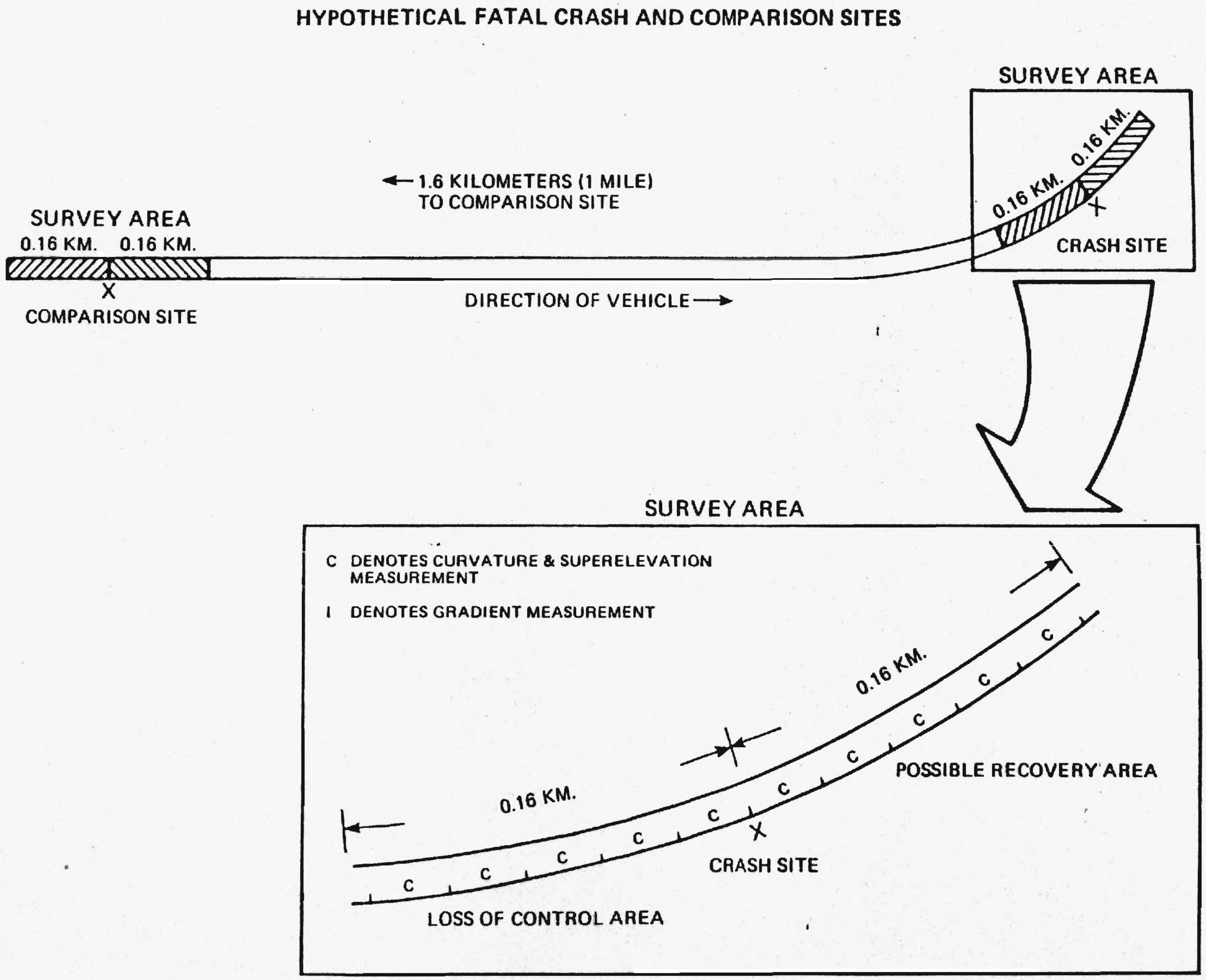

Figure 1. Hypothetical crash and comparison sites.

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 degrees 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 degrees and the gradient was negative and greater than 1 percent at both locations.

Inventories were taken of various types of fixed-objects in 3-meter (10-foot) segments of a 9-meter (30 foot) border for 161 meters (0.1 miles) 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-point) lead block, mounted on small rubber shoes, along the roadway and measuring the resistance by means of a spring scale.

The data collection procedures employed in this study were essentially the same as those used in earlier studies of single-vehicle roadside obstacle crashes (2, 3).

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 degrees while only 13 percent of the comparison sites had a maximum curvature greater than 6 degrees (Figure 2). At half of the comparison sites, but only 28 percent of the crash sites, the roadway was straight or had negligible curvature (degree of curve $\leq$ 1 deg). The differences in distribution of curvature between the crash and comparison locations shown in Figure 2 could not commonly occur from chance fluctuations in sampling ($X^2 = 218.5$, d.f.= 6, $p < 0.001$).

The curvature usually occurred near the crash site or upstream. The largest differences in curvature occurred in the area from 107m (350 ft) upstream to 15m (50 ft) downstream from the sites. The maximum curvature tended to occur at a point located 46m (150 ft) upstream from the crash site, as Figure 3 illustrates. 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 (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-tests indicated that the differences were significant at the 5 percent level for four locations (46m upstream, and 76, 107 and 137m downstream).

Table 1 shows a distribution of the fatal rollover and fixed-object crashes by general type of alignment and direction of departure. The distribution shows a marked tendency for vehicles in rollover crashes to leave the

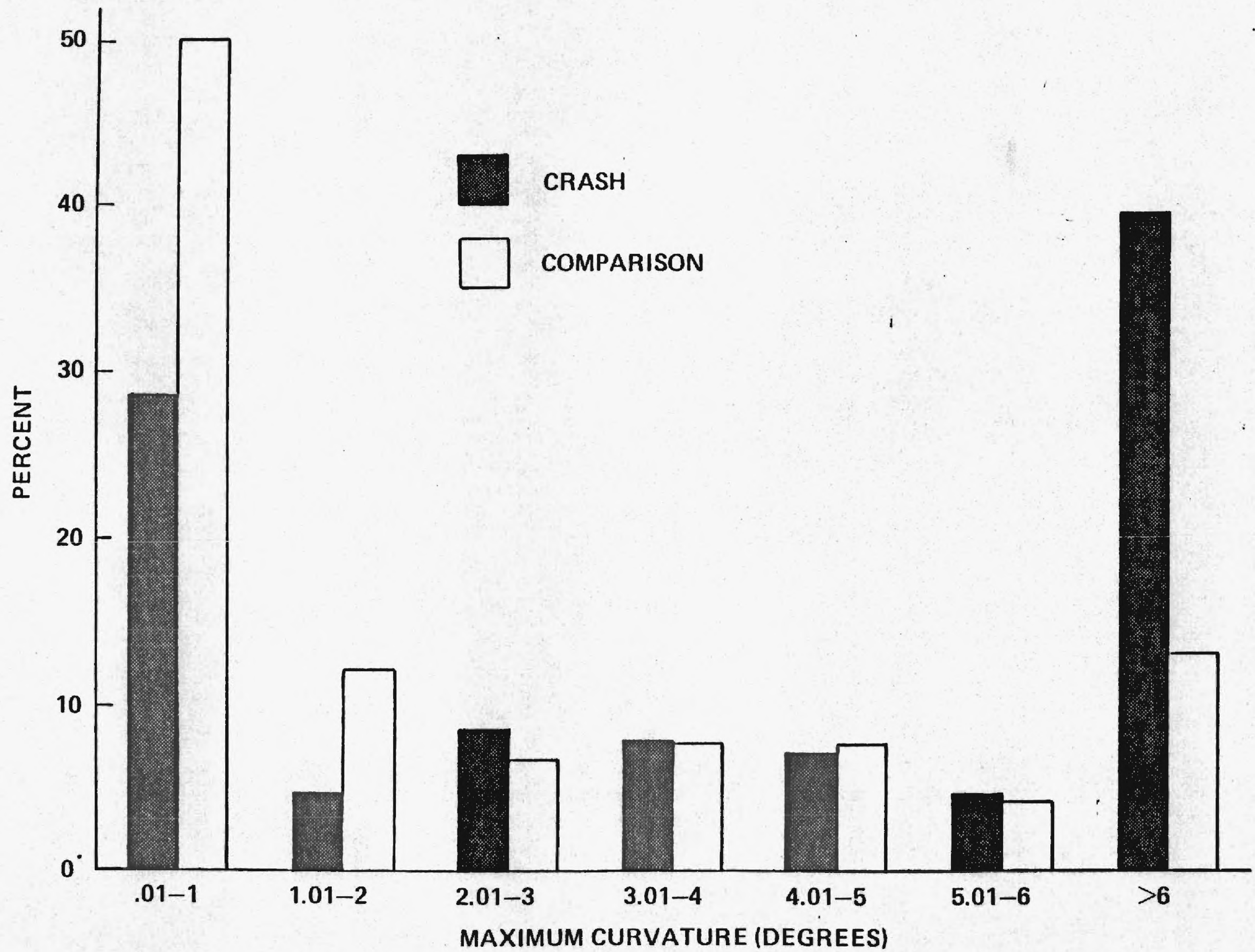

Figure 2. A distribution of maximum road curvature at the fatal rollover crash and comparison sites.

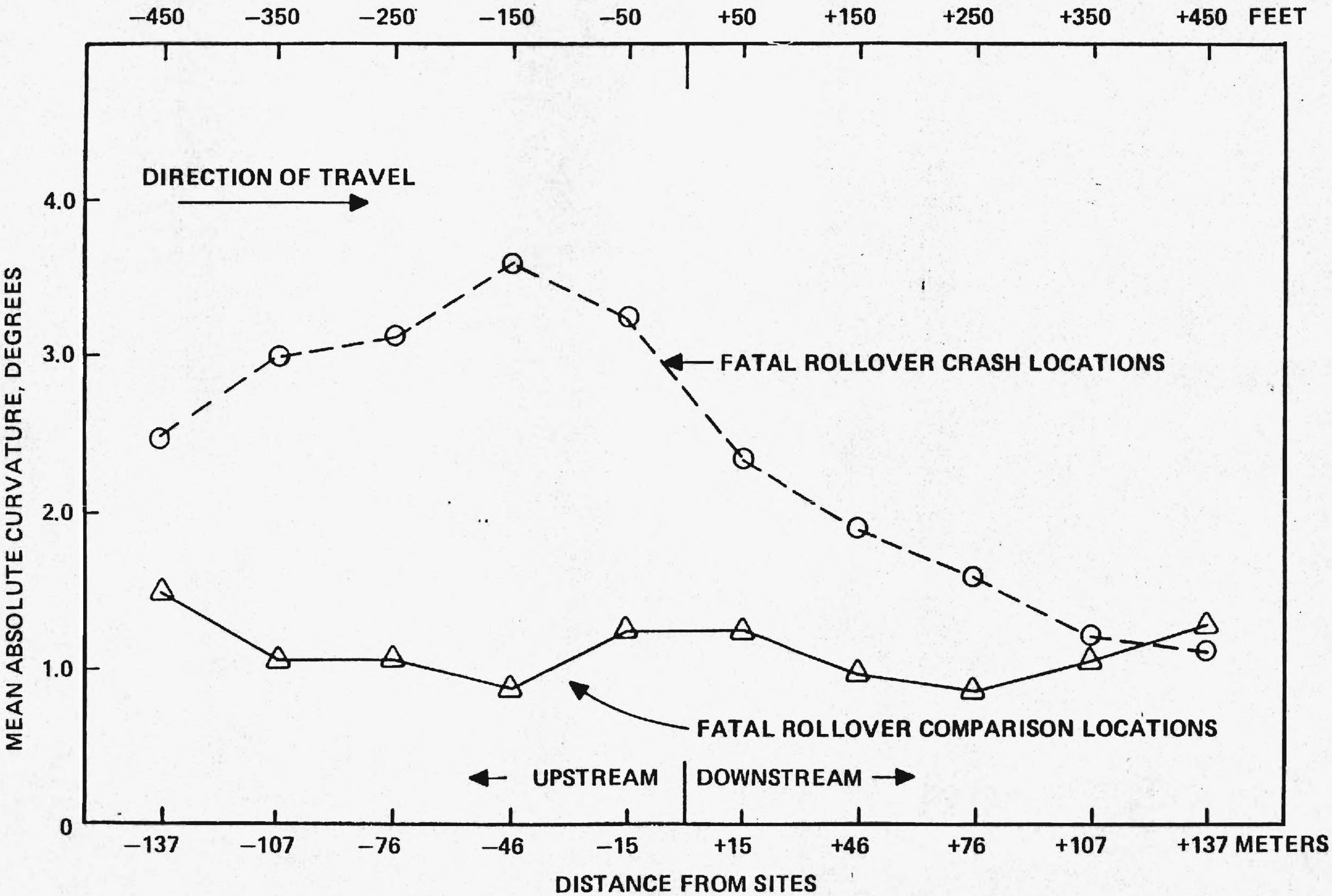

Figure 3. Mean curvature (degree of curve) observed at various section positions at the crash and comparison locations.

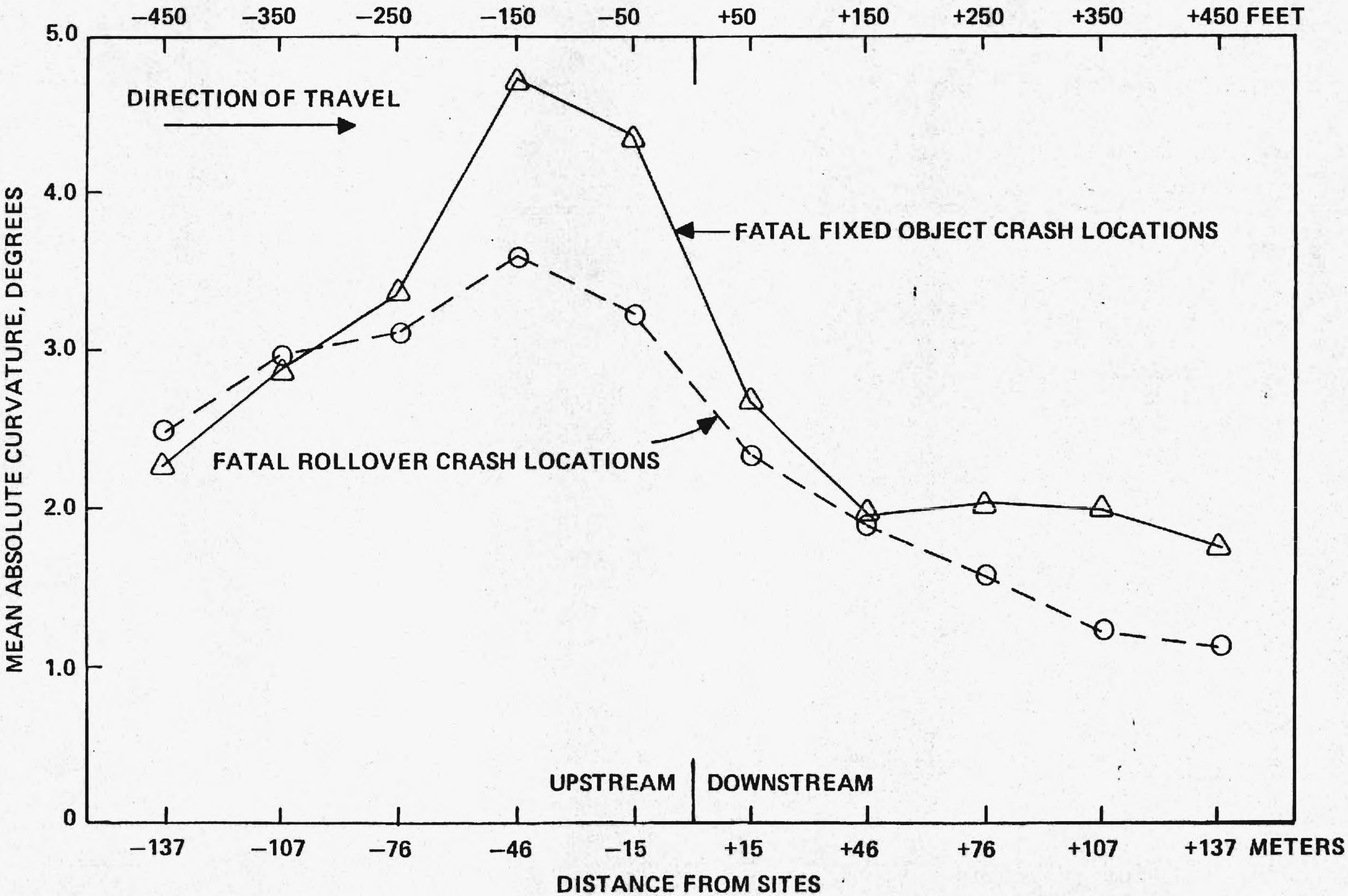

Figure 4. Mean curvature (degree of curve) observed at various section positions at fixed object crash and rollover crash locations.

Table 1. A Distribution of Crashes by Type of Alignment and Departure Direction

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

roadway along left turning curves, and among these curves, vehicles leaving the roadway on the outside (or right side) are over-represented. Among crashes in which the vehicle left a straight road section on the left side there were more off-the-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 represents both superelevation values (for curved roadways) and crown values (for straight roadways). Slightly higher mean values are noted in the upstream area, reflecting 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 fixed-object crash locations than at the rollover crash locations, but in only two instances (at 107m and 137m downstream) were the differences significant.

Gradient

Figure 6 shows the pattern of variation of mean gradient for crash and comparison locations. The apparent differences in mean gradients were tested for each of the 11 positions by 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, as compared to crash sites, prompted further analysis of these data. Table 2 shows the percentages of rollover crash sites having various combinations of average curvature and gradient in a 91m section immediately upstream from these sites.

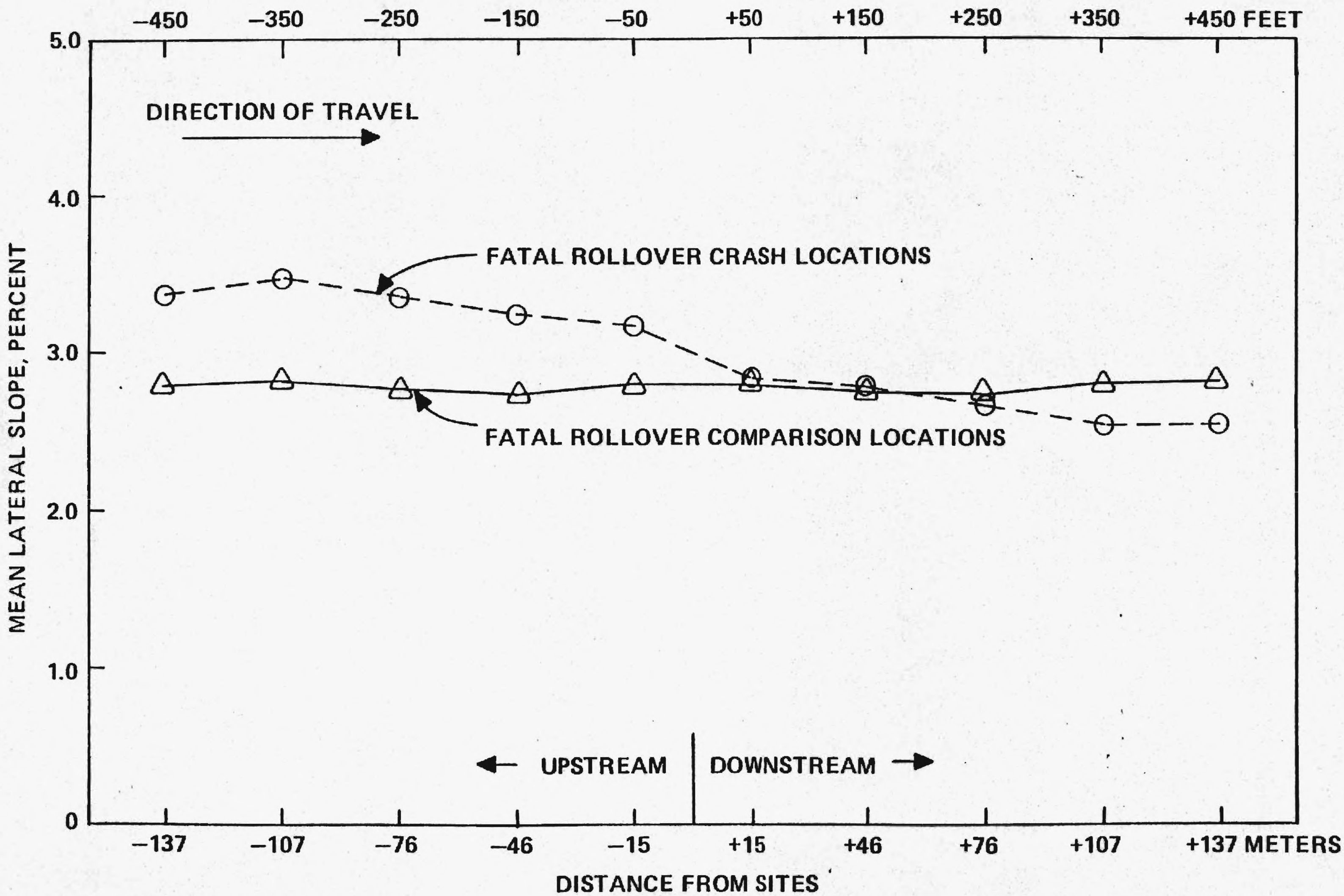

Figure 5. Mean lateral slope observed at various section positions.

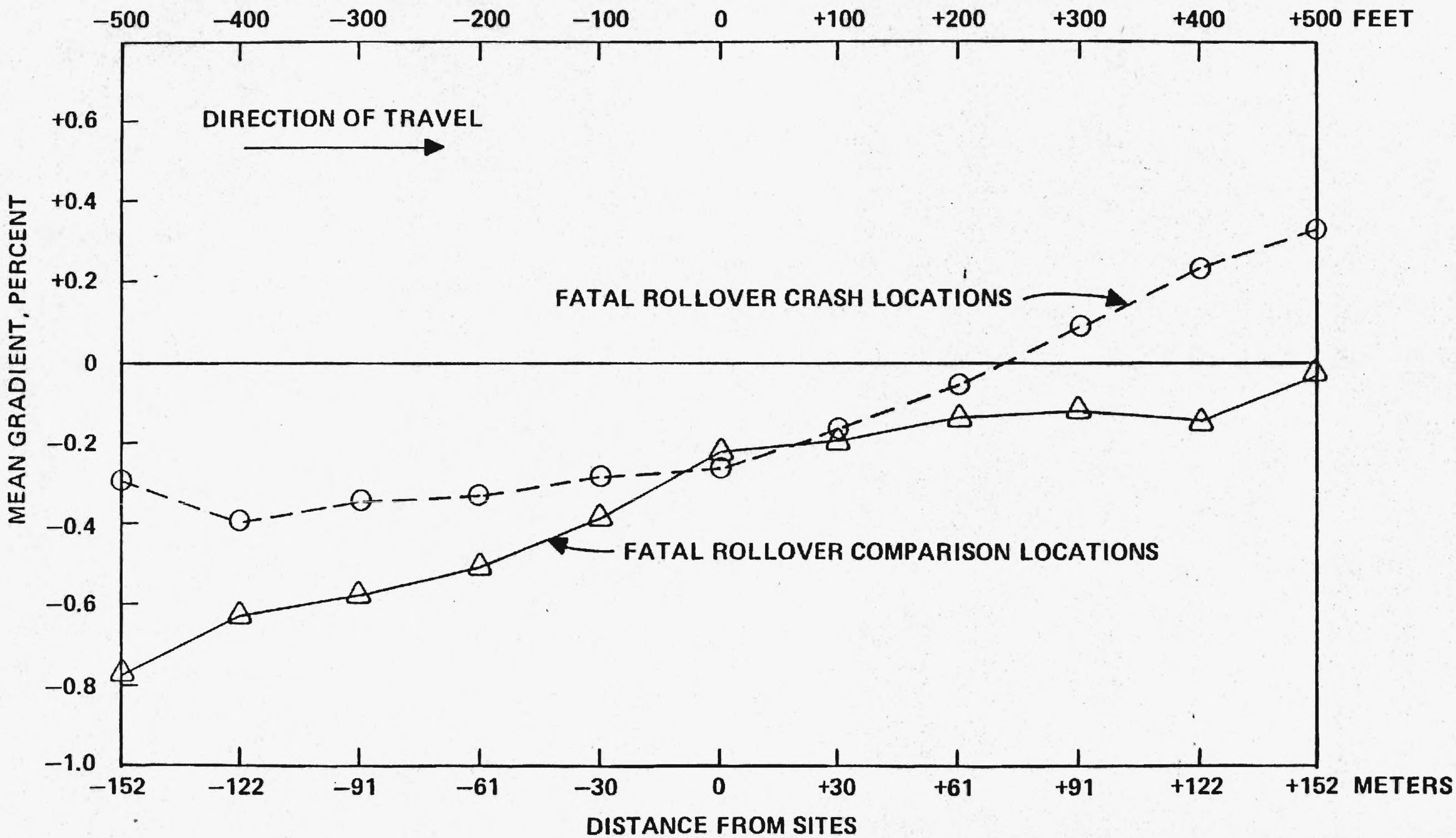

Figure 6. Mean gradient observed at various section positions at rollover crash and comparison locations.

Table 2. Percentages of crash sites having various combinations of curvature compared with similar percentages for opposite side of road and ratios of these percentages.

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

The comparable percentage distribution for the opposite sides of these road sections is also shown, in parentheses, in this table. 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. (See the third entry in each cell in Table 2 for ratios of these percentages.) 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 fatal fixed-object and rollover crash locations were not significantly different. The patterns of distribution of gradients at the two classes of locations were remarkably similar, with more negative slopes upstream of the sites and positive slopes downstream (Figure 7).

Roadside

Measurement of eight key lateral dimensions or slopes along the roadside were made at 48 locations selected from the original set of 214 locations. (Fifty locations were selected, but field survey teams were unable to perform surveys at two locations.) In the vicinity of each crash and comparison site, measurements of the cross-sectional dimensions and slopes were made at stations 30m (100 ft) upstream and 30m downstream. The measurements were:

Shoulder width

Shoulder slope

Inside slope

Back slope

Depth of ditch

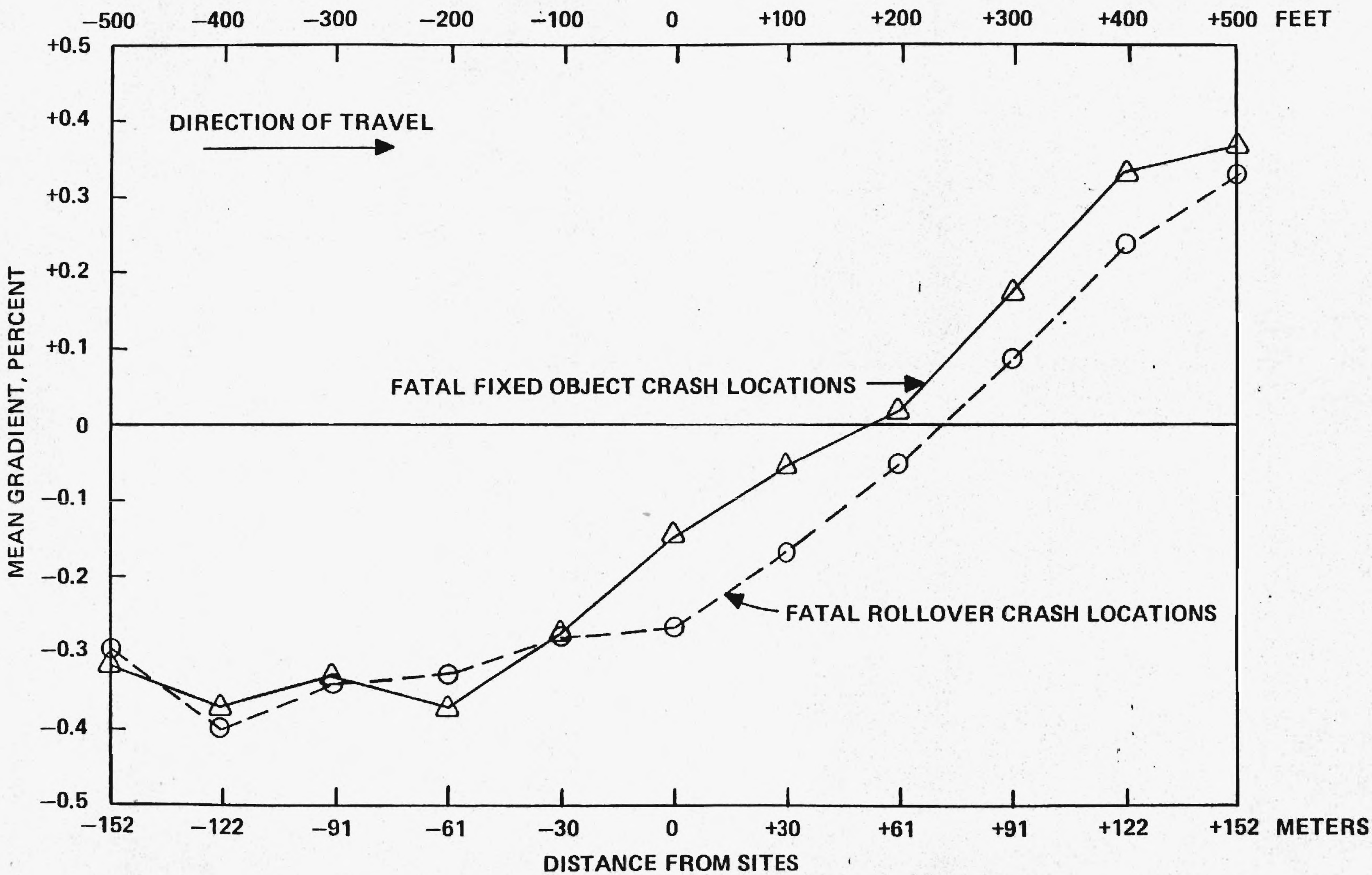

Figure 7. Mean gradient observed at various section positions at fixed object crash and rollover crash locations.

Lateral distance from edge of shoulder to bottom of embankment

Extent of drop-off at the pavement edge

Height of curb

Twenty-four t-tests were made comparing 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 shown 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 30m (100 ft) 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 inslope at the crash site was steeper than at the comparison site.
4. The shoulder slope 30m (100 ft) downstream was steeper at the comparison location than at the crash location.
5. The inslope 30m (100 ft) 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 only 22.0 percent (38.9 - 6.9). Similar results were obtained when comparing the mean changes in slopes 30m (100 ft) downstream.

As Figure 8 illustrates, about 90 percent of rollover crashes were precipitated at points within 9.1m (30 ft) of the pavement edge. The distribution of lateral displacement of such points was similar to that for lateral distances to objects struck in the fixed-object study. The average angle of

Table 3. Mean Dimensions of Cross-Section, Rollover Study, Various Locations

Variable	Position		
	30m 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, Percent			
Crash	5.2	4.6*	4.1*
Comparison	5.5	6.9*	6.6*
Inslope, Percent			
Crash	30.7	37.5*	38.9*
Comparison	28.2	28.9*	29.2*
Backslope			
Crash	26.3	21.7	17.8
Comparison	21.5	13.5	20.1
Depth of Ditch, m			
Crash	0.37	0.37	0.38
Comparison	0.36	0.36	0.35
Lateral Length of Embankment, m			
Crash	3.8	3.2	4.4
Comparison	3.3	3.9	3.6
Height of Curb, cm			
Crash	0.70*	1.16	1.24
Comparison	2.48*	3.10	1.58
Drop-off at Shoulder, cm			
Crash	3.92	4.57	3.16
Comparison	2.95	3.31	4.17

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

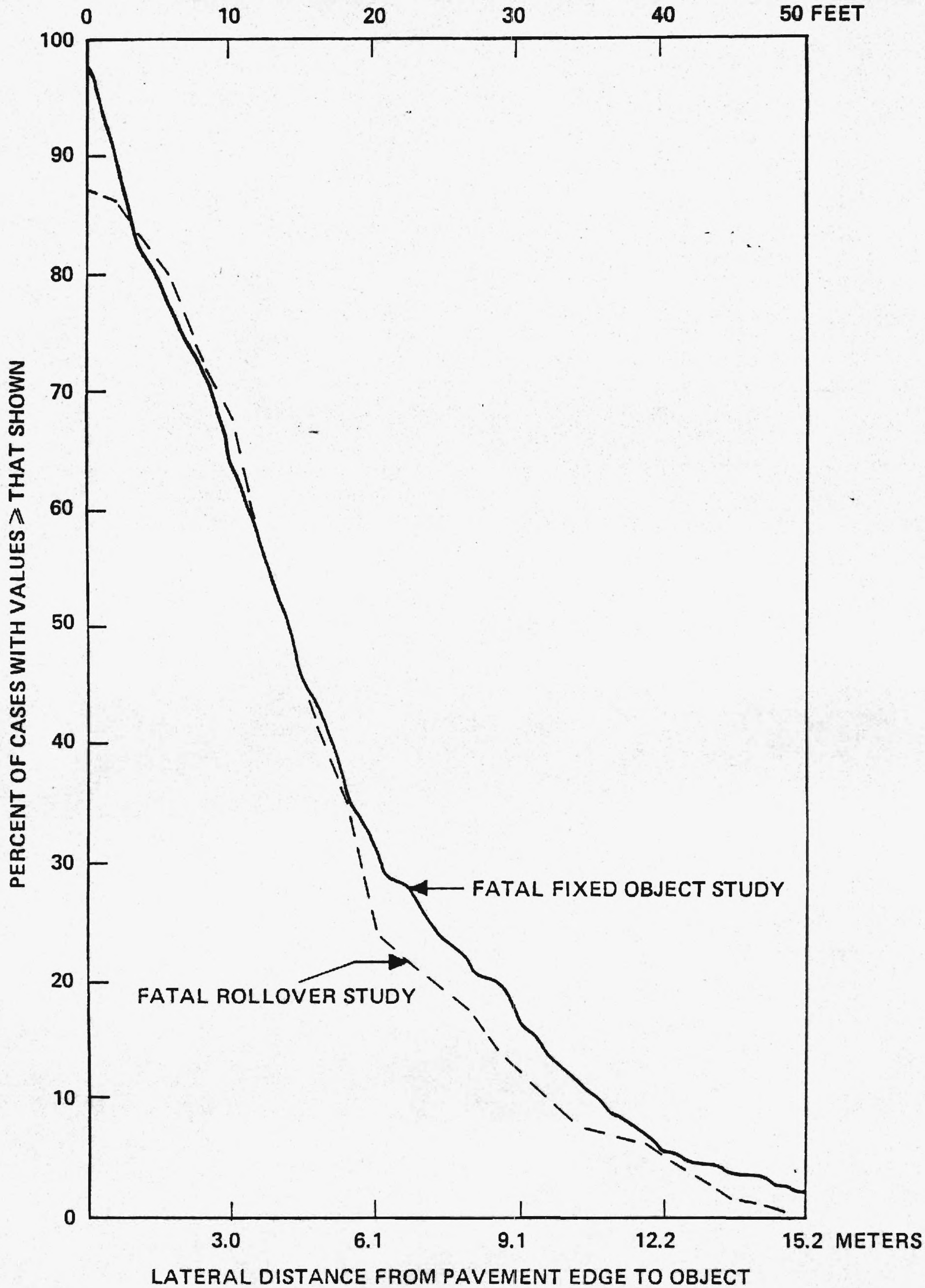

Figure 8. Distributions of lateral distances to crash points for fatal fixed object and fatal rollover studies.

departure was 9.6 degrees, a value that compares favorably to encroachment angles reported by other researchers (4, 5).

Roadside Objects

Tables 4 and 5 show the average numbers of narrow obstacles and the lengths of elongated obstacles in 0.16km (0.1 mile) sections upstream and downstream from rollover sites (crash and comparison), as well as at fixed-object crash sites.

Hazard densities at the rollover crash sites were compared with densities at both the rollover comparison sites and the fixed-object crash sites. The t-tests employed 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 Tables 4 and 5). The relatively few and small differences between single-vehicle crash and comparison sites in hazard densities confirm the field observation that the placement and frequency of roadside hazards vary relatively little along highways.

Figure 9 shows the average lengths of embankments, banks, and ditches combined in the 161m sections upstream and downstream from the sites. Sharp peaks are noted within 3-6m 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 narrow fixed objects combined in the 161 sections upstream and downstream from the sites. There were twice as many narrow fixed objects per section within 3m (10 ft) of the pavement edge at the fixed-object crash sites than at the rollover crash sites. On the

Table 4. Average Number of Narrow Potential Hazards and Meters of Elongated Potential Hazards at Crash and Comparison sites 9m off Pavement and within 161m in Direction for which Vehicle Traveled (Upstream)

	METERS FROM PAVEMENT											
	Rollover Crash Sites				Rollover Comparison Sites				Fixed Object Crash Sites			
Hazards	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total
Narrow potential hazard (number)												
Trees	0.2	3.3	7.3	10.8	0.4	2.4	4.1*	6.9	0.7*	2.7	3.9*	7.3
Utility poles	0.2	0.2	0.3	0.7	0.2	0.3	0.2	0.7	0.6*	0.4*	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*	0.1	1.0
Street luminary poles	a	a	a	---	a	a	a	---	0.1	a	a	0.1
Other narrow objects	0.8	0.7	0.3	1.8	0.5*	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
Elongated potential hazards, in meters												
Curbs	4.3	2.8	0.1	7.2	8.4	2.5	0.1	11.0	9.3*	1.7	0.6	11.6
Embankments	17.6	50.4	11.7	79.7	8.4*	37.9*	13.8	60.1	11.1*	19.2*	4.9*	35.2
Banks - cuts	1.7	17.7	11.2	30.6	1.0	10.9*	13.9	25.8	4.6*	10.0*	4.6*	19.2
Ditches	11.5	42.1	12.9	66.5	16.5	42.5	14.1	73.1	13.0	18.3*	4.4*	35.7
Guardrail	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

a <0.05 but not 0.00
*Significantly different from rollover crash site data, p<0.10. Note: 1 m = 3.28 ft.

Table 5. Average Number of Narrow Potential Hazards and Meters of Elongated Potential Hazards at Crash and Comparison Sites 9m off Pavement and within 161 m Beyond Sites in Direction Vehicle Was Traveling (Downstream)

Hazards	METERS FROM PAVEMENT											
	Rollover Crash Sites				Rollover Comparison Sites				Fixed Object Crash Sites			
	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total
Narrow potential hazard (number)												
Trees	0.6	1.5	4.5	6.6	0.3	1.7	3.7	5.7	1.0*	3.1*	4.9*	9.0
Utility poles	0.1	0.1	0.3	0.5	0.2	0.2	0.3	0.7	0.6*	0.4*	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	a	a	a	---	a	a	a	---	a	a	a	---
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
Elongated potential hazards, in meters												
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*	40.6	14.8	65.8	9.9*	18.7*	5.2*	33.8
Banks - cuts	0.1	11.7	9.7	21.5	2.5*	15.1	18.2*	35.8	5.0*	11.4	6.0*	22.4
Ditches	9.0	47.3	11.7	68.0	13.1	42.9	15.4	71.4	15.5*	15.7*	3.8*	35.0
Guardrail	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

a < 0.05 but not 0.00

*Significantly different from rollover crash site data, p<0.10.

Note: 1 m = 3.28 ft.

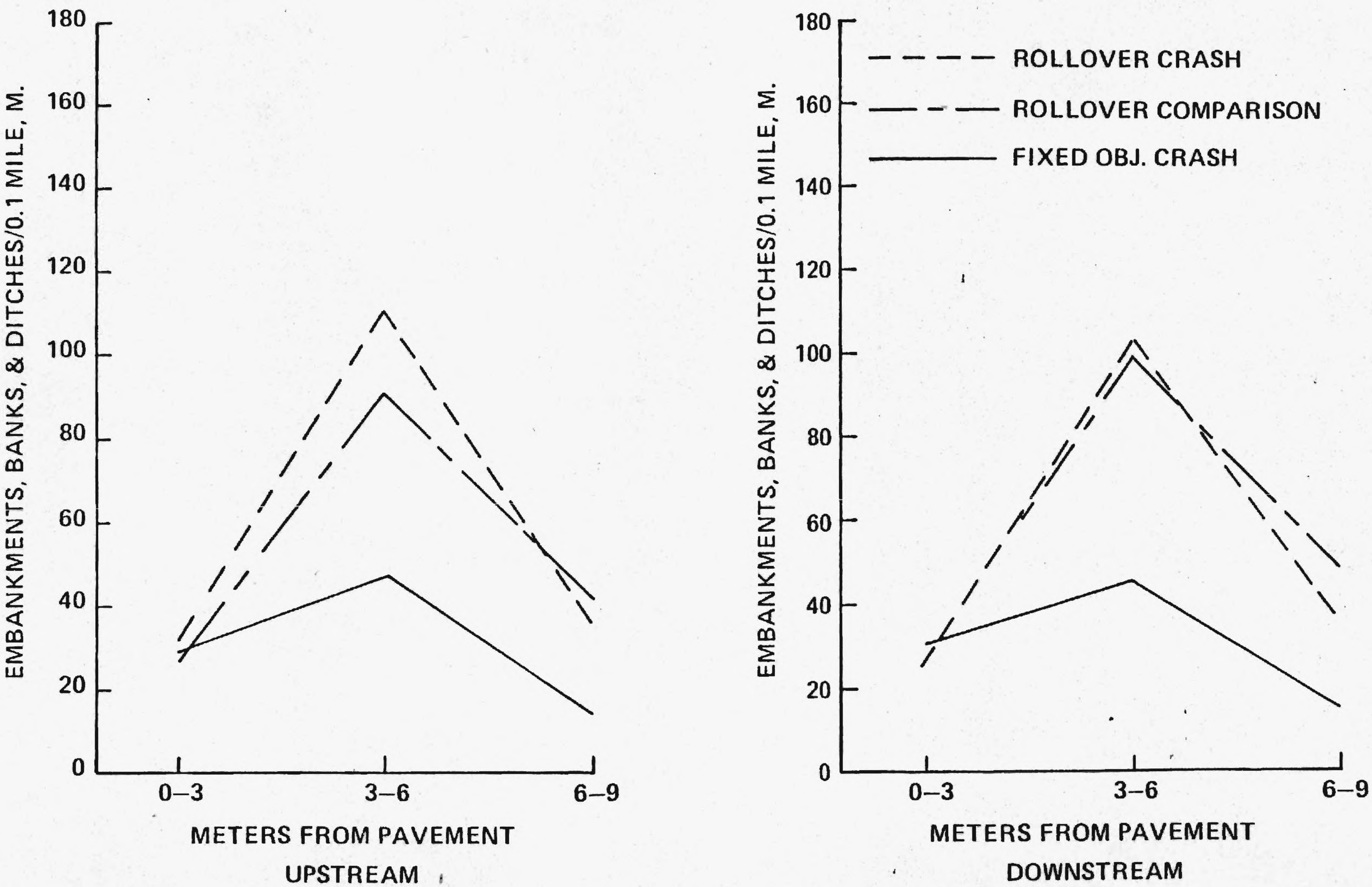

Figure 9. Average lengths of embankments, banks, and ditches combined in the 161 m sections upstream and downstream from the sites.

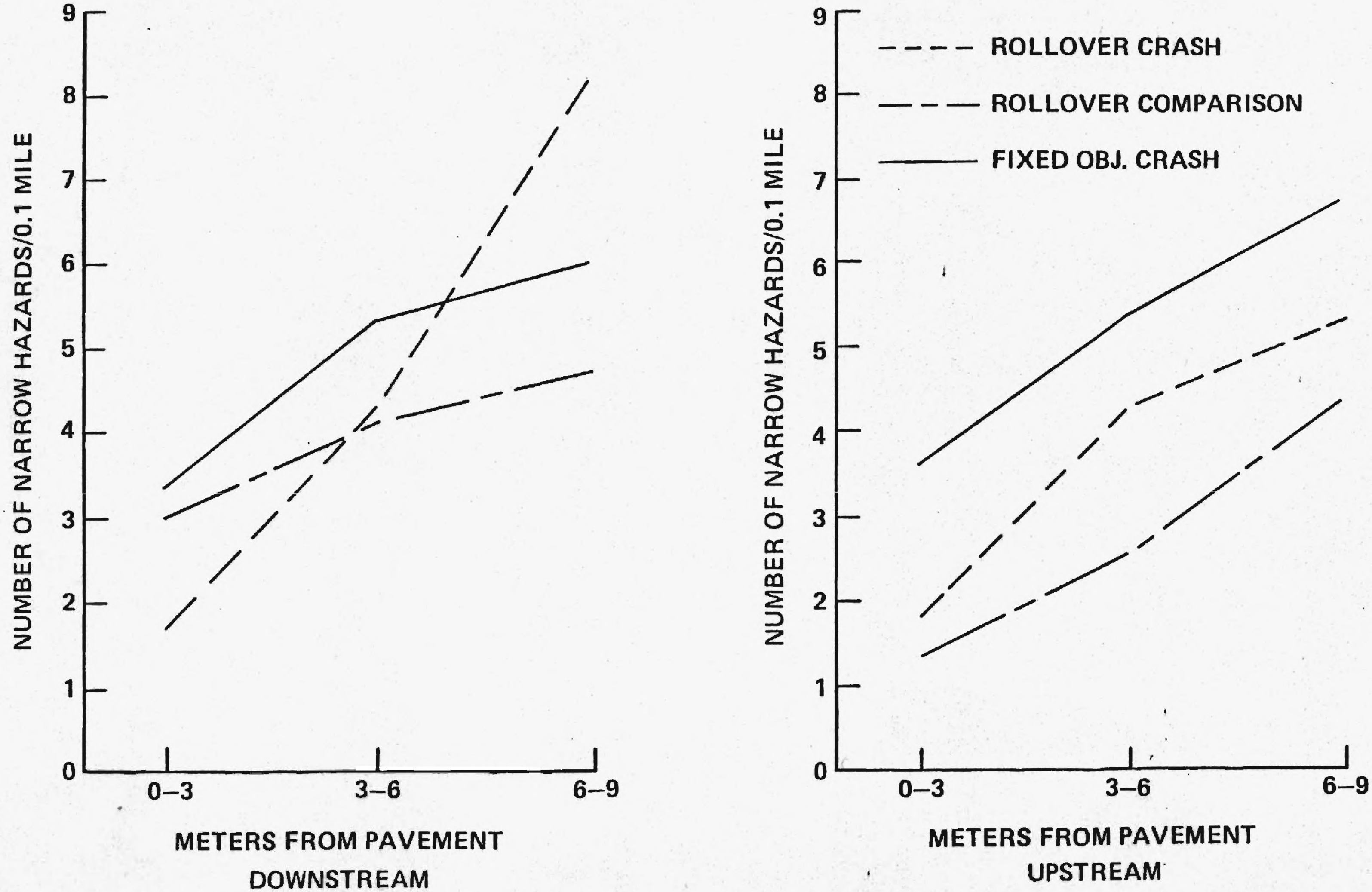

Figure 10. Average number of narrow fixed objects combined in the 161 m sections upstream and downstream from the sites.

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 the 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 is shown in Table 6, along with a similar breakdown for all Georgia roads in rural and urban areas. The data suggest that there was an over-representation of principal and minor arterial roadways in the crash population and under-representation of local roads. This phenomenon, which was also noted in the case of fixed-object crash studies (2, 3), reflects the heavier traffic flows on non-local roads. As expected, the distribution of functional roadway classes at comparison locations was almost identical to that at crash locations.

Table 6. A Comparison of Roads at Crash Site and All Georgia Roads, By Functional Class.

Roadway Class	Percent in Class Shown 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
	100.0	100.0

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 1.6km (1 mile) upstream from the crash locations. The field survey procedures were similar to those used in two earlier studies of fixed-object crashes (2, 3). It was found that single-vehicle fatal rollover crashes are more likely to occur:

1. along non-local (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 fatal rollover crash locations can be discriminated from comparison locations by curvature greater than six degrees, 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.

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 to have embankments along the roadside than the comparison sites, but less likely to have trees and certain other narrow fixed objects.

Similarly, the rollover crash sites had greater lengths of 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 it 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 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 on to 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 (2, 3) based on horizontal curvature and gradient should be suitable for identifying and establishing priorities for the correction of potential rollover crash locations in Georgia and other states with similar topography, demography and climate.

The modifications undertaken at a specific location depend on several factors: the number and types 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.

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