COST-EFFECTIVENESS
OF
DRIVEWAY SLOPE IMPROVEMENTS

by

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in cooperation with the
NEBRASKA DEPARTMENT OF ROADS

CIVIL ENGINEERING DEPARTMENT
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UNIVERSITY OF
NEBRASKA

Engineering Research Center
College of Engineering and Technology
University of Nebraska
Lincoln, Nebraska 68588

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ABSTRACT

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In the development of roadside safety improvement programs, many types of obstacles have been identified as being hazardous. However, little attention has been given to the hazard of driveway slopes along non-controlled and limited access roadways. It was the purpose of this study to assess the hazard posed by such driveway slopes and to determine the cost-effectiveness of flattening them.

The degree of hazard presented by a driveway slope was measured in terms of the expected number of injury (fatal or nonfatal) accidents per year resulting from a vehicle traversing the slope. The probability of injury in a run-off-the-road encroachment of a driveway slope, which was used to compute the degree of hazard, was derived from severity indices computed from results obtained using the Highway-Vehicle-Object-Simulation Model to simulate a standard size automobile (3,800 lb) traversing driveway slopes under encroachment conditions of 55 mph speed and 10 deg encroachment angle in a free-wheeling steer mode.

The results of this study indicate that: (a) the rate of rollovers decreased as the driveway slopes were flattened with none occurring on slopes flatter than 6:1; (b) flattening to an 8:1 driveway slope was the most cost-effective improvement; (c) a 10:1 driveway slope improvement was not cost-effective; and (d) depending on the ADT and amount of underdrainage involved driveway slope improvements can have cost-effectiveness priority ratings comparable to those of other types of roadside safety improvements. Also the cost-effectiveness methodology used in this study provides a common basis for comparing driveway slope improvements with other types of improvements in the management of roadside safety improvement programs.

ABSTRACT

Key Words: Safety, Driveways, Encroachments, Auto-Simulation, Cost-Effectiveness

Little attention has been given to the hazard of driveway fill slopes located along the roadsides of non-controlled and limited access rural highways. The severity of a standard size automobile (3,800 lb) traversing driveway slopes under the run-off-the-road encroachment conditions of 55 mph and 10 deg was investigated using the Highway-Vehicle-Object-Simulation-Model (HVOSM) in a free-wheeling steer mode.

The results of a cost-effectiveness analysis on improving a typical driveway slope from a 3:1 to flatter slopes indicated that: (a) the 8:1 slope improvement was the most cost-effective alternative and could be made with 95 percent confidence that it would result in a reduction of injuries, (b) the 10:1 slope improvement alternative was not cost-effective, and (c) driveway improvement alternatives without underdrainage were more cost-effective than those with underdrainage. The injury probabilities used in this study were based on the magnitude of the computed resultant automobile accelerations averaged over a time duration of 50 msec, except rollovers were assigned an injury probability of one. The rate of rollovers decreased as the driveway slopes were flattened with none occurring on slopes flatter than 6:1.

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INTRODUCTION

During the past two decades, a considerable amount of attention has been devoted to improving roadside safety by removing, relocating, or reducing the impact severity of obstacles along the roadsides. Many types of obstacles have been identified as being hazardous, and as a result, comprehensive safety improvement programs have been undertaken.

However, very little attention has been given to the hazard of driveway slopes along the roadside of non-controlled access or limited access roadways, and to the cost-effectiveness of improving driveway slopes. Several apparent reasons for the lack of information on driveway slopes are:

1. Driveway slopes are inconspicuous. Encroachments, in which an errant vehicle initially encounters a driveway slope and abruptly becomes airborne and beyond the immediate control recovery of the driver, have in all probability been recorded as: a rollover accident; or a tree or fixed object collision accident because of the vehicle's final resting position; or some other reason that only identifies correctly the second collision event.
2. The ditch bottom and/or culvert lies slightly beyond the widely accepted "Clear Recovery Area" of 30 ft. Therefore, in the situation where the side slopes of the ditch are 4:1 and flatter, the driveway slope nearer the roadway gives the illusion of being non-hazardous in the event of a vehicle encroachment.

The objectives and goals of this study were twofold. First, the degree-of-hazardousness of a typical driveway slope configuration along the roadside of a modern non-controlled access or limited access roadway facility was investigated and ascertained. And second, the cost-effectiveness of improving the selected driveway slope configuration from a 3:1 to flatter slopes was investigated and ascertained.

Roadside safety improvement programs must compete with other ongoing highway programs for the limited funds available. The cost-effectiveness technique is a managerial tool which provides the highway administrator with a means of evaluating safety improvement alternatives on a common data base and a priority ranking scale to realize the greatest return on the investment made to reduce injury accidents.

The probability of injury in a run-off-the-road encroachment of a driveway slope must be determinable in order to conduct a cost-effectiveness analysis. The severity of such an event can be expressed as the ratio of the resultant automobile accelerations to the resultant accelerations "tolerable" to an unrestrained occupant. This ratio, commonly referred to as a severity-index, was computed from the results obtained by a mathematical computer model simulation program named HVOSM (Highway-Vehicle-Object- Simulation-Model). The methodology used to express severity-indices in terms of probability of injuries is discussed in this paper.

DESCRIPTION OF DRIVEWAY SITE

The driveway selected for this review and research was chosen as a typical rural-suburban example. The selected driveway is shown in Figure 1.

The driveway is located along a four lane divided rural highway section. The roadway itself is in a rural-urban transition area and has a depressed median; however, there is limited access and left-turn storage lanes across the median. The driveways along this particular highway section are developed as a part of the limited access and future frontage-road system. This development of the access system is intended to function as the arterial interconnections for the street network in the future of the prime development area the highway traverses.

Major arterial is the functional classification of this stretch of highway and it serves not only as a major highway but also as a link to the Interstate System. The speed limit posted in the area of the driveway is the current national standard of 55 mph. The design speed of the highway section is 65 mph and the horizontal and vertical alignments through the study area are both tangent. The topography traversed is primarily flood plain of a local stream and the total area of research is flat and level.

The traffic projections and geometric data for the highway section are as follows:

Traffic	1970	1990
ADT	4000	8475
DHV	440	890
Trucks (Percentage)	19%	19%
V (Design Speed)	65 M.P.H.	

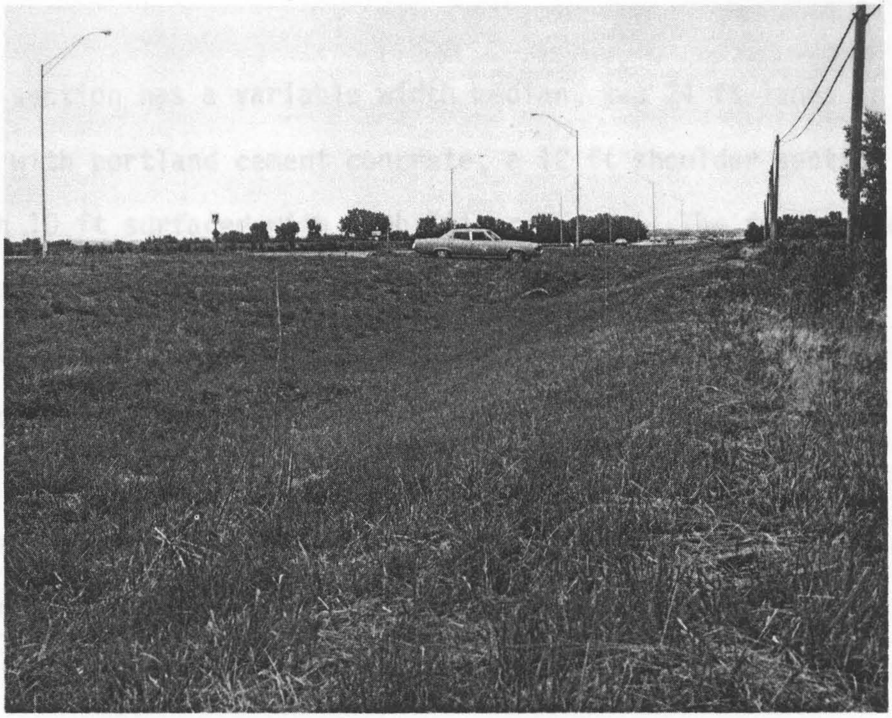

FIGURE I : PHOTOGRAPHS OF DRIVEWAY SITE

The section has a variable width median, two 24 ft lanes in each direction surfaced with portland cement concrete, a 12 ft shoulder section on the outside with 10 ft surfaced with asphaltic concrete. The fore-slope is 6:1 to a minimum of 30 ft from edge of pavement. Beyond 30 ft the fore-slope is 4:1 to the 10 ft flat bottom ditch. The back-slope is uniformly 4:1 from ditch bottom to original terrain elevation.

The actual driveway geometrics include 3:1 fill slopes with a 60 ft wide grading top, for future intersection development, and an essentially tangent grade line from the shoulder point to the original terrain. The driveway used for this research did have drainage involved; however, based on prior research on flared-end-sections and bar grates no special consideration was given to this area and the main thrust of the research was directed to the driveway fill slopes. The goemetric connection of driveway embankment to roadway embankment is basically defined by intersecting planes with a variable but extremely limited amound of rounding. This connection should be one of the areas to be reviewed in detail as it is one of the areas of concern in the path of an automobile leaving the roadway and traversing an intersecting driveway.

COMPUTER MODEL OF AUTOMOBILE

During the past three decades, many highway organizations have relied heavily upon experience and judgement in the design of roadside appurtenances; and, trial and error full scale tests were often conducted to determine the feasibility of these appurtenances. Significant advancements in technology and an increase in safety have evolved from these efforts. However, this type of design approach appears to be insufficient by itself because one or more full scale tests were required to effectively evaluate the influence of any one variable. Conducting many full scale tests can be both time consuming and costly.

Mathematical model simulation provides a rapid and economical method to investigate the many variables involved in a run-off-the-road automobile collision or maneuver. A limited number of full scale tests can then be conducted to confirm the simulation results. When supplemented by experience, judgement and tests, model simulation can be a very helpful tool in achieving efficient and safe designs.

The Highway-Object-Simulation-Model, designated as HVOSM, was used in the subsequent work to study the dynamic motion of an automobile traversing the ditch and driveway configurations described in the preceding section. HVOSM was developed by McHenry (1,2) of the Cornell Aeronautical Laboratories and modified for specific field applications by the Texas Transportation Institute (3).

The idealized-free-body-diagram of HVOSM is shown in Figure 2. The model has 11 degrees of freedom and consists of four isolated masses. The masses of the automobile include: (a) the sprung mass of the body, engine

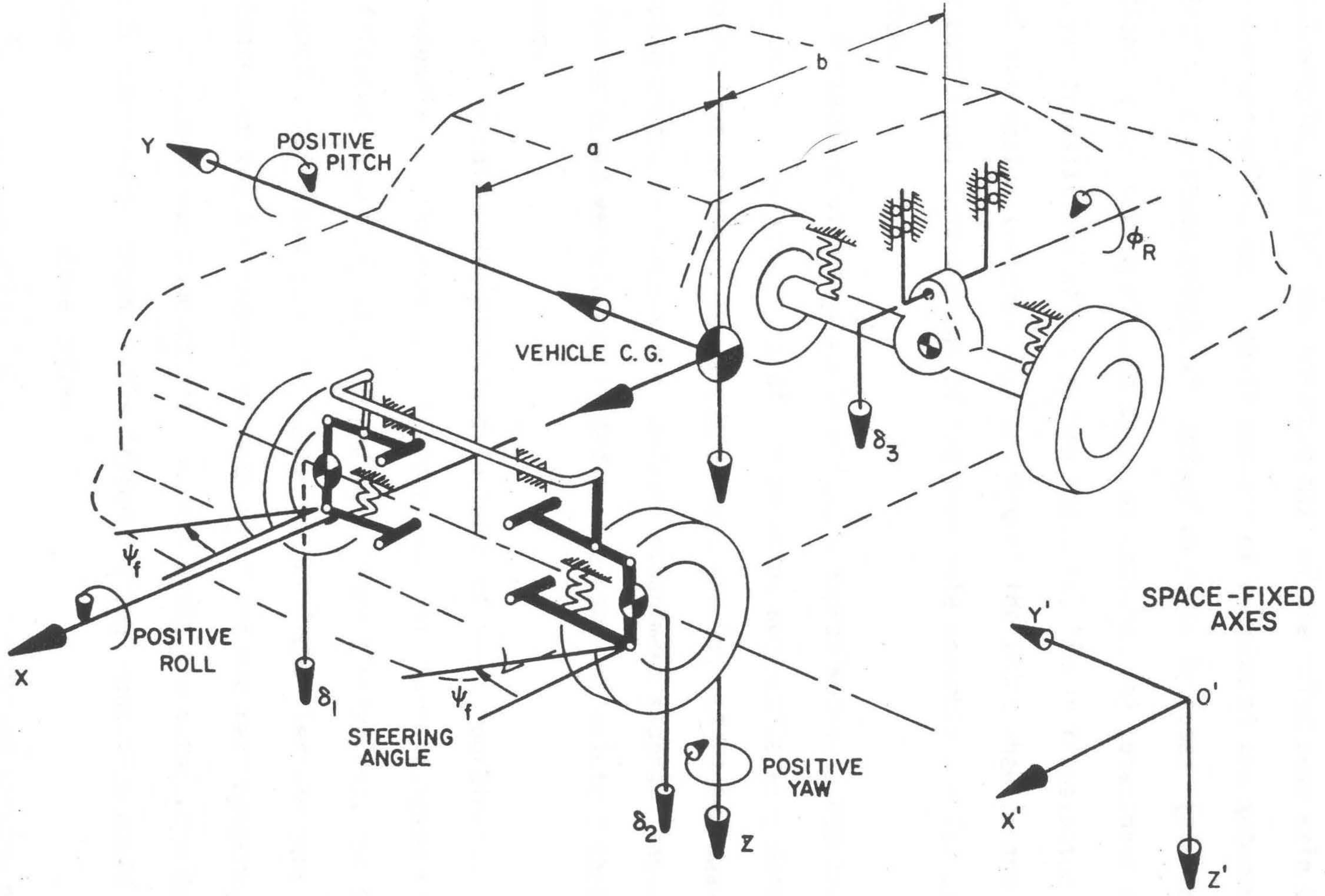

FIGURE 2 : IDEALIZATION OF HVOSM

and transmission supported by the front and rear suspension system, (b) the unsprung masses of the left and right independent suspension systems of the front wheels, and (c) the unsprung mass of the solid rear axle assembly and its suspension system. The 11 degrees of freedom of the automobile measured relative to a fixed coordinate system in space include: (a) linear translations of the sprung mass in three directions, (b) rotational roll, pitch and yaw translations of the sprung mass, (c) linear translation of the front wheel suspension systems, (d) steering of the front wheels, and (e) linear and rotational translations of the rear axle assembly and its suspension system.

A standard size automobile weighing approximately 3,800 lbs was used in this study. The properties of the selected automobile were defined in previous research work conducted by Ross and Post (4,5) and Weaver (6) on sloping grates in medians and roadside embankment slopes. The properties of the selected vehicle are listed on the computer printout sheets in Appendix A.

The terrain data, expressed in terms of x-y-z coordinates, are presented in Appendix B. The roadway, shoulder, and soil were assigned friction coefficient values of 0.8, 0.6 and 0.2, respectively; and, the soil was assigned a stiffness value of 4,000 lbs per inch. Terrain contact was only monitored at the two corners of both the front and rear bumpers.

No attempt was made to steer and/or brake the automobile during any of the driveway simulations. This "free-wheeling" condition would be representative of an inattentive driver.

The Texas Transportation Institute's (3) modified version of the HVOSM program was used in this study. On the average, 1 sec of event time required approximately 1 min of time on the University of Nebraska IBM 360 computer system. Computer costs per simulation ranged from 10 to 20 dollars. In comparison, full scale tests range from 5,000 to 15,000 dollars depending on the repetitiveness of the tests, vehicle control apparatus, type and amount of electronic instrumentation, and data reduction analysis techniques including high speed photography.

PROBABILITY OF INJURY

The criteria used in the majority of the research work conducted during the past decade for evaluating the safety aspects of roadside hazard improvements were based on levels of vehicle deceleration that would be tolerable to an unrestrained occupant. An attempt was made in this study to expand the existing technology to include the probability of occurrence of injury type accidents. This task was required in order to determine the "cost-effectiveness" for making driveway slope improvements.

Severity-Index Concept

The severity-index concept attempts to take into consideration the combined and simultaneous effects of the longitudinal (x-axis), lateral (y-axis), and vertical (z-axis) accelerations of the automobile at its center-of-mass. The coordinate axes were shown in Figure 2. The severity-index is computed as the ratio of the measured or computed resultant automobile acceleration to the resultant "tolerable" automobile acceleration that defines an ellipsoidal surface. This ratio can be expressed mathematically by Eq 1. An in-depth discussion on the development of Eq 1 was presented by Ross and Post (7) and Weaver (6).

$$SI = \sqrt{\left[\frac{G_{LONG}}{G_{XL}}\right]^2 + \left[\frac{G_{LAT}}{G_{YL}}\right]^2 + \left[\frac{G_{VERT}}{G_{ZL}}\right]^2} \quad \text{----Eq 1}$$

The relationship between the accelerations experienced by an occupant and the accelerations of an automobile at its center-of-mass during a run-off-the-road collision or maneuver are largely dependent on the degree of restraint. In other words, the greater the degree of restraint the more similar are the accelerations experienced by an occupant and the accelerations of the automobile. At the present time, however, accident data shows that in the majority of the accidents occupants were unrestrained. The tolerable accelerations suggested by Weaber (6) for use in the severity-index equation are presented in Table 1.

Table 1

TOLERABLE ACCELERATION LIMITS SELECTED FOR DITCH TRAVERSALS (TENTATIVE)

Degree of Occupant Restraint	Accelerations (g's)		
	G_{YL}	G_{XL}	G_{ZL}
Unrestrained	5	7	6
Lap Belt only	9	12	10
Lap Belt and Shoulder Harness	15	20	17

It is also well known that the accelerations of an automobile can reach high values over some small time duration ranging from 2 to 10 msec. These accelerations are commonly referred to as "spikes". For reasons discussed above, it is unlikely that unrestrained occupants would ever experience spike accelerations. Nordlin (8) concluded from conducting numerous full scale tests on traffic barriers in California that the accelerations of an automobile at its center-of-mass should be averaged over a time interval of 50 msec. Ross (7) indicates that this time duration appears reasonable for automobile embankment traversals because in the most of the instances investigated the highest acceleration time duration upon contacting the ditch was less than 80 to 100 msec.

The relationship between accelerations experienced by unrestrained occupants and accelerations of an automobile is continouly changing as more and better safety devices are incorporated into the design of automobiles. However, until the more sophisticated mathematical models of occupants and the area of bio-mechanics are further developed and validated, the severity-index concept will undoubtedly continue to be one of the better tools for evaluating the safety aspects of roadside hazard improvements.

The severity-index computations in the subsequent work will be based on accelerations tolerable to an unrestrained occupant, and the automobile accelerations will be averaged over a time duration of 50 msec.

Severity-Index and Injury Probability

In 1967, Michalski (9) of the National Safety Council statistically established from the results of a study involving 951 automobile traffic accidents that the incidence of occupant injury was directly related to the position of impact and the corresponding magnitude of vehicle damage. The severity of damage to a vehicle was rated on a 7-point photographic scale (10) by police officers and researchers at the scene of an accident.

The work of Michalski was applied and extended by Olson and Post (11) to include vehicle decelerations. Selecting vehicles damaged in full scale tests conducted by California, New York, and the Texas Transportation Institute, Olson had research engineers rate the severity of vehicle damage using the National Safety Council's 7-point photographic scales. The corresponding average vehicle decelerations could then be computed knowing the impact conditions of the tests, vehicle dimensions, and the type of objects struck. The results of that study are shown in Figure 3a and 3b.

An insight into establishing a relationship between severity-index and injury probability can be obtained based on the combined work of Michalski (9) and Olson (11) for an angle type collision such as a traffic barrier. In this type of collision in which vehicle snagging was minimized, it was determined that the average longitudinal vehicle decelerations (G_{long}) were equal to:

$$G_{long} = \mu G_{lat} = \mu(10\ P) \qquad \text{----Eq 2}$$

where: μ = coefficient of friction between vehicle body and traffic barrier

G_{lat} = average lateral decelerations = 10 P (Fig. 3a)

P = injury probability

Upon the substitution of Eq 2 into the severity-index equation (Eq 1) and assuming that the (a) vertical accelerations are negligible, (b) occupants are unrestrained, and (c) friction coefficient is 0.3, one obtains the following relationship.

$$SI = \sqrt{\left[\frac{G_{long}}{G_{x1}}\right]^2 + \left[\frac{G_{lat}}{G_{y1}}\right]^2}$$

$$= \sqrt{\left[\frac{10\mu P}{7}\right]^2 + \left[\frac{10\ P}{5}\right]^2}$$

$$SI = 2.0\ P \qquad \text{----Eq 3}$$

Further insight into the relationship between severity-indicies and injury probability can be obtained by combining the later work of Young and Post (12) with that of Michalski (9) and Olson (11). In 1971, Young conducted a research study on the rigid Texas Concrete Median Barrier which is similar

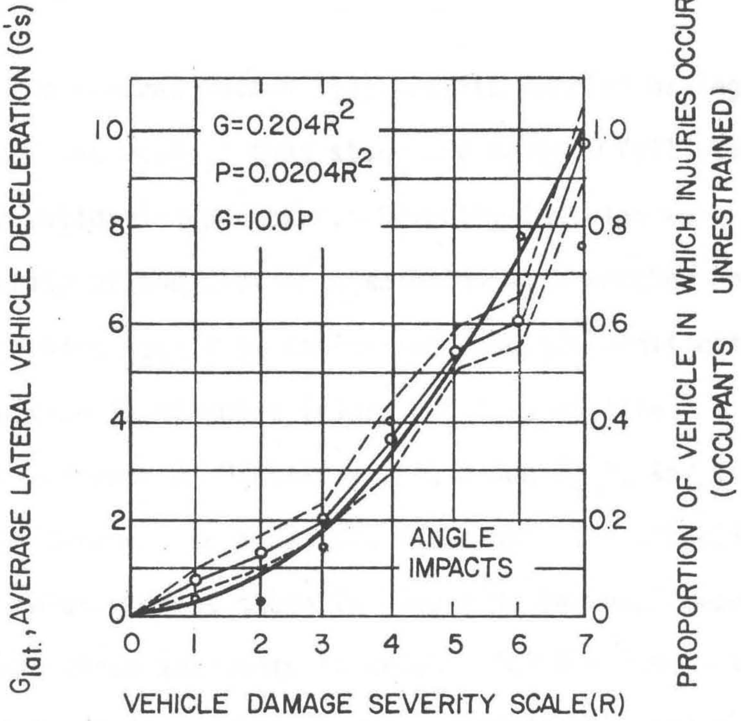

FIGURE 3a: CURVE RELATING LATERAL DECELERATION, PROPORTION OF INJURIES, AND DAMAGE RATING SCALE.

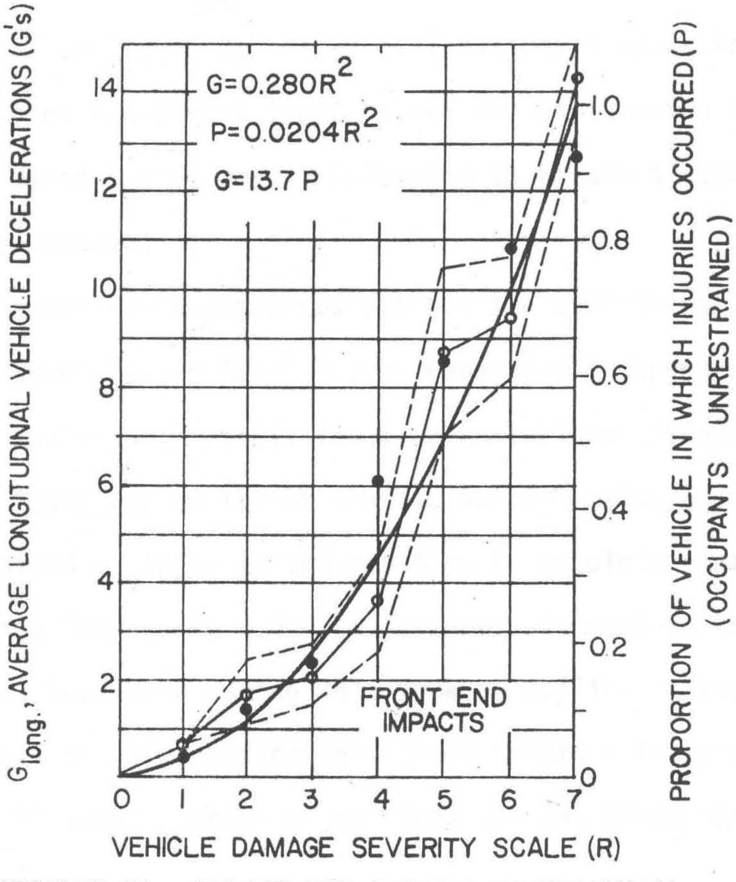

FIGURE 3b: CURVE RELATING LONGITUDINAL DECELERATION, PROPORTION OF INJURIES, AND DAMAGE RATING SCALE.

in design to the General Motors (13) traffic barrier having inclined surfaces. The HVOSM model was used in that study and several full scale tests were conducted for validation purposes. Severity-indicies were computed to compare the severity of one test or simulation with another and also to serve as an aid in making decisions concerning roadside modifications that should effect a reduction in occupant injury and loss of life.

The combined work of Michalski (9), Olson (11), and Young (12) is presented in Figure 4. In addition, Michalski statistically established the angle impact relationships shown in Figure 3a between "mean" vehicle damage ratings (R) and those accidents in which: (a) R = 1.99---vehicles were drivable, (b) R = 4.08---vehicles were non-drivable, (c) R = 2.49---no injuries occurred, and (d) R = 4.73---injuries occurred. The average lateral vehicle decelerations, G_{lat}, that correspond to these mean damage ratings were obtained from Figure 3a. The decelerations levels, in turn, were expressed as a function of the impact speed and angle using an equation contained in Olson's (11) work. Referring to Figure 4, the following conclusions were reached:

1. The severity-index curves exhibit the same characteristic shape as the deceleration level curves generated independently by Olson.
2. The "no injury" prediction by Michalski and Olson agrees well with the tests run on the GM traffic barrier using a live driver who received no injuries and remained in complete control of his vehicle during 50 mph and 8 deg collisions. It must be kept in mind, however, that even during this type of collision resulting in low levels of deceleration that there exists a low probability for injury.
3. The "injury" prediction by Michalski and Olson corresponds to a

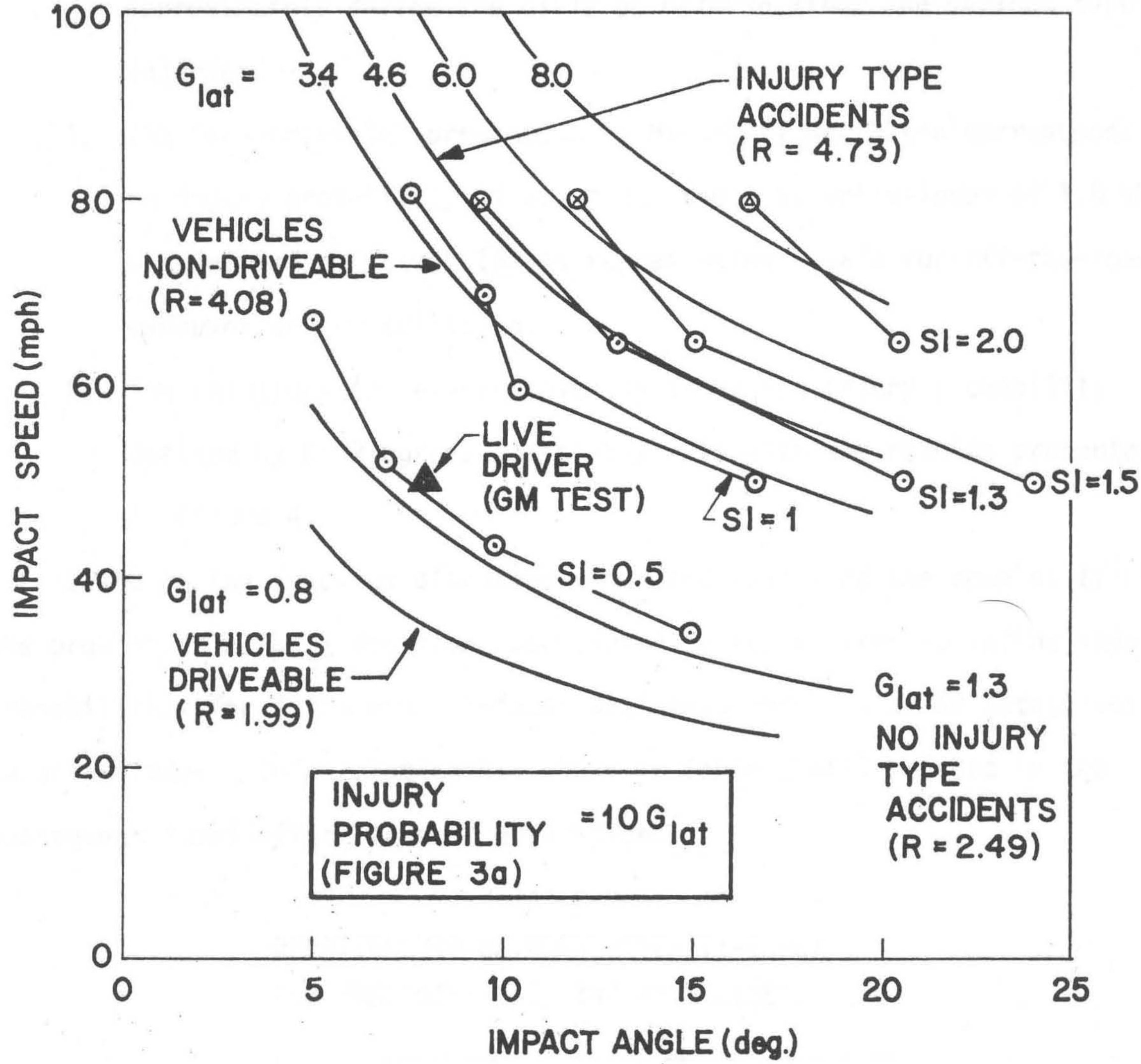

FIGURE 4 : RELATIONSHIP BETWEEN IMPACT CONDITIONS AND VEHICLE LATERAL ACCELERATIONS, SEVERITY-INDEX, AND PROBABILITY OF INJURY DURING COLLISION WITH TEXAS CONCRETE MEDIAN BARRIER.

severity-index of 1.3 and an injury probability of about 50%. No attempt was made by Michalski to classify the severity of an injury. However, it is the opinion of the writers that this condition may approximately define the division between minor and serious type injuries.

4. The "non-drivable" prediction by Michalski and Olson corresponds to an injury probability of about 35% and a severity-index of 1.0 which was defined by Weaver (6) as representing a safe run-off-the-road maneuver and/or collision.
5. The relationship between severity-index and injury probability defined by Eq 3 agrees reasonably well with the results presented in Figure 4.

Based on the findings discussed above and realizing the complexity of the problem at hand, a decision was reached by the writers to define injury probabilities for fatal and non-fatal accidents over six broad categories of severity-index. This relationship shown in Table 2 will be used in the subsequent "cost-effectiveness" evaluation.

TABLE 2
RELATIONSHIP BETWEEN SEVERITY-INDEX
AND PROBABILITY OF INJURY ACCIDENT

Severity-Index (SI)	Probability of Injury Accident
SI≤0.5	0.1
0.5<SI≤1.0	0.3
1.0<SI≤1.5	0.5
1.5<SI≤2.0	0.7
2.0<SI≤2.5	0.8
2.5<SI	1.0

RESULTS OF MATHEMATICAL SIMULATIONS

The paths of an automobile at its center-of-gravity for the 31 computer simulation runs made in this study on driveway slopes of 3:1 and flatter are shown in Figures 5 through 9. The automobile was assumed to encroach on the roadside from the center of the outside lane at a speed and angle of 55 mph and 10 deg. Simulations were made across the entire width of the driveway slope in increments of roughly 10 ft which was considered adequate for conducting a cost-effective analysis. The probabilities of the vehicle being on any one path were determined in a subsequent section.

The position of a vehicle along its path where the severity-index was computed is marked by an "x". In the majority of the runs this occurred near the intersection of the ditch slope and driveway front slope before the automobile was abruptly airborne, and at or slightly beyond the point where the automobile touches down after being airborne. The longitudinal, lateral and vertical accelerations and the computed severity-indices are presented in Table 3. The relationship between severity-index and injury probability was discussed in a previous section.

The "dotted" portion along a vehicle's path defines the area and distance over which the automobile was airborne. The distances and heights airborne for the various driveway slopes are presented in Table 3. Similarly, a large single "dot" along the vehicle's path defines the position where the roll angle was approximately 90 deg and rollover was imminent. As discussed in a subsequent section, rollover was considered to result in an injury probability of 1.0.

The maximum roll, pitch and yaw attitudes of an automobile before and after being airborne are also presented in Table 3. The yaw angle before

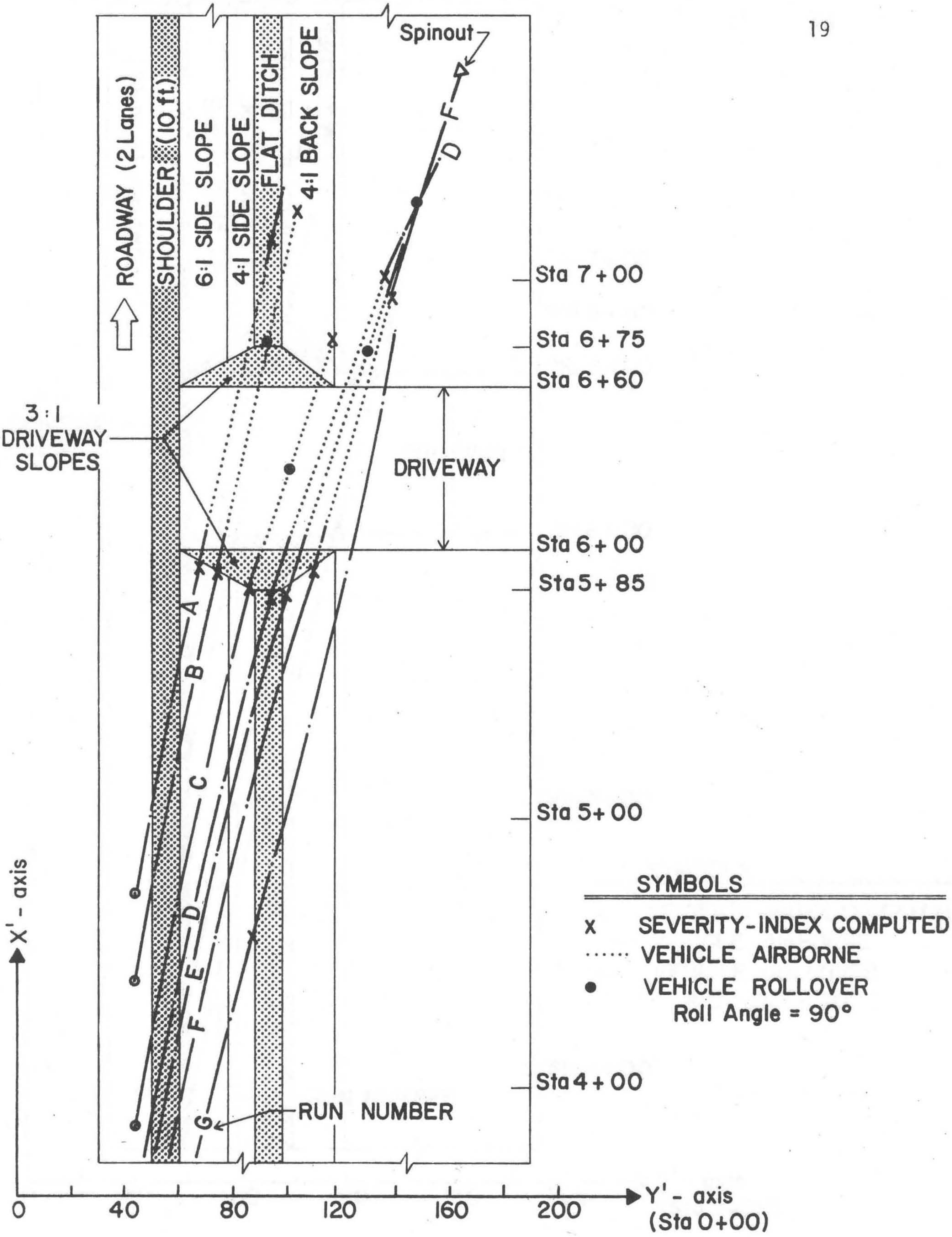

FIGURE 5 : DRIVEWAY 3:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

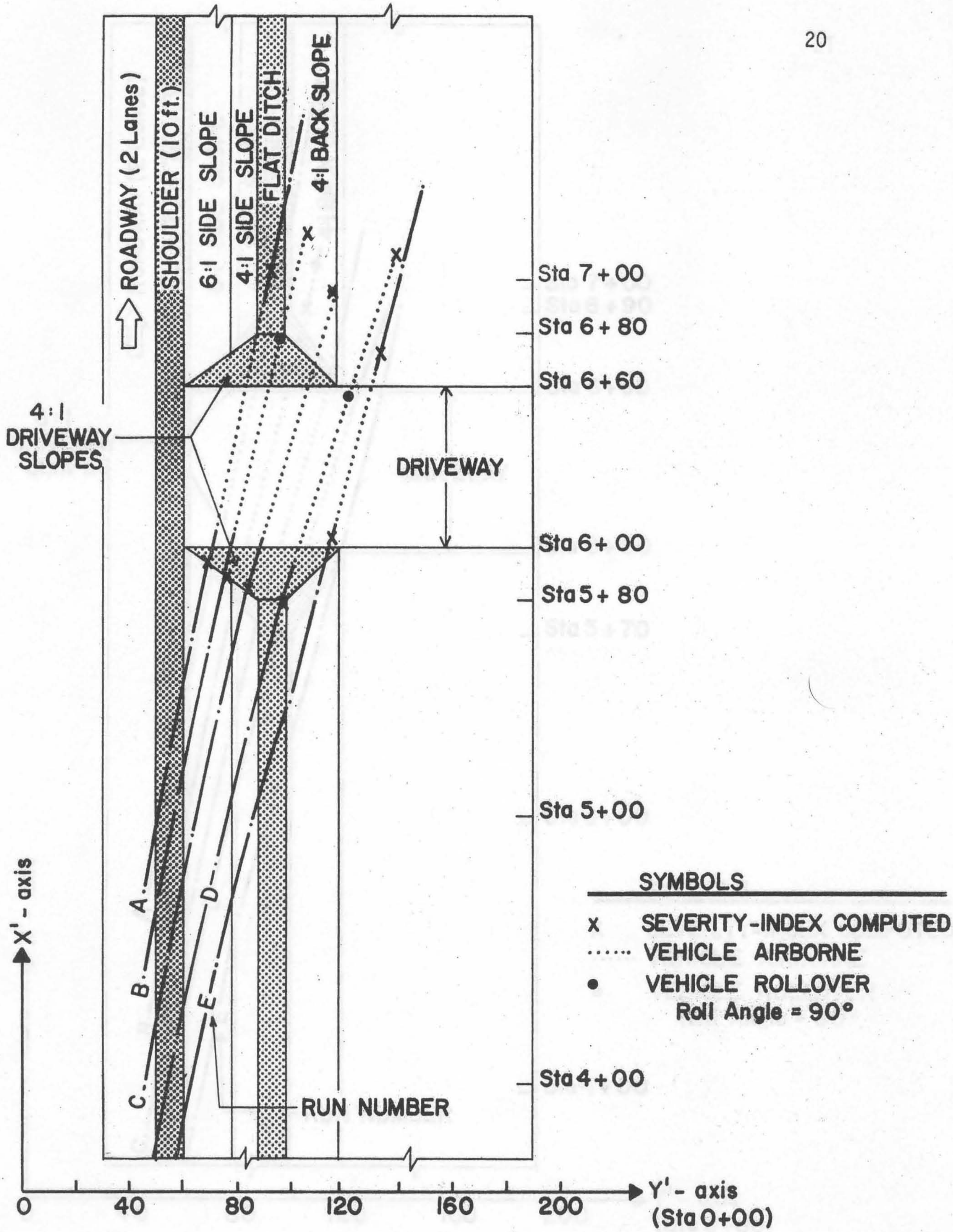

FIGURE 6 : DRIVEWAY 4:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

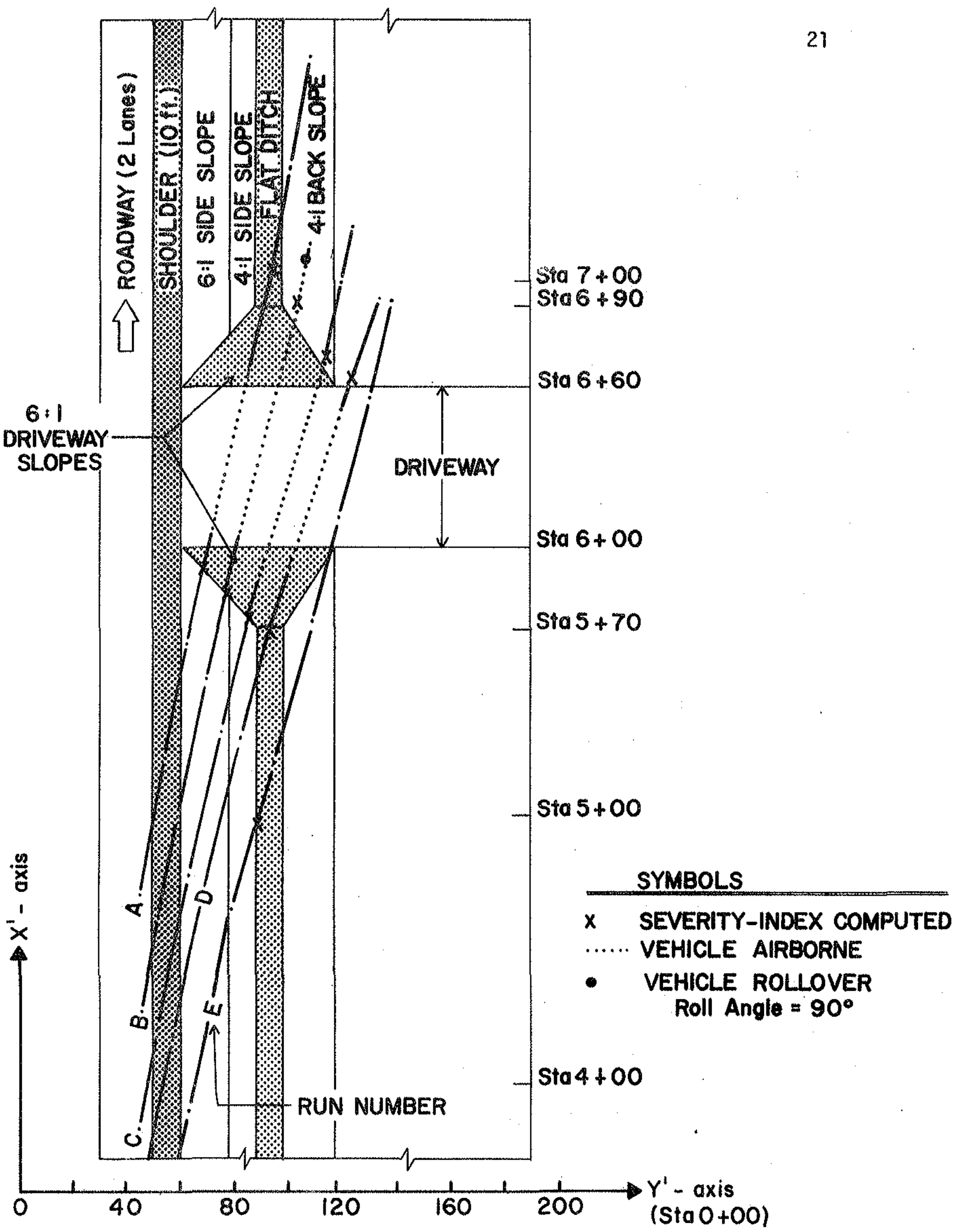

FIGURE 7 : DRIVEWAY 6:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

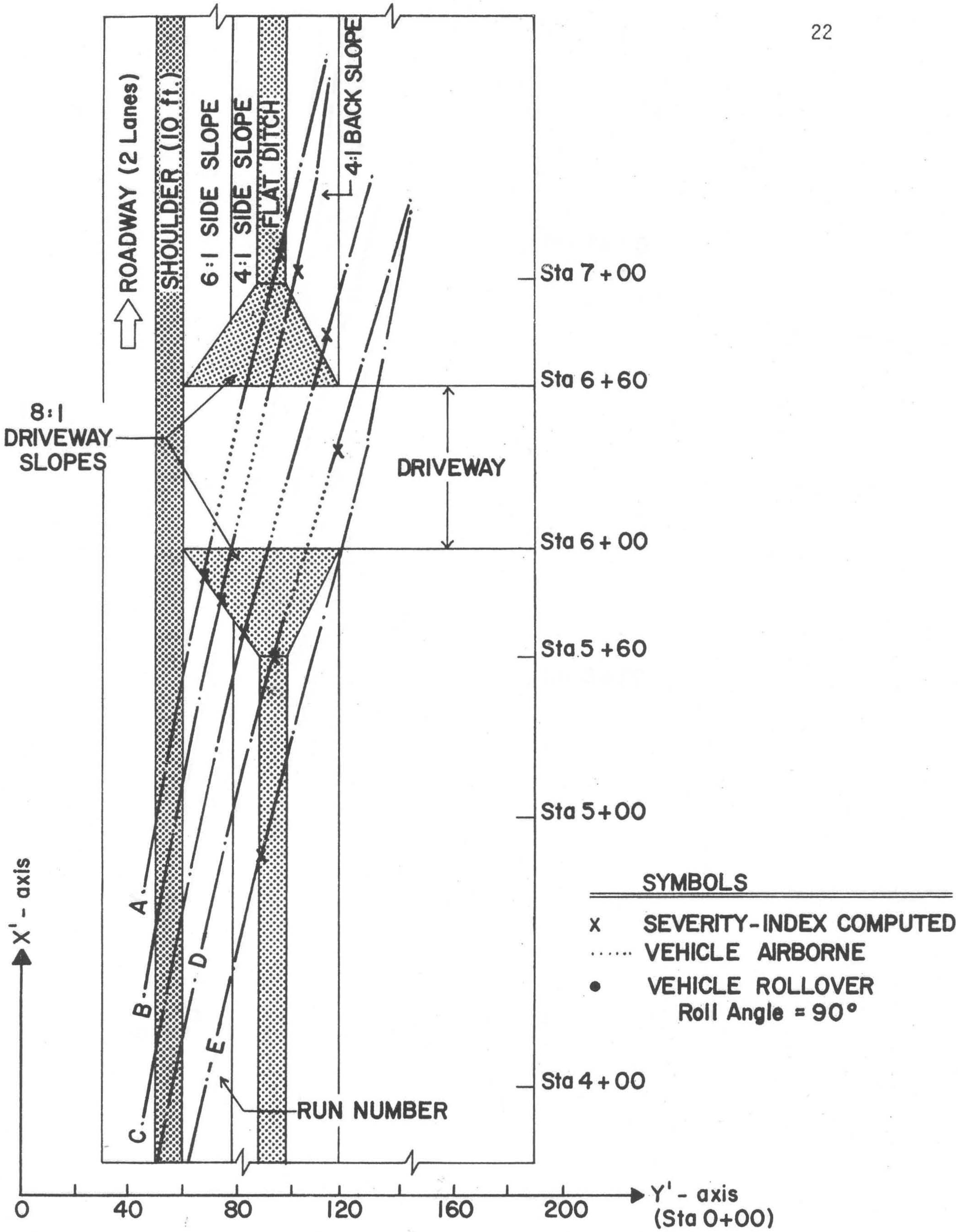

FIGURE 8 : DRIVEWAY 8:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

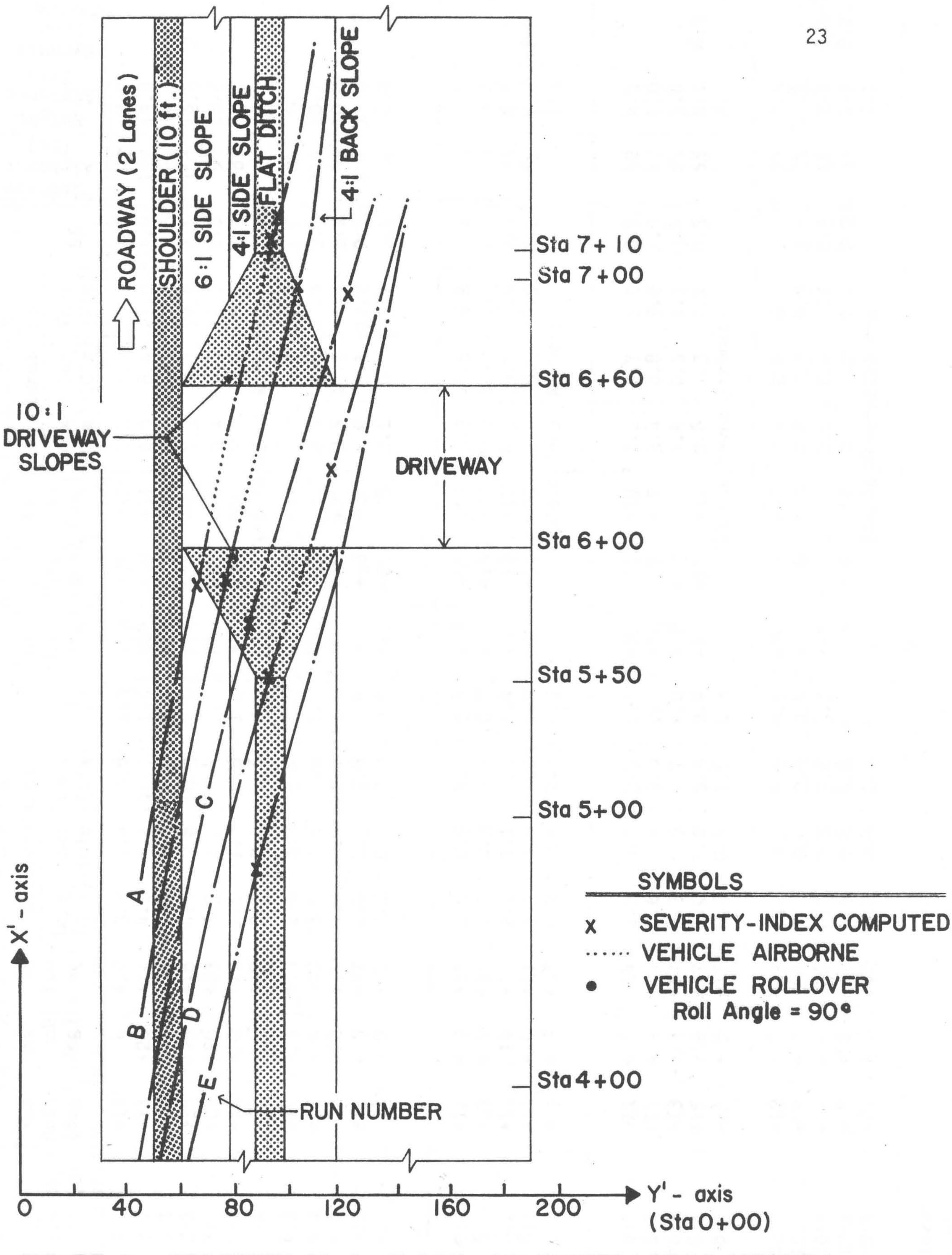

FIGURE 9 : DRIVEWAY 10:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

TABLE 3. RESULTS OF DRIVEWAY SLOPE SIMULATIONS UNDER ENCROACHMENT CONDITIONS OF 55 MPH AND 10 DEG

Run No.	Driveway Slope	BEFORE AIRBORNE							AFTER AIRBORNE							Distance Airborne (ft)	Height Airborne (ft)	Dynamic Load Factor
		Max Roll (deg)	Max Pitch (deg)	Max Yaw (deg)	Accelerations			SI	Max Roll (deg)	Max Pitch (deg)	Max Yaw (deg)	Accelerations			SI			
					Long (G's)	Lat (G's)	Vert (G's)					Long (G's)	Lat (G's)	Vert (G's)				
A	3:1	+12	- 4	+12	3.2	1.4	8.6	1.5	+47	+31	+12	1.1	2.2	9.2	1.6	97	8.7	
B	3:1	+13	+28	+14	4.2	1.1	10.7	1.9	RO[a]	+59	+51	2.8	8.4	21.0	3.9	122	13.8	
C	3:1	+14	- 4	+16	8.2	1.6	17.0	3.1	RO	+77	+78	11.1	3.5	3.1	1.8	84	15.6	
D	3:1	+35	+25	+18	4.3	2.8	10.3	1.9	RO	+25	+39	1.3	3.7	13.5	2.4	102	12.8	12.2
E	3:1	+21	+26	+23	3.9	1.2	6.4	1.2	RO	+43	+64	6.1	6.3	11.9	2.5	98	12.3	
F	3:1	-18	+12	+19	1.9	1.7	5.6	1.0	+37	-21	SO[b]	4.5	3.7	5.5	1.3	85	9.9	
G	3:1	-21	+ 6	+17	0.2	0.4	1.6	0.3			Vehicle	Never	Airborne			0	2.1	
A	4:1	+14	+13	+13	2.4	1.3	6.4	1.2	-51	+18	+13	1.7	4.5	8.1	1.6	84	7.4	
B	4:1	+13	- 4	+13	3.0	0.6	7.9	1.4	RO	+37	+32	2.5	0.8	21.6	3.6	115	10.7	
C	4:1	+13	+22	+19	4.3	0.9	10.7	1.9	RO	+42	+23	2.5	14.7	4.8	3.1	95	10.0	
D	4:1	+15	- 5	+17	2.6	1.5	7.8	1.4	RO	+38	+28	1.9	3.1	12.2	2.1	121	13.0	8.3
E	4:1	-21	+ 9	+17	0.0	0.6	3.3	0.6	+16	-25	+18	3.1	0.0	3.3	0.7	59	6.0	
A	6:1	+12	+ 9	+13	1.6	0.9	4.4	0.8	+38	-12	+13	0.3	1.5	6.2	1.1	61	5.4	
B	6:1	+13	+14	+16	1.1	0.3	4.3	0.7	RO	+14	+20	6.8	11.1	1.5	2.4	88	6.7	
C	6:1	+13	+14	+17	2.6	1.1	8.1	1.4	+42	+18	+17	4.7	9.8	6.9	2.4	85	6.5	
D	6:1	+15	+14	+17	1.9	1.2	7.1	1.2	-17	+14	+23	0.6	0.3	6.9	1.2	65	5.6	8.3
E	6:1	+15	+ 5	+17	0.2	0.4	1.8	0.3			Vehicle	Never	Airborne				2.1	
A	8:1	+11	+ 8	+14	1.3	0.7	3.3	0.6	+21	- 9	+19	1.2	0.7	3.0	0.5	42	4.3	
B	8:1	+13	+ 9	+14	0.6	0.4	3.0	0.5	+52	-17	+95	3.4	0.8	5.0	1.0	47	5.0	
C	8:1	+13	+13	+17	1.3	0.5	4.7	0.8	+26	+ 7	+17	1.4	0.5	2.3	0.4	21	3.8	
D	8:1	+15	+12	+17	1.0	1.0	5.3	0.9	-27	+11	+19	0.8	1.3	2.1	0.5	55	4.1	6.3
E	8:1	-21	+ 5	+17	0.2	0.4	1.8	0.3			Vehicle	Never	Airborne				2.1	
A	10:1	+12	+ 6	+13	1.2	0.9	4.5	0.8	-26	- 8	+17	0.4	0.8	6.4	1.1	33	3.5	
B	10:1	+13	+ 7	+14	0	0.4	2.5	0.4	-44	+ 8	+20	2.8	3.3	4.9	1.1	33	3.9	
C	10:1	+13	+ 6	+16	0.1	0.8	3.8	0.7	+17	+ 4	+17	0.0	0.2	1.7	0.3	18	2.1	6.0
D	10:1	+15	+11	+17	0.5	0.8	4.6	0.8	- 5	+ 9	+17	0	0.2	1.4	0.2	36	2.1	5.2
E	10:1	-21	+ 6	+17	0.2	0.4	1.6	0.3			Vehicle	Never	Airborne				2.1	

[a] Rollover

[b] Spinout

the automobile becomes airborne provides some insight into the lateral distances that the ditch side slopes tend to pull the automobile off of its encroachment path of 10 deg. For example, a path deviation of about 7 deg occurred for a traversal (path D) in the area of the flat ditch and driveway front slope--that is, the automobile was pulled from its encroachment path about 8 to 10 ft toward the ditch under a "free-wheeling" condition. This observation suggests that obstacles located beyond the hinge point of side slopes of say 4:1 and steeper and and outside the clear recovery area of 30 ft should receive careful attention in safety improvement programs. The cost-effectiveness program of Texas (15) treats this situation in a unique manner; whereby, obstacles located beyond the hinge point of side slopes of 3.5:1 and steeper are considered to be fictitiously located at the hinge point when computing the probability of the obstacle being struck. However, no special consideration was given to this matter in the cost-effectiveness evaluation in this study.

Other than being reflected in the severity-index, no attempt was made to evaluate the significance of the automobile being airborne on the driver's behavior. Research on this subject is, to the writer's knowledge, non-existent. A few of many questions that may be worthy of further research are:

1. At what distance and height airborne would most drivers over-react by rapidly turning the front wheels in the direction of the roadway? This action could precipitate, upon terrain contact, complete loss of vehicle control; or rollover; or a spinout resulting in high centrifugal forces and possible ejection of unrestrained occupants.
2. At what distance and height airborne could most drivers maintain their composure, and upon re-contacting the terrain, safely guide

the automobile back onto the roadway or slowly brake to a safe stop.

The distances airborne in traversing driveway slopes of 3:1 and flatter, as a function of the lateral offsets from the roadway when the automobile became airborne are shown in Figure 10a. Also, a bar graph showing the weighted or mean distance airborne for a particular slope improvement is shown in Figure 10b. The weighted distance airborne, H_i, can be computed as follows:

$$H_i = \frac{\sum(h_j P_j)}{\sum P_j} = \sum_{j=A}^{E} (h_j P_j)$$

where:

h_j = distance airborne along encroachment path j

P_j = probability of automobile being on path j (discussed in subsequent section)

Referring to Figure 10b, one can reach the following conclusions in regard to distances airborne during the traversal of a driveway slope.

1. No reduction in distance airborne would occur in flattening a driveway slope from 3:1 to 4:1.
2. No significant reduction in distance airborne would occur by flattening a driveway slope the additional amount from 8:1 to 10:1.
3. The greatest reduction in distance airborne would occur in flattening a driveway slope from 3:1 to 8:1.

The last item in Table 3 that is in need of discussion involves the dynamic vertical load factor. The factor is defined as the ratio of the maximum dynamic tire load to the weight of the automobile. In the design of bar grates on culverts, it is important that the grate have sufficient

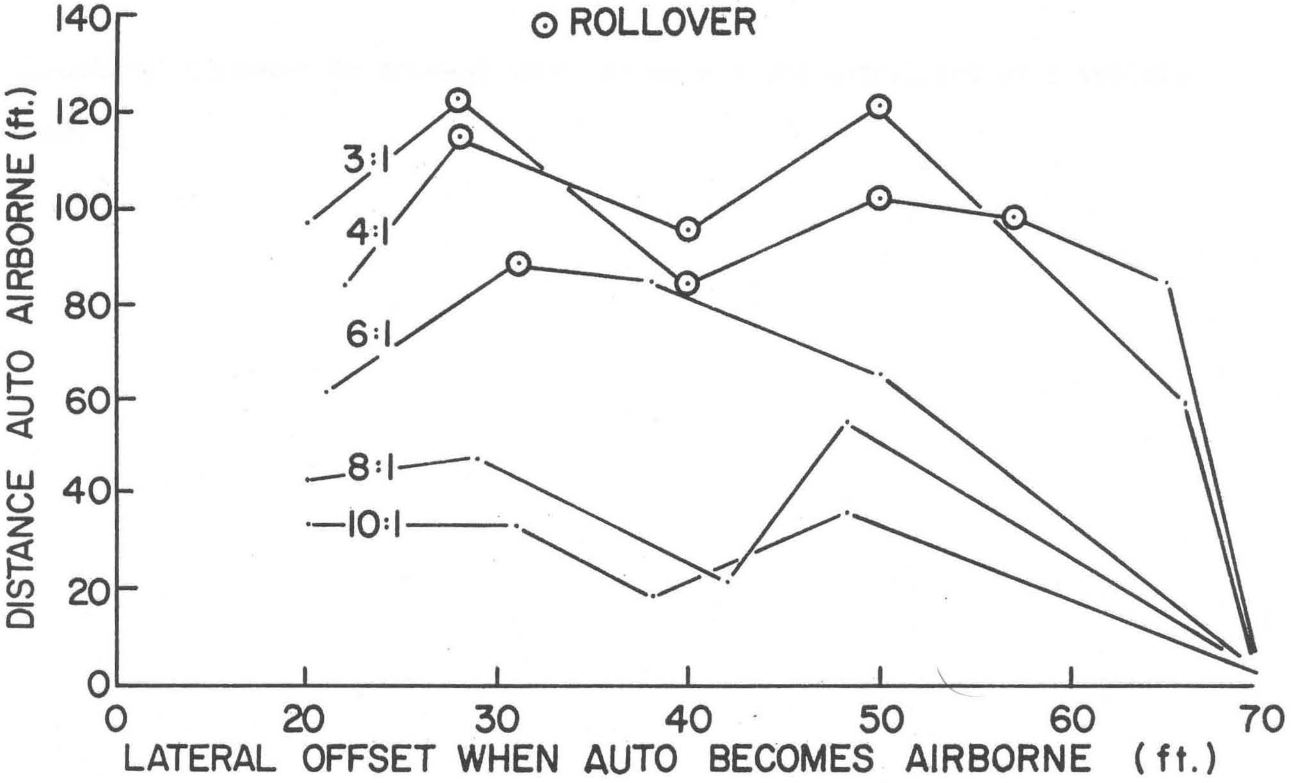

FIGURE 10a : AIRBORNE DISTANCE VERSUS LATERAL OFFSET FROM ROADWAY WHEN AUTO BECOMES AIRBORNE

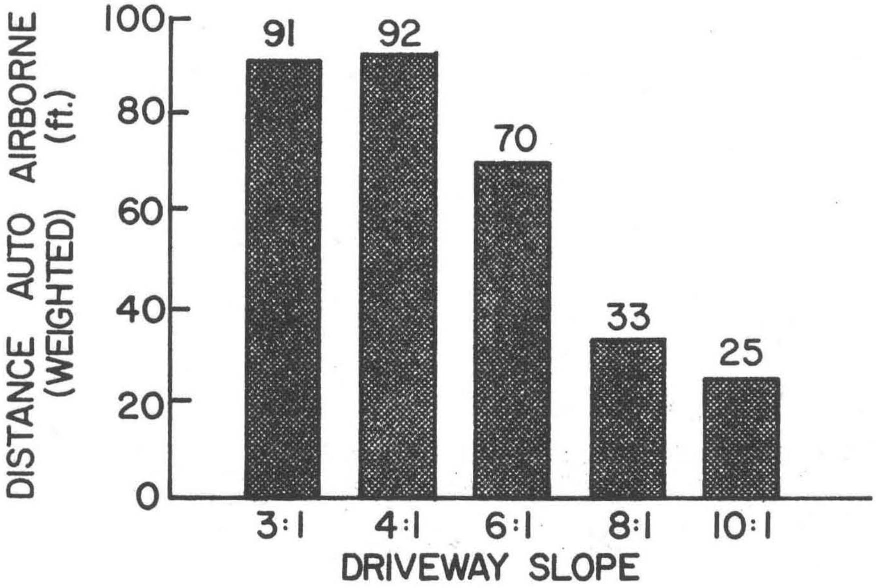

FIGURE 10b : DISTANCE AUTO AIRBORNE (WEIGHTED) VERSUS DRIVEWAY SLOPE structural strength to prevent penetration and the entrapment of a vehicle wheel.

COST-EFFECTIVENESS ANALYSIS

The cost-effectiveness analysis conducted in this study was based on the cost-effectiveness priority approach formulated by Glennon (14), and implemented in Texas for managing roadside safety improvement programs on both non-controlled access roadways and freeways (15). The cost-effectiveness measure used in this approach was:

Cost-Effectiveness = annualized cost of improvement alternative per unit hazard reduction achieved;

= cost to eliminate one injury (fatal or non-fatal) accident.

The measure of effectiveness was defined as the difference between the hazard indices before and after an improvement expressed in terms of number of fatal and non-fatal accidents per year. Thus, in order to apply the cost-effectiveness priority approach in this analysis it was necessary to compute the hazard index for each driveway-slope alternative and its annual cost.

Hazard Index

The hazard index was computed for each driveway-slope alternative using the following equation:

$$H_i = E_f\,[P(C/E)]\,[P(I/C)_i] \qquad \text{----Eq 4}$$

where:

H_i = hazard index for driveway slope i; expected number of injury (fatal or non-fatal) accidents per year (i = 3:1, 4:1, 6:1, 8:1, 10:1)

E_f = encroachment frequency; number of encroachments per mile per year

$P(C/E)$ = probability that a driveway slope will be traversed given that an encroachment has occurred

$P(I/C)_i$ = probability of an injury (fatal or non-fatal) accident given that a driveway slope i has been traversed.

A brief discussion of how each of the independent variables in this equation were computed follows.

Encroachment Frequency

Knowledge of the frequency with which vehicles encroach on the roadside of non-controlled access facilities is extremely limited. In fact, no comprehensive studies of encroachment frequency on these types of roadways have been reported. Therefore, the encroachment frequency used by Glennon (14) was assumed to be applicable for the purposes of this analysis. The relationship between encroachment frequency and average daily traffic is shown in Figure 11a.

Probability of Traversing Driveway

The probability that a driveway slope will be traversed given that an encroachment has occurred is proportional to the longitudinal length of the roadway within which the path of an encroaching vehicle would intersect a driveway slope. For the conditions simulated in this study (encroachment angle of 10 degrees), it was determined that this length was about 200 ft per driveway. Due to the lack of data on the effects of roadway conditions such as geometrics and speed and on the frequency and nature of encroachments, it was assumed that the longitudinal distribution of encroachments was uniform. Therefore, the probability of traversing a driveway slope

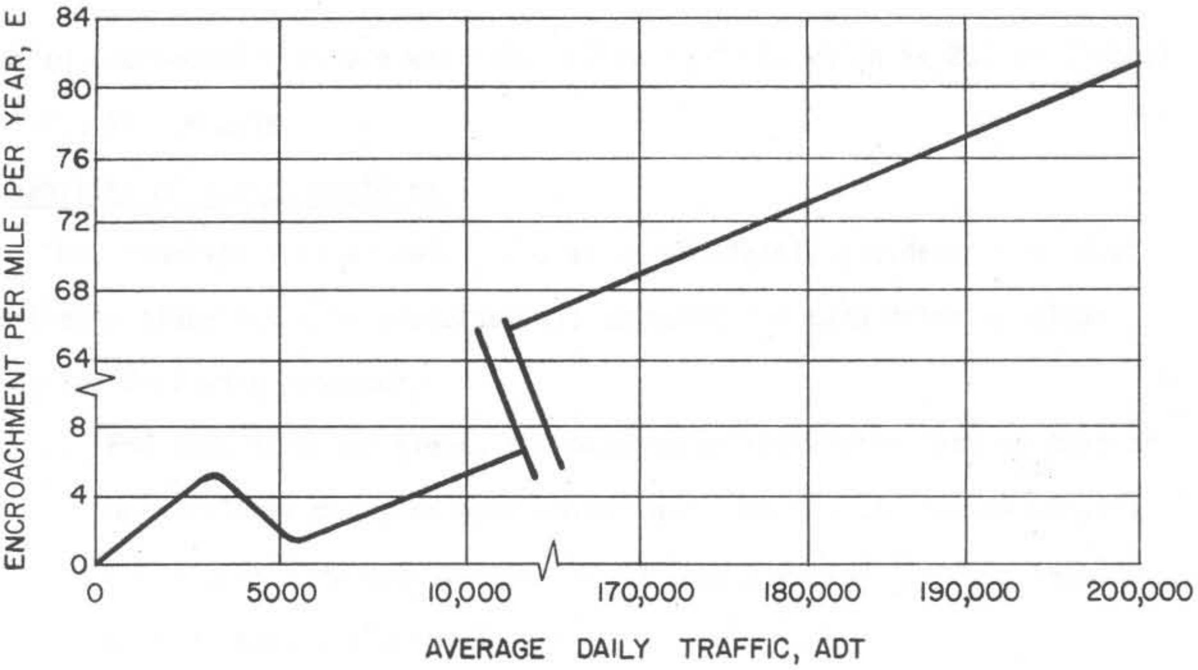

FIGURE 11 a: ROADSIDE ENCROACHMENT FREQUENCY. SOURCE : HUTCHINSON AND KENNEDY (16)

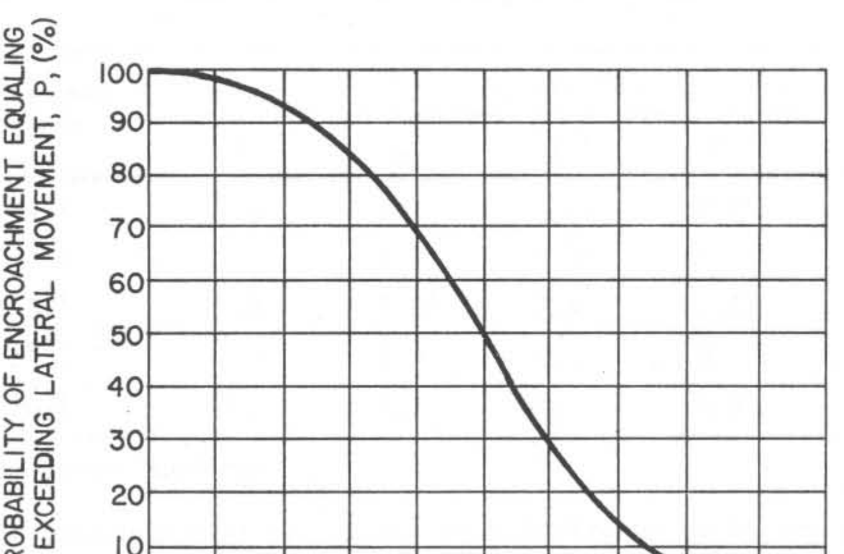

FIGURE 11 b: DISTRIBUTION OF LATERAL DISPLACEMENTS OF ENCROACHING VEHICLES. SOURCE : HUTCHINSON AND KENNEDY (16) when an encroachment occurs was computed to be 0.04, which is 200 ft divided by 5,280 ft per mile.

Probability of Injury Accident

The probability of an injury (fatal or non-fatal) accident given that a driveway slope has been traversed was computed for each driveway slope using the following procedure:

1. For each driveway slope, the maximum severity-index and whether or not rollover occurred were determined from the simulation results on each of five encroachment paths (A,B,C,D, and E). The results of this step are shown in Table 4.

TABLE 4

SUMMARY OF MAXIMUM SEVERITY-INDICIES AND

ROLLOVERS ALONG ENCROACHMENT PATHS

Driveway Slope	Encroachment Path				
	A	B	C	D	E
3:1	1.6	3.9*	3.1*	2.4*	2.5*
4:1	1.6	3.6*	3.1*	2.1*	0.7
6:1	1.1	2.4*	2.4	1.2	0.3
8:1	0.6	1.0	0.8	0.9	0.3
10:1	0.7	1.1	0.7	0.8	0.3

* Rollover Occurred

2. For each driveway slope, the probability of an injury (fatal or non-fatal) accident was determined for each encroachment path as follows:

   (a) If rollover occurred, a probability of one was assigned.

   (b) If rollover did not occur, a probability was assigned on the basis of the maximum severity-index experienced on the encroachment path using the relationship presented in Table 2. The derivation of this relationship was explained in a previous section of this report.

The results of this step are shown in Table 5.

TABLE 2

RELATIONSHIP BETWEEN SEVERITY-INDEX AND PROBABILITY OF INJURY ACCIDENT

Severity-Index (SI)	Probability of Injury Accident
$SI \leq 0.5$	0.1
$0.5 < SI \leq 1.0$	0.3
$1.0 < SI \leq 1.5$	0.5
$1.5 < SI \leq 2.0$	0.7
$2.0 < SI \leq 2.5$	0.8
$2.5 < SI$	1.0

TABLE 5

SUMMARY OF PROBABILITIES OF INJURY ACCIDENT ON ENCROACHMENT PATHS

Driveway Slope	Encroachment Path				
	A	B	C	D	E
3:1	0.7	1.0	1.0	1.0	1.0
4:1	0.7	1.0	1.0	1.0	0.3
6:1	0.5	1.0	0.8	0.5	0.1
8:1	0.3	0.3	0.3	0.3	0.1
10:1	0.3	0.5	0.3	0.3	0.1

3. For each of the five encroachment paths, the probability that it would be the path of an encroaching vehicle was derived from the the distribution of lateral displacements of encroaching vehicles

shown in Figure 10b, which was generated by Glennon (14). These encroachment path probabilities were determined as follows:

(a) For each encroachment path, the lateral distances between the edge of the traveled way and the point at which the path intersects each driveway slope were calculated, and the range of these values were determined.

(b) The probabilities of the lateral displacements of vehicle encroachments being within each of these ranges were computed using Figure 11b.

The results of this step are presented in Table 6.

TABLE 6

SUMMARY OF ENCROACHMENT PATH PROBABILITIES

Encroachment Path	Lateral Displacement Range (ft.)	Encroachment Path Probability
Shoulder	0-10	0.07
A	10-20	0.24
B	20-25	0.20
C	25-35	0.35
D	35-45	0.12
E	>45	0.02

The expected probability of an injury accident for each driveway slope was calculated by using the following equation:

$$P(I/C)_i = \sum_{j=A}^{E} P(j)\ [P(I/j)] \qquad \text{----Eq 5}$$

where:

$P(I/C)_i$ = probability of an injury (fatal or non-fatal) accident given that driveway slope i has been traversed

P(j) = probability that encroaching vehicle will follow encroachment path j (j = A,B,C,D,E)

P(I/j) = probability of an injury (fatal or non-fatal) accident given that the encroaching vehicle follows path j

The results of this step are presented in Table 7.

TABLE 7

PROBABILITIES OF INJURY ACCIDENTS ON DRIVEWAY SLOPES

Driveway Slope	Probability of Injury Accident
3:1	0.9
4:1	0.8
6:1	0.7
8:1	0.3
10:1	0.3

Costs

The construction costs of the driveways studied were estimated using 1977 average unit price data obtained from the Nebraska Department of Roads. In each case, three cost estimates were made to reflect the effects of different drainage requirements. These cost estimates are shown in Table 8.

TABLE 8

DRIVEWAY CONSTRUCTION COSTS

Driveway Slope	With No Underdrainage	With One 24-in. Dia. Underdrain	With Two 24-in. Dia. Underdrains
3:1	$320	$1,890	$3,460
4:1	340	2,060	3,790
6:1	380	2,400	4,420
8:1	420	2,730	5,040
10:1	460	3,070	5,670

Evaluation

The cost and hazard index data presented in the preceding sections were used to determine the cost effectiveness of improving driveway slopes as part of a roadside safety improvement program. The cost of improving driveway slopes was assumed to be equal to the difference in the cost of constructing a driveway with the existing slope and the cost of constructing a driveway with the improved slope. This cost was then annualized using an 8 percent interest rate, 20-year service life, and zero salvage value. The hazard indices for before and after an improvement were computed using Equation 4 and the probabilities of an injury accident given in Table 7 for the before and after driveway slope, respectively. An ADT of 3,000 was assumed, which corresponds to an encroachment frequency of 6 per mile per year (refer to Figure 11a). The results of this cost-effectiveness analysis are presented in Tables 9, 10, and 11.

On these basis of these results, the following conclusions were made relative to the cost-effectiveness of driveway slope improvement alternatives:

TABLE 9

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH NO UNDERDRAINAGE INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

IMPROVING TO:	IMPROVING FROM:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$ 2	.03	$ 70	-	-	-	-	-	-	-	-	-
6:1	6	.05	120	$ 4	.02	$200	-	-	-	-	-	-
8:1	10	.15	70	8	.12	70	$4	.10	$40	-	-	-
10:1	14	.15	90	12	.12	100	8	.10	80	$4	0	Infinite

C = Annualized cost of improvement using 8-percent interest rate, 20-year service life, and zero salvage value;

E = Difference between the hazard indices before and after improvement;

C/E = Cost to eliminate one injury (fatal or non-fatal) accident.

TABLE 10

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH ONE 24-in. DIA. UNDERDRAIN INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

IMPROVING TO:	IMPROVING FROM:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$ 17	.03	$570	-	-	-	-	-	-	-	-	-
6:1	51	.05	1020	$34	.02	$1700	-	-	-	-	-	-
8:1	84	.15	560	67	.12	560	$33	.10	$330	-	-	-
10:1	118	.15	790	101	.12	840	67	.10	670	$34	0	Infinite

C = Annualized cost of improvement using 8-percent interest rate, 20-year service life, and zero salvage value;

E = Difference between the hazard indices before and after improvement;

C/E = Cost to eliminate one injury (fatal or non-fatal) accident.

TABLE 11

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH TWO 24-in. DIA. UNDERDRAINS INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

IMPROVING TO:	IMPROVING FROM:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$ 33	.03	$1100	-	-	-	-	-	-	-	-	-
6:1	96	.05	1920	$ 63	.02	$3150	-	-	-	-	-	-
8:1	158	.15	1050	125	.12	1040	$ 62	.10	$ 620	-	-	-
10:1	221	.15	1470	188	.12	1570	125	.10	1250	$63	0	Infinite

C = Annualized cost of improvement using 8-percent, 20-year service life; and zero salvage value;

E = Difference between the hazard indices before and after improvement;

C/E = Cost to eliminate one injury (fatal or non-fatal) accident.

1. In every case, improving to an 8:1 driveway slope was the most cost-effective alternative.
2. The most cost-effective improvement was improving a 6:1 driveway slope to an 8:1 driveway slope.
3. Improving an 8:1 driveway slope to a 10:1 driveway slope was not cost-effective.
4. The more underdrainage involved, the less cost-effective were driveway slope improvements.
5. According to the cost-effectiveness priority scale suggested by Glennon (14) and presented in Table 12, 8:1 driveway slope improvements have the following priority classes:
    - (a) No underdrainage: Priority Class 3 to 4.
    - (b) Underdrainage: Priority Class 6 to 7.

Of course, on roadways with higher ADT's and encroachment frequencies greater than 6 per mile per year, driveway slope improvements would be more cost-effective.

TABLE 12

EXAMPLE COST-EFFECTIVENESS RATIO PRIORITY SCALING FOR A ROADSIDE SAFETY IMPROVEMENT PROGRAM

PRIORITY CLASS	C/E RATIO ($/INJURY ACCIDENT REDUCED)
1	0
2	1-20
3	21-50
4	51-100
5	101-200
6	201-400
7	401-1,000

Also, it was determined, using a Poisson distribution as explained by Glennon (14), that the hazard reduction effectiveness of improving driveway slopes to 8:1 provided a probability that no reduction would result from the improvement of only 0.05 for improving from 3:1 and 0.14 for improving from 6:1. In other words, this improvement could be made with 85-to-95-percent confidence that it will result in a reduction in injury accidents.

SUMMARY AND CONCLUSIONS

Little attention has been given to the hazard of driveway fill slopes located along the roadsides of non-controlled and limited access rural highways. Therefore, the objectives and goals of this study were twofold. First, the degree-of-hazardousness of a typical driveway slope on a limited access roadway constructed to high design standards was investigated and ascertained. And second, the cost-effectiveness of improving the selected driveway slope configuration from a 3:1 to flatter slopes was investigated and ascertained.

Specific findings relevant to the computer simulations of a standard size automobile (3,800 lb) traversing driveway slopes in a free-wheeling steering mode under the run-off-the-road encroachment conditions of 55 mph and 10 deg are summarized in the work to follow.

Severity-Index and Injury Probability

The probability of injury during a driveway slope traversal must be determinable in order to conduct a cost-effectiveness analysis. The severity of an event was expressed in terms of a computed severity-index, which has been defined in previous research as the ratio of the resultant automobile accelerations averaged over a time duration of 50 msec <u>to</u> the resultant accelerations tolerable to an unrestrained occupant. The relationship shown below was established in this study for injury probabilities likely to occur for six borad categories of severity-index, except rollovers were assigned an injury probability of one.

Severity-Index (SI)	Probability of Injury Accident
$SI \leq 0.5$	0.1
$0.5 < SI \leq 1.0$	0.3
$1.0 < SI \leq 1.5$	0.5
$1.5 < SI \leq 2.0$	0.7
$2.0 < SI \leq 2.5$	0.8
$2.5 < SI$	1.0

Tolerable Accelerations: Long. = 7 g's
Lat. = 5 g's
Vert. = 6 g's

The rate of automobile rollovers decreased as the driveway slopes were flattened with none occurring on slopes flatter than 6:1.

Distance Automobile Airborne

Other than being reflected in the severity-index, no attempt was made to evaluate the significance of the automobile being airborne on the driver's behavior and what effect his responses might have on the control stability of the vehicle upon re-contacting the terrain. However, in a free-wheeling steer mode, one can reach the following conclusions:

1. In general, the severity-index was directly proportional to the distance the automobile was airborne.
2. No reduction in distance airborne would occur in flattening a driveway slope from 3:1 to 4:1.
3. No significant reduction in distance airborne would occur by flattening a driveway slope the additional amount from 8:1 to 10:1.
4. The greatest reduction in distance airborne would occur in flattening a driveway slope from 3:1 to 8:1.

As would be expected, these findings support the findings of the cost-effectiveness analysis.

Cost-Effectiveness Evaluation

Roadside safety improvement programs must compete with other ongoing highway programs for the limited funds available. The cost-effectiveness technique is a managerial tool which provides the highway administrator with a means of evaluating safety improvement alternatives on a common data base and a priority ranking scale to realize the greatest return on the investment made to reduce injury accidents.

The cost-effectiveness analysis conducted in this study was based on the cost-effectiveness priority approach formulated in NCHRP 148 and implemented in Texas for managing roadside safety improvement programs on both non-controlled access roadways and freeways.

The findings of the cost-effectiveness analysis of driveway slope improvement alternatives are summarized below.

1. In every case, improving to an 8:1 driveway slope was the most cost-effective alternative.
2. The most cost-effective improvement was improving a 6:1 driveway slope to an 8:1 driveway slope.
3. Improving an 8:1 driveway slope to a 10:1 driveway slope was not cost-effective.
4. The more underdrainage involved, the less cost-effective were driveway slope improvements.
5. According to the cost-effectiveness priority scale presented in NCHRP 148, 8:1 driveway slope improvements have the following priority classes:

(a) No underdrainage: Priority Class 3 to 4.

(b) Underdrainage: Priority Class 6 to 7.

Of course, on roadways with ADT's higher than 3,000 and encroachment frequencies greater than 6 per mile per year, driveway slope improvements would be more cost-effective.

Also, it was determined, using a Poisson distribution that the hazard reduction effectiveness of improving a driveway slope from 3:1 to 8:1 could be made with 95 percent confidence that it would result in a reduction in injury accidents.

Dynamic Load Factor

The dynamic load factor is defined as the ratio of the maximum dynamic vertical tire load to the curb weight of the aubomobile. In the design of bar grates on culverts, it is important that the grate have sufficient structural strength to prevent penetration and the entrapment of a vehicle wheel. The dynamic load factors obtained in this study for various driveway slopes are shown in the following Table.

Driveway Slope	Dynamic Load Factor
3:1	13
4:1	9
6:1	9
8:1	7
10:1	6

Auto Weight = 3,800 lb

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APPENDIX

A. VEHICLE PROPERTIES

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UNL-NDR DRIVEWAY STUDY IN RURAL-SUBURBAN AREA (LINCOLN, NEBRASKA)
SPEED=55 MPH, ENCROACHMENT ANGLE=10 DEG.    (RUN NO. 3E)



         PROGRAM CONTROL DATA

  START TIME               =   0.0    SEC
  END TIME                 =   7.000
  INCR FOR INTEGRATION =   0.0050 ''
  PRINT INTERVAL           =   0.010  ''
  THETA MAX (TO SWITCH)=  70.000 DEG
  UVWMIN(STOP)             =   0.0
  PQRMIN(STOP)             =   0.0
  INDCRB                   =  -1   (=0.NO CURB,=1 CURB,=-1 STEER DEG.OF FREEDOM)
  MODE OF INTEGRATION  =   1   (=0 VAR.ADAMS-MOULT.,=1 RUNGE-KUTTA,=2FIX.AM)
  DTCMP1                   =  0.   (=1.0 SUPPLY INITIAL POSITION)
                                   (=0.0 CAR RESTS ON TERRAIN)


                        ACCELEROMETER POSITIONS

                         X1    = -34.480  INCHES
                         Y1    =    0.0     ''
                         Z1    =    4.000   ''
                         X2    =  -5.983    ''
                         Y2    = -16.500    ''
                         Z2    =    3.138   ''


              DIMENSIONS

     A      = 54.5170  INCHES          KF      = 100.000 LB./IN.
     B      = 64.4830    ''            KR      = 105.000 LB./IN.
     TF     = 61.0000    ''            CF'     =  30.000 LBS.
     TR     = 60.0000    ''            CR'     =  45.000 LBS.
     ZF     = 10.1380    ''          EPSILONF=    0.001 IN./SEC.
     ZR     = 12.0880    ''          EPSILONR=    0.001 IN./SEC.
     RHO    = -2.0000    ''            CF      =   3.500 LB-SEC/IN
     RW     = 14.0000    ''            CR      =   3.900 LB-SEC/IN

                                     AKFC    = 300.000 LB/IN
                                     AKFCP =     2.000 LB/IN3
                                     OMEGFC=    -3.000 IN
                                     AKFE    = 300.000 LB/IN
                                     AKFEP =     2.000 LB/IN3
                                     OMEGFE=     5.000 IN


SUSPENSION DATA                                         INERTIAL DATA

  LAMBDAF =     0.500                          MS    =   8.4402 LB.-SEC.**2/IN
  LAMBDAR =     0.500                          MUF   =   0.5507         ''
  OMEGAF  =     3.000 INCHES                   MUR   =   0.8952         ''
  OMEGAR  =     4.000 INCHES
  TS      =    46.500 INCHES                   IX    =   6200.0 LB.-SEC.**2-IN
  PR      = 32500.0 LB-IN/RAD                  IY    = 34400.0            ''
  PF      = 98500.0 LB-IN/RAD                  IZ    = 36000.0            ''
  KRS     =     0.070 ROLL STEER COEFF.        IXZ   =-192.000            ''
                                               IR    =   600.00           ''
  AKRC    = 300.000 LB/IN                      G     = 386.400 IN/SEC.**2
  AKRCP   =     2.000 LB/IN3
  OMEGRC  =    -4.000 IN
  AKRE    = 300.000 LB/IN
  AKREP   =     2.000 LB/IN3
  OMEGRE  =     4.500 IN
```

```
                                         INITIAL CONDITIONS

PHI0    =    1.330 DEGREES    XCG'   =4272.000INCHES     P0         =   0.0     DEG/SEC
THETA0 =     0.668    "       YCG'   = 528.000   "       Q0         =   0.0       "
PSI0    =   10.000    "       ZCG'   = 227.074   "       R0         =   0.0       "
PHIR0   =    0.0      "       DELTA1=     0.0    "    D(PHIR)/DT=   0.0       "
PSIFI0=      0.0      "       DELTA2=     0.0    "    D(PSIF)/DT=   0.0     RAD/SC
                              DELTA3=     0.0    "

                          U0          = 968.000 IN/SEC
                          V0          =   0.0     "
                          W0          =   0.0     "
                       D(DEL1)/DT=       0.0      "
                       D(DEL2)/DT=       0.0      "
                       D(DEL3)/DT=       0.0      "



          TIRE DATA                       TERRAIN TABLE ARGUMENTS

    KT          1098.000 LB/IN
    SIGMAT   =     3.000
    LAMBDAT  =    10.000
    A0        =4400.000                  SOIL DAMPING= 0.001 SPI
    A1        =    8.276                 SOIL FRICT. = 0.250
    A2        =2900.000                  SSTIFF      =    4000. LB/IN
    A3        =    1.780                 NU.X TEMPS. =  8
    A4        =3900.000                  NU.Y TEMPS. = 11
    AMU       =    0.200                 NO. VAR  AMU = 21
    CMEGT     =    1.000                 TABLES

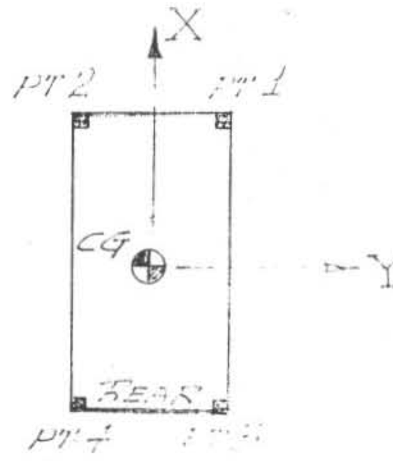

    COEFF. OF TIRE FRICTION
               VS.
    (SPEED AND  LOAD) DATA
    ALPHA=  0.0              1/(LB-MPH)
    XKVTH=  0.0              1/ MPH
      XKL=    0.0              1/LB



       VEHICLE MONITOR POINTS

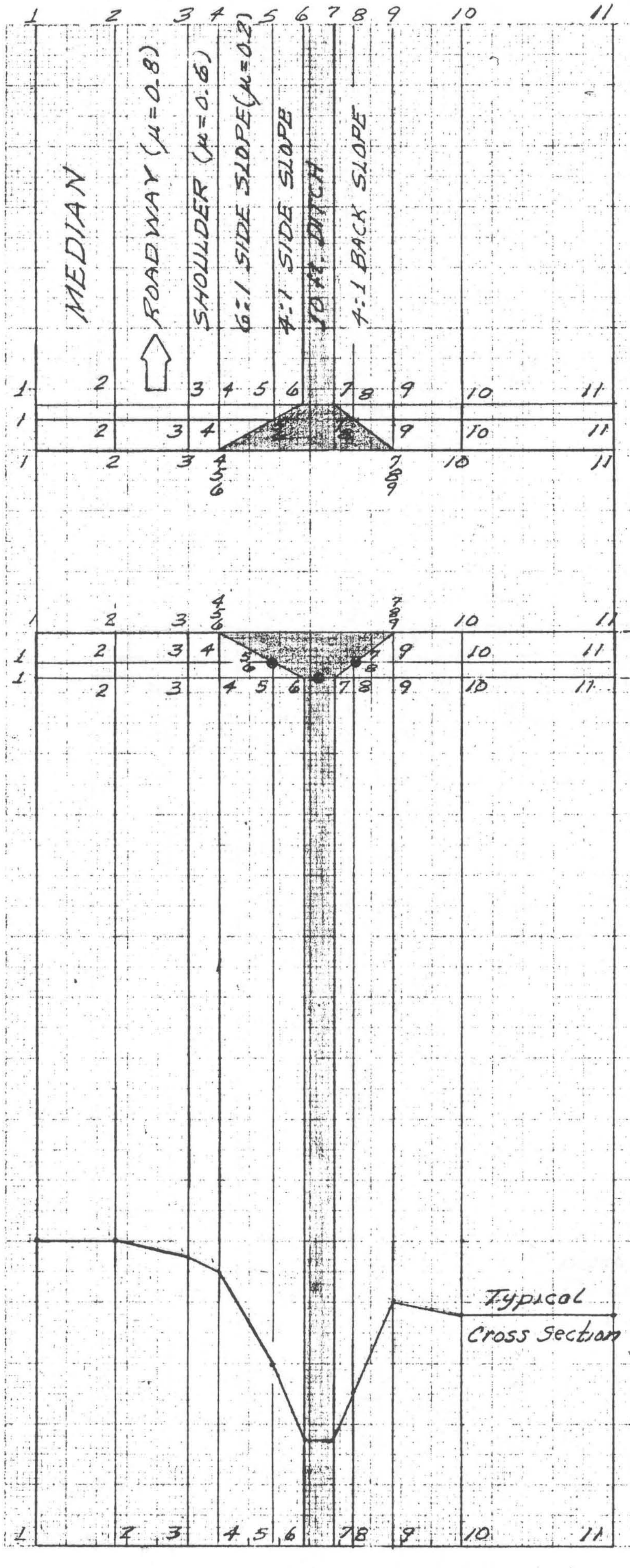
                   X          Y          Z
                 (IN.)      (IN.)      (IN.)

    POINT 1   81.517    39.500     12.138
    POINT 2   81.517   -39.500     12.138
    POINT 3-117.483    39.000      8.138
    POINT 4-117.483   -39.000      8.138
```



APPENDIX

B. TERRAIN DATA

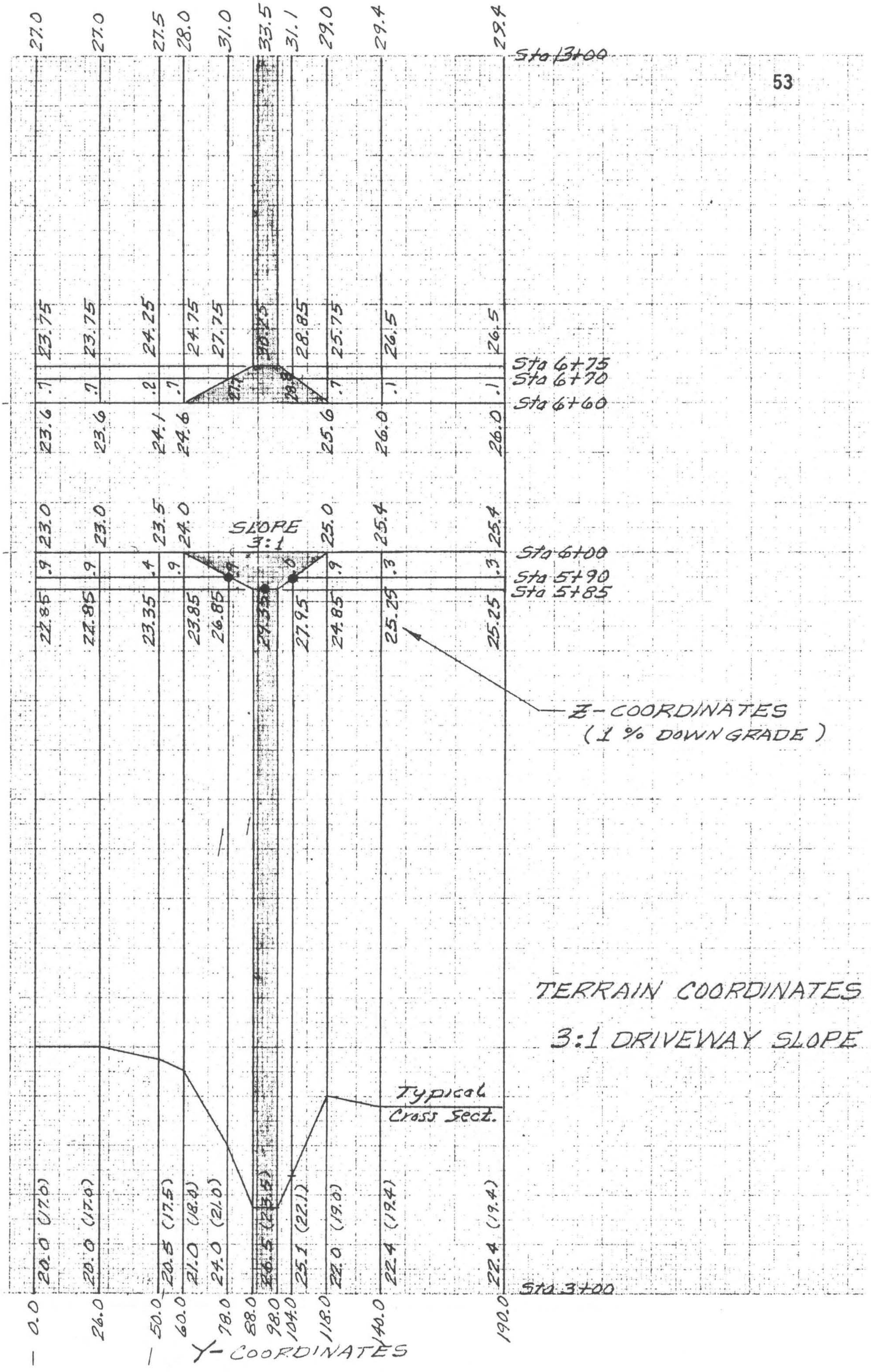


TERRAIN DATA POINTS

$I=8$

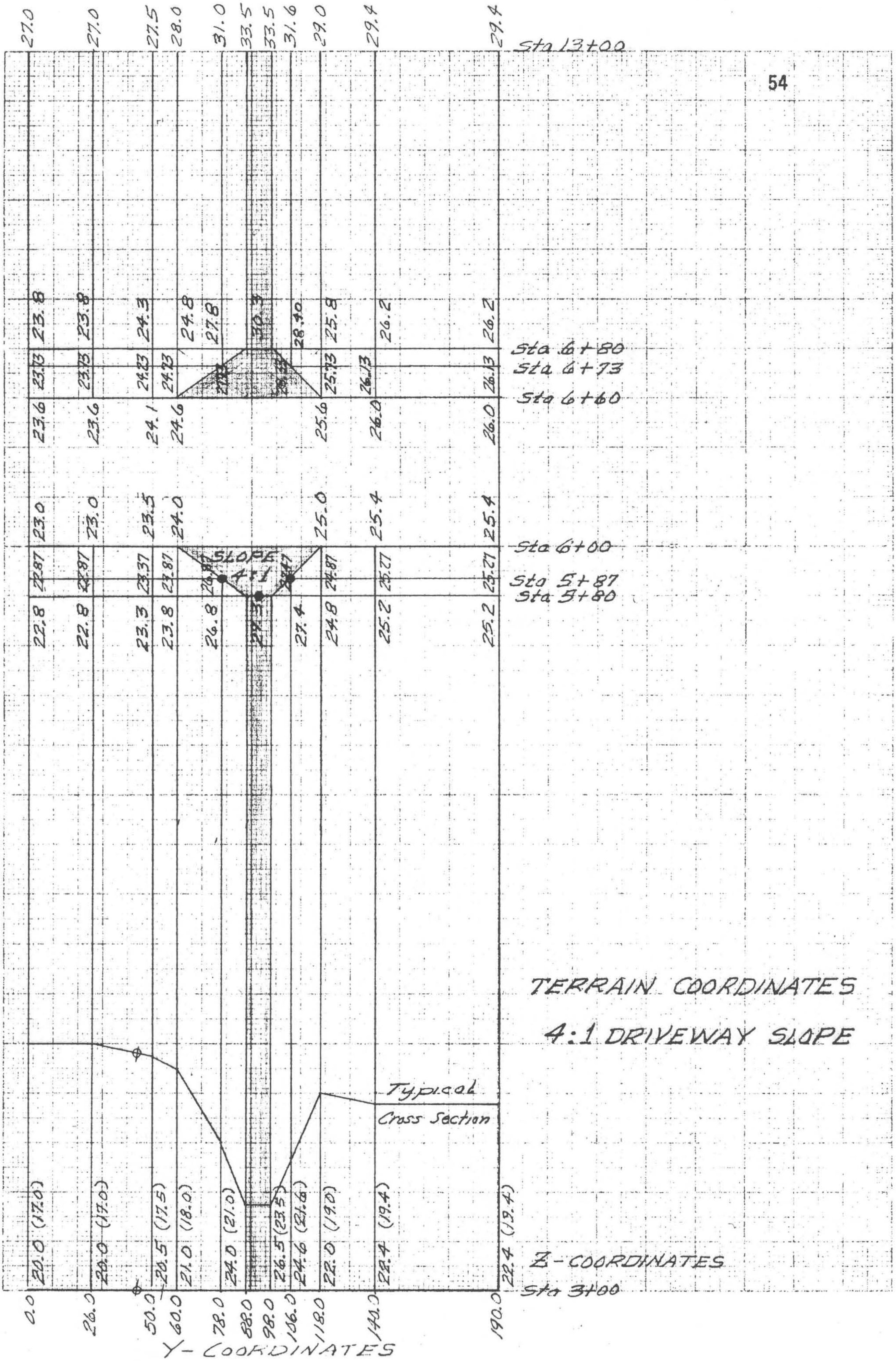
$J=11$

UNL-NDR DRIVEWAY
STUDY IN RURAL
SUBURBAN AREA
6/16/77



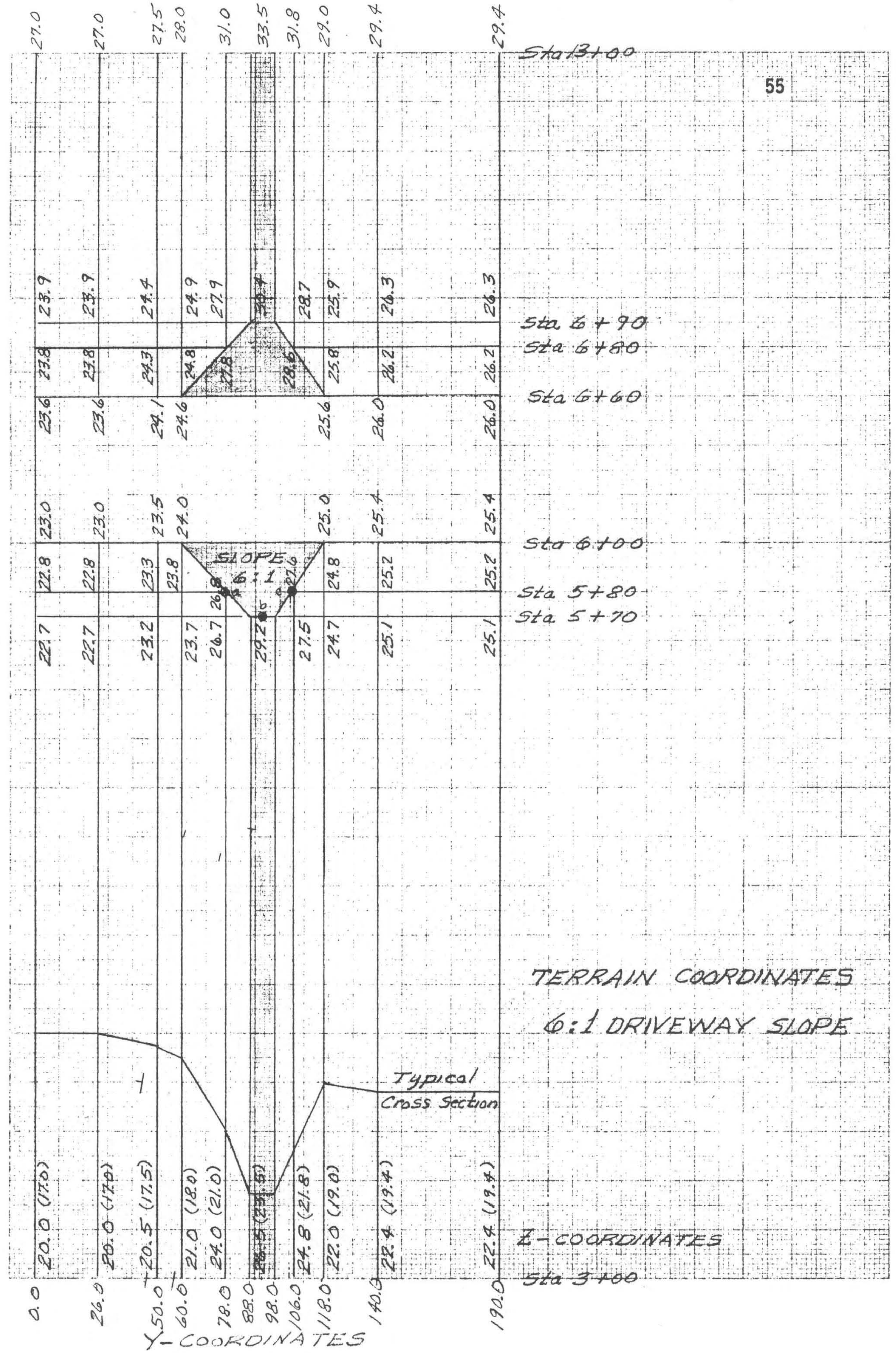
TERRAIN COORDINATES

3:1 DRIVEWAY SLOPE



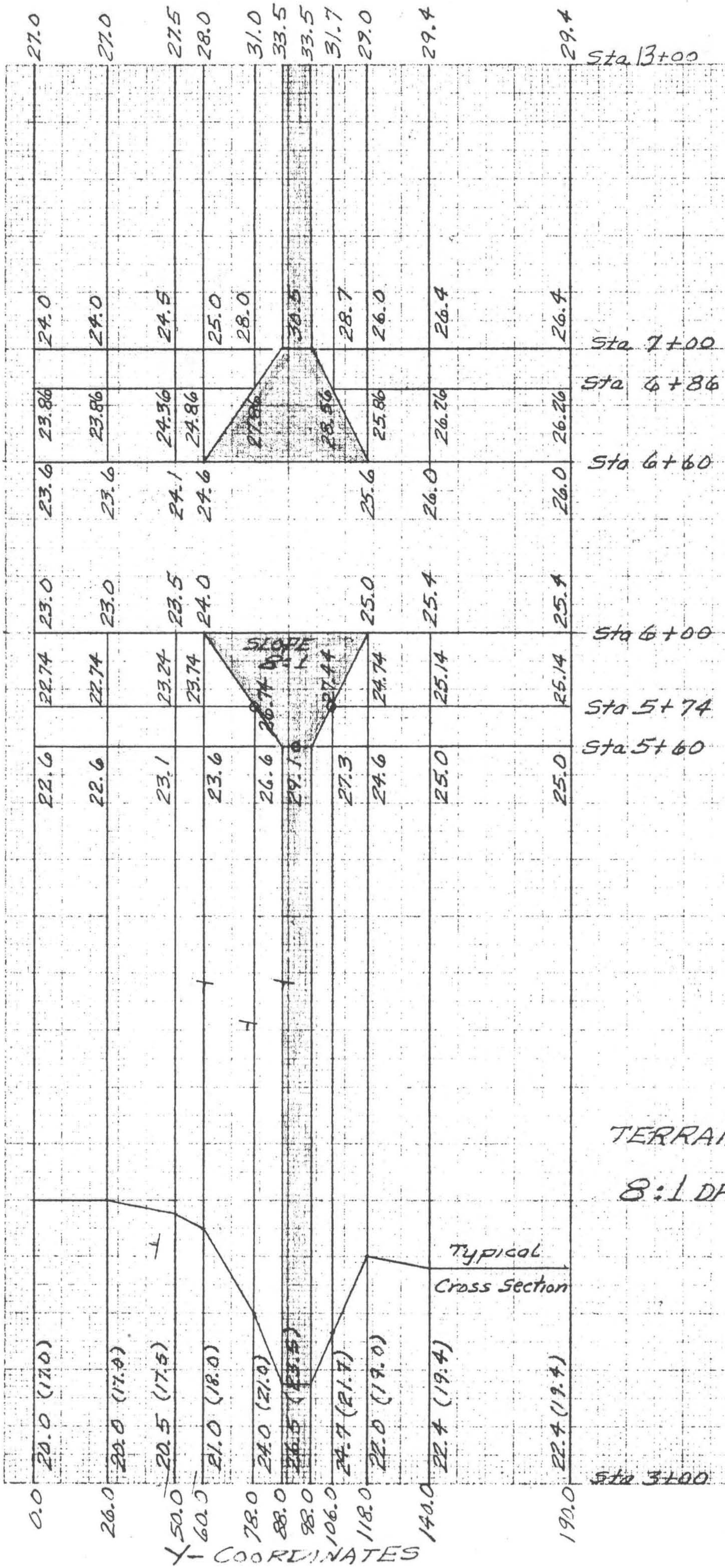
TERRAIN COORDINATES

4:1 DRIVEWAY SLOPE



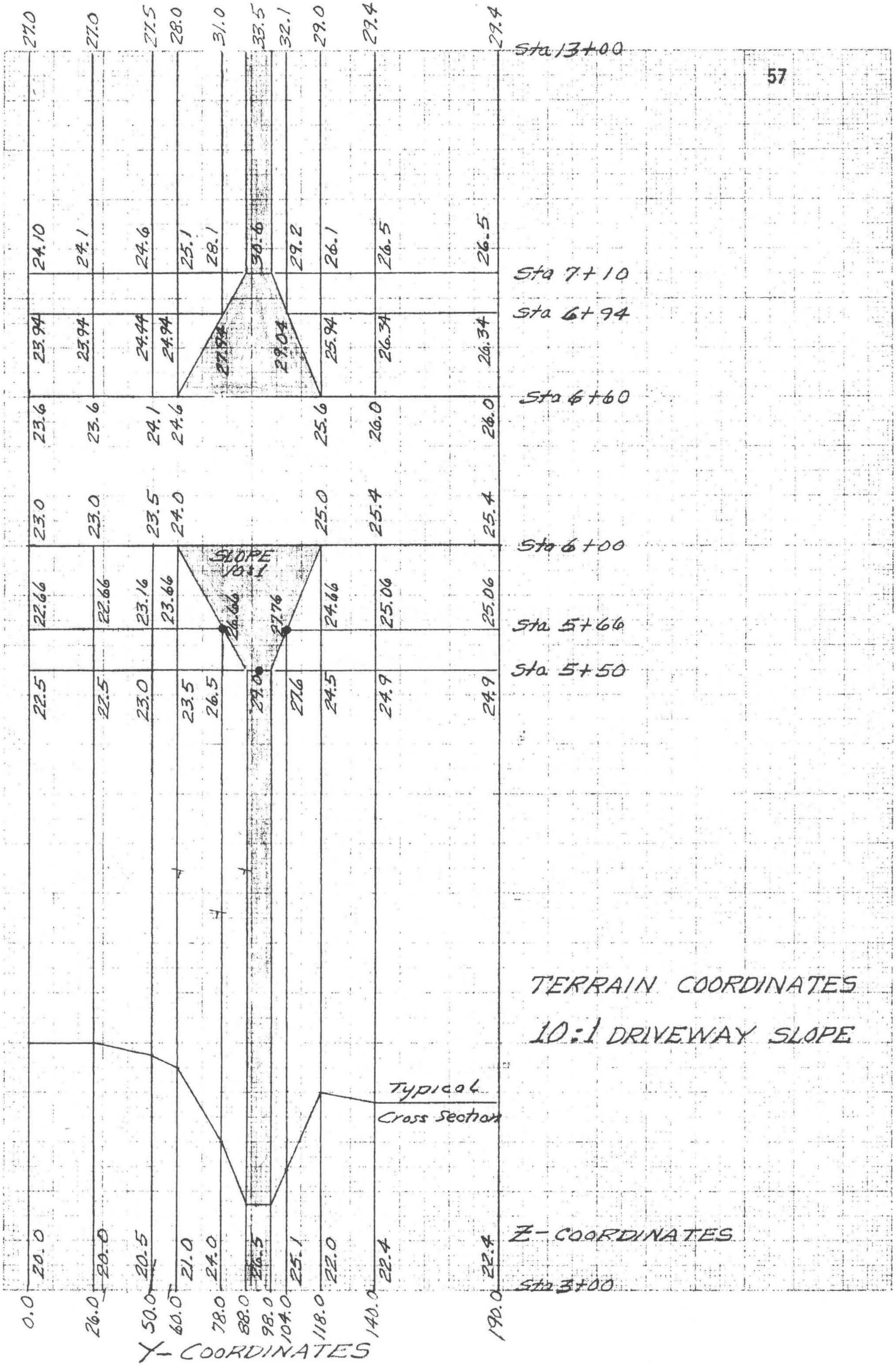
TERRAIN COORDINATES

6:1 DRIVEWAY SLOPE



TERRAIN COORDINATES

8:1 DRIVEWAY SLOPE



TERRAIN COORDINATES

10:1 DRIVEWAY SLOPE

APPENDIX

C. TRANSPORTATION RESEARCH BOARD SLIDES

(Session 4, 1978)

STUDY OBJECTIVES

1. DETERMINE HAZARDOUSNESS OF DRIVEWAY SLOPES BY MODEL SIMULATION.

2. DETERMINE COST-EFFECTIVENESS OF FLATTENING DRIVEWAY SLOPES FROM 3:1 TO 10:1.

3. DETERMINE MOST COST-EFFECTIVE DESIGN STANDARD FOR DRIVEWAY SLOPES.

PARAMETERS

- HVOSM -- TTI MODIFIED VERSION
  STANDARD SIZE AUTO (3,800 LBS.)
  FREE WHEELING STEERING MODE
- DRIVEWAY SLOPE IMPROVEMENTS -- 3:1
  4:1
  6:1
  8:1
  10:1
- ENCROACHMENT CONDITIONS -- SPEED = 55 MPH
  ANGLE = 10 DEG
- SOIL STIFFNESS DURING
  BUMPER(S) CONTACT -- 4 KIP/INCH

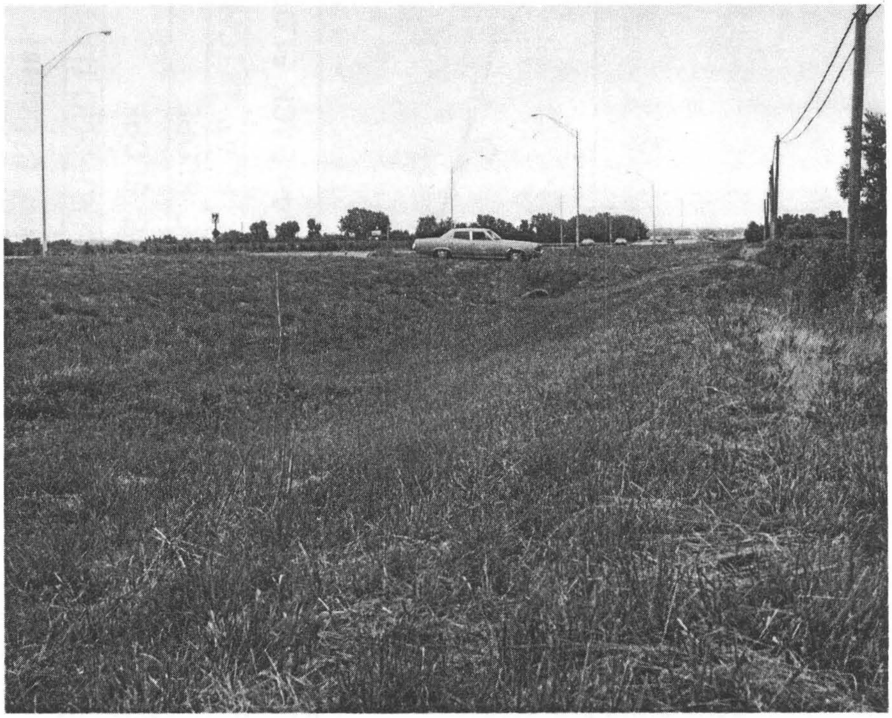


FIGURE I : PHOTOGRAPHS OF DRIVEWAY SITE

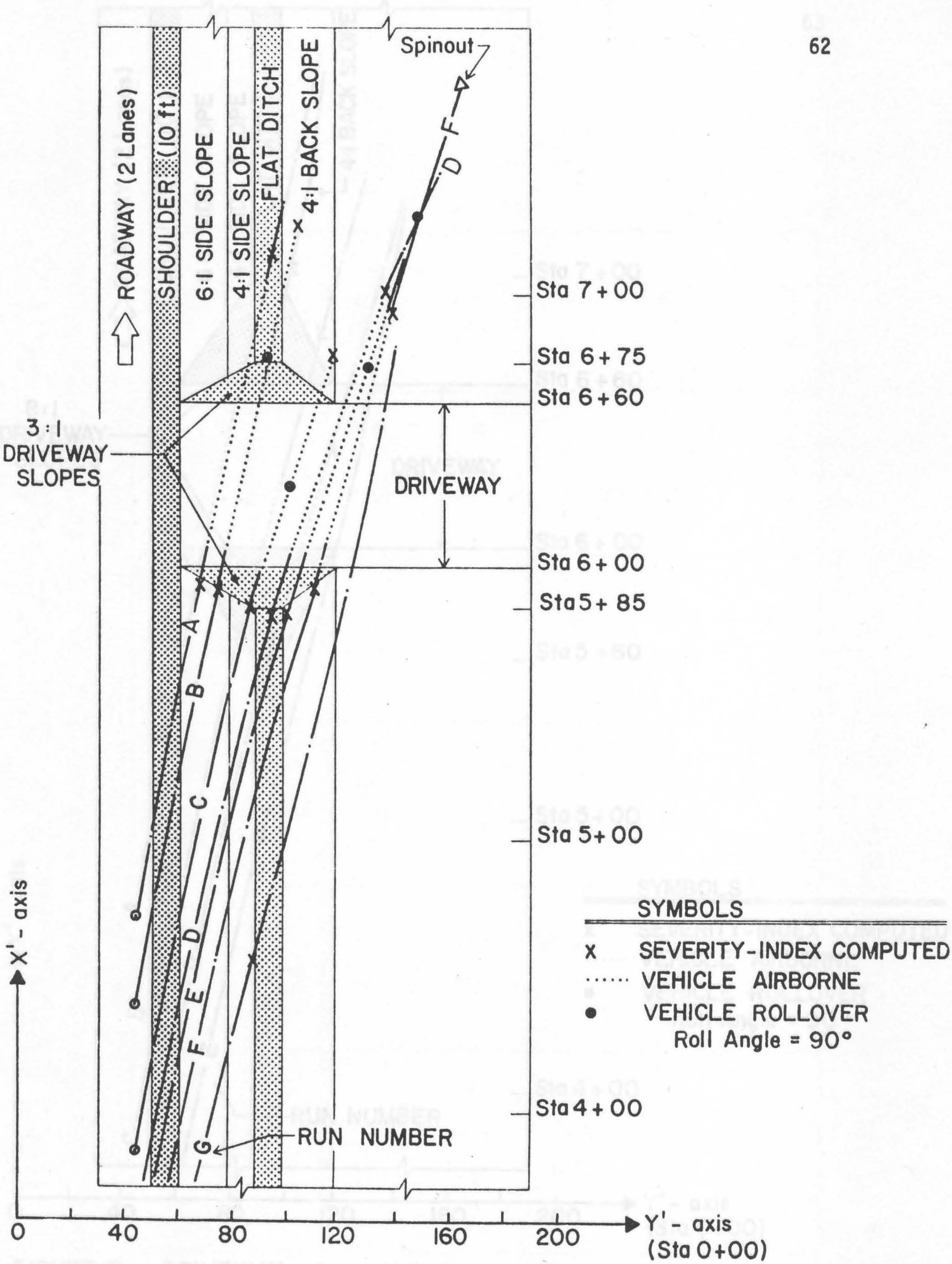


FIGURE 5 DRIVEWAY 3:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

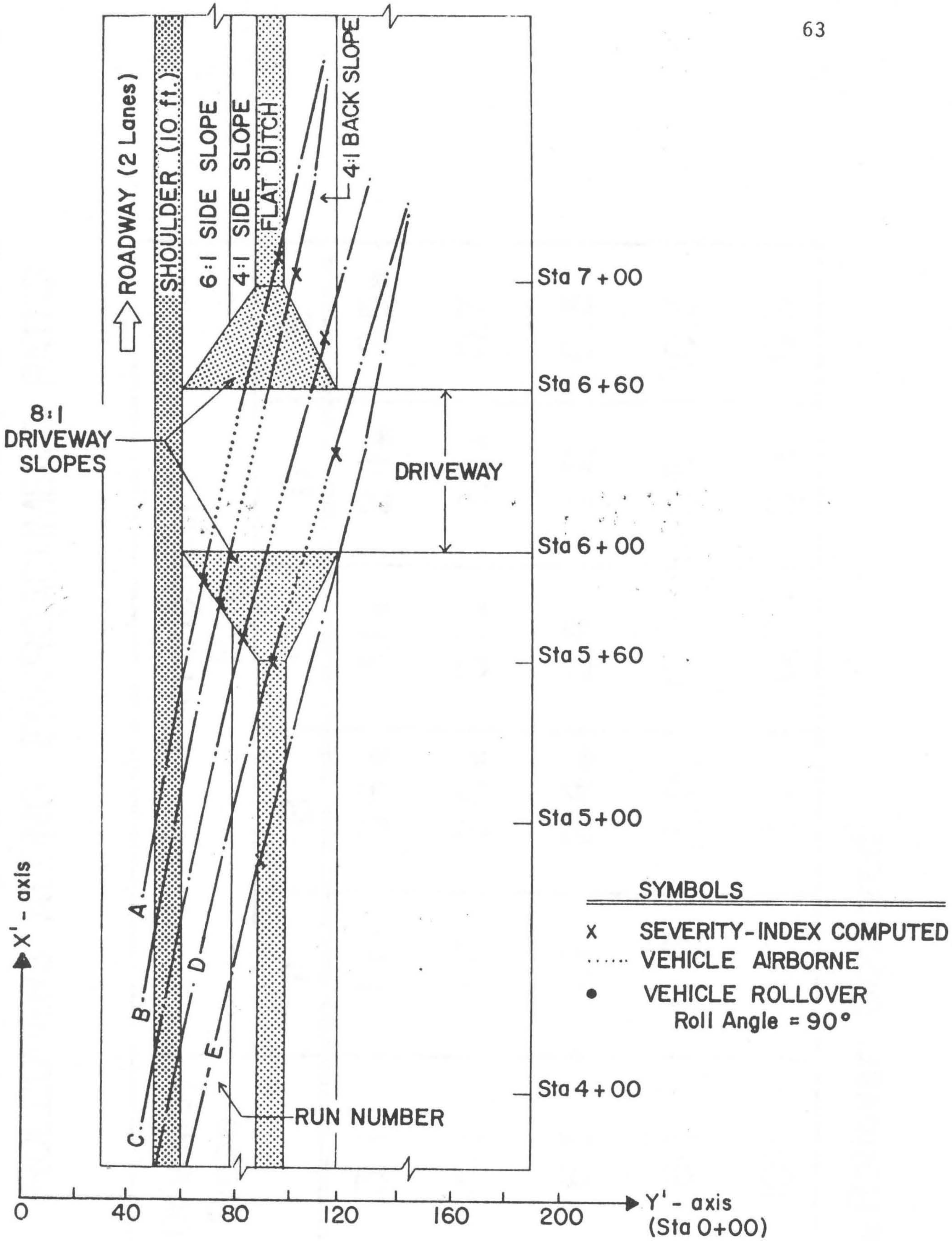
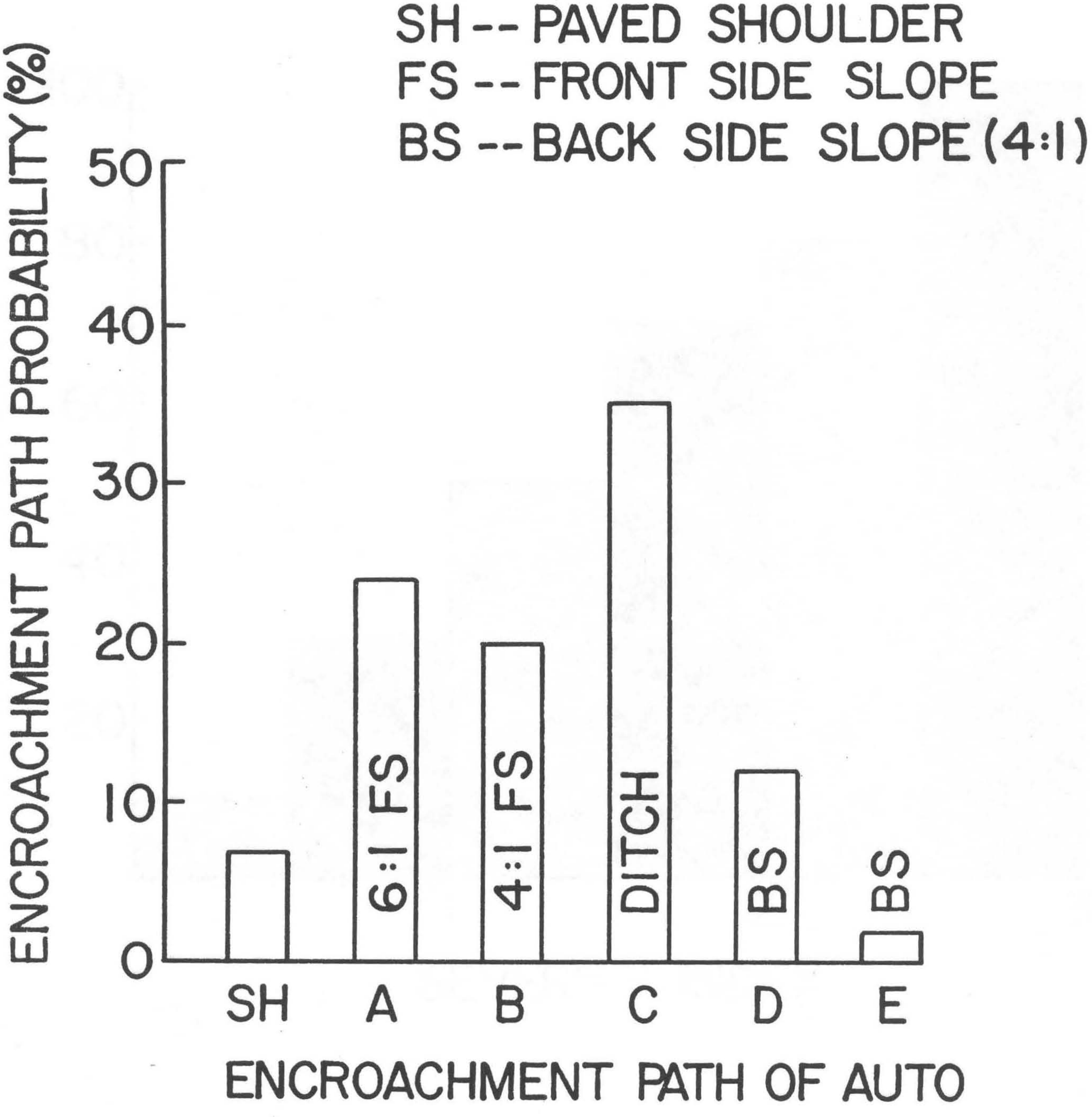


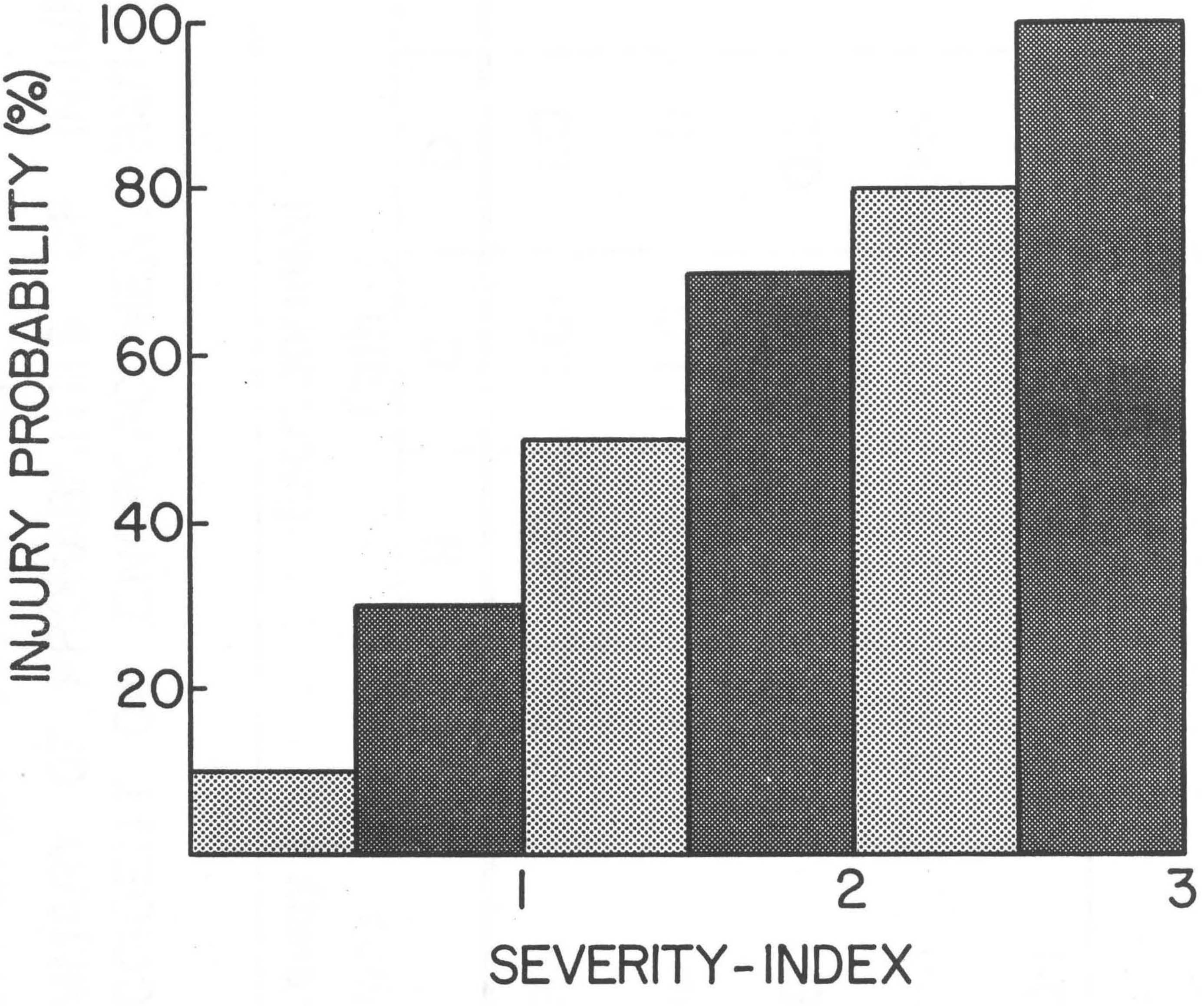
FIGURE 8 : DRIVEWAY 8:1 SLOPE COMPUTER SIMULATIONS OF AUTOMOBILE C.G. PATHS

SUMMARY OF MAXIMUM SEVERITY-INDICIES AND ROLLOVERS ALONG ENCROACHMENT PATHS

Driveway Slope	Encroachment Path				
	A	B	C	D	E
3:1	1.6	3.9 *	3.1 *	2.4 *	2.5 *
4:1	1.6	3.6 *	3.1 *	2.1 *	0.7
6:1	1.1	2.4 *	2.4	1.2	0.3
8:1	0.6	1.0	0.8	0.9	0.3
10:1	0.7	1.1	0.7	0.8	0.3

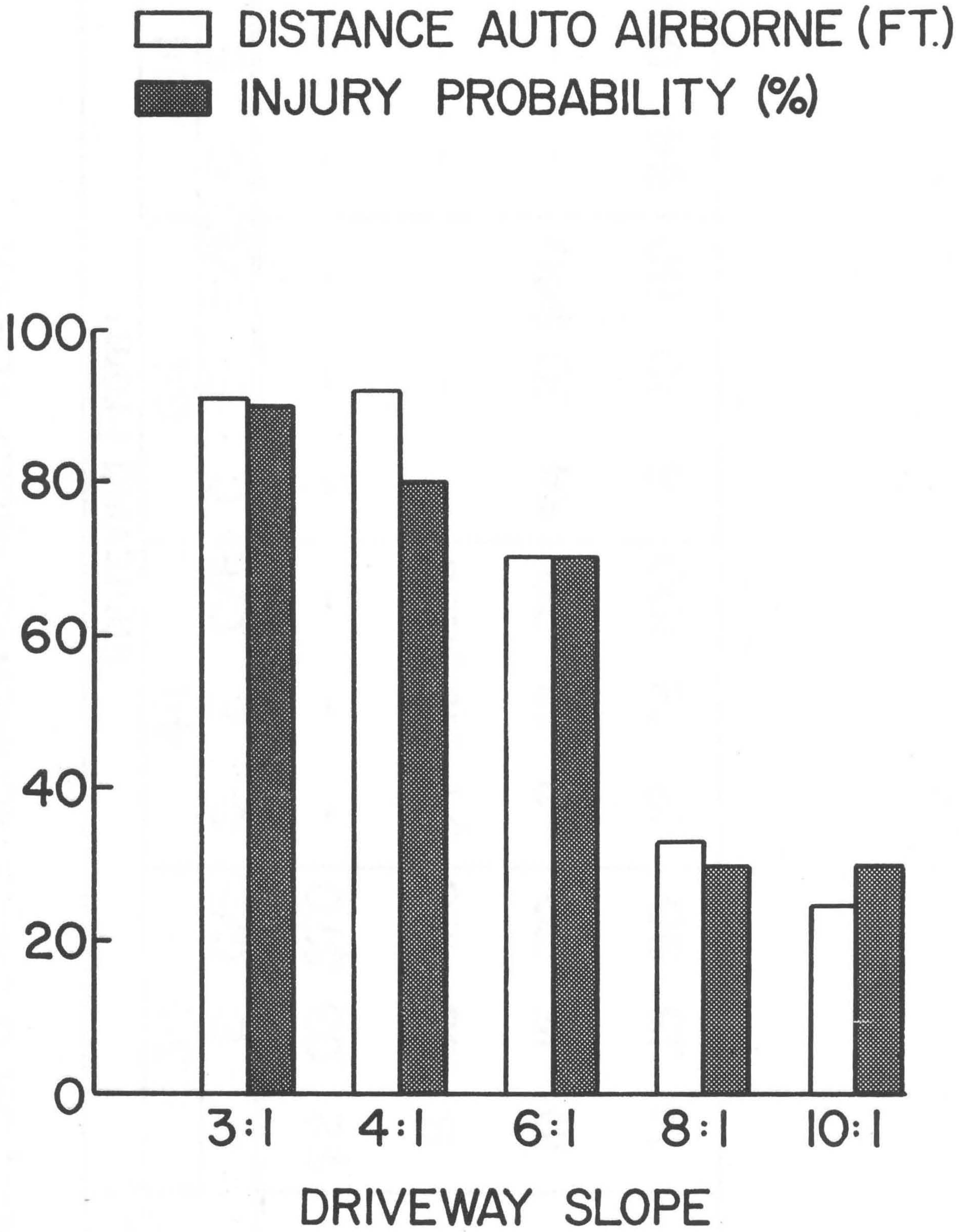
* Rollover Occurred


SH -- PAVED SHOULDER
FS -- FRONT SIDE SLOPE
BS -- BACK SIDE SLOPE (4:1)
ENCROACHMENT PATH PROBABILITY (%)
50
40
30
20
10
0
6:1 FS
4:1 FS
DITCH
BS
BS
SH
A
B
C
D
E
ENCROACHMENT PATH OF AUTO


100
80
60
40
20
INJURY PROBABILITY (%)
1
2
3
SEVERITY-INDEX

SUMMARY OF PROBABILITIES OF INJURY ACCIDENT ON ENCROACHMENT PATHS

Driveway Slope	Encroachment Path				
	A	B	C	D	E
3:1	0.7	1.0	1.0	1.0	1.0
4:1	0.7	1.0	1.0	1.0	0.3
6:1	0.5	1.0	0.8	0.5	0.1
8:1	0.3	0.3	0.3	0.3	0.1
10:1	0.3	0.5	0.3	0.3	0.1


DISTANCE AUTO AIRBORNE (FT.)
INJURY PROBABILITY (%)
100
80
60
40
20
0
3:1
4:1
6:1
8:1
10:1
DRIVEWAY SLOPE

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE DESIGN WITH NO UNDERDRAINAGE INVOLVED. (BASED ON 3000ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$2	.03	$70	-	-	-	-	-	-	-	-	-
6:1	6	.05	120	$4	.02	$200	-	-	-	-	-	-
8:1	10	.15	70	8	.12	70	$4	.10	$40	-	-	-
10:1	14	.15	90	12	.12	100	8	.10	80	$4	0	**Infinite**

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH NO UNDERDRAINAGE INVOLVED (BASED ON 3000 ADT, OR 6 ENCROACHMENTS / MILE / YEAR)

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$10	.03	$330	-	-	-	-	-	-	-	-	-
6:1	24	.05	480	$14	.02	$700	-	-	-	-	-	-
8:1	38	.15	250	28	.12	230	$14	.10	$140	-	-	-
10:1	53	.15	350	43	.12	360	29	.10	290	$15	0	Infinite

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE DESIGN WITH ONE 24-in. DIA. UNDERDRAIN INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$17	.03	$570	-	-	-	-	-	-	-	-	-
6:1	51	.05	1020	$34	.02	$1700	-	-	-	-	-	-
8.1	84	.15	560	67	.12	560	$33	.10	$330	-	-	-
10:1	118	.15	790	101	.12	840	67	.10	670	$34	0	Infinite

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH ONE 24-in DIA. UNDERDRAIN INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR)

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$25	.03	$830	-	-	-	-	-	-	-	-	-
6:1	70	.05	1400	$45	.02	$2250	-	-	-	-	-	-
8:1	114	.15	760	88	.12	730	$43	.10	$430	-	-	-
10:1	159	.15	1060	133	.12	1110	89	.10	890	$45	0	Infinite

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE DESIGN WITH TWO 24-in. DIA. UNDERDRAINS INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR).

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$33	.03	$1100	-	-	-	-	-	-	-	-	-
6:1	96	.05	1920	$63	.02	$3150	-	-	-	-	-	-
8:1	158	.15	1050	125	.12	1040	$62	.10	$620	-	-	-
10:1	221	.15	1470	188	.12	1570	125	.10	1250	$63	0	Infinite

COST-EFFECTIVENESS OF ALTERNATIVE DRIVEWAY SLOPE IMPROVEMENTS WITH TWO 24-in DIA. UNDERDRAINS INVOLVED. (BASED ON 3000 ADT, OR 6 ENCROACHMENTS/MILE/YEAR)

Improving To:	Improving From:											
	3:1			4:1			6:1			8:1		
	C	E	C/E	C	E	C/E	C	E	C/E	C	E	C/E
4:1	$41	.03	$1370	-	-	-	-	-	-	-	-	-
6:1	116	.05	2320	$75	.02	$3750	-	-	-	-	-	-
8:1	189	.15	1260	148	.12	1230	$73	.10	$730	-	-	-
10:1	265	.15	1770	224	.12	1870	149	.10	1490	$76	0	Infinite

CONCLUSIONS

1. DRIVEWAY DO PRESENT A HAZARD.

2. MOST COST - EFFECTIVE

   IMPROVEMENT : FLATTEN TO 8:1

3. MOST COST - EFFECTIVE

   DESIGN STANDARD : 8:1

NEEDED RESEARCH

- CONDUCT FULL-SCALE TESTS TO VALIDATE HVOSM
- DEVELOP TEST METHODS TO MEASURE SOIL STIFFNESS
- CONDUCT ACCIDENT INVESTIGATION
- CONDUCT SENSITIVITY ANALYSIS
- ESTABLISH ACCIDENT SEVERITY AND SEVERITY-INDEX RELATIONSHIP
- DEVELOP DESIGN GUIDELINES