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COOPERATIVE
RESEARCH

CRITERIA FOR THE DESIGN OF SAFE SLOPING CULVERT GRATES--VOLUME ONE, DEVELOPMENT OF CRITERIA

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 140-3
STUDY 2-5-69-140
EVALUATION OF THE ROADWAY ENVIRONMENT

CRITERIA FOR THE DESIGN OF SAFE SLOPING CULVERT GRATES

VOLUME I: DEVELOPMENT OF CRITERIA

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Research Report 140-3
Volume I

Evaluation of the Roadway Environment by
Dynamic Analysis of the Interaction Between
the Vehicle, Passenger, and Roadway

Research Study No. 2-5-69-140

Sponsored by
The Texas Highway Department

in cooperation with the
U. S. Department of Transportation, Federal Highway Administration

August 1971

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

FOREWORD

The information contained herein was developed on Research Project 2-5-69-140 entitled "Evaluation of the Roadside Environment by Dynamic Analysis of the Interaction Between the Vehicle, Passenger, and Roadway". It is a cooperative research study sponsored jointly by the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration.

Basically, the objectives of the study are to apply mathematical simulation techniques in determining the dynamic behavior of automobiles and their occupants when in collision with various roadside objects or when traversing curves in the road, shoulders, or other situations. It is a continuing study, having been initiated in September 1968.

As part of the first year's work, the computer program HVOSM (formerly known as CALSVA) was obtained from Cornell Aeronautical Laboratory and made operational on the IBM 360 computer facilities at Texas A&M University. In adapting the program, additions and modications were made which increased its flexibility and usefulness. These changes and the input requirements of the program are documented in Research Report 140-1.

The primary emphasis of the second year's work was the development of an analytical model to predict the dynamic response of an automobile's occupant in three-dimensional space. Research Report 140-2 presents the derivation of the occupant model, a validation study, and a description of computer input data for determining the occupant's response.

In the 1970-71 year, the emphasis was on application of HVOSM to specific roadway design problems. Volume I of Research Report 140-3 describes an investigation of the *traffic-safe* characteristics of different culvert sloping grate configurations. Criteria are presented for designing a *traffic-safe* sloping grate. Volume II contains computer input and sample output of this study. The other studies pertain to the development of criteria for determining the need for and location of guardrail on embankments, and to the development of data on the dynamic behavior of a vehicle impacting the New Jersey type concrete median barrier.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Texas Highway Department or the Federal Highway Administration.

ABSTRACT

Key Words: Highway Safety, Culverts, Sloping Grates, Medians, Vehicle Simulation, Math Model

Some highway drainage structures have a geometrical configuration that can cause an errant automobile to stop abruptly or veer out-of-control. One such structure is the end culvert inlet with or without headwalls. In recent years, highway engineers have used sloping inlet and outlet grates which allow an automobile to traverse the culvert opening rather than come to an abrupt stop. Sloping grates are currently designed on judgement and experience because objective criteria are practically nonexistant.

Using a mathematical simulation technique, this study investigated the dynamic behavior of a standard size automobile traversing a median containing a crossover and a sloping culvert inlet grate. Twenty-three computer simulations were made in which the effects of vehicle path, ditch side slope, and grate slope were analyzed. It was determined that an 8:1 ditch side slope in conjunction with a 10:1 lvert grate slope would not produce intolerable automobile accelerations to an unrestrained occupant. Steeper combinations of side and grate slopes were found to produce severe accelerations and/or rollover and should be avoided where possible.

For purposes of structural design, it was found that the dynamic load factor per tire on 8:1 and flatter grate slopes was about five. And, for 6:1 and steeper grate slopes, the dynamic load factor reached values of about 10.

SUMMARY

The objective of this study was to develop criteria from which a *traffic-safe* sloping grate configuration could be designed. To accomplish this, a mathematical computer simulation technique was used to investigate the dynamic behavior of a standard size automobile as it traversed various combinations of ditch and grate slopes. Parameter studies were conducted to determine the influence that automobile departure angle and path, ditch side slope, grate slope, and ditch depth had on the automobile's response. Both headon and angle automobile departures were studied. For evaluation criteria, the configurations were judged on their ability to minimize the severity of automobile accelerations (as measured by a severity index), prevent rollover, and to minimize the chance of the automobile setting down in the opposite lane of traffic after being airborne.

Of the several configurations investigated, an 8:1 side slope in conjunction with 10:1 culvert grate slope appears to be the optimum combination. It was the only combination which satisfied the above evaluation criteria and it is probably feasible from an economic and hydraulic standpoint. It is noted that in a recent National Cooperative Highway Research Program report, guidelines were presented which suggested that side slopes and sloping culvert grates should be 10:1 and flatter. To be assured of a traffic-safe design, it may be advisable to conduct a limited number of full-scale tests to substantiate the findings of the mathematical simulation.

IMPLEMENTATION STATEMENT

This study provides information to assist highway engineers in the design of *traffic-safe* highway drainage structures, in particular, the sloping culvert grate. Practically no criteria exist for this purpose.

A review of current design procedures in some Texas Highway Department districts showed that culvert grate slopes of 6:1 and steeper are being used. This study indicates that grate slopes of 10:1 or flatter should be used in conjunction with 8:1 or flatter ditch side slopes, where possible. This combination of ditch and grate slope was found to be the most practical one which, when traversed by an errant vehicle minimized accelerations, prevented rollover, and minimized the chance of the vehicle landing in the opposing lane of traffic. It was not within the scope of this study to investigate the cost-effectiveness or the hydraulics of various side and grate slope configurations. Nevertheless, the 8:1 side slope and 10:1 grate slope combination appears feasible, in many cases, from both a cost-effectiveness and hydraulic ındpoint.

Although this study was based entirely on a mathematical computer simulation, the capability of the simulation to accurately predict the dynamic behavior of an actual automobile traversing configurations (ramps) similar to those of this study has been demonstrated and documented. Confidence in the simulation's capabilities is therefore very high. It may be desirable, however, before incorporating new design procedures to conduct a limited number of field tests to verify the findings of this study.

INTRODUCTION

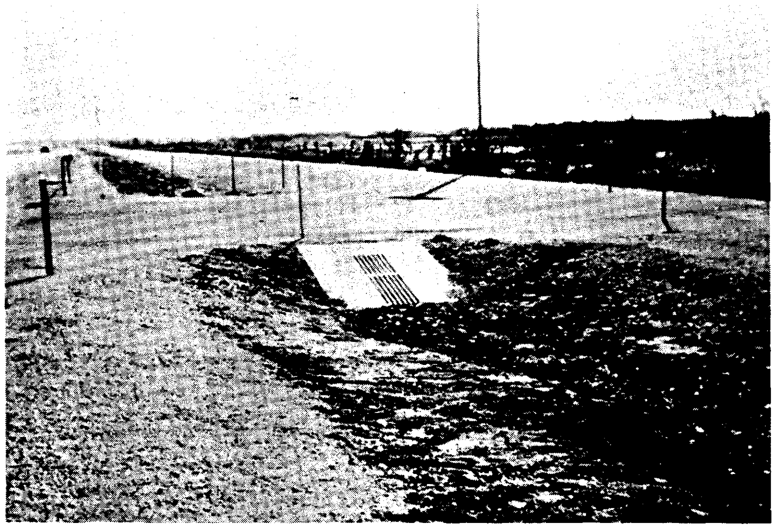
As discussed and illustrated in a recent National Cooperative Highway Research Program publication (1) (NCHRP 3), some highway drainage structures are potentially hazardous and, if located in the path of an errant vehicle, can substantially increase the probability of an accident. These structures consist of crossdrains and their appended culvert end structures, median and curb inlets, roadside channels or ditches, and other special drainage structures.

In the introduction section of NCHRP 3, an objective for which the highway engineer should strive was defined as follows:

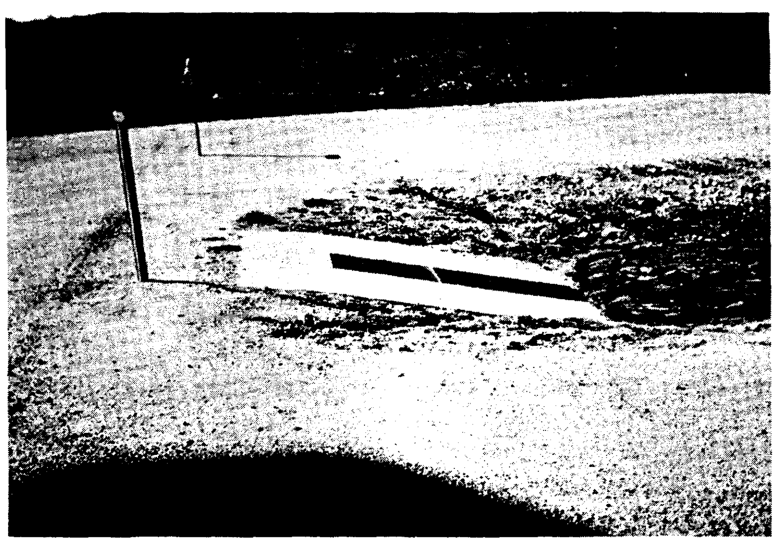
> "A traffic-safe drainage structure is one which does not inhibit the driver's ability to regain control of his vehicle -- permitting him either to return to the traveled roadway or to stop safely without damage or injury."

To aid the highway engineer in the design of a *traffic-safe* drainage structure, general guidelines were presented in NCHRP 3. These guidelines reflect the best knowledge available concerning those measures most successful in minimizing the potential hazards associated with drainage structures, while maintaining hydraulic efficiency.

A sloping inlet or outlet grate is a structure occassionally used as an alternate to the abrupt culvert inlet with or without headwalls. Photographs of a typical sloping grate installation are shown in Figure 1. This study provides criteria for the design of a *traffic-safe* sloping culvert grate.



(a) APPROACH TO A SLOPING GRATE



(b) SIDE VIEW OF A SLOPING GRATE

FIGURE 1. A TYPICAL SLOPING CULVERT GRATE

To study the *traffic-safe* characteristics of a sloping grate slope configuration, a mathematical simulation technique described in a subsequent section was employed. The simulation provided information on the motion, forces, and accelerations of an automobile that could be expected during the event. Twenty-three different events were studied to identify important parameters and to make recommendations concerning grate design. The additional information provided will, when used in conjunction with NCHRP 3, better assure the highway engineer that an errant automobile can safely traverse some defined side slope and adjoining grate slope configuration.

Although the study was aimed at providing data for the sloping grate design, the results are applicable to other areas of interest. They can be used to select slopes on driveways or roads that abut the main highway or slopes on crossover culverts which may be raised above the normal terrain elevation (see Figure 4).

MATHEMATICAL MODEL OF AN AUTOMOBILE

To facilitate in the evaluation and design of a roadway and its environment, it is important to understand the effects of various roadway geometric features on the dynamic response of an automobile and its occupants.

The mathematical model described herein was used to investigate the dynamic response of an automobile negotiating various side slope and adjoining sloping grate terrain configurations. It is worthy to note that the model can also be used to investigate various other problems associated with the roadway environment, such as highway traffic barrier collisions, rapid lane change maneuvers, handling response on horizontal curves, and collisions with drainage ditch cross sections.

The mathematical model, designated HVOSM*, was developed by Cornell Aeronautical Laboratory (CAL) (2,3) and later modified for specific problem studies by the Texas Transportation Institute (TTI) (4). A conceptual idealization of the model is shown in Figure 2. The model is idealized as four rigid masses, which include: (a) the sprung mass (M_S) of the body supported by the springs, (b) the unsprung masses (M_1 and M_2) of the left and right independent suspension system of the front wheels, and (c) the unsprung mass (M_3) representing the rear axle assembly. The eleven degrees of freedom of the model include translation of the automobile in three directions measured relative to some fixed coordinate axes system; rotation about the three coordinate axes of the automobile; independent displacement of each front wheel suspension system; suspension displacement and rotation of the rear axle assembly; and steer of the front wheels. A more detailed discussion of the mathematical model is given in the references quoted earlier.

The validity of the model is dependent to a large extent on the :uracy of the input parameters pertaining to the automobile selected. In this study, a 1963 Ford Galaxie, four door sedan was selected because of: (a) the availability of data on the automobile parameters; (b) the excellent comparisons obtained by CAL (2,3) between full-scale tests and mathematical simulation during a variety of maneuvers; and (c) it is representative of a large population of automobiles from a size,

*HVOSM - Highway-vehicle-object simulation model

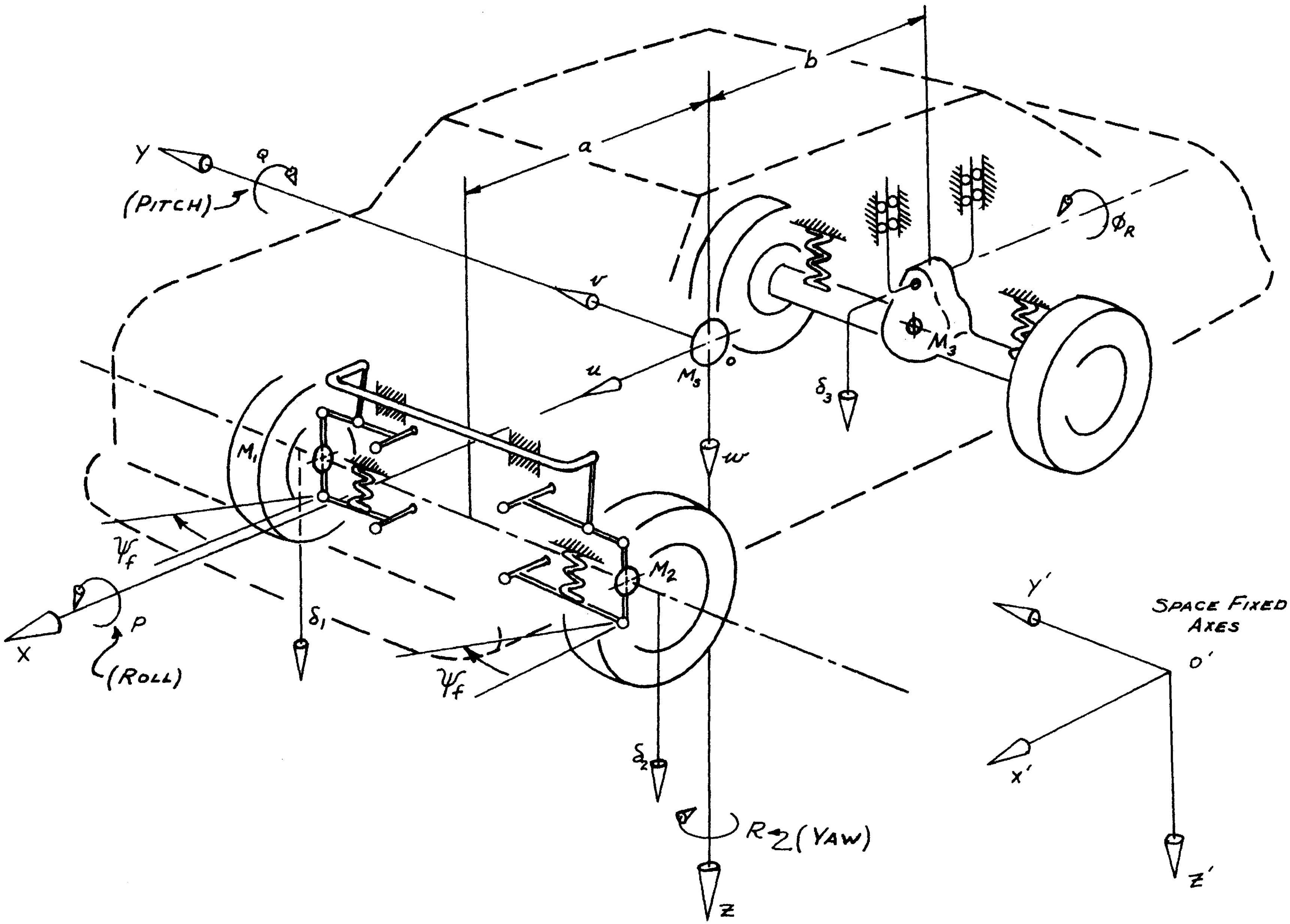


FIGURE 2. IDEALIZATION OF AUTOMOBILE (2, 3)

weight, and suspension standpoint.

It is noteworthy that very good comparisons were observed between full-scale ramp traversal tests and corresponding simulated tests conducted by CAL (3). The nature of a ramp traversal by an automobile is very similar to that experienced during traversal of a sloping grate.

Mathematical simulation provides a rapid and economical method to investigate the many parameters involved as an automobile traverses some defined terrain configuration. Once the limiting parameters are identified, it may be desirable to conduct a limited number of full-scale tests prior to final selection of a particular design. This approach, in contrast to a full-scale trial-and-error approach, will yield more meaningful results with considerably less resource expenditure.

The mathematical simulation was facilitated by the use of an IBM 360 computer. Approximately one minute of computer time is required for one second of event time. On the average, it takes three seconds for an automobile departing the roadway at 60 mph to traverse a side slope and sloping grate configuration. The computer cost for :ee minutes of time is approximately 25 dollars.

EVALUATION CRITERIA

The criteria used to investigate the "traffic-safe" characteristics of a terrain configuration in the vicinity of sloping grate culvert were: (1) automobile stability, (2) distance automobile airborne, and (3) automobile acceleration severity index.

The "stability" criterion requires that the automobile, after becoming airborne on the sloping grate, remain in an upright position. Rollover was considered sufficient to evaluate a terrain configuration as not being "traffic-safe." Rollover was observed to occur in one of two ways. First, rollover occurred about the roll-axis of the automobile (X-axis in Figure 2) as it is airborne. And second, rollover occurred about the pitch-axes of the automobile (Y-axis in Figure 2) upon contacting the terrain after being airborne.

The "distance airborne" criterion requires that the automobile, after becoming airborne on the sloping grate, set-down in a location that would not endanger the lives of motorists in the opposing traffic lanes.

The "acceleration severity-index" requires that the combined longitudinal, lateral, and vertical accelerations of the automobile at its center-of-mass have a severity-index equal to or less than unity. The equation used to determine the severity-index was discussed in some depth in a recent publication by Weaver (5). The severity-index equation is:

$$SI = \sqrt{\left(\frac{G_{long.}}{G_{XL}}\right)^2 + \left(\frac{G_{lat.}}{G_{YL}}\right)^2 + \left(\frac{G_{vert.}}{G_{ZL}}\right)^2}$$

where:

$G_{long.}$ = actual acceleration in longitudinal X-axis, G's

$G_{lat.}$ = actual acceleration in lateral Y-axis, G's

$G_{vert.}$ = actual acceleration in vertical Z-axis, G's

G_{XL} = limit acceleration in longitudinal X-axis, G's

G_{YL} = limit acceleration in lateral Y-axis, G's

G_{ZL} = limit acceleration in vertical Z-axis, G's

The "limit" accelerations in the above equation were defined as the highest automobile accelerations that an occupant could sustain without serious or fatal injury. The limit accelerations used in this study are for an unrestrained occupant and are as follows:

$$\left.\begin{array}{l} G_{XL} = 7 \text{ G's} \\ G_{YL} = 5 \text{ G's} \\ G_{ZL} = 6 \text{ G's} \end{array}\right\} \text{From Weaver } (\underline{5})$$

It is well known that the actual accelerations of an automobile may reach very high values over small time intervals, ranging from roughly 2 to 10 milliseconds. Such accelerations are commonly referred to as "spikes". There is much discussion among highway and research engineers as to whether these automobile acceleration "spikes" are actually felt by the occupants. In a recent publication, Nordlin (6) concluded from investigation of available literature that the accelerations of an automobile at its center-of-mass should be measured as an average over a time interval of 50 milliseconds. The acceleration values reported in this study were in accordance with the findings of Nordlin.

MATHEMATICAL SIMULATION RESULTS

To develop criteria the HVOSM model was used to investigate the dynamic behavior of an automobile as it left the traveled roadway and traversed various sloping grate and surrounding terrain configurations. A total of 23 simulated traversals were made, the results of which are described in the following paragraphs. Volume II of this report contains all of the computer input required to generate the 23 runs together with sample output.

In all cases the simulated roadway site consisted of a median crossover where the median width was 50 feet. Refer to Figure 3 for an illustration of the terrain configuration. With one exception, the ditch depth was 3 feet. The departure speed of the automobile was taken as 60 mph, whereas the departure angle was treated as a variable. The terrain surfaces were assumed to be hard i.e. effects of tire penetration were considered negligible. It is to be noted that the results of this study would also apply to at least two other roadway sites where: (a) two sloping grates would collect and distribute water into a culvert pipe placed under the traveled roadway to a drainage ditch in the right-of-way as shown in Figure 4, and, (b) a driveway or roadway abuts the main highway. Details of the 23 computer runs are given in Table 1.

Runs 1 through 6 were designed to determine the effect of the grate slope, ditch depth, and departure path on the automobile's response. A median side slope of 6:1 and a departure angle of 25 degrees were used in each of the six runs. The slope of the grate was varied from 4:1 to 10:1. As indicated in Table 1, rollover

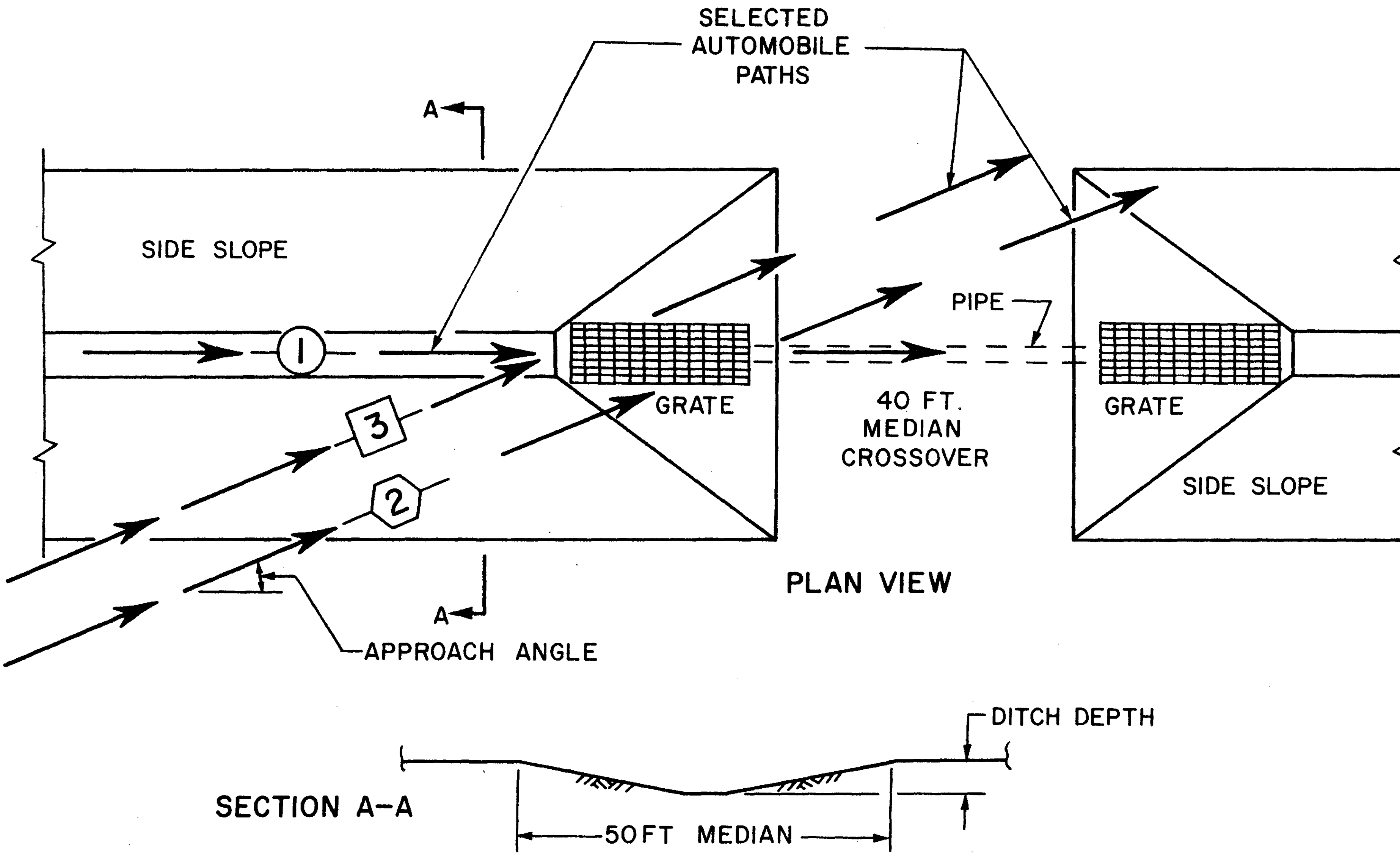
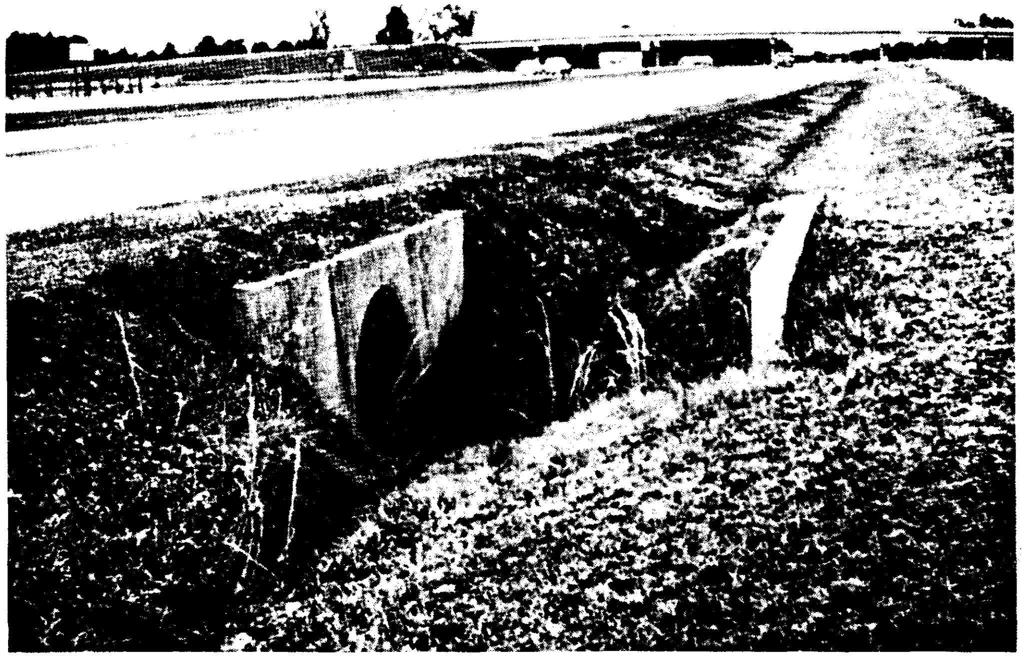
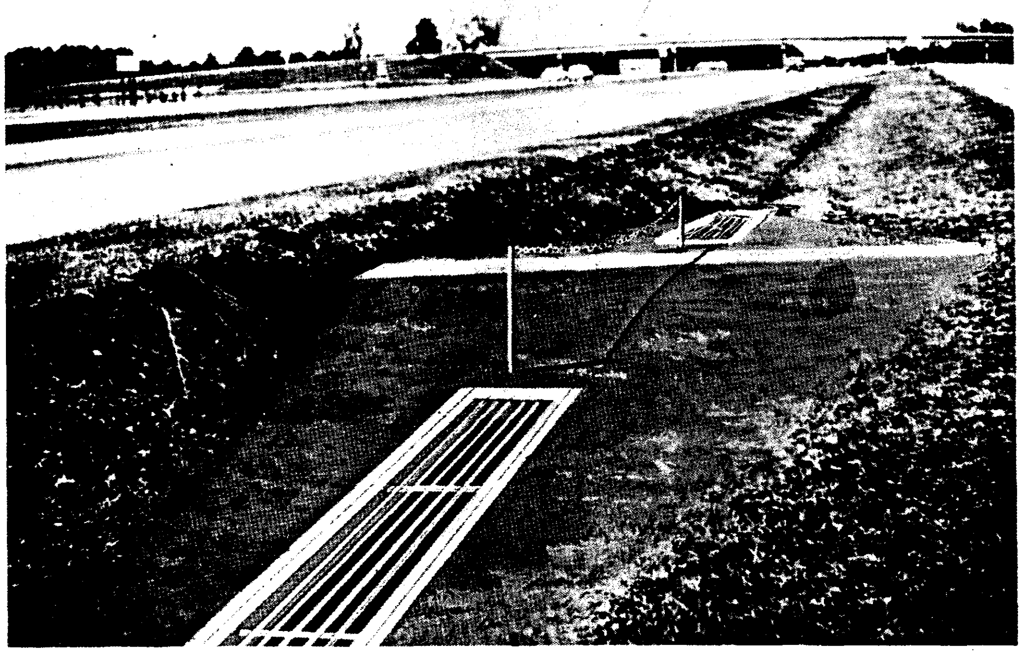


FIGURE 3. SIMULATED MEDIAN TERRAIN CONFIGURATION AND SELECTED RAN-OFF-ROAD AUTOMOBILE PATHS



(A) Existing



(B) Suggested Modifications

FIGURE 4. MODIFICATIONS OF EXISTING CULVERT CROSSOVER (1)

1. RESULTS OF MATHEMATICAL SIMULATIONS OF AN AUTOMOBILE TRAVERSING VARIOUS SIDE AND GRATE SLOPE CONFIGURATIONS AT 60 MPH

	TERRAIN			AUTOMOBILE														
											ACCELERATIONS OVER 50 MILLISECONDS							
											GRATE SLOPE CONTACT				TERRAIN CONTACT AFTER AIRBORNE			
RUN NUMBER	DITCH DEPTH (FT)	SIDE SLOPE	GRATE SLOPE	APPROACH ANGLE (DEG)	PATH (SEE FIG. 3)	MAXIMUM ROLL ANGLE (DEG)	RISE OF C.G. ABOVE TERRAIN (FT)	DISTANCE AIRBORNE (FT)	MAXIMUM VERTICAL TIRE LOAD ON GRATE (KIPS)	IMPACT LOAD FACTOR	$G_{LONG.}$	$G_{LAT.}$	$G_{VERT.}$	SEVERITY INDEX	$G_{LONG.}$	$G_{LAT.}$	$G_{VERT.}$	SEVERITY INDEX
1	3	6:1	4:1	25	2	RO[a]	11.8	93[c]	44.0	9.3	5.1	1.9	10.8	2.1	----	---	---	---
2	3	6:1	6:1	25	2	RO[a]	6.3	85[c]	34.2	7.2	3.5	1.1	6.8	1.3	----	---	---	---
3	3	6:1	8:1	25	2	RO[a]	5.8	58[c]	31.9	6.7	1.8	0.9	4.6	0.9	----	---	---	---
4	3	6:1	10:1	25	2	RO[b]	4.7	52	24.6	5.2	0.3	1.3	6.5	1.1	----	---	---	---
5	3	6:1	6:1	25	3	51	6.7	86	22.4	4.7	1.1	0.6	4.4	0.8	1.3	4.8	3.9	1.0
6	2	6:1	6:1	25	2	RO[a]	7.8	87[c]	52.3	11.0	1.9	1.1	7.1	1.3	----	---	---	---
7	3	8:1	6:1	25	2	7	8.8	101[d]	30.1	6.3	2.8	0.4	9.1	1.7	0.3	0.7	9.7	1.6
8	3	8:1	6:1	15	2	34	9.9	98	25.4	5.3	2.3	0.3	6.9	1.2	2.2	2.9	4.1	0.9
9	3	NA	4:1	0	1	0	18.2	147[e]	29.0	6.1	3.6	0	8.7	1.6	1.9	0	18.4	3.1
10	3	NA	6:1	0	1	0	12.2	116	22.1	4.7	1.3	0	5.3	0.9	8.4	0	7.7	2.1
11	3	NA	8:1	0	1	0	7.2	98	19.3	4.1	0.6	0	3.7	0.6	4.5	0	6.6	1.4
12	3	NA	10:1	0	1	0	4.7	86	14.9	3.1	0.1	0	3.1	0.5	3.0	0	5.9	1.1
13	3	8:1	8:1	5	3	50	6.6	82	23.9	5.0	0.2	0.4	3.6	0.8	2.9	5.4	2.7	1.1
14	3	8:1	8:1	5	2	RO[b]	6.1	97	18.9	4.0	0.2	0.5	3.6	0.6	----	---	---	---
15	3	8:1	8:1	10	2	40	6.4	78	21.2	4.5	0.9	0.3	4.4	0.8	2.2	3.7	2.9	0.8
16	3	8:1	8:1	15	2	50	6.3	68	22.7	4.8	1.2	0.4	4.4	0.8	1.9	3.2	2.0	0.7
17	3	8:1	8:1	20	2	21	6.2	78	21.2	4.5	1.4	0.3	6.3	1.1	1.2	1.2	2.4	0.5
18	3	8:1	8:1	25	2	12	6.2	81[d]	23.6	5.0	1.5	0.3	7.1	1.2	1.1	1.0	2.4	0.5
19	3	8:1	10:1	5	2	50	4.8	73	17.8	3.7	0.1	0.5	3.4	0.6	2.7	4.8	2.4	1.0
20	3	8:1	10:1	10	2	32	5.0	68	20.3	4.3	0.1	0.4	3.6	0.6	1.8	2.5	2.6	0.7
21	3	8:1	10:1	15	2	34	4.8	62	21.6	4.6	0.7	0.3	3.5	0.6	1.7	3.0	3.3	0.8
22	3	8:1	10:1	20	2	17	4.8	65	17.7	3.7	0.9	0.3	5.2	0.9	0.3	0.7	4.9	0.8
23	3	8:1	10:1	25	2	26	4.8	63	20.5	4.3	0.9	0.3	5.4	0.9	0.3	0.6	3.6	0.6

a. Rollover occurs when automobile is airborne
b. Rollover occurs when automobile contacts terrain after being airborne
c. Approximate distance as automobile contacts its top
d. Automobile sets-down in opposing traffic lane
e. Front-end rollover when automobile contacts terrain after being airborne

occurred in negotiating a grate slope of 10:1 and steeper for a path 2 departure. A computer graphic illustration of the results of run number 2 is shown in Figure 5. Rollover did not occur when the automobile departure path from the roadway was such that the automobile encountered the flat ditch prior to negotiating the grate slope (path 3 in Figure 3). As shown in run number 6, a change in the ditch depth from 3 feet to 2 feet did not prevent rollover for the 6:1 side slope and 6:1 grate slope.

Runs 7 and 8 pertain to median side slopes of 8:1 and a grate slope of 6:1. Rollover did not occur in either of these cases but the acceleration severity index indicated that serious injuries would be inflicted on the automobile's occupants. Also, in run number 7, the airborne criteria was not satisfied; the automobile landed in the opposing traffic lane.

It is probable that a large number of traversals will be the headon type. To study this situation, runs 9 through 12 were made. The grate slope was varied from 4:1 to 10:1, all other variables being held constant. The results obtained for the headon simulations are illustrated graphically in Figure 6. For headon traversals, the steeper the grate slope the greater the automobile accelerations, dynamic vertical tire loads, and height and distance airborne. At a grate slope of 6:1, the automobile upon contacting the terrain after being airborne rolled over about its front end as illustrated in the computer graphic drawings in Figure 7. For a path 1 traversal, the accelerations for a 10:1 grate slope are on the borderline and the severity index indicates that severe injuries may occur, whereas, for grate

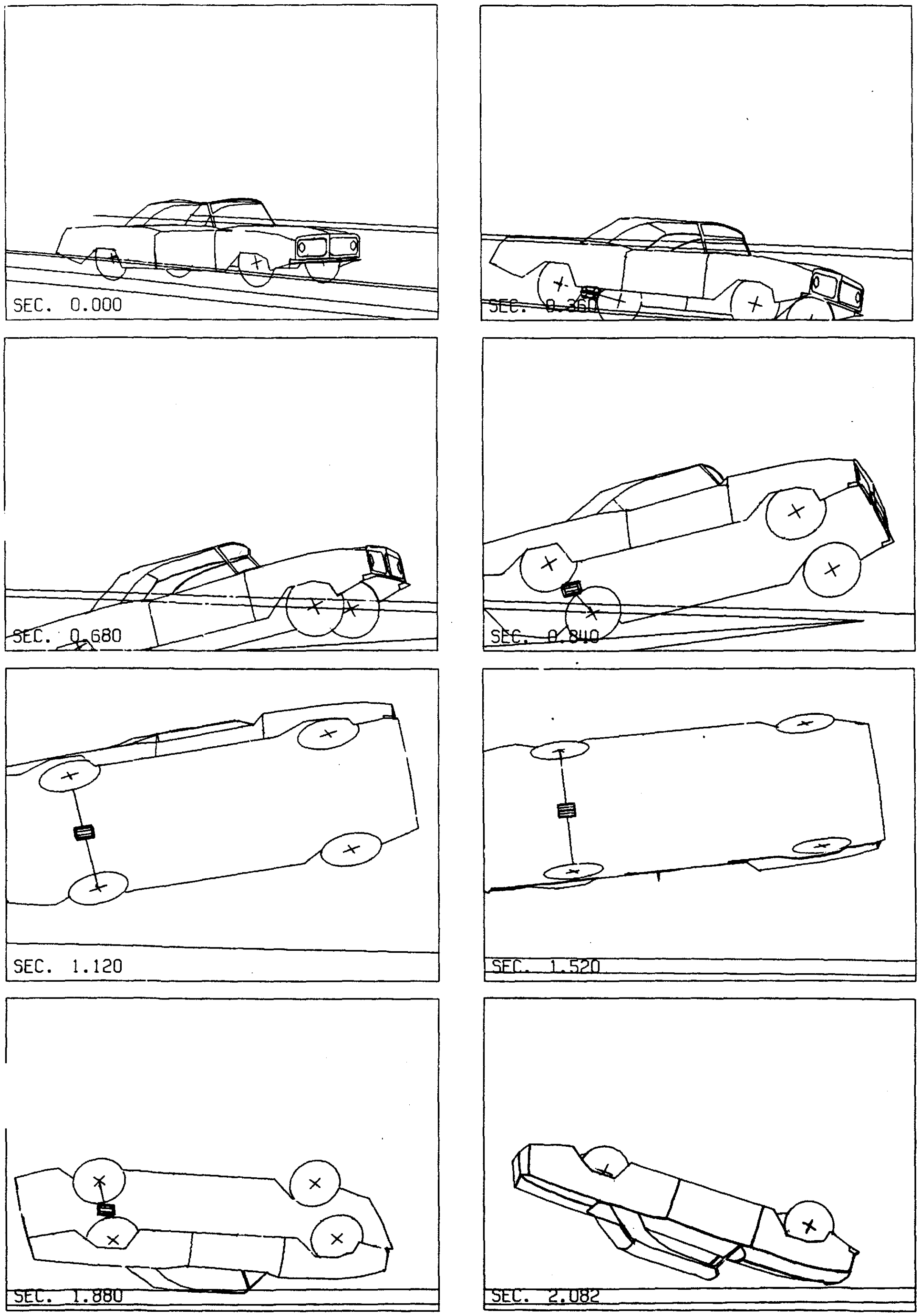


FIGURE 5. 60 MPH/25 DEG SIMULATION OF AUTOMOBILE NEGOTIATING 6:1 SIDE SLOPE AND 6:1 CULVERT GRATE SLOPE

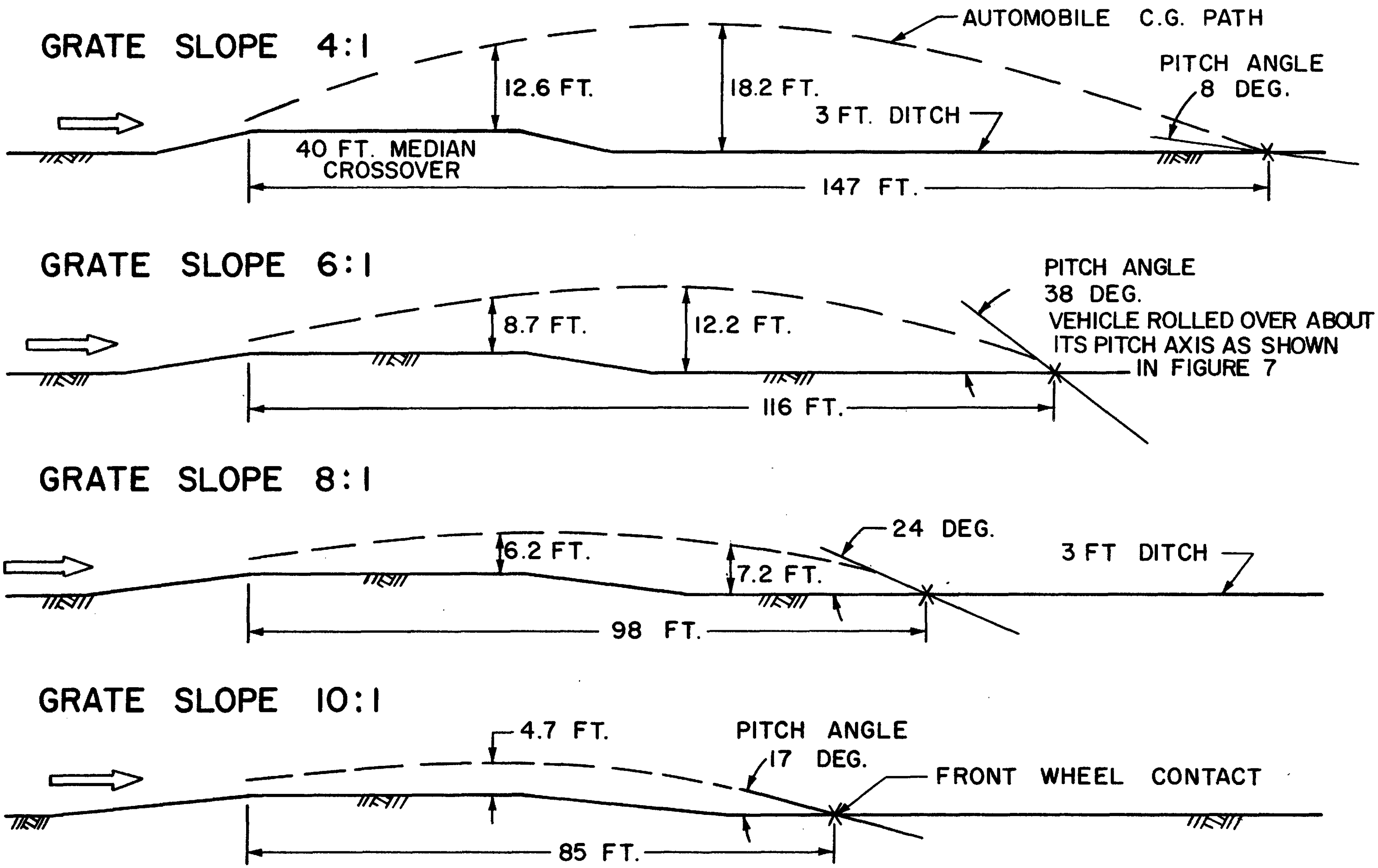


FIGURE 6. HEAD-ON 60 MPH SIMULATIONS OF AUTOMOBILE TRAVERSING VARIOUS SLOPING GRATE CONFIGURATIONS

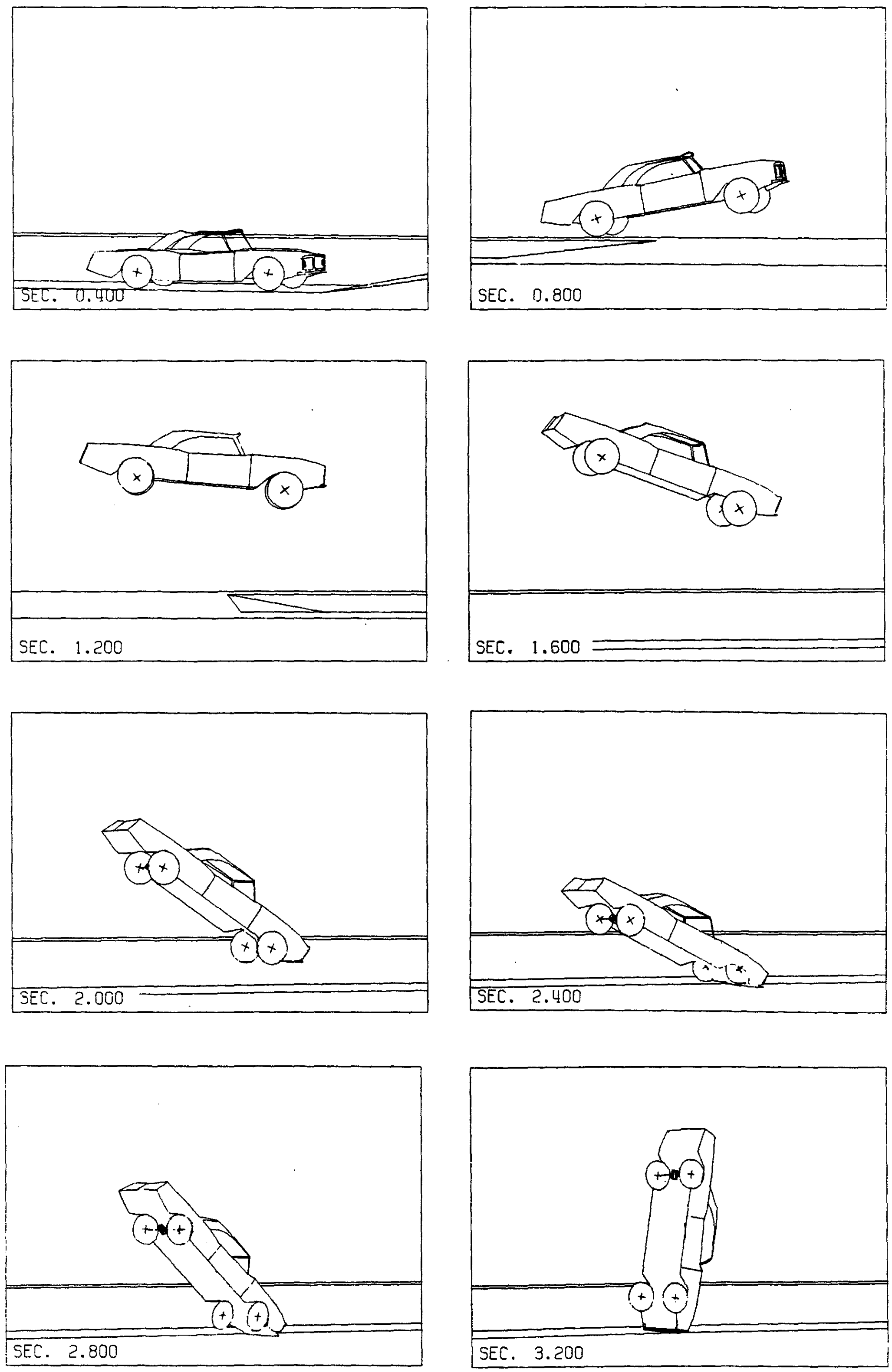


FIGURE 7. HEAD-ON 60 MPH SIMULATION OF AUTOMOBILE NEGOTIATING A 6:1 CULVERT GRATE SLOPE

slopes steeper than 10:1, the severity index definitely indicates that severe injuries would occur.

Runs 13 through 18 were made to determine the feasibility of using a median side slope of 8:1 in conjunction with a grate slope of 8:1. The departure angle of the automobile was treated as a variable. As evident in Table 1, rollover occurred at a very shallow departure angle of 5 degrees in negotiating path 2 in Figure 3. If, however, the automobile encountered the flat ditch prior to negotiating the grate slope (path 3 in Figure 3) at the same shallow departure angle of 5 degrees, rollover did not occur.

After evaluating the results up to this point, it appeared that an 8:1 side slope and 10:1 grate slope were a reasonable combination which would satisfy the safety, economic, and the hydraulic requirements. Thus, runs 19 through 23 pertain to a median side slope of 8:1 and a grate slope of 10:1, whereas the automobile departure angle was treated as the variable. As evident in Table 1, the acceleration severity index of the automobile was unity or less for all cases. As mentioned earlier, however, the acceleration severity index slightly exceeded unity for a headon 10:1 grate slope simulation indicating that severe injuries may occur. The terrain locations where the automobile will land after being airborne are shown in Figure 8. For departure angles of 20 degrees and less, the automobile will land in the median on the other side of the 40 foot crossover; whereas, for a departure angle of 25 degrees, the automobile will set down on the outside edge of the opposite traffic lane shoulder. Simulations were not made for automobile departure angles greater than 25 degrees because the findings of

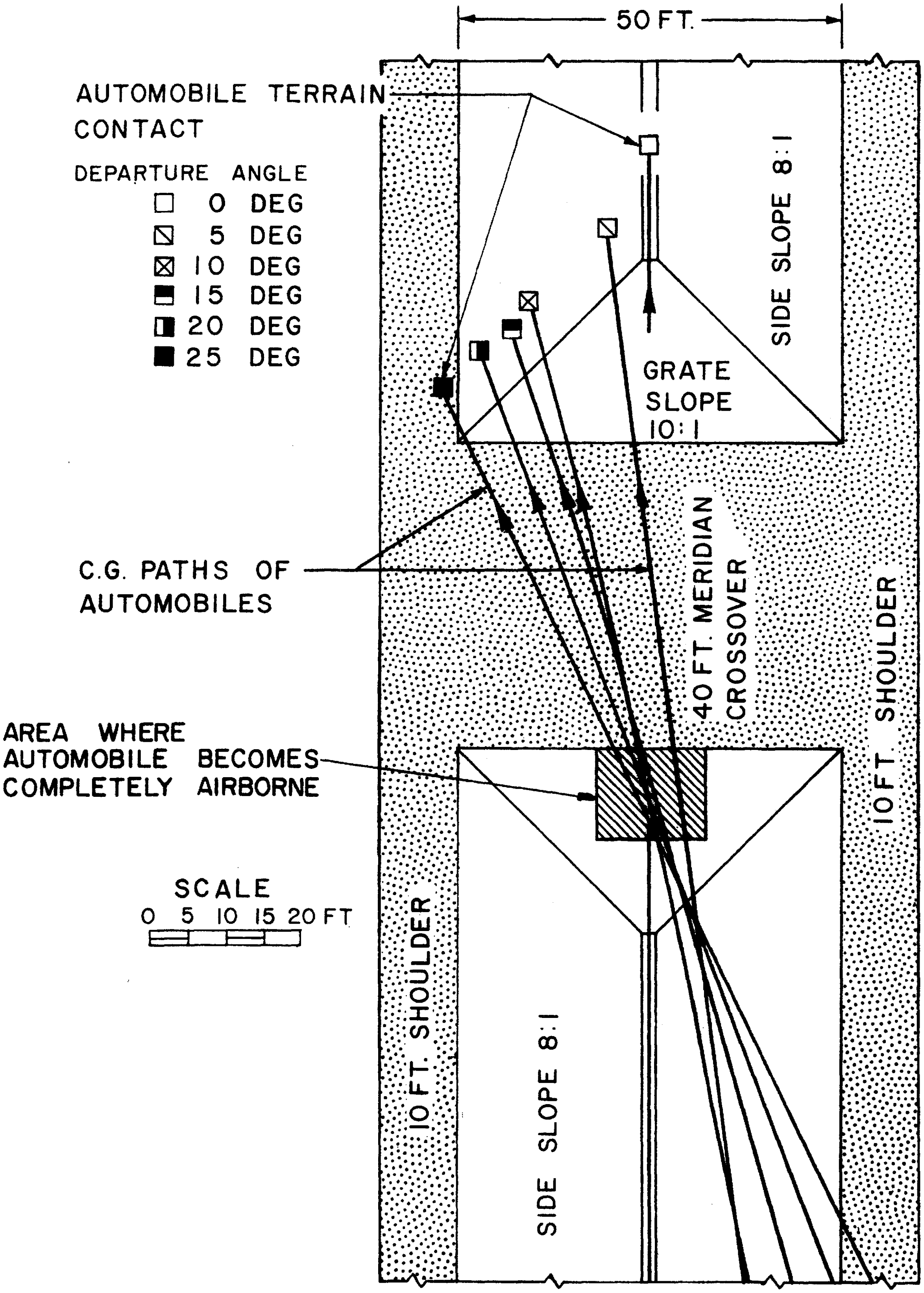


FIGURE 8. LOCATIONS WHERE AUTOMOBILE CONTACTS TERRAIN AFTER BEING AIRBORNE

Hutchinson (7) showed that only a very small percentage (about 11%) of the median encroachments exceed 25 degrees. It is interesting to note in Table 1 that the maximum roll angle as the automobile was airborne occurs at a shallow departure angle of 5 degrees.

In addition to providing information to determine if a terrain configuration in the vicinity of a sloping grate culvert is *"traffic-safe"*, this study further provides information on the dynamic loads (see Table 1) imposed by the automobile tires on the culvert grate. Load impact factors, which are defined as the ratio of the dynamic tire loads to the static tire loads, were computed and listed in Table 1. In the absence of additional data it may be assumed that these load impact factors for a standard size automobile would pertain to any size vehicle such as a larger size automobile, bus, or truck.

FINDINGS

Parameter studies were conducted to determine the influence automobile departure angle and path, median side and grate slopes, and ditch depth had on the automobile's response. Both headon and angle automobile departures were studied. The speed at which the automobile left the roadway was taken as 60 mph. For evaluation criteria, the median side and grate slope configurations were judged on their ability to minimize automobile accelerations (which is measured by a severity index), prevent rollover, and to minimize the chance of the automobile landing in the opposite lane of traffic after being airborne.

The following are specific findings:

1. For side slope to grate slope traversals, the tendency for a automobile to roll over increases as the angle of departure decreases.
2. For headon traversals of grate slopes: (a) The acceleration severity index for a grate slope of 10:1 indicates that an automobile's occupant could usually sustain the maneuver without serious injury. (b) For grate slopes steeper than 10:1, the severity index indicates that severe injuries would probably occur. (c) Rollover (actually pitch over) will occur for a 6:1 slope with a ditch depth of 3 feet.
3. Rollover will occur for certain departure paths for a 6:1 side slope used in conjunction with 10:1 and steeper grate slopes.
4. For a 6:1 side slope and 6:1 grate slope, reducing the ditch

depth from 3 to 2 feet did not prevent rollover.

The results further indicate that an automobile departing at angles of 25 degrees and less could "safely" negotiate a terrain configuration having side slopes of 8:1 and a culvert grate slope of 10:1. Information on the automobile dynamic response as it negotiates this configuration can be summarized as follows:

1. The acceleration severity index was unity or less for angle traversals and 1.1 for headon traversals indicating that an occupant could probably sustain the maneuvers without serious injury.
2. The maximum roll angle, which occurred at a 5 degree departure angle, was 50 degrees.
3. The distance airborne was sufficiently low so that the automobile would set-down on the shoulder of the opposing traffic lane or median and hence probably not endanger traffic in the opposing lanes of travel.
4. The dynamic vertical tire load on the sloping grate was about 5 times greater than the static weight of the automobile.

In NCHRP 3 (1) guidelines are presented which suggest side slopes and culvert sloping grates should be 10:1 and flatter. The findings of this study tend to substantiate these guidelines.

Although this study was directed specifically toward sloping grates on median crossovers, the results will be applicable to at least two other roadside sites. These are:

1.) two sloping inlet grates which collect water in a median and distribute it to a culvert placed under the traveled roadway, and

2.) a driveway or roadway which abuts the main highway.

ACKNOWLEDGEMENT

The consultation and suggestions of Mr. John Nixon and Mr. Dave Hustace of the Texas Highway Department and Mr. Edward Kristaponis of the Federal Highway Administration during the course of this study were appreciated. Mr. Wayne Lammert's assistance in conducting computer runs and in data reduction is acknowledged.

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