EVALUATION OF ROADWAY SAFETY FEATURES BY COMPUTER SIMULATION--A FINAL REPORT

by

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Research Report 140-10F

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

Research Study No. 2-10-69-140

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16. Abstract

Research on evaluation of the roadway environment by dynamic analysis of the interaction between the vehicle, passenger, and the roadway began in 1968 and was concluded in 1974. The broad objective of the research was to develop criteria beneficial to the design of a safe highway and its roadside features. Math models and limited full-scale tests were the basic research tools to be used in developing the criteria.

Since the comprehensive research began, a total of nine individual studies were undertaken. This report briefly summarizes these studies.

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Median Barriers, Crash Tests, Math Simulations, Warrant Angles, Impact Severity, Sloping Grates, Guardrails, Traffic Barriers.

FOREWORD

The information contained herein was developed on Research Study 2-5-69-140 entitled "Evaluation of the Roadside Environment by Dynamic Analysis of the Interaction Between the Vehicle, Passenger, and Roadway." Study 140 was a cooperative research study sponsored jointly by the Texas Highway Department and the U.S. Department of Transportation, Federal Highway Administration. It began in September of 1968 and terminated August, 1974.

The basic objective of the study was to develop criteria to aid in the design of a safe highway. This was accomplished through the application of mathematical simulation techniques, verified by selected crash tests, to determine the dynamic behavior of automobiles and their occupants when in collision with roadside objects or when traversing highway geometric features such as ditches, sloping culvert grates, etc.

Several significant findings have resulted from the study and these are documented in the following reports:

1. "Documentation of Input for Single Vehicle Accident Computer Program," Young, R. D., et al., TTI Research Report 140-1, July, 1969.

2. "A Three-Dimensional Mathematical Model of an Automobile Passenger," Young, R. D., TTI Research Report 140-2, August, 1970.

3. "Criteria for the Design of Safe Sloping Culvert Grates," Ross, H. E., Jr., and Post, E. R., TTI Research Report 140-3, August, 1971.

4. "Criteria for Guardrail Need and Location on Embankments," Ross, H. E., Jr., and Post, E. R., TTI Research Report 140-4, April, 1972.

5. "Simulation of Vehicle Impact with the Texas ete Median Barrier," Young, R. D., et al., TTI Research t 140-5, June, 1972.

6. "Dynamic Behavior of an Automobile Traversing Selected Curbs and Medians," Ross, H. E., Jr., TTI Research Report 140-6, January, 1975.

7. "Comparison of Full-Scale Embankment Tests with Computer Simulations," Ross, H. E., Jr., and Post, E. R., TTI Research Report 140-7, December, 1972.

8. "Impact Performance and a Selection Criterion for Texas Median Barriers," Ross, H. E., Jr., TTI Research Rerpot 140-8, April, 1974.

9. "HVOSM User's Manual," James, M. E., Jr., and Ross, H. E., Jr., TTI Research Report 140-9, August, 1974.

SUMMARY

Research on evaluation of the roadway environment by dynamic analysis of the interaction between the vehicle, passenger, and the roadway began in 1968 and was concluded in 1974. The broad objective of the research was to develop criteria beneficial to the design of a safe highway and its roadside features. Math models and limited full-scale tests were the basic research tools to be used in developing the criteria.

Since the comprehensive research began, a total of nine individual studies were undertaken. This report briefly summarizes these studies.

The first study (Research Report 140-1) involved the documentation of imput requirements for the Highway-Vehicle-Object-Simulation-Model (HVOSM)*. The HVOSM was the basic research tool used throughout the study. The second study (Research Report 140-2) concerned the development of a dynamic occupant math model. As originally envisioned, the occupant math model would be used in conjunction with HVOSM to determine the occupants dynamic behavior during a given crash. However, due to other priorities, the occupant model was not implemented in this study.

The third study (Research Report 140-3) involved the application of the HVOSM to investigate the dynamic behavior of an automobile as it traversed sloping culvert grates. The objective was to develop criteria from which a traffic-safe sloping grate could be designed. In the fourth study (Research Report 140-4), criteria were developed for use in determining guardrail need on embankments. The HVOSM was used, in combination with crash tests, to develop the criteria.

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*Previously known as CALSVA.

In the fifth study (Research Report 140-5), the HVOSM was used, in combination with crash test data, to determine the impact performance of the Texas Concrete Median Barrier. The sixth study (Research Report 140-6), involved application of the HVOSM to investigate the dynamic behavior of an automobile as it traversed selected curb and median configurations. This study was conducted at the request of several districts within the Texas Highway Department.

The seventh study (Research Report 140-7), concerned full-scale embankment tests and a comparison of these tests with HVOSM simulations. The objective of these tests and this study was to substantiate the criteria presented in Research Report 140-4. The eighth study (Research Report 140-8), involved the development of selection criteria for the two most widely used Texas Median Barriers. These are the Concrete Median Barrier and the Metal Beam Guard Fence (Double Flex Beam).

The ninth and final study (Research Report 140-9), concerned the writing of an updated user's manual for TTI's version of HVO

IMPLEMENTATION STATEMENT

The results of this study have proven to be beneficial to the Texas Highway Department (THD) in the area of highway safety. Success of this study can be attributed in large part to the close cooperation that existed between the Texas Highway Department, the Federal Highway Administration, and the Texas Transportation Institute. Studies have been conducted which have general interest to the state as a whole. In some cases, the studies originated from design questions which arose in certain districts within the THD.

In most cases, the studies were also of national interest. Of the nine individual studies conducted, five have been published in the Transportation Research Board's Records.

Criteria have been developed to aid in the design and selection of sloping culvert grates, roadside quardrail, median barriers, curbs, and medians. In some cases, these criteria have been incorporated in the Operations and Procedures Manual of the Highway Design Di\ the Texas Highway Department.

The researchers at TTI have also developed considerable expertise in the modification and application of the HVOSM computer program. Should future needs arise in the Texas Highway Department, the HVOSM could be used in an expedient and inexpensive manner to investigate a wide range of problems.

ACKNOWLEDGEMENTS

The conception of this study must be attributed in most part to the late Dr. Thomas C. Edwards of TTI. It was largely through his foresight and planning that it began.

The success of the study is due to the contributions of many individuals. Mr. John Nixon and Mr. Dave Hustace of the Texas Highway Department and Mr. Edward Kristaponis of the Federal Highway Administration worked very closely with the researchers throughout the program. Their valuable input and cooperation was most appreciated. Other members of the Texas Highway Department who contributed to the study included Messrs. Harold Cooner, H. D. Butler, Paul Tutt, T. R. Kennedy, Jim Thomas, and Phil Darby.

Several TTI staff members made significant contributions to the study. They included Drs. Ron Young, Edward Post, Mike James, and Messrs Joe Bridwell and Lionel Milberger. Drs. T. J. Hirsch, and R. M. Olson of TTI also provided leadership and guidance along the way helpful suggestions. Mr. Louis Horn was very helpful in the publication of the reports. Several other individuals provided assistance during the study, including support personnel at the Research Annex, secretaries, and graduate students.

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INTRODUCTION

This study was initiated in 1968 by the Texas Transportation Institute (TTI) in cooperation with the Texas Highway Department (THD) and the Federal Highway Administration (FHWA). The objective of the study was to develop criteria from which a safer roadway and roadside could be designed. The objective was to be accomplished through the application of automobile and occupant math models, with limited full-scale tests when needed for validation.

The primary research tool in this study was a computer program known as the Highway-Vehicle-Object-Simulation-Model* (HVOSM) (1, 2). During the early stages of the study, the researchers became familiar with the program and its input requirements. The second year of the study was devoted to the development of an occupant model for simulating the dynamic behavior of a human during a crash. However, due to other priorities within the THD, the occupant model was never used in any of the research of this study. The remainder of the study was devoted to the n of the HVOSM to investigate specific problems.

The contents of this report are intended as a summary of each of the nine reports which have been prepared during the course of this study. They are summarized in chronological order.

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*Known originally as the Cornell Aeronautical Laboratory Single Vehicle Accident program (CALSVA).

"DOCUMENTATION OF INPUT FOR SINGLE VEHICLE
ACCIDENT COMPUTER PROGRAM"

by

Ronald D. Young, Thomas C. Edwards,
Richard J. Bridwell, and Hayes E. Ross, Jr.

Research Report 140-1
JULY, 1969

To facilitate the design and evaluation of a roadway and its near environment, it is beneficial to know the effects that various design features have on the dynamic response of the vehicle and passenger. Roadway alignment of horizontal curves, superelevation, and ramps are determined, to a large degree, by the ability of a vehicle to negotiate these features. This ability is dependent upon the dynamic interaction between the vehicle and the roadway surface. Design of the roadway subgrade, pavement, and bridges is dependent upon static and dynamic loads imposed by vehicular traffic. From the safety aspect it is advantageous to know the effects of vehicle collisions with [illegible]ad-side obstacles, such as guardrails, bridge rails, median ba[illegible], sign posts, and others. In the areas adjacent to the traveled way it is important to know the effects that shoulders, side slopes, and back slopes have on a vehicle's motion.

These problems can be studied and evaluated satisfactorily with the use of mathematical simulation techniques. If these problems were studied using full-scale tests, the expense would likely be prohibitive and the number of variables that could be studied would be limited.

As an initial step in this study, a computer program, called HVOSM, was adapted to the computer facilities at Texas A& [illegible]ersity. Basically, the program determines the motions of a single vehicle that occur prior to and during departures from the roadway for given terrain and/or obstacle configurations.

To adapt the program and to take advantage of its many applications, a comprehensive study was made to determine its logic, coding and input requirements. Considerable time was expended in determining various input parameters required for specific situations.

As an aid to the researchers and the sponsor, this report, describing the program's input and its format, was written. All available quantitative input data were presented. Comments regarding some of the input parameters are included to help reduce the time needed for setting up the data and in some cases to reduce computer time.

In adapting the program, additions and modifications were made which increased its flexibility and usefulness. These changes are also documented in this report.

It is noted that this report is intended as a *supplemen*
viously published reports by CALSPAN Incorporated on the HVC 1.
When used in this manner, it should reduce the work involved in implementing the program.

"A THREE-DIMENSIONAL MATHEMATICAL MODEL
OF AN AUTOMOBILE PASSENGER"

by

Ronald D. Young

Research Report 140-2
AUGUST 1970

Highway engineers are continually striving to reduce the severity of vehicle accidents by designing and building a safer roadway environment. To accomplish this, considerations must be given to the expected dynamic response of the vehicle and occupant during a collision with roadside obstacles.

This report presents the development of an analytical model that predicts the response of an automobile passenger during vehicle motion of a general nature, i.e., a three-dimensional path including simultaneous rotations about the three directions. This model reduces the problem of predicting the accelerations and forces acting on a passenger during a collision or violent maneuver to that of specifying the path of the vehicle as a function of time plus the deformation properties of the [illegible]erior.

The vehicle occupant is defined mathematically in three dimensions as an independent system which is then placed inside the vehicle but not connected to it. The vehicle interior contains the passenger within its boundaries by applying contact forces while the vehicle moves through space. The vehicle interior is idealized with 25 planar surfaces and includes lap and torso restraint belts.

The geometry of the vehicle occupant is idealized by 12 rigid mass segments interconnected in a pattern which reflects the articulated nature of the human body. This system has 31 degrees of fre[illegible]hich correspond to the set of generalized coordinates used in Lagrange[illegible]s equations to derive equations of motion. These equations are solved numerically with the aid of the IBM 360/65 computer.

"Spinal elasticity" is simulated with rotational springs in the back joints of the articulated body, and "muscle tone" is simulated with rotational viscous dampers in every body joint.

Validation of the model has been achieved for frontal collisions. The model's predicted response of a dummy on a test cart compared well with actual test data. Both restrained and unrestrained conditions were analyzed. There were two restrained conditions: (1) lap belt only and (2) lap and torso belt.

Features of this program include: automatic seating of the passenger inside the vehicle; seating the passenger at either the left front, right front, left rear, or right rear positions; a lap restraint belt at any of these four positions; and/or a torso restraint belt at any of these four positions.

Output from the program is presented in three forms: (1) digital printout, (2) X-Y plots of selected parameters, and (3) orthographic views of the passenger with respect to the vehicle interior for any g during an event.

The model provides the highway engineer with a tool which will enable him to apply biomechanics data on human tolerance limits to the problem of modifying roadside structures such that occupant injuries during vehicle accidents can be reduced.

"CRITERIA FOR THE DESIGN OF SAFE SLOPING CULVERT GRATES"

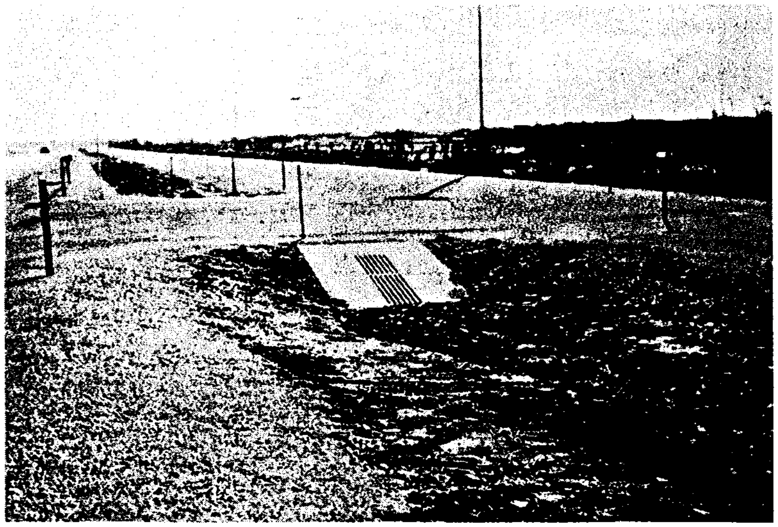
by

Hayes E. Ross, Jr., and Edward R. Post

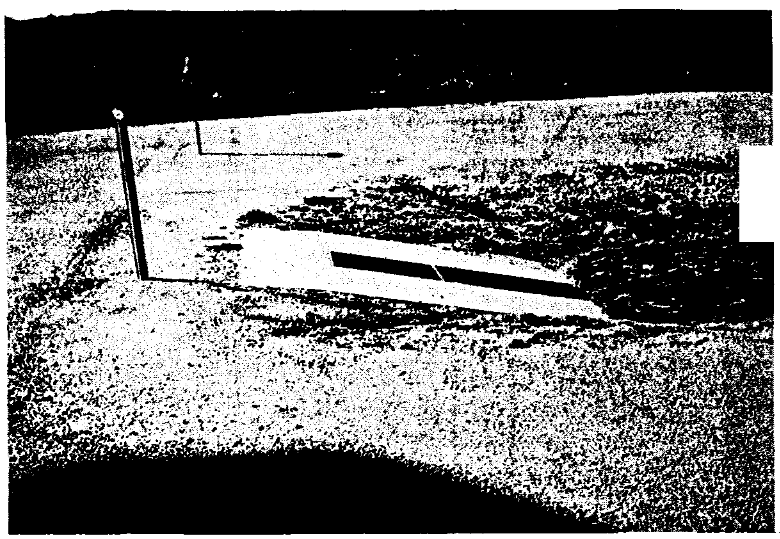
Research Report No. 140-3
AUGUST, 1971

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 culvert inlet, with or without headwalls. In recent years, a limited number of sloping inlet and outlet grates have been installed, which allow an automobile to traverse the culvert opening rather than come to an abrupt stop. Figure 1 shows a typical sloping culvert grate. Sloping grates are currently designed primarily on judgement and experience due to the absence of objective criteria.

The objective of this study was to develop criteria from which a traffic-safe sloping grate configuration could be designed. A traffic-safe drainage structure has been defined as "one which does not inhibit the ability to regain control of his vehicle...permitting him to return t... ...eled roadway or to stop safely without damage or injury (3)". To meet the objective, a mathematical computer simulation technique was used to investigate the dynamic behavior of a standard size automobile as it left the roadway at 60 mph and traversed various combinations of ditch and grate slopes. A plan view of the selected site is shown in Figure 2. Parameter studies were conducted to determine the influence that automobile departure angle and path, ditch or median side slope, grate slope, and ditch depth had on the automobile's response. The automobile encroachment angle to the sloping grate varied from 0 degrees (head-on) to 25 degrees. For evaluation cr..., the configurations were judged on their ability to minimize the severity of automobile acceleration



(a) APPROACH TO A SLOPING GRATE



(b) SIDE VIEW OF A SLOPING GRATE

FIGURE 1. A TYPICAL SLOPING CULVERT GRATE

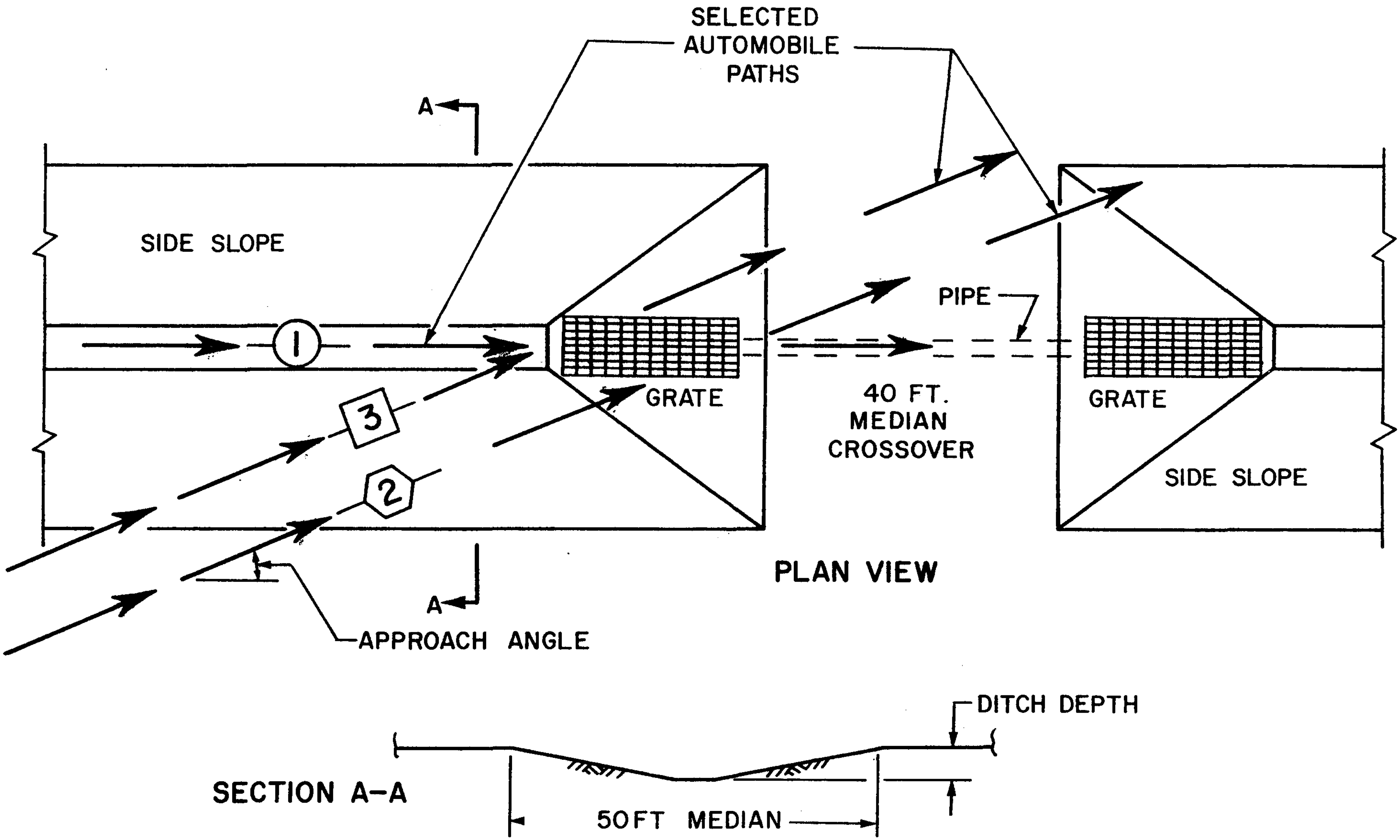
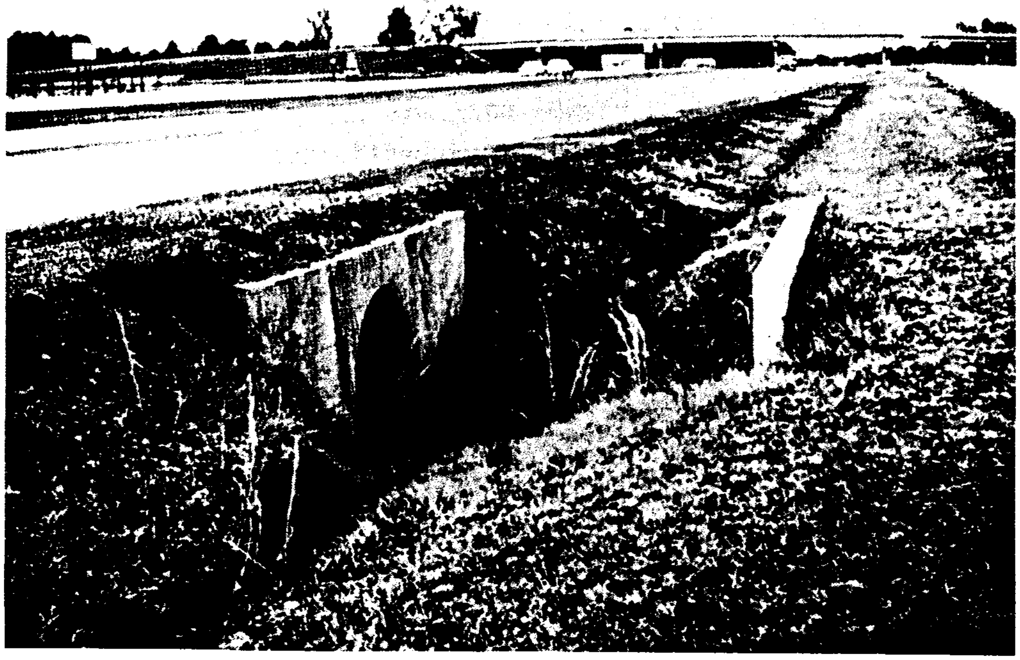
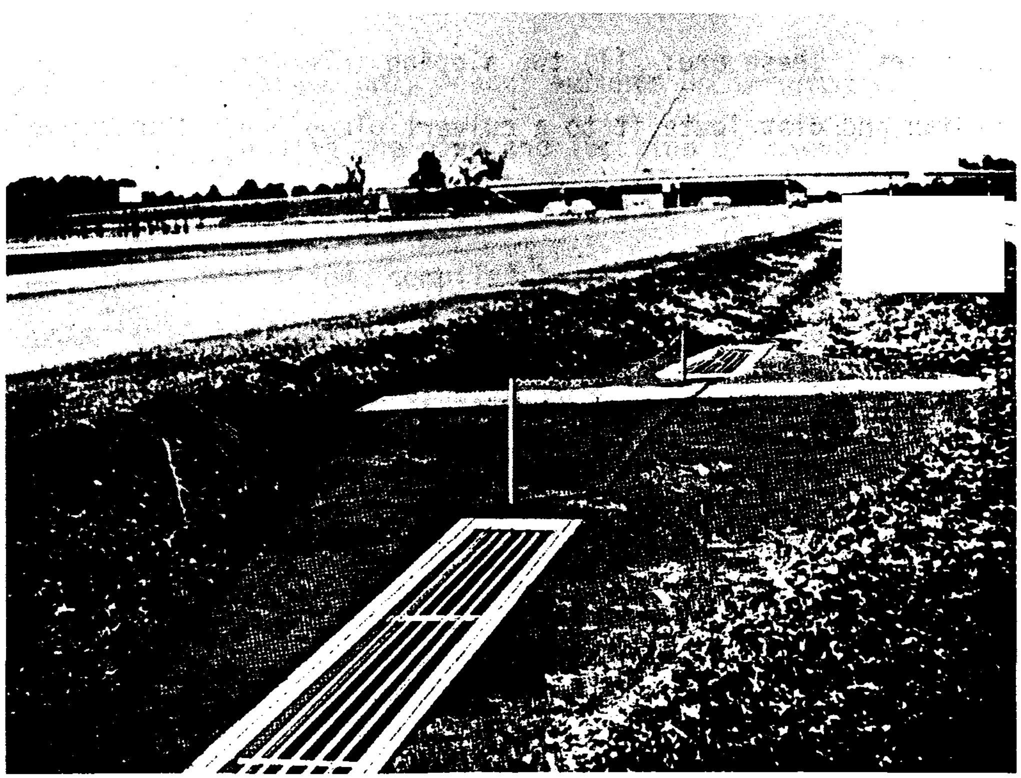


FIGURE 2. SIMULATED MEDIAN TERRAIN CONFIGURATION AND SELECTED RAN-OFF-ROAD AUTOMOBILE PATHS



(A) Existing



(B) Suggested Modifications

FIGURE 3. MODIFICATIONS OF EXISTING CULVERT CROSSOVER (3)

(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 congifurations investigated, an 8:1 side slope in conjuntion with 10:1 culvert grate slope was the only combination which satisifed the above evaluation criteria. This combination of side and grate slope is probably feasible from an economic and hydraulic standpoint. Flatter side and grate slopes would be even more traffic-safe. 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.

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, as shown in Figure 3, and (2) a driveway or roadway which abuts the [illegible]ay.

"CRITERIA FOR GUARDRAIL NEED AND LOCATION ON EMBANKMENTS"

by

Hayes E. Ross, Jr., and Edward R. Post

Research Report 140-4
APRIL, 1972

When a vehicle, traveling at a high speed, leaves the roadway and strikes a guardrail, a hazardous situation obviously exists. It is also hazardous when there is no guardrail and the vehicle must traverse the ditch. Neither event is desirable. Nevertheless, for a given type of guardrail, a given ditch or embankment configuration, and given vehicle encroachment conditions, one situation will be less severe than the other. The primary objective of this study was to develop criteria from which the less severe condition can be selected.

Highway engineers have had only meager amounts on information to make an objective decision regarding the need and location of guardrail. In many cases criteria are based on the results of a particular statisti(analysis of accident information, compiled by the California Division of Highways in 1966 (4). The results of that study, while of significance for the specific guardrails used in California during the period of the accident records (before 1966), should be used with discretion on other guardrail designs. The guardrail, used in California during this period, was mounted on posts spaced either on 10 foot centers or on 12 1/2 foot centers. As the post spacing decreases the lateral stiffness of the guardrail increases. In general, as the lateral stiffness of guardrail increases its resistance to impact deformation increases, and as a consequence the collis verity increases. In Texas, most of the guardrail is supported on posts spaced on 6 foot-3 inch centers.

To determine the severity of an automobile traversing an embankment the HVOSM computer program was used. The orientation and accelerations of the automobile were computed as it traversed the embankment. A combination of mathematical simulations and full-scale test data was used to determine the severity of an automobile in collision with a guardrail. Accelerations at the center of gravity of the automobile served as the indicator or measure of severity.

Guardrail should be used for conditions in which the severity of an errant automobile redirected by the guardrail would be less than the severity of the automobile traversing the unprotected embankment. For an automobile leaving the roadway at 60 mph with a 25 degree encroachment angle, criteria were established for selecting the less severe alternative, i.e., guardrail versus no guardrail. The criteria are developed for a steel W-beam guardrail with a 6 ft.-3 in. post spacing. This is the primary type guardrail used by the Texas Highway Department.

The criteria, shown in Figure 4, are in graphical form for application. The dotted line represents the best estimate or av l- Severity-Curve. If a given combination of side slope and ditch depth falls below the curve, guardrail is not recommended, and vice-versa for combinations above the curve. Discretion would obivously be necessary for those configurations below the curve where obstacles exist along or at the bottom of the side slope. In those cases, guardrail in the immediate vicinity of the hazard would probably be needed.

It should be noted that the safer option (guardrail versus no guardrail) determined by use of this criteria will not necessarily insure a "safe" situation, i.e., severe injuries may still occur. This ch will, however, provide an objective means of selecting the safer of two hazardous situations.

EMBANKMENT SLOPE (b:a)

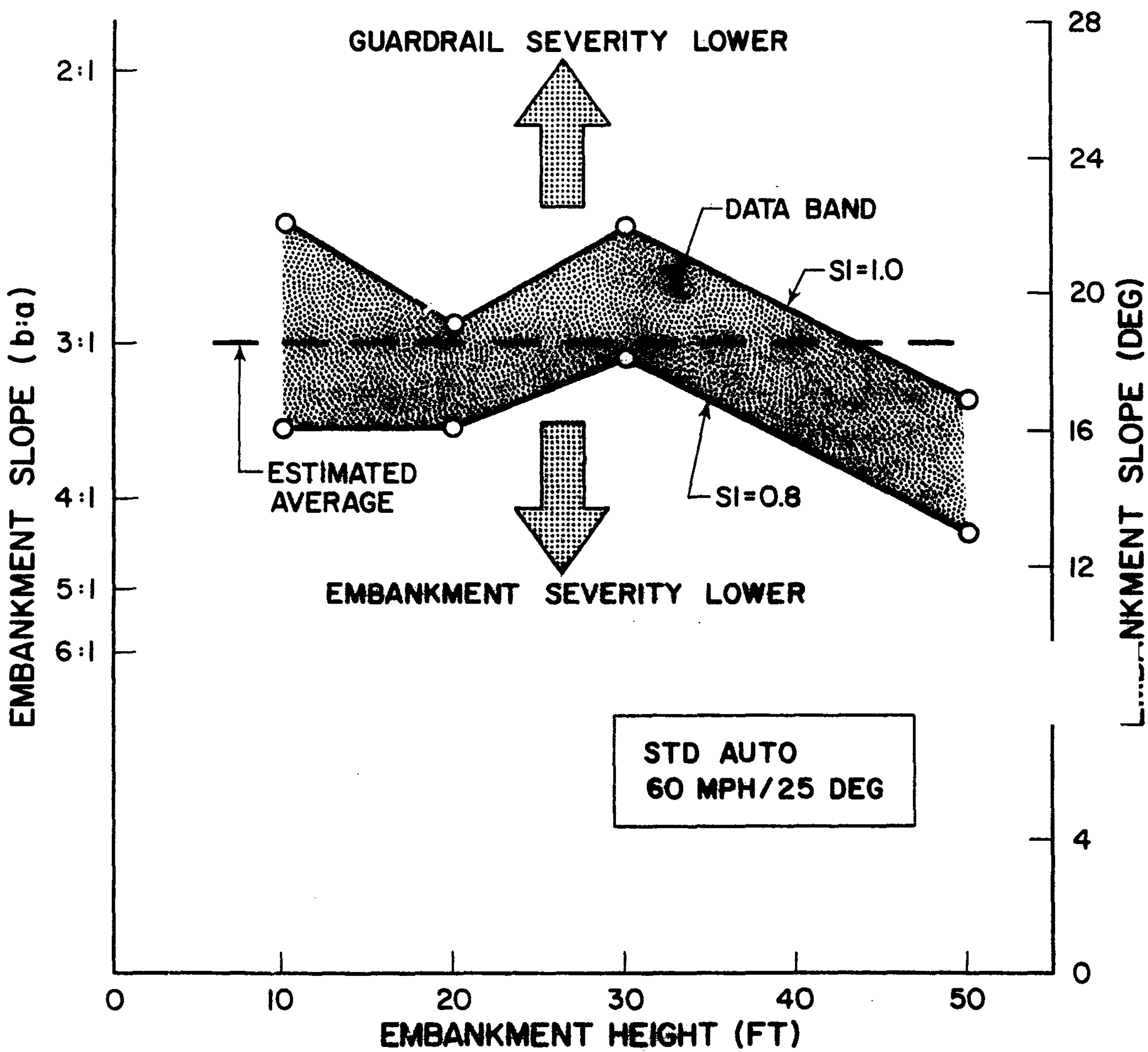


Figure 4. Warrant for guardrail on embankments.

In another phase of this study, an investigation was made to determine the relative severity between the W-beam guardrail with 6 ft.-3 in. post spacing and no guardrail for a 3:1 embankment, 20 feet in depth with a flat-bottom ditch, and various automobile encroachment conditions (50 mph, 60 mph, and 70 mph in combination with encroachment angles of 10 degrees, 17.5 degrees, and 25 degrees). It was concluded that for shallow angles, a guardrail collision is higher in severity than traversing the 3:1 embankment. However, as the speed and angle of departure increases, the severity of traversing the embankment approaches that of striking a guardrail.

In terrain where large fill heights are required, a 6:1 slope is often provided up to 20 feet off the shoulder's edge and a 1 1/2:1 slope from that point to the bottom of the fill. Guardrail protection is usually provided for the steeper 1 1/2:1 slope. The final phase of this study was addressed to the question: If the rail is placed on the 6:1 slope, how far off the shoulder should it be located to minimize the possibility of an automobile vaulting it? It was concluded that the rail should be 12 feet or further from the shoulder's edge.

"SIMULATION OF VEHICLE IMPACT WITH THE TEXAS CONCRETE MEDIAN BARRIER--TEST COMPARISONS AND PARAMETER STUDY"

by

R. D. Young, E. R. Post, H. E. Ross, Jr., and R. M. Holcomb

Research Report 140-5
JUNE, 1972

The concrete median barrier (CMB) is a wall separating opposing lanes of traffic. Its cross-section, which has been called the "safety shape," is generally patterned after the New Jersey and General Motors designs. Maintenance of the CMB is virtually nonexistent and tests have shown that vehicle impacts at low angles are not hazardous to the occupants. Therefore, this barrier is especially well suited for use in narrow medians of roadways carrying high traffic volume.

The objective of this study was to produce additional detailed information which would aid the highway designer in making decisions during the evaluation of an existing roadway for possible installation of the CMB and durin[illegible] design of a new roadway for accommodating the CMB. The objective wa[illegible] using a modified version of HVOSM to predict the response of a standard size automobile impacting the Texas CMB (New Jersey type) at specified speeds and impact angles.

The ability of HVOSM to simulate a vehicle impacting the CMB was successfully demonstrated by numerically reconstructing three full-scale tests on the Texas CMB with a 4000-lb. car at 60 mph and impact angles of 7, 15, and 25 degrees (5). After validation, the model was used to extrapolate the test results to encroachment conditions of 50, 70, and 80 mph and angles of 5, 10, and 15 degrees for each speed.

In addition, the severity of each of the simulated CMB impacts (as computed from an index based on vehicle G-levels) was related to probable occupant injury as a function of encroachment conditions (Figure 5). For example, Figure 5 suggests that for a design speed of 70 mph, the roadway and median widths should be adjusted such that a vehicle could not be steered into the barrier to achieve an impact angle any greater than 10 degrees. Deleys (6) has suggested a method of estimating impact angle as a function of lateral distance, speed, and tire-roadway friction. Such a method is needed to apply the information in Figure 5.

Other significant findings of the study were that: (1) vehicle rollover can be expected for speeds of 70 mph and greater at impact angles of 15 degrees and greater, (2) for speeds of 80 mph and less at impact angles of 15 degrees and less, the car exhibited no tendency to vault or climb the barrier, and (3) for the ten impact conditions simulated, where rollover did not occur, the car's exit angle after impact was shallow (less than 6 degrees).

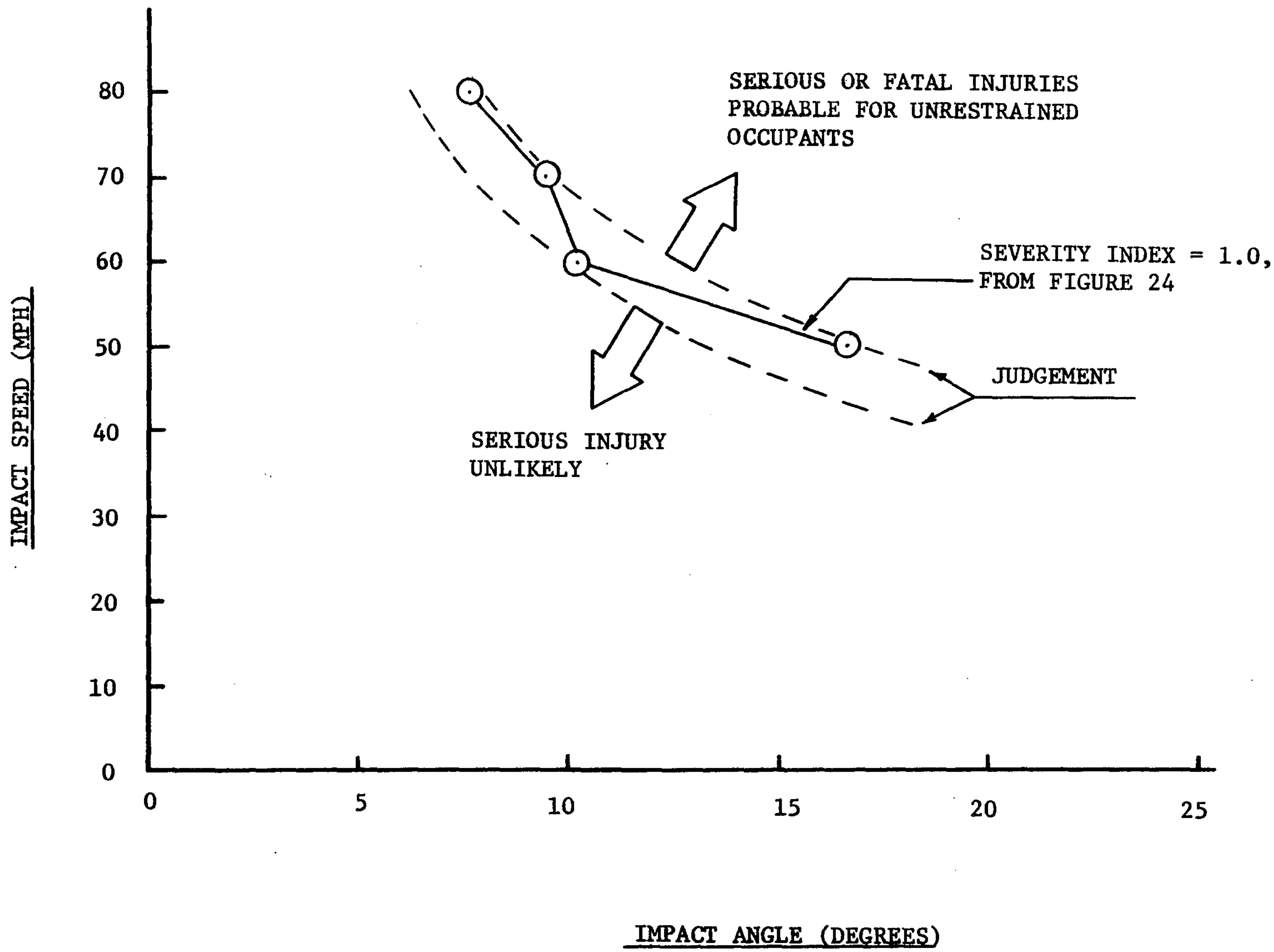


FIGURE 5. - RELATION EN ENCROACHMENT CONDITIONS AT A SEVERITY INDEX NEAR UNITY FOR CMB

"DYNAMIC BEHAVIOR OF AN AUTOMOBILE TRAVERSING SELECTED CURBS AND MEDIANS"

by

Hayes E. Ross, Jr.

Research Report 140-6
JANUARY, 1975

At the request of several districts within the Texas Highway Department (THD), studies were conducted to determine the behavior of an automobile traversing selected curbs and sloped median configurations. The purpose of these studies was to determine if a potential existed for the automobile to vault a barrier placed behind the curb or on the sloped medians.

Six inch and eight inch curb configurations were investigated. Medians having slopes of 1.1 inches per foot, 1.5 inches per foot, and 4.6 inches per foot were also investigated. Figure 6 shows the automobile as it approaches the barrier and at the moment of impact for one of the sloped medians under consideration.

The Highway-Vehicle-Object-Simulation-Model (HVOSM) was use[illegible]mine the dynamic behavior of the automobile. A full-size automobile [illegible]ndard suspension system was simulated in each case. An extensive validation study, conducted in another TTI study, has shown that the HVOSM can accurately predict vehicle behavior after traversing curbs.

It was concluded that barriers should not be placed behind curbs. Curbs can either cause the vehicle to vault the barrier, or to impact it at a lower than normal position which can cause snagging of the vehicle. A flat approach area to the barrier seems to be the most desirable configuration.

It was also concluded that problems with barriers [illegible]ised curb-median or curb-roadside configurations can be reduced in some [illegible] by sloping the median or roadside up to the barrier. Concrete median barriers on narrow raised medians should be avoided where possible.

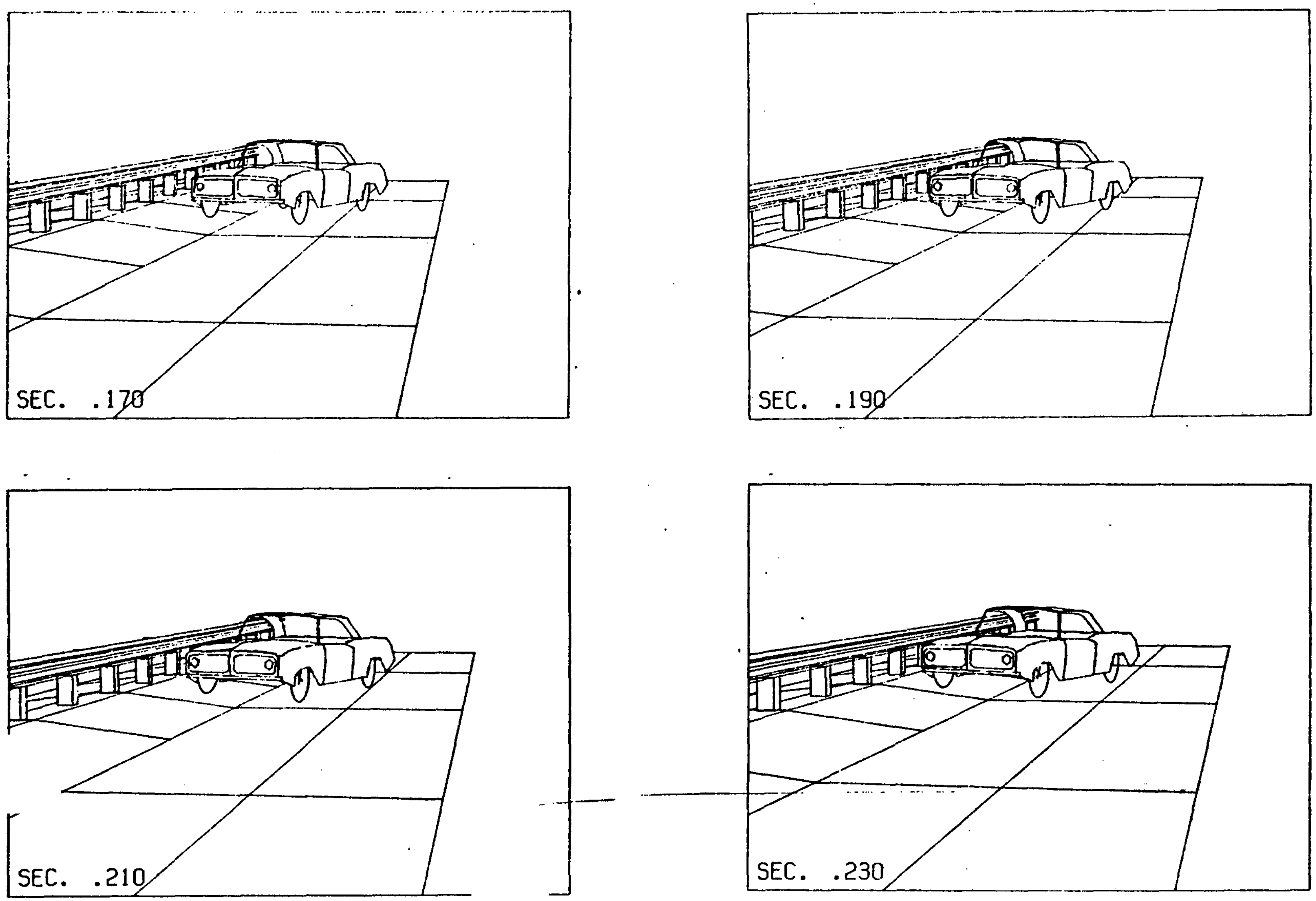


FIGURE 6. AUTOMOBILE BEHAVIOR UP TO IMPACT WITH BARRIER

"COMPARISONS OF FULL-SCALE EMBANKMENT TESTS WITH COMPUTER SIMULATIONS"

by

Hayes E. Ross, Jr. and Edward R. Post

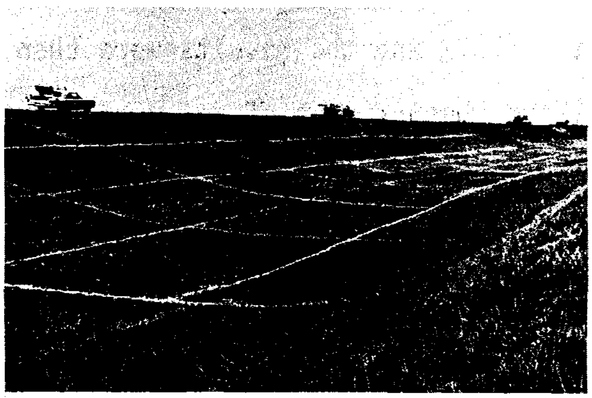
Research Report 140-7
DECEMBER, 1972

Criteria were presented in Research Report 140-4 identifying embankments which needed guardrail protection. A portion of the criteria was based on output from the Texas Transportation Institute's version of the HVOSM computer program. Since HVOSM had not been validated for embankments with relatively steep side slopes and since implementation of the criteria would require changes in current Texas Highway Department design procedures, it was decided that a limited validation study should be conducted.

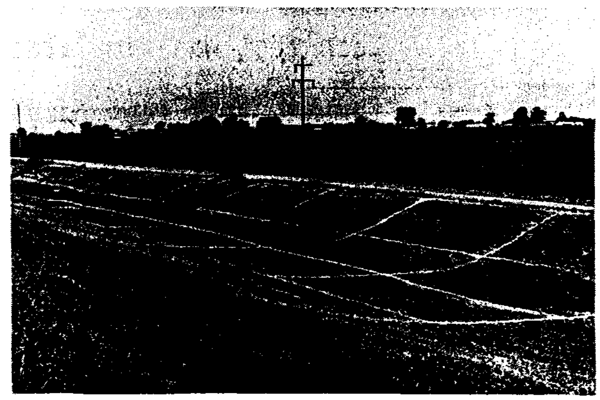
Six full-scale automobile tests were conducted on an embankment of Texas State Highway 21, an in-service roadway. The embankment, shown in Figure 7, had a side slope of approximately 3.5:1 and a flat bottom ditch approximately 20 feet below the roadway. The grassy slope, ditc and back slope were well compacted.

The test vehicle, a 1963 Ford, was instrumented with accelerometers. A radio control system was developed to accelerate the test vehicle to the desired speed and then to guide it off the roadway at the desired point and at the desired angle. Its subsequent response was recorded on high speed film and electronic instrumentation.

A wide variety of encroachment conditions were obtained in the six tests. Encroachment speeds ranged from 45.1 mph to 63.6 mph, and encroachment angles ranged from 8.6 degrees to 20.4 degrees. In addition, suspension failures and, in one case, an attempt to steer back on the side slope ed special test conditions. This range of test conditions is believed to encompass many of



(a) View from top of backslope



(b) View from roadway

(c) View from ditch bottom

FIGURE 7. PHOTOS OF TEST SITE.

the conditions that occur in run-off-the-road accidents. It is significant that for these conditions both test and simulation results showed that a car could traverse the embankment with no tendency to roll over.

Each test was simulated by the HVOSM and the results were then compared with the measured test results. Three basic types of data were compared, namely vertical accelerations, paths of the vehicles, and vehicle attitudes. Figure 8 shows the comparisons for a portion of one of the tests.

The following conclusions were drawn as a result of this study:

1. The Highway-Vehicle-Object-Simulation-Model can accurately predict the dynamic behavior of an automobile traversing an embankment, with the exception of those instances when mechanical failures occur in the vehicle (see conclusion 4).

2. As a consequence of conclusion 1, the criteria on guardrail need, presented in Research Report 140-4 has been substantiated.

3. An automobile and its occupants can traverse a 3.5:1 side slope with a flat bottom ditch 20 feet below the roadway with relative tolerable accelerations for a wide variety of encroachment condi.......

4. HVOSM is incapable of predicting mechanical failures which may occur in an automobile and the subsequent effects of such failures. The suspension failures that occurred in two of the six tests were attributed in part to the condition of the test car's suspension system. The condition of the suspension system degenerated with each test.

5. Although vehicle control was lost due to mechanical failures in two of the six tests, the vehicle remained in a stable attitude and traversed the embankment without any serious problems.

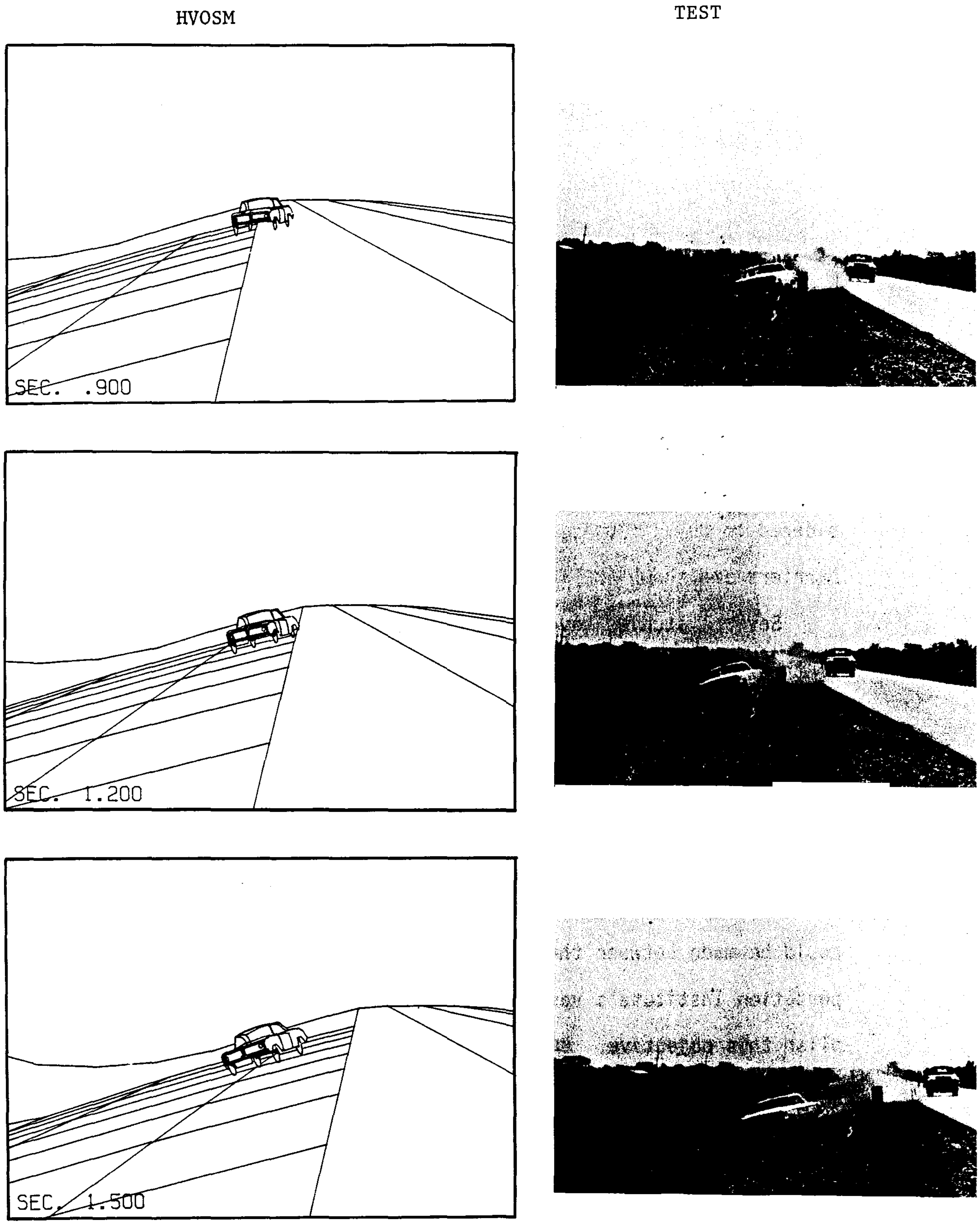


FIGURE 8. HVOSM TEST RESULTS, TEST NO. 1. CAMERA NO. 2.

"IMPACT PERFORMANCE AND A SELECTION CRITERION FOR TEXAS MEDIAN BARRIERS"

by

Hayes E. Ross, Jr.

Research Report 140-8
APRIL, 1974

To prevent median crossover accidents, the Texas Highway Department (THD) uses, in most cases, one of two basic median barriers. These are the concrete median barrier (CMB) and the metal beam guardfence (MBGF). The CMB is for all practical purposes a "rigid" unyielding barrier, while the MBGF is considered to be a "flexible" barrier, one that deforms upon impact. The two barriers are shown in Figures 9 and 10.

Several studies have been conducted to determine the impact performance of the CMB. It has been shown that for small impact angles the CMB can safely redirect an encroaching vehicle. However, these studies also showed that as the impact angle increases the impact severity increases considerably.

With regard to the MBGF, only a very limited amount of impa ance data existed prior to this study. One of the objectives of this study was therefore to determine its impact performance so that objective comparisons could be made between the CMB and the MBGF. Crash tests and the Texas Transportation Institute's version of the HVOSM computer program were used to accomplish this objective. Before applying the HVOSM, however, an extensive validation study was performed. Crash test data were compared with the HVOSM predictions. Some modifications were made to the HVOSM in order to achieve an acceptable comparison.

Another task this study addressed concerned the rel ship between median width and the probable angle of impact into a median barrier for errant vehicles. This relationship was needed to develop a selection criterion for the two barrie

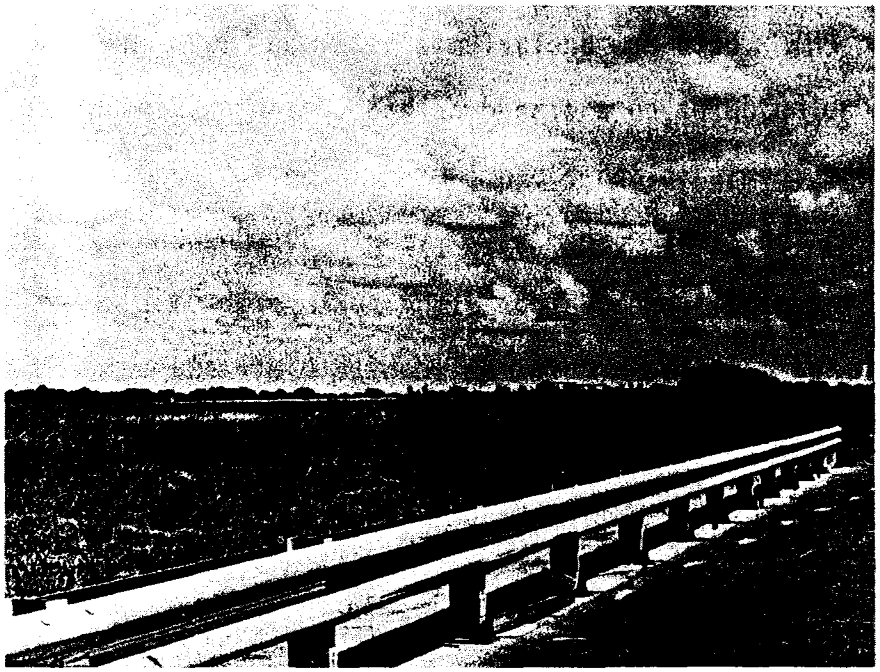


FIGURE 9. METAL BEAM GUARD FENCE.

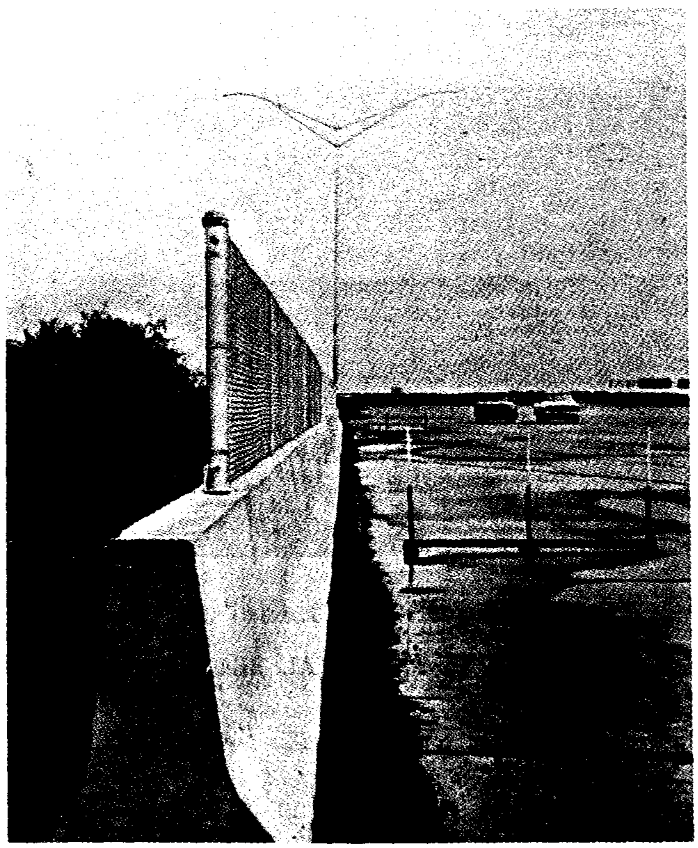


FIGURE 10. CONCRETE MEDIAN BARRIER.

systems. It has been postulated that the CMB is best for "narrow" medians where high impact angles are improbable and that the MBGF should be used for "wide" medians. However, objective criteria to quantify what "narrow" and "wide" means had to be developed. To accomplish this task, a combination of field measurements and HVOSM computer simulations was used. THD personnel conducted the field measurements. Median barriers on selected urban freeways were inspected for impact damage. Where impacts had occurred, measurements of the angle of impact, median width, etc., were made. These data were then statistically analyzed to determine impact angle probabilities. The HVOSM was used to supplement the field data by defining "upper limits" on impact angles as a function of median widths.

The end result of this study was an objective criterion which can be used in the median barrier selection process. The criterion, which is given in Figure 11, shows the relationship between impact severity and median width, on a probability basis, for the CMB and the MBGF barriers.

The Texas Highway Department used this criterion to establish for the determination of median barrier type. It is noted that the lines were established in consideration of other factors also, such as initial costs, maintenance, safety to repair crews, and others. The guidelines are as shown in Table 1.

The following conclusions were drawn as a result of this study:

1. The Texas standard metal beam guardfence will contain and redirect and automobile impacting at 60 mph at impact angles of 7 degrees, 15 degrees, and 25 degrees. There is no tendency for the automobile to become unstable after impact with the MBGF and the exit angle of the vehicle is not large.

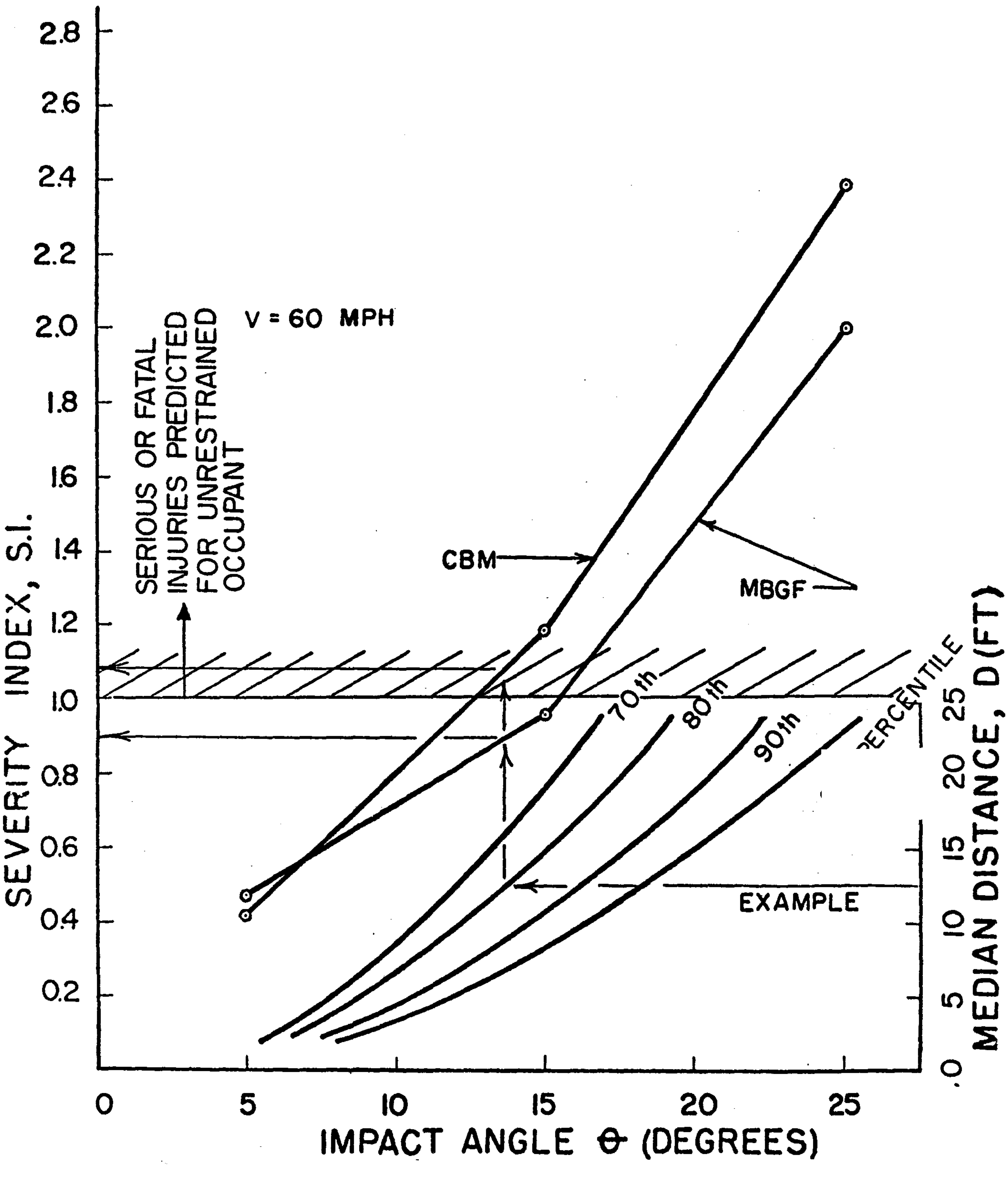


FIGURE 11. SELECTION CRITERION.

TABLE 1. TEXAS HIGHWAY DEPARTMENT MEDIAN BARRIER WARRANTS

MEDIAN WIDTH	BARRIER TYPE
Up to 18 Feet	Concrete
18 to 24 Feet	Concrete or Double Steel Beam
24 to 30 Feet	Double Steel Beam

Serious or fatal injuries are not predicted for impacts at angles less than 15 degrees and speeds less than 60 mph.

2. The as-modified version of the HVOSM can be used to simulate automobile impacts with the MBGF. Close correlations between test and simulated results forms a basis for this conclusion.

3. The severity of impact with the Texas standard concrete median barrier at 60 mph is approximately equal to that of the MBGF for angles of impact of 7 degrees or less. However, as the angle of impact increases, impacts become progressively more severe with the CMB than with the MBGF.

4. The CMB is practically maintenance free whereas it costs a ly $500 to repair the MBGF after a 60 mph, 15 degree, impact. Based o estimates, automobile repair costs resulting from an impact with the CMB are slightly higher than those for the MBGF at an impact speed of 60 mph and an impact in excess of 7 degrees.

5. Sufficient field data were obtained to determine the percentile distribution of impact angles for a barrier placed in the center of a 24-foot median. A theoretically derived distribution, obtained by application of the HVOSM, compared favorably with the field data. Percentile distributions of impact angles as a function of median distance (distance from roadway edge to barrier face) were obtained by the theoretical analysis.

6. An objective barrier selection criterion was developed from which the impact severity of the MBGF and the CMB can be determined for any given median distance. The criterion is based on a design speed of 60 mph and impacts with a full-size automobile. The Texas Highway Department used this criterion to develop warrants for the use of these two barriers.

"HVOSM USER'S MANUAL"

by

Mike E. James, Jr. and Hayes E. Ross, Jr.

Research Report 140-9
August, 1974

Research Report 140-1 was written in 1969 to document the input requirements of the Texas Transportation Institute's version (V-3 modified slightly) of the Highway-Vehicle-Object-Simulation-Model. Since that time, several additional changes have been incorporated in the model by TTI researchers. This document was therefore written to amplify the information contained in Report 140-1. This report will supersede Report 140-1.

Values of vehicle parameters are included where available. Comments regarding some of the input parameters are included to help reduce the time needed for setting up the data. Sample problems are given which illustrate how the input is determined and how the corresponding output is presented.

CONCLUSIONS

The results of the comprehensive research clearly demonstrate the value of math models in the area of highway safety. When used in conjunction with limited full scale tests the math model can be a very effective research tool. In this research, the HVOSM computer program was used to supplement limited crash test data on barriers and embankments. Sloping culvert grates, curbs, and sloped medians were also investigated.

This report summarized the nine individual studies which have been conducted during the course of the study. Criteria have been developed relevant to guardrails, median barriers, curbs, sloping culvert grates, and sloped medians. These criteria have been incorporated in the Operations and Procedures Manual of the Texas Highway Department and are being implemented.

The HVOSM remains as a very effective research tool, which is available to the THD should the need arise.

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