COST-EFFECTIVENESS OF GUARDRAIL IMPROVEMENTS FOR PROTECTING BRIDGE PIERS IN DEPRESSED MEDIANS ON HORIZONTAL CURVES

by

EDWARD R. POST, P.E.

PATRICK T. McCOY, P.E.

WALTER E. WITT, P.E.

TERRY J. WIPF

PATRICK A. CHASTAIN

in cooperation with

NEBRASKA DEPARTMENT OF ROADS

CIVIL ENGINEERING DEPARTMENT

RESEARCH REPORT NO. TRD-03-002-78

UNIVERSITY OF NEBRASKA

Engineering Research Center

College of Engineering and Technology

University of Nebraska

Lincoln, Nebraska 68588

COST-EFFECTIVENESS OF GUARDRAIL IMPROVEMENTS FOR PROTECTING BRIDGE PIERS IN DEPRESSED MEDIANS ON HORIZONTAL CURVES

by

Edward R. Post, P.E.
Associate Professor of Civil Engineering

Patrick T. McCoy, P.E.
Associate Professor of Civil Engineering

Walter E. Witt, P.E.
Research Safety Coordinator
Nebraska Department of Roads

Terry J. Wipf
Graduate Research Assistant

Patrick A. Chastain
Undergraduate Research Assistant

Research Report No. TRD-03-002-78

Sponsored by

Engineering Research Center
College of Engineering and Technology
University of Nebraska

in cooperation with

Nebraska Department of Roads

August 1978

Civil Engineering Department
University of Nebraska-Lincoln
Lincoln, Nebraska 68588

ABSTRACT

<u>Key Words</u>: Guardrail, Roadside Safety, HVOSM, BARRIER VII

During the past two decades, many full-scale crash tests have been conducted on guardrail located on level and flat terrain. However, little attention has been given to the testing and placement of guardrail on embankment slopes, and as a result, errant vehicles have vaulted over guardrail and snagged on guardrail posts.

To investigate this problem, a typical site was selected on Interstate 80 near Lincoln, Nebraska on which a guardrail of current design, G4(2W)*, was protecting bridge piers in a depressed median on curved horizontal alignment. The existing guardrail was 200 ft. long, offset 15 ft. from the roadway and 4 ft. in front of the bridge piers, and its upstream anchored end was not flared or safety treated.

Seven improvement alternatives were evaluated. BARRIER VII simulations of a standard size automobile were conducted to obtain guardrail impact severities. Severity adjustments were made to account for probable cases of vaulting and snagging as predicted from HVOSM bumper trajectories. Impact condition probabilities were established to properly weight the severities under all possible combinations of encroachment speed and angle.

The results of this study indicated that the most attractive improvement alternative was guardrail and over a 20 yr life at 9% compound interest it would result in (1) a reduction of 1.12 injury type accidents, and (2) a net present worth injury accident savings of $60,500. The improvement consisted of relocating the existing guardrail 2 ft closer to the bridge piers, reducing its length from 200 to 95 ft, installing a rub rail, flaring the upstream turned-down end, and providing vertical slip joints on the first 5 posts so that the guardrail can breakaway under head-on type impacts. The feasibility of providing downstream end anchorage is uncertain in this study because the computer model simulations were made at one point of impact in the vicinity of the upstream bridge pier.

---

*AASHTO Designation

ACKNOWLEDGEMENTS

The consultation, suggestions and assistance provided by the following professional engineers during the course of this project were appreciated.

Dr. Donald M. Edwards, P. E.
Associate Dean of Engineering and Technology
Director of Engineering Research Center
University of Nebraska-Lincoln

Dr. Edward M. Wilson, P. E.
Professor and Chairman of Civil Engineering Department
University of Nebraska-Lincoln

Mr. Richard J. Ruby, P. E.
Engineering Support Services
Nebraska Department of Roads

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The University of Nebraska is currently conducting a research project in cooperation with the Nebraska Department of Roads to develop a cost-effective policy for the use of guardrail in Nebraska. A study of one specific use of guardrail is presented in this report.

During the past two decades, many full-scale crash tests have been conducted on guardrail located on level and flat terrain. However, little attention has been given to the testing and placement of guardrail on embankment slopes and in depressed medians, and as a result, out-of-control automobiles have vaulted over guardrail and snagged on guardrail posts under various combinations of encroachment speed and angle.

One objective of this study was to select a typical site and investigate the performance of guardrail located on a sloped embankment. The site selected was located on a sharp horizontal curve of Interstate 80 near Lincoln, Nebraska. On the site was located a guardrail of current design protecting bridge piers in a depressed median. Primary emphasis was placed on mathematical computer model simulations to ascertain the performance of the guardrail placement. The models used were HVOSM and BARRIER VII. Impact condition probabilities were established and used to properly weight the impact severities of the guardrail under all possible combinations of encroachment speed and angle.

A second objective of this study was to define and evaluate improvement alternatives. The probabilistic methods of Cost-Effectiveness and Benefit-Cost were used to compare and priority rank the alternatives. Relationships between impact severity and (a) injury accident probability, (b) injury accident costs, and (c) collision maintenance costs were established to facilitate in achieving this objective.

DESCRIPTION OF SITE

The site selected for the purpose of this study was a four-lane divided highway section of Interstate 80. The interstate bypasses Lincoln, Nebraska, on the north side where a small lake (Capital Beach) is located. This lake forced designers to use a relatively sharp horizontal curve to negotiate the terrain. Near the P.I. of the curve a bridge overpass crosses the interstate with concrete piers placed about 5 ft. from both outside shoulders and also in the center of the median, as shown in Figure 1a.

The median is 40 ft. wide and has a maximum depression of about 3 ft. below the edge of the travelled way. Side slopes in the median are 19:1 for the shoulder, 8:1 out 6 ft. more, and then 4:1 down to the piers. The 2 ft. diameter bridge piers located in the center of the median are 19 ft. from the edge of the travelled roadway.

The roadway consists of two 24 ft. P.C. concrete lanes travelling in each direction with an outside paved shoulder of 10 ft. and a soil-treated inside shoulder of 4 ft. The horizontal curvature is about 3 degrees on an upgrade of 2 percent. Superelevation of the roadway at the overpass is 0.07 ft/ft. The ADT for this section of the interstate is 15,000 vehicles/day with an average speed of 58.7 $\pm$ 4.0 mph. A plan view and cross sections of the terrain and its coordinate system are shown in Appendix B.

The guardrail currently used to protect the bridge piers is a blocked out W-Beam section mounted on 6 in. by 8 in. wood posts at a 6 ft.-3 in. post spacing. The height of the guardrail is 27 in. above the ground and is located 15 ft. from the left edge of the travelled roadway and about 4 ft. from the face of the bridge piers as shown in Figure 1b. The total length of the guardrail is 200 ft. and the upstream end is turned down and anchored but not safety-treated.

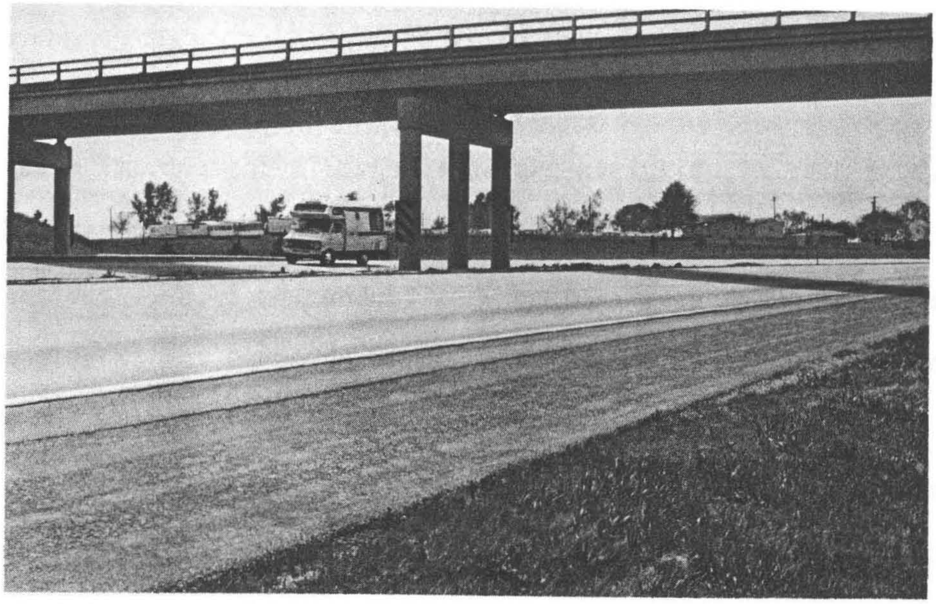


FIGURE 1a

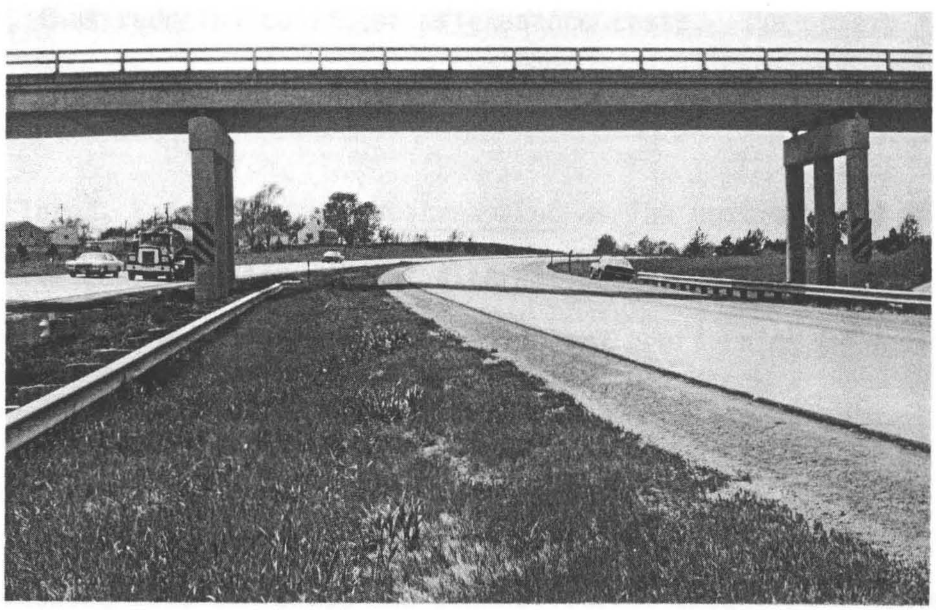


FIGURE 1b

FIGURE 1. PHOTOGRAPHS OF BRIDGE PIER SITE

IMPROVEMENT ALTERNATIVES

Seven improvement alternatives were evaluated in this study. Details of each alternative are presented in Table 1. Five of the alternatives (Alternatives 1, 2, 3, 4, and 5) were guardrail-type improvements, and one (Alternative 6) was composed of Fitch Modules with a concrete median barrier between the bridge piers. Also, in order to provide a basis for determining the cost-effectiveness of protecting bridge piers in depressed median, Alternate 7 (removing the existing guardrail and leaving the piers unprotected) was included as one of the alternatives.

The primary objective of the five guardrail improvement alternatives was to reduce the expected severity of impacts by encroaching vehicles. A secondary consideration was to minimize the expected collision damage to the guardrail system, thus reducing collision maintenance costs. The safety features included among the five guardrail improvement alternatives were the following:

Flared, Safety Treated Upstream End -- The upstream end of each of the five guardrail improvement alternatives was a flared, modified turned down end design to prevent ramping and overturning of vehicles that impact the upstream end.

Rubbing Rail -- Three of the alternatives include the addition of a rubbing rail to reduce the probability of impacting vehicles snagging on the guardrail posts.

Thrie-Beam -- Two of the alternatives featured the use of thrie-beam to

TABLE 1. IMPROVEMENT ALTERNATIVES

Standard Size Automobile: 3,800 lbs.
Encroachment Speeds: <45, 50, 60, and 70 mph
Encroachment Angles: <7.5, 10, 15, 20, 25, and >25 deg.

Improvement Alternative	Type of Traffic Barrier	Lateral Offset Distances		Height	Length	Upstream End Flared		Upstream End Safety Treated[a]		Downstream End Anchored		Rubbing Rail	
		From Road (ft)	From Piers (ft)	(in)	(ft)	Yes	No	Yes	No	Yes	No	Yes	No
Exist.	W-Beam [G4(2W)][b] (see Figure 1)	15.0	4.2	27	200		X		X		X		X
1	W-Beam [G4(2W)] (Modify Existing)	15.0	4.2	27	200	X		X			X	X	
2	W-Beam [G4(2W)]	17.0	2.2	27	95[c]	X		X			X	X	
3	Thrie-Beam (G9)	17.0	2.2	30	95[c]	X		X			X		X
4	W-Beam [G4(2W)]	17.0	2.2	27	95[c]	X		X		X		X	
5	Thrie-Beam (G9)	16.0	3.2	34	95[c]	X		X		X			X
6	Fitch Modules + CMB between Piers (see Figure 7)	15 19		32	21 22		10 deg						
7	Leave Piers Unprotected	19.2											

a. Modified Turned Down End [see Hirsch (10)]
b. AASHTO Designation (9)
c. Nebraska Department of Roads standard design shown in Figure 2 (11)

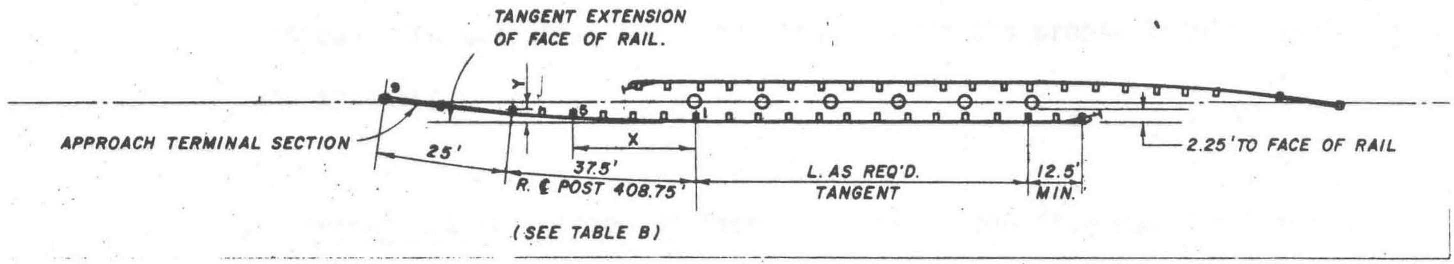
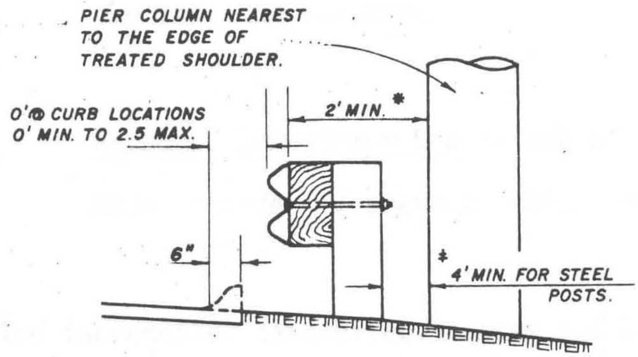


TABLE B		
POST NO.	X DISTANCE	Y OFFSET
1		1.25
2	6.23	1.30
3	12.45	1.44
4	18.68	1.68
5	24.90	2.01
6	31.11	2.44
7	37.31	2.96
8	49.84	3.21
9	62.27	4.51

THE LONGITUDINAL PLACEMENT OF POSTS SHALL BE ADJUSTED AS NECESSARY AND IN SO FAR AS POSSIBLE SO THAT A POST WILL NOT BE PLACED DIRECTLY OPPOSITE A PIER COLUMN.

THE STATIONING OF THE GUARD RAIL AS SHOWN IN THE PLANS IS FOR DESCRIPTIVE PURPOSES ONLY AND MAY BE MODIFIED AS REQUIRED.



GUARD RAIL ADJACENT TO PIER COLUMN

‡ WHERE 4 FOOT IS NOT AVAILABLE, WOODEN POSTS MUST BE USED. WHERE TREATED TIMBER POSTS ARE USED TO PROTECT OUTSIDE PIERS, TREATED TIMBER POSTS MUST BE USED TO PROTECT CENTER PIERS.

REV. NO	DATE	DESCRIPTION OF REVISION
R1	10-10-74	ALT. "C" POST - SPLICE BOLT SLOT

NEBRASKA DEPARTMENT OF ROADS

STANDARD PLAN Nº 704

SAFETY BEAM GUARD RAIL

APPROVED DECEMBER 21, 1973
DATE

Kenneth J. Gottula
ROADWAY DESIGN ENGINEER

SCALE AS SHOWN

5/6

FIGURE 2.

GUARDRAIL INSTALLATION AT BRIDGE PIERS

increase the guardrail depth and thus reduce the probability of vaulting and snagging.

Increased Lateral Offset Distance -- Four of the five guardrail improvement alternatives had greater lateral offset distances from the traveled way than did the existing guardrail. The increased lateral offset distance was intended to reduce the probability of encroaching vehicles impacting the guardrail because: (1) the guardrail would be further from the traveled way and (2) the guardrail is closer to the piers and therefore it would not need to be as long to protect the piers. And, the increased lateral offset distances were intended to increase the probability of the guardrail properly intercepting the trajectories of those vehicles that do impact the guardrail, thus reducing the chances of vaulting and snagging.

Anchored Downstream End -- Two of the alternatives had anchored downstream ends in order to prevent vehicle penetration of the guardrail.

The incremental cost-effectiveness and benefit-cost analyses of these alternatives which were conducted in this study provided insight as to the cost-effectiveness and economic worthwhileness of each of these safety features. And, thus a basis was established for developing a cost-effective policy related to their use.

COMPUTER MODELS OF AUTOMOBILE

During the past three decades, many highway organizations have relied heavily upon experience and judgment 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, judgment and tests, model simulation can be a very helpful tool in achieving efficient and safe designs.

HVOSM

The Highway-Object-Simulation-Model, designated as HVOSM, was used in the subsequent work to study the dynamic motion of an automobile traversing the depressed median 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 3. The model has 11 degrees of freedom and consists of four isolated masses. The

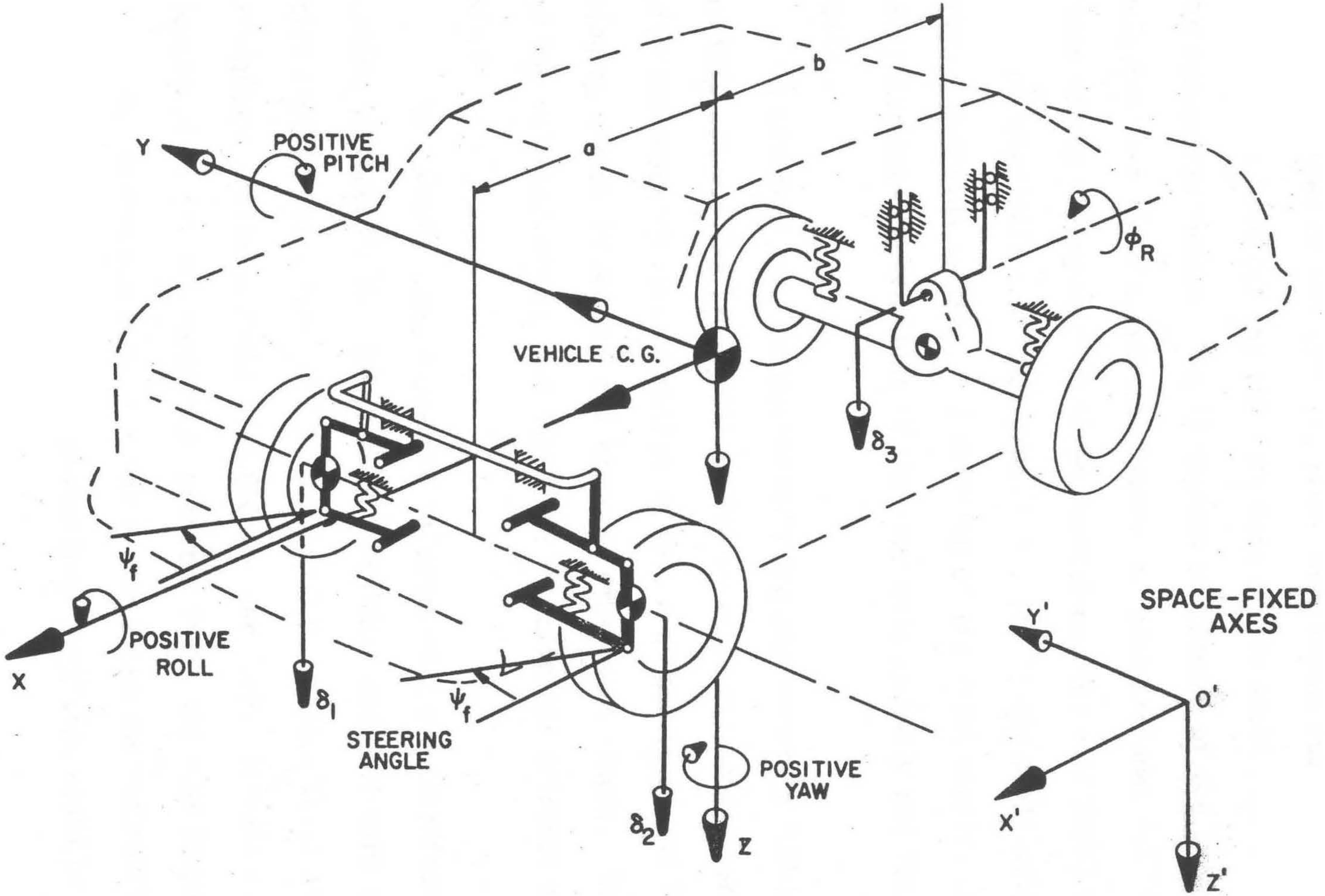


FIGURE 3: IDEALIZATION OF HVOSM

masses of the automobile include: (a) the sprung mass of the body, engine and transmission supported by the front and rear suspension system, (b) the unsprung masses of the left and right independent suspensions 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 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.

BARRIER VII

The BARRIER VII program was utilized subsequently in this study to determine the dynamic effect of an automobile interacting with a traffic barrier system. BARRIER VII was developed by Powell (7,8).

The traffic barrier is idealized as a plane framework composed of elastic inelastic one-dimensional elements of a variety of types. The automobile is idealized as a plane rigid body surrounded by a cushion of springs. A large displacement dynamic structural analysis problem is solved by numerical methods.

The analysis is two-dimensional in the horizontal plane. Out-of-plane effects, which include vertical displacements of both the automobile and the barrier, are not considered. The automobile slides along the barrier, and the effects of normal force, friction forces, and wheel drag forces are considered in determining its motion. Data necessary for input to the program consist of the barrier configuration, the properties of the barrier members and automobile and the velocity and trajectory of automobile before impact. Output consists of barrier member forces, barrier deflections, time histories of automobile positions, and velocities and acceleration of automobile.

BARRIER VII is a two-dimensional program and therefore it placed limtations on this study. BARRIER VII cannot predict roll motion of the vehicle, wheel snagging or vehicle vaulting. For this reason it was necessary to use judgment to determine the severity of these particular situations.

TRAJECTORIES OF AUTOMOBILE BUMPER

Experience has shown that the successful redirection or deceleration of an automobile colliding with a traffic barrier is largely dependent on the height of the vehicle bumper in relation to the height of the traffic barrier. The normal impact height of a standard size automobile relative to a standard W-beam design (G4W)*, a concrete median barrier (MB5), and a 400 lb sand module is illustrated in Figure 4. Impact bumper heights above normal can result in vaulting or ramping; whereas, impact bumper heights below normal can result in guardrail post snagging.

In this study, the following criteria was used for evaluating the performance of a traffic barrier using the lowest point on the corner of the automobile bumper as the reference:

1. Guardrail

   a) Normal Impact - - - Bumper point within lower 2/3 portion of beam depth

   b) Post Snagging - - - Bumper point more than 5 in. below bottom edge of beam

   c) Vaulting - - - - - Bumper point within upper 1/3 portion of beam depth

2. Fitch Module

   a) Normal Impact - - - Bumper point within lower 3/4 portion of module height

   b) Ramping - - - - - - Bumper point within upper 1/4 portion of module height

The encroachment conditions and terrain configuration must be taken into consideration when investigating impact bumper heights. A computer program was written (see Appendix D) to calculate bumper heights from

---

* Traffic Barriers designations in AASHTO (9)

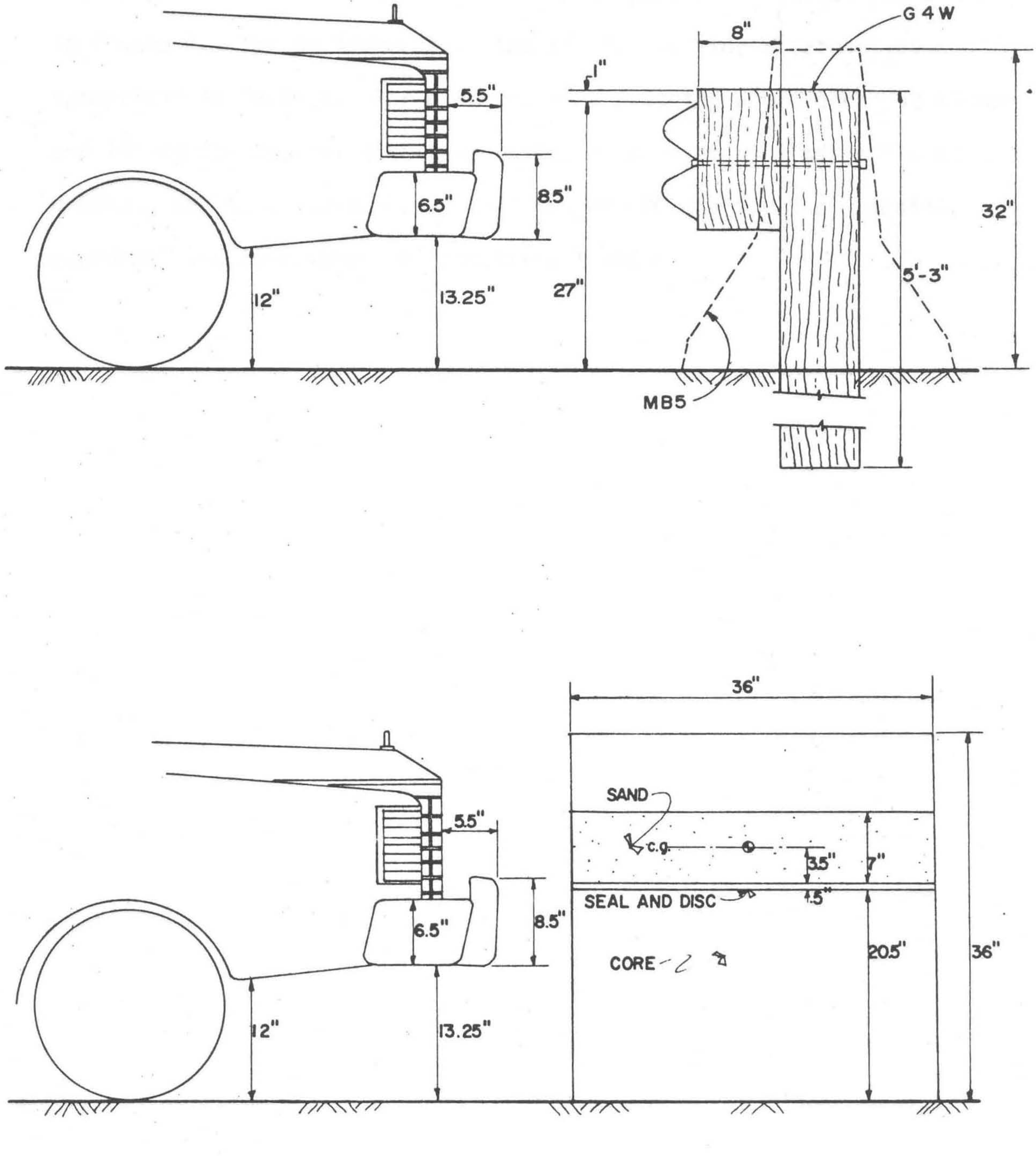


FIGURE 4. NORMAL BUMPER POSITION OF
STANDARD SIZE AUTOMOBILE

output provided by the HVOSM (3) computer model. The trajectories of the bumper point in relation to the improvement alternatives are shown in Figure 5. The performance of the traffic barrier alternatives are summarized in Table 2. For example, post snagging would occur at 50 mph and 10 deg for the existing guardrail and Improvement Alternative 5; whereas, vaulting would occur at 70 mph and 20 deg for the existing guardrail and Improvement Alternatives 1 and 6.

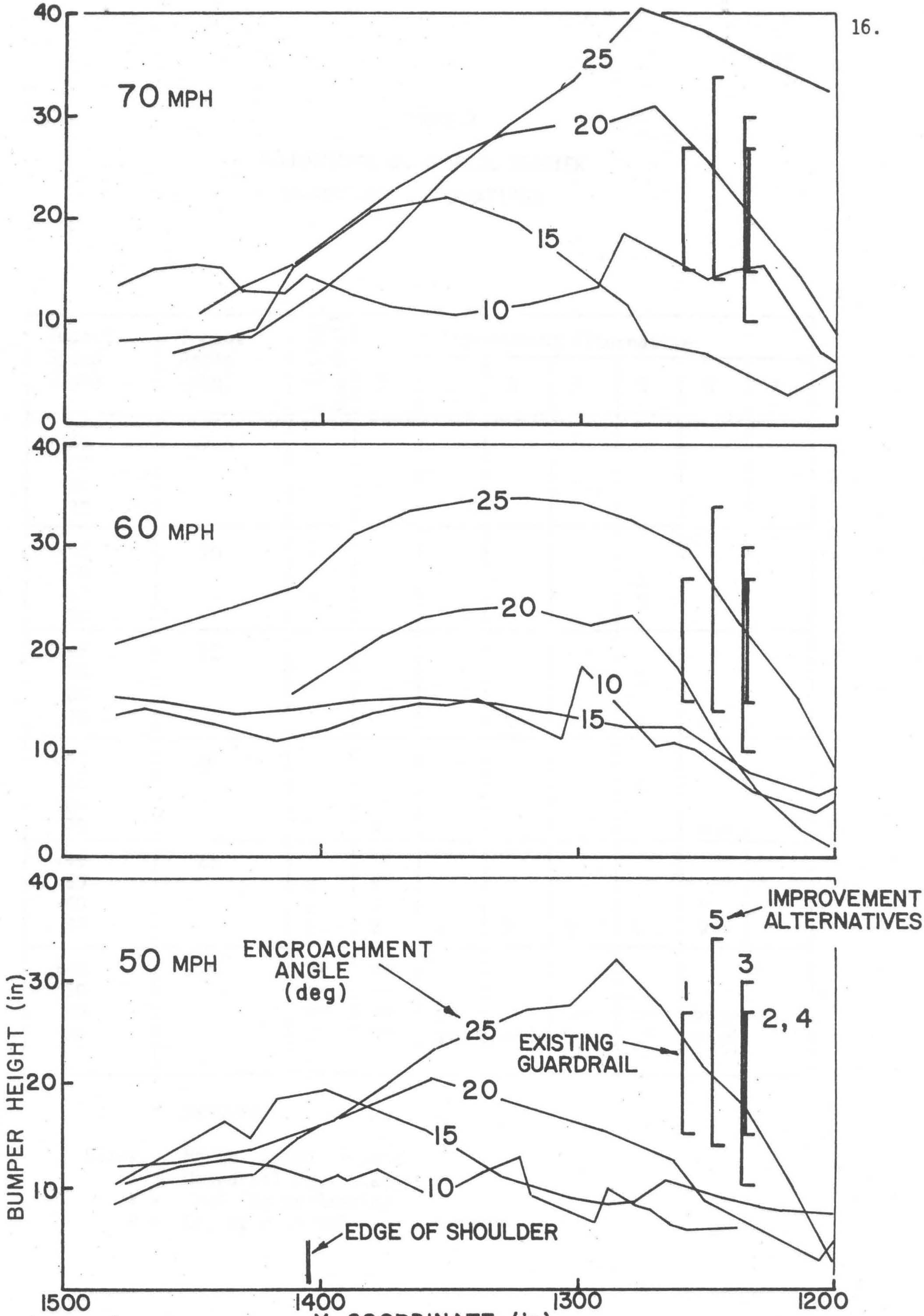


FIGURE 5. AUTOMOBILE BUMPER TRAJECTORIES

TABLE 2

PERFORMANCE OF TRAFFIC BARRIER IMPROVEMENT ALTERNATIVES

Impact Speed (mph)	Impact Angle (deg)	Existing Guardrail	Improvement Alternative						
			1	2	3	4	5	6	7
<45	<7.5								
50									
60									
70									
<45	10								
50		S					S		
60		S					S		
70									
<45	15								
50							S		
60									
70					S		S	R	
<45	20								
50							S		
60									
70		V	V					R,V	
<45	25								
50		V	V						
60		V	V					V	
70		V	V	V	V	V	V	R,V	
<45	>25	V*	V*						
50		V*	V*						
60		V*	V*	V*	V*	V*	V*	R*,V*	
70		V*	V*	V*	V*	V*	V*	R*,V*	

* Assumed

Blank = Normal Bumper Impact
S = Guardrail Post Snagging
V = Vaulting or Ramping
R = Rollover on CMB

SEVERITY OF AUTOMOBILE COLLISIONS WITH TRAFFIC BARRIERS

The severity of an automobile colliding with a traffic barrier was expressed in terms of a Severity-Index. 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 (12) and Weaver (6).

$$SI = \frac{G_{total\ Auto}}{G_{total\ Occupant}} = \sqrt{\left[\frac{G_{long}}{G_{XL}}\right]^2 + \left[\frac{G_{lat}}{G_{YL}}\right]^2 + \left[\frac{G_{vert}}{G_{ZL}}\right]^2} \qquad \text{---Eq. 1}$$

where:

SI = Severity-Index

$G_{total\ Auto}$ = Resultant Auto Acceleration

$G_{total\ Occupant}$ = Resultant Tolerable Acceleration

G_{long} = Auto Acceleration along longitudinal x-axis (see Figure 3)

G_{lat} = Auto Acceleration along lateral y-axis

G_{vert} = Auto Acceleration along vertical z-axis

G_{XL} = Tolerable Acceleration along x-axis

G_{YL} = Tolerable Acceleration along y-axis

G_{ZL} = Tolerable Acceleration along z-axis

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. The relationship between severity-index and injury levels will be discussed in a later section. Tolerable accelerations suggested by Weaver (6) for use in the severity-index equation are shown in Table 3.

TABLE 3

TOLERABLE AUTOMOBILE ACCELERATIONS

Degree of Occupant Restraint	Accelerations G_{YL}	G_{XL}	G_{ZL}
Unrestrained	5	7	6
Lap Belt Only	9	12	10
Lap Belt and Shoulder Harness	15	20	17

Guardrail

The BARRIER VII (7,8) program was used to obtain severities for an automobile colliding with a guardrail. As mentioned earlier in the report, it was necessary to specify input values for the post, barrier rail, and vehicle inertial properties. The values for the parameters used in this study were obtained primarily from the work of the Southwest Research Institute (13) in which BARRIER VII results were correlated with similar full scale tests. Some correlation work was also done in this study. Although the correlations that were made were not excellent with respect to all variables obtained from BARRIER VII, the correlations were believed to be satisfactory. The severity-indices (SI) computed for the guardrail improvement alternatives are presented in Tables 4, 5, 6, 7, and 8.

One situation that had to be considered for this study was the problem of the vehicle impacting a bridge pier if the barrier rail deflections exceeded the clear distance from the rail to the pier. Alternative 1 never

TABLE 4. SEVERITY-INDICIES FOR ALTERNATIVE 1

VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI
50 - 10	0.59	60 - 10	0.73	70 - 10	1.02
50 - 15	0.79	60 - 15	1.02	70 - 15	1.11
50 - 20	1.02	60 - 20	1.09	70 - 20	1.10
50 - 25	1.17	60 - 25	1.35	70 - 25	1.44

TABLE 5. SEVERITY-INDICIES FOR ALTERNATIVE 2

VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI
50 - 10	0.70	60 - 10	0.78	70 - 10	0.93
50 - 15	0.84	60 - 15	0.88	70 - 15	0.97 1.07*
50 - 20	0.84	60 - 20	1.05 1.21*	70 - 20	1.14 1.60*
50 - 25	0.85 1.08*	60 - 25	1.07 1.66*	70 - 25	1.14 2.17*

TABLE 6. SEVERITY-INDICIES FOR ALTERNATIVE 3

VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI
50 - 10	0.69	60 - 10	0.83	70 - 10	0.82
50 - 15	0.83	60 - 15	0.89	70 - 15	0.94 1.23*
50 - 20	0.86	60 - 20	1.00 1.15*	70 - 20	1.12 1.59*
50 - 25	0.94 1.16*	60 - 25	1.03 1.57*	70 - 25	1.18 2.36*

* Value based on vehicle impacting pier because of excess rail deflection.

TABLE 7. SEVERITY-INDICIES FOR ALTERNATIVE 4

VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI
50 - 10	0.70	60 - 10	0.78	70 - 10	0.93
50 - 15	0.87	60 - 15	0.91	70 - 15	1.00
50 - 20	0.91	60 - 20	1.13 1.16*	70 - 20	1.23 1.57*
50 - 25	0.94 1.13*	60 - 25	1.18 1.71*	70 - 25	1.27 2.35*

TABLE 8. SEVERITY-INDICIES FOR ALTERNATIVE 5

VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI	VELOCITY-ANGLE (MPH) (DEG)	SI
50 - 10	0.69	60 - 10	0.83	70 - 10	0.82
50 - 15	0.85	60 - 15	0.92	70 - 15	0.97
50 - 20	0.93	60 - 20	1.08	70 - 20	1.21
50 - 25	1.03	60 - 25	1.13 1.22*	70 - 25	1.25 2.50*

* Value based on vehicle impacting pier because of excess rail deflection.

fell into this category because the barrier rail deflection never exceeded the clear distance of 4.2 ft. There were specific cases in alternatives #2, 3, 4, and 5 where barrier rail deflections exceeded the minimum clearance. It was evident that the SI would increase because of the possibility of pier impact. The assumption made to increase the SI in cases of excess deflection was as follows. The SI will increase linearly as a function of deflection of rail past the pier face. An arbitrary value of two times the SI obtained by decelerations will be used for the situation in which the maximum excess deflection takes place. For example, the plot in Figure 6 used to generate increases in SI for Alternatives 2, 3 and 4 will be based on a maximum rail deflection in this group of 56 in. minus the clear distance from rail to pier is 38 in. or 30 in. For alternative 5 in Figure 6 the clear distance from rail to pier was 38 in. so that the plot to generate increased SI values will be based on a maximum deflection of 52 in. minus 38 in. or 13 in.

Adjustments of the guardrail severity-indices were also made for those situations in which snagging and vaulting appeared to be a problem as predicted from the HVOSM bumper trajectories (see Figure 5). In the case of post snagging, the SI was increased by 75 percent; whereas, in the case of vaulting, the SI was taken as 2.5 which will result in an injury accident probability of 100 percent.

In all of the BARRIER VII simulations the path of the vehicle prior to impact was along a line that would have intersected the upstream bridge pier. It can be conjectured that had the point of guardrail impact been further downstream that the vehicle would have penetrated the 95 ft. length of guardrail of Alternatives 2 and 3 with unanchored downstream ends. In the 70 mph/25 deg. simulations the last 9 guardrail posts failed

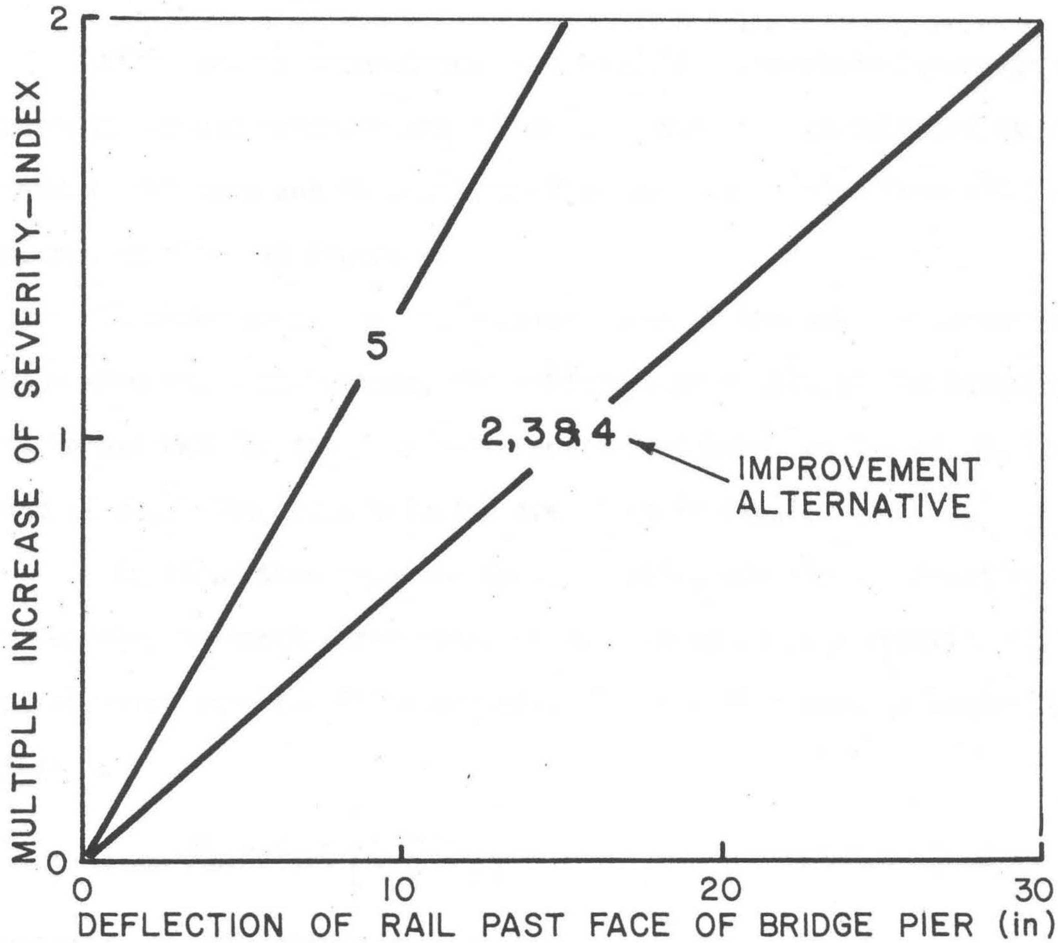


FIGURE 6

SEVERITY-INDEX ADJUSTMENT FACTORS WHEN GUARDRAIL BOTTOMS-OUT ON BRIDGE PIERS completely; however, the vehicle was still redirected. This action prompted the response of anchoring the guardrail downstream end in Alternatives 4 and 5.

Fitch Energy Attenuator

Fitch energy attenuators were used in Improvement Alternate 6 to protect the end bridge piers. The particular system selected is widely used in Nebraska and it consists of 15 modules ranging from 400 to 2100 pounds as shown in Figure 7.

In order to obtain the decelerations of the vehicle during an impact with the Fitch system, the vehicle's path through the barrels had to be defined for the four different encroachment angles of 10, 15, 20, and 25 deg. The paths selected are shown in Figure 7.

The first step required in calculating vehicle decelerations was to develop a smooth curve relating vehicle speed as a function of vehicle penetration into the Fitch modules. The equation used to accomplish this task was:

$$V_n = V_{n-1} \left[\frac{W}{W + aW_n} \right] \qquad \text{- - - Eq. 2}$$

where: W = vehicle weight

W_n = weight of sand in modules of row "n"

V_{n-1} = vehicle velocity before impacting modules of row "n"

V_n = vehicle velocity after crushing modules of row "n"

a = estimated percentage of modules in row "n" that contribute to speed reduction

The vehicle decelerations were calculated over intervals of 1 ft. from the velocity vs. penetration curve by use of the following equation:

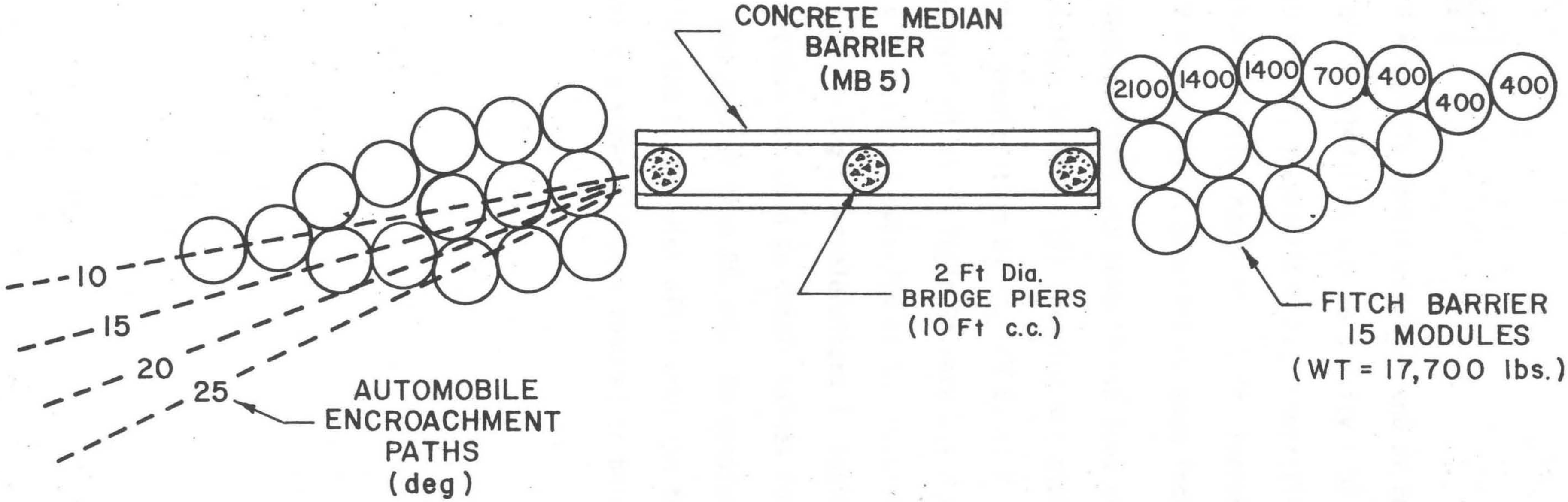


FIGURE 7
IMPROVEMENT ALTERNATIVE 6

$$G = \frac{V}{g}\left[\frac{\Delta V}{\Delta S}\right] \qquad \text{- - - Eq. 3}$$

where: G = vehicle deceleration at end of each 1 ft. increment

g = acceleration due to gravity = 32.2 ft./sec^2

ΔS = 1 ft. increments along penetration axis

ΔV = velocity change over 1 ft. increments

V = velocity at midpoint of each increment

The vehicle decelerations and severity-indices are shown in Table 9a. Based on the discussions in AASHO (9), ramping was assumed to occur for bumper impact heights greater than 24 in. An SI of 2.5 was assigned for ramping. The severity-indices in Table 9a were based on a tolerable resultant acceleration of 9 g's which was computed as the resultant of the longitudinal (7 g's) and the lateral (5 g's) accelerations in Table 3 for unrestrained occupants. Extrapolation was used to obtain values for encroachment angles less than 7.5 deg. and greater than 25 deg. No consideration was given to the vehicle impacting the bridge pier after crushing the Fitch modules because in all cases the vehicle speed had been reduced to below 10 mph.

TABLE 9a

SEVERITY-INDICES FOR

ALTERNATIVE 6 (FITCH)

Vehicle Impact Speed (mph)	VEHICLE PATH							
	10 deg		15 deg		20 deg		25 deg	
	G (g's)	SI	G (g's)	SI	G (g"s)	SI	G (g's)	SI
50	7.6	0.8	6.3	0.7	8.9	1.0	9.8	1.1
60	10.0	1.1	9.3	1.0	13.1	1.5	Ramp	2.5
70	13.8	1.5	12.0	1.3	Ramp	2.5	Ramp	2.5

Notes 1. Accelerations averaged over 50 msec

Concrete Median Barrier

A concrete median barrier (CMB) was also used between the bridge piers in Improvement Alternative 6 (see Figure 7). The severity of colliding with the CMB was obtained from the findings presented by Young and Post (14) using the HVOSM (3) program. These findings are presented in Table 9b.

TABLE 9b
SEVERITY-INDICES FOR ALTERNATIVE 6 (CMB)

VEHICLE SPEED (mph)	SEVERITY-INDICES					
	<7.5 deg	10 deg	15 deg	20 deg	25 deg	>25 deg
<45	0.23*	0.38*	0.65*	0.80*	1.00	2.00
50	0.33	0.64	0.91	1.18*	1.47	2.00
60	0.41*	0.87*	1.48	1.60*	1.90	Rollover
70	0.52	1.07	Rollover	Rollover*	Rollover	Rollover

* Extrapolated or assumed

Non-Yielding Barriers

The severity of the vehicle impacting the bridge piers in Alternative 7 was assumed to result in an injury probability of 100 percent under all combinations of encroachment speed and angle.

SEVERITY-INDEX RELATIONSHIPS

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 acceleration that would be tolerable to an unrestrained occupant. One method used to accomplish this task was to define a Severity-Index which is computed as the ratio of the measured resultant automobile acceleration to the resultant "tolerable" automobile acceleration. An improvement resulting in a Severity-Index value of one or less was considered to be safe; whereas, an improvement resulting in a Severity-Index value greater than one was considered to be unsafe. The work to follow will expand the existing technology to include the probability of occurrence of roadside injury type accidents.

Injury Probability

An indepth discussion on a tentative relationship between Severity-Index and the probability of occurrence of injury type accidents was recently presented by Post (15) to the Transportation Research Board. The relationship established for injury probability is shown in Table 10. For simplicity purposes in this study, the histogram relationship was approximated by the two linear relationships as shown in Figure 8.

Injury Accident Costs

An approach very similar to that used by Weaver (16) was used to establish a relationship between Severity-Index and Injury Accident Costs. Referring to Table 11, the Severity-Index and Probability of an Injury Accident were expressed by a percentage distribution in terms of three accident classifications: Property Damage Only Accidents, Injury Accidents, and Fatal

TABLE 10

RELATIONSHIP BETWEEN SEVERITY-INDEX

AND PROBABILITY OF INJURY ACCIDENTS

(AFTER POST 10)

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

Accidents. The total accident costs in Table 11 were determined by using the following slightly adjusted societal cost figures for motor vehicle accidents published by the National Highway Traffic Safety Administration (17):

PDO Accident - - - - $700

Injury Accident- - - $10,000

Fatal Accident - - - $200,000

The histogram relationship in Table 11 was approximated by the linear relationships shown in Figure 9.

Barrier Collision Maintenance Costs

The length of guardrail damaged and the number of posts that failed during an automobile collision were estimated from the BARRIER VII (7,8)

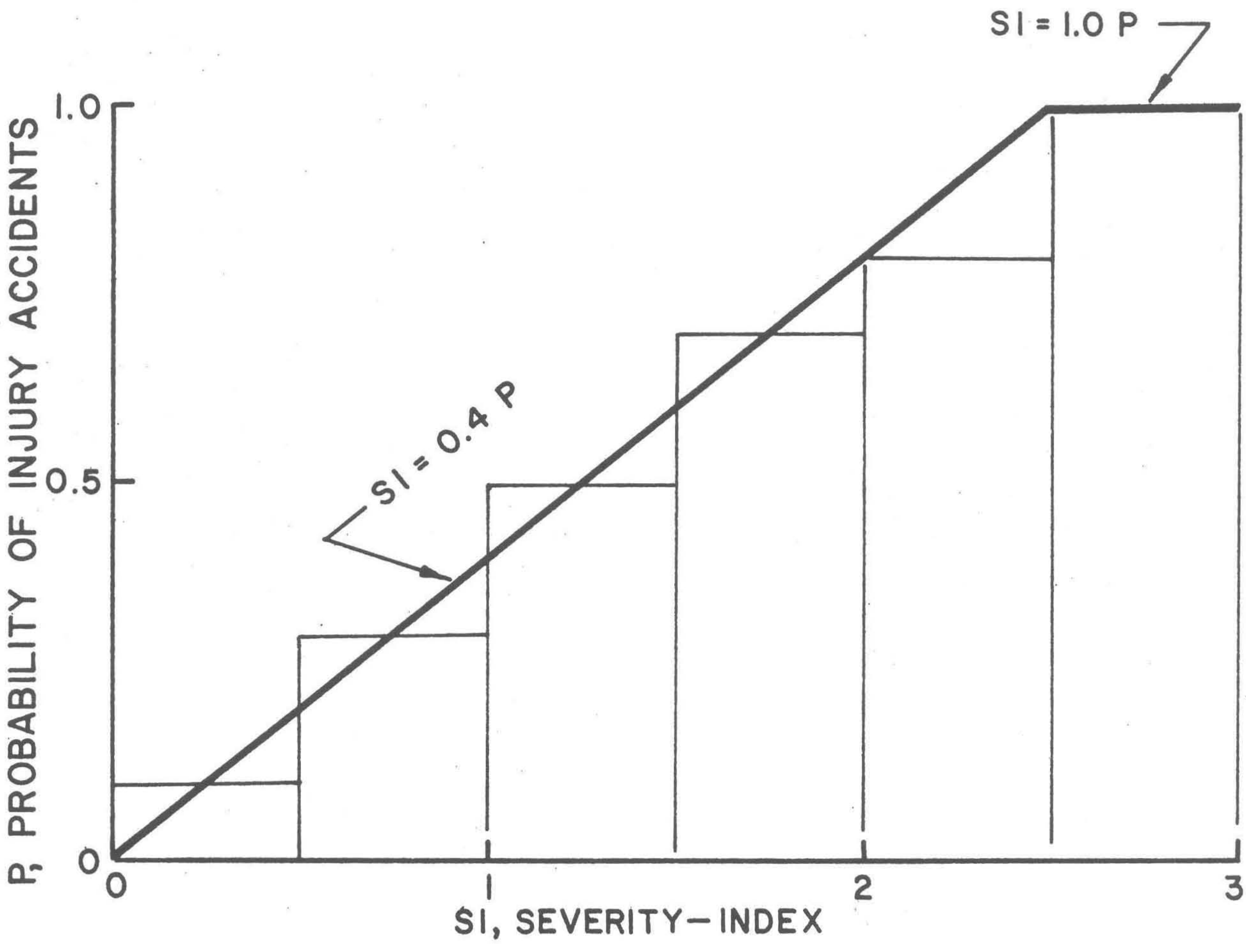


FIGURE 8. RELATIONSHIP BETWEEN SEVERITY-INDEX AND PROBABILITY OF INJURY ACCIDENTS

TABLE 11.

RELATIONSHIP BETWEEN SEVERITY-INDEX AND INJURY ACCIDENT

PROBABILITIES, ACCIDENT CLASSIFICATIONS, AND TOTAL ACCIDENT COSTS

Severity-Index[a]	Probability of Injury Accident[b]	Accident Classification[c]			Total Accident Cost[d] ($)
		PDO Accidents (%)	Injury Accidents (%)	Fatal Accidents (%)	
SI ≤ 0.5	0.1	90	10	0	1,600
0.5 < SI ≤ 1.0	0.3	60	40	0	4,400
1.0 < SI ≤ 1.5	0.5	40	50	10	25,300
1.5 < SI ≤ 2.0	0.7	10	60	30	66,100
2.0 < SI ≤ 2.5	0.8	0	50	50	105,000
2.5 < SI	1.0	0	10	90	181,000 (TAC)

a. Computed by HVOSM and BARRIER VII Simulations

b. Refer to Table 10

c. Assumed in similar manner as done in TTI Report (16)

d. Refer to Reference No. 16 ---- $200,000 per fatal accident
10,000 per injury accident
700 per property damage only

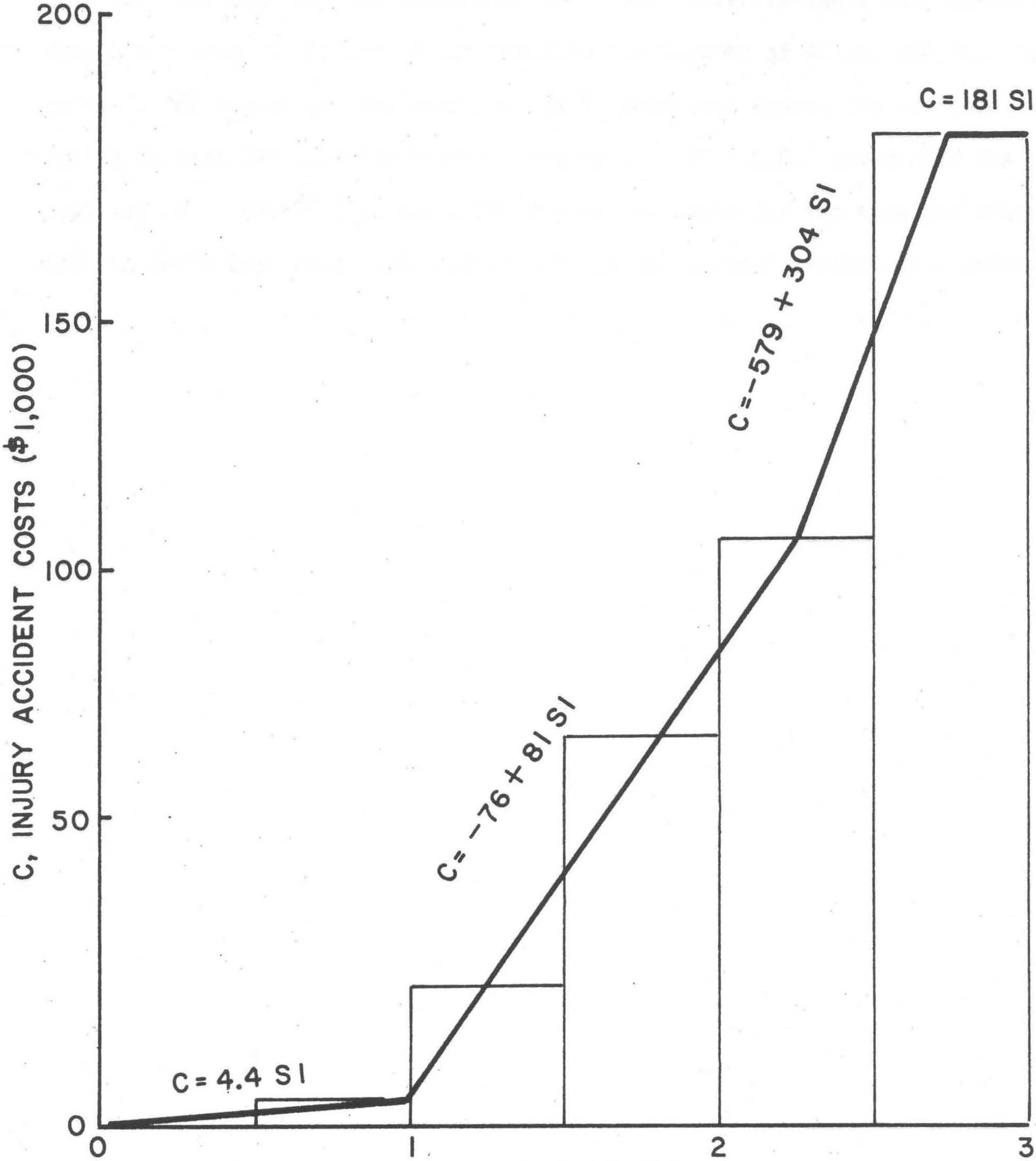


FIGURE 9
RELATIONSHIP BETWEEN SEVERITY-INDEX AND INJURY ACCIDENT COSTS

computer simulations. The relationships between severity-index and guardrail damage are shown in Figure 10 for installation lengths of 95 and 200 ft. As evident, the longer 200 ft. guardrail is stiffer; and hence, the corresponding damage is less for severity-indices greater than SI = 0.8. Based upon the cost values in AASHTO (9), the collision repair costs for the standard W-Beam and the Thrie-Beam were estimated as 9/10 of the current installation costs.

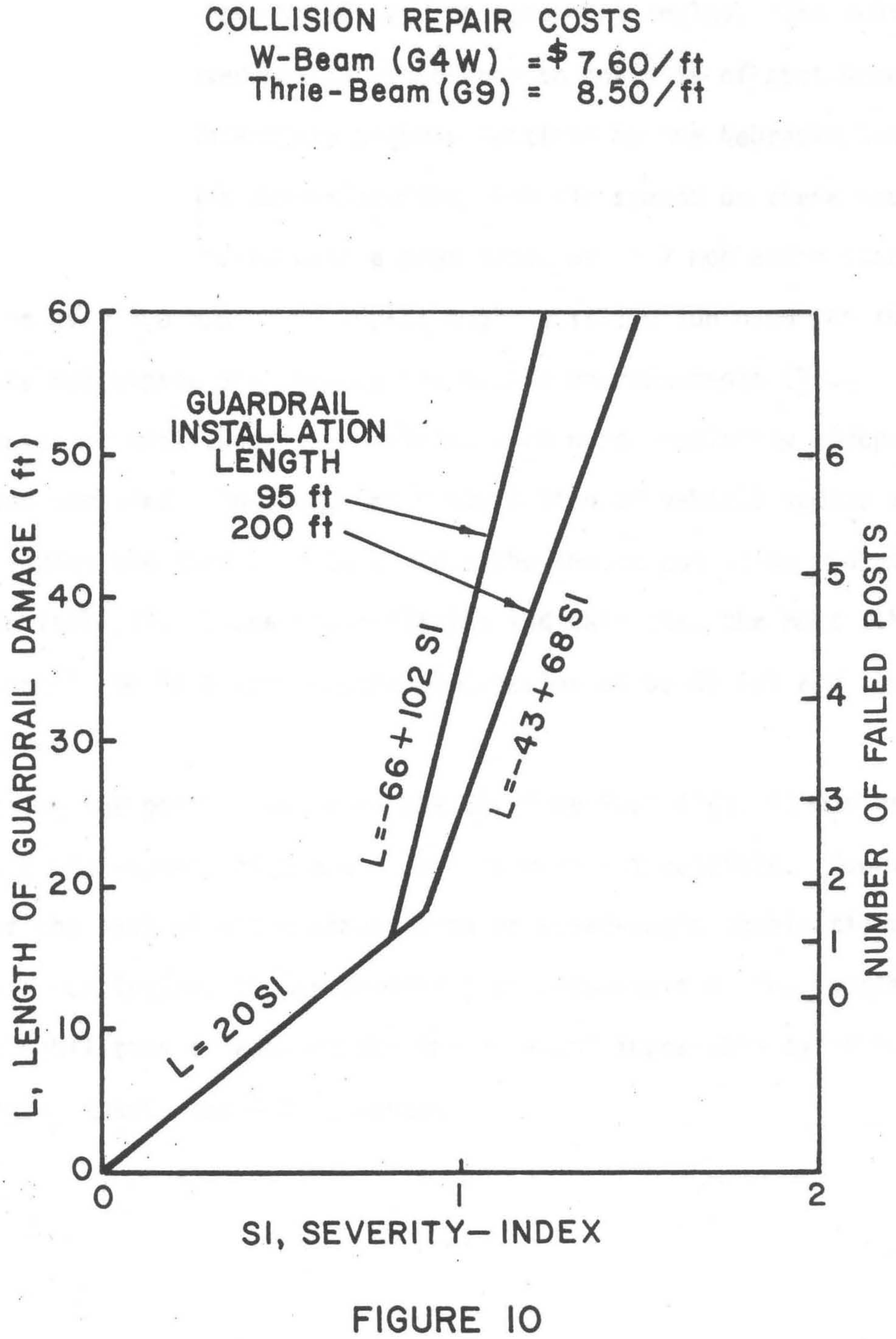


FIGURE 10

RELATIONSHIP BETWEEN SEVERITY-INDEX AND LENGTH OF GUARDRAIL DAMAGE

IMPACT CONDITION PROBABILITIES

The impact condition probabilities were computed by combining distributions of vehicle speeds and encroachment angles. The vehicle speed distribution used was obtained from an analysis of spot speed data collected on rural interstate highway sections by the Nebraska Department of Roads. It was determined that vehicle speeds on these sections were normally distributed with a mean speed of 58.7 mph and a standard deviation of ± 4.0 mph. The impact angle distribution used was that reported by Hutchinson and Kennedy for median encroachments (18).

Assuming that these two distributions were completely independent, they were combined. The combined distribution of vehicle speeds and impact angles was then used to compute the impact condition probabilities shown in Table 12. These probabilities indicate that the most likely impact condition is a speed-angle combination of 55-65 mph and less than 7.5 degrees.

Using the point mass model presented by Ross (19), it was determined that some high-speed, high-angle impacts were not possible. However, because of the lack of encroachment data on speed-angle combinations to support this conclusion, it was decided that adjustment of the impact condition probabilities to account for the apparent impossibility of high-speed, high-angle impacts was not warranted.

TABLE 12 - IMPACT CONDITION PROBABILITIES

Vehicle Speed (mph)	IMPACT ANGLE (DEGREES)					
	<7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	>27.5
<45	0.000	0.000	0.000	0.000	0.000	0.000
45-55	0.083	0.035	0.021	0.014	0.009	0.012*
55-65	0.369	0.154	0.092	0.062	0.039*	0.054*
65-75	0.027	0.011	0.007	0.004*	0.003*	0.004*
>75	0.000	0.000	0.000	0.000	0.000	0.000

* Condition not possible according to point mass model.

EVALUATION OF IMPROVEMENT ALTERNATIVES

Roadside safety improvement programs must compete with other ongoing highway programs for the limited funds available. The "Cost-Effectiveness" and "Benefit-Cost" methods of analysis were used to compare the improvement alternatives for protecting bridge piers in a median on curved horizontal alignment. Both methods, which yield similar results, are management tools for providing the highway administrator with a means of evaluating safety improvement alternatives on a common data base to realize the greatest return on the investment to reduce injury accidents.

Cost-Effectiveness Analysis

The cost-effectiveness analysis conducted in this study was based on the cost-effectiveness priority approach formulated by Glennon (20), and implemented in Texas for managing roadside safety improvement programs on both non-controlled access roadways and freeways (21). 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 improvement alternative and its annualized cost.

Hazard Index

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

$$H = \frac{E_f D}{5280} (HI_1 + HI_2 + HI_3) \qquad \text{----Eq 4}$$

where:

H = hazard-index for each alternative (Injury Accidents per yr.)

HI_1 = hazard-index for side type impacts

$$= P_{(s)} \sum_{\Theta} \sum_{V} [(SP)(PI)(L_1)]$$

HI_2 = hazard-index for side impacts in which guardrail bottomed-out on bridge piers

$$= P_{(s)} \sum_{\Theta} \sum_{V} [(SP)(PI)(L_2)]$$

HI_3 = hazard-index for end type impacts

$$= P_{(s+3)} \sum_{\Theta} \sum_{V} [(SP)(PI)(L_3)]$$

V = encroachment speed: <45, 50, 60, 70 mph

Θ = encroachment angle: <7.5, 10, 15, 20, 25, >25 deg.

E_f = encroachment frequency (see Figure 11a)

D = directional traffic split = 1/2

SP = impact condition probabilities (see Table 12)

PI = injury accident probability for each combination of encroachment speed and angle (see Figure 8)

$P_{(s)}$ = lateral impact probability at some offset distance "s" (see Figure 11b)

L_1 = length of traffic barrier - L_2

L_2 = effective length of traffic barrier in contact with bridge pier due to bottoming-out

L_3 = length along roadway from which vehicle could impact the end of barrier

$= d (\csc \theta) + w (\cot \theta)$

d = width of vehicle = 6 ft.

w = width of traffic barrier

Encroachment Frequency

Knowledge of the frequency at which vehicles encroach on the roadside is very limited. Therefore, the encroachment frequency used by Glennon (20) was assumed to be applicable for the purposes of this analysis. The relationship between encroachment frequency and ADT is shown in Figure 11a. The ADT for the study site was 15,000 vpd which will result in an encroachment frequency of:

$$E_f = 1.1 + (0.000415)\, ADT \quad ; \text{ for } ADT > 6{,}000$$

$$= 7.3 \text{ encroachments per yr. per mile}$$

Lateral Impact Probability

Given that an encroachment has occurred, the probability of a vehicle impacting a roadside obstacle decreases as the distance from the edge of the travelled roadway increases. Lateral impact probabilities were obtained from the relationship used by Glennon (20) in Figure 11b.

Capital Costs

The construction costs of the improvement alternatives were estimated using 1978 average unit cost data provided by the Nebraska Department of

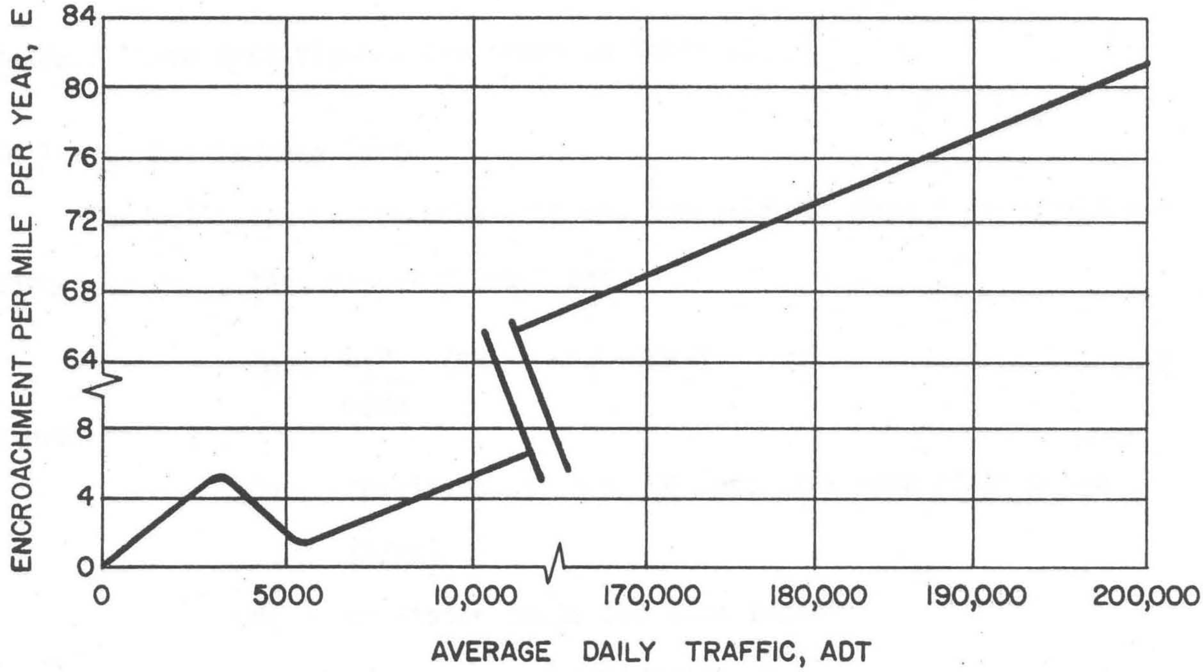


FIGURE 11 a: ROADSIDE ENCROACHMENT FREQUENCY. SOURCE : HUTCHINSON AND KENNEDY (18)

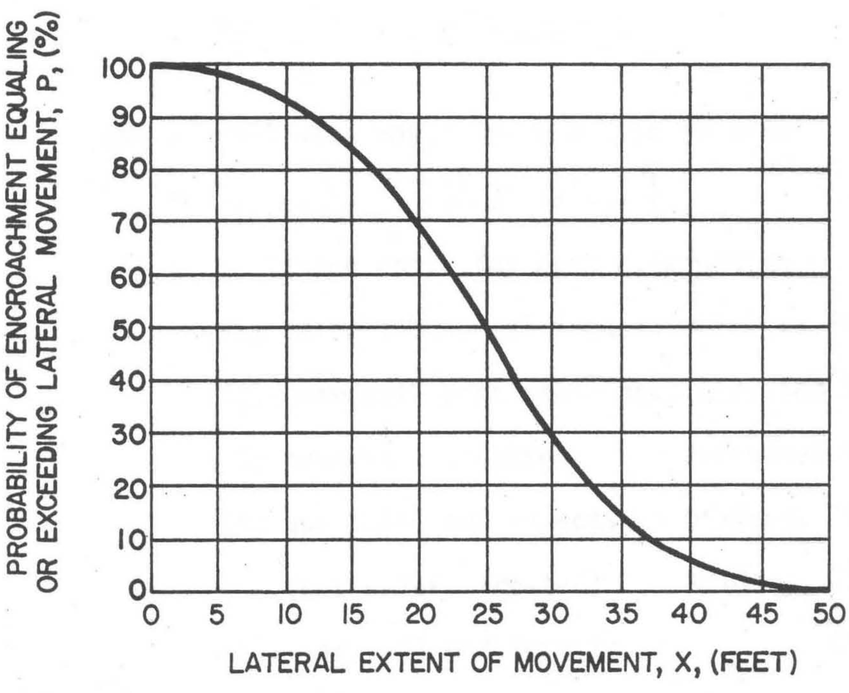


FIGURE 11 b: DISTRIBUTION OF LATERAL DISPLACEMENTS OF ENCROACHING VEHICLES. SOURCE : HUTCHINSON AND KENNEDY (18)

Roads. These cost figures are shown in Table 13.

Collision Maintenance Costs

The collision maintenance cost was computed for each improvement alternative using the following equation:

$$C_M = \frac{E_f D}{5280} (CM_1 + CM_2 + CM_3) \qquad \text{---Eq 5}$$

where:

C_M = collision maintenance costs for each alternative ($/yr)

CM_1 = collision costs for side Impacts

$= P_{(s)} \sum_{\Theta} \sum_{V} [(SP)(CS)(L_1)]$

CM_2 = collision costs for side impacts in which guardrail bottomed-out on bridge piers

$= P_{(s)} \sum_{\Theta} \sum_{V} [(SP)(CS)(L_2)]$

CM_3 = collision costs for end type impacts

$= P_{(s+3)} \sum_{\Theta} \sum_{V} [(SP)(CS)(L_3)]$

CS = collision costs for each alternative

(1) guardrail normal impact: refer to Figure 10

(2) guardrail post snagging: Increased SI by 25%

(3) guardrail vaulting : Decreased SI by 50%

(4) guardrail end impacts : $\Theta \leq 10$deg; CS=$400
(not safety treated) $\Theta > 10$deg; CS=$200

(5) guardrail end impacts : CS=$200
(flared and safety treated)

TABLE 13

CONSTRUCTION COSTS

ITEM	COST ($/unit)	Unit
W-Beam Guardrail, G4W*	8.14	ft
Thrie-Beam Guardrail, G9	9.39	ft
Concrete Median Barrier, MB5	14.04	ft
W-Beam End Anchorage	295.85	ea.
Thrie-Beam Adaptor	110.00	ea.
Removal of Guardrail	0.74	ft
Fitch Modules		
400 lb	253.53	ea
700 lb	234.06	ea
1400 lb	223.11	ea
2100 lb	217.80	ea
Filler Material for Modules	12.50	cyd
4 in. Concrete Slab for Modules	1.50	ft^2

* Increase unit cost for rub rail by $2.00

(6) Fitch System : AASHTO (9); CS=$1,025
(weighted cost and
includes 9% inflation factor)

All the remaining terms in Eq 5 have been previously defined in Eq 4.

The results of the hazard index calculations for each improvement alternative are summarized in Table 14. Capital costs and collision maintenance costs are also shown in this table.

Evaluation

The cost-effectiveness of one alternative (A) with respect to another (B) was computed as follows:

$$C/E = \frac{C_A - C_B}{H_B \; H_A} \qquad \text{---Eq 6}$$

where

C/E = cost-effectiveness ratio of alternative A with respect to alternative B

C_A, C_B = total annual costs of alternatives A and B ($C_A \geq C_B$)

H_A, H_B = hazard indices of alternatives A and B

The cost-effectiveness ratio represents the cost to eliminate one injury accident. Thus, the lower the cost-effectiveness ratio, the more cost-effective is the alternative. Also, in this study, the alternatives were compared in order of increasing total annual costs so that the total annual cost of the base alternative was always less than, or equal to, that of the improvement alternative ($C_B \leq C_A$). Therefore, a negative cost-effectiveness ratio indicates that the improvement alternative is not cost effective, because it costs more and does not reduce the hazard index.

TABLE 14.

RESULTS OF HAZARD INDEX, CAPITAL COST, AND COLLISION MAINTENANCE COST COMPUTATIONS

ADT = 15,000
E_f = 7.3 Encroachments/mile-year

Improvement Alterative	Lateral Offset Distance (ft)	Lateral Probability		Hazard Index (Inj. Accid) per yr)	Capital Costs		Collision Maintenance Costs ($/yr)	Total Annual Costs ($/yr)
		Side Impact	End Impact		($)	($/yr)		
Existing	15	0.84	0.74	0.081	0	0	30	30
1	15	0.84	0.74	0.052	600	65	25	90
2	17	0.80	0.69	0.025	1,600	175	15	190
3	17	0.08	0.69	0.025	1,690	185	15	200
4	17	0.80	0.69	0.025	1,900	208	10	218
5	16	0.83	0.71	0.028	1,990	218	10	228
6	15 (Fitch) 19 (CMB)	0.71	0.73	0.023	4,020	440	50	490
7	19	0.71	0.64	0.085	160	20	0	20

Note 1. Annualized capital cost using a 20-year service life, 9-percent interest rate, and zero salvage value.

The results of the cost-effectiveness analysis are presented in Table 15. Alternative 7, removing the existing guardrail and leaving the bridge piers unprotected, was the lowest cost alternative and, therefore, served as the initial basis of comparison. It is obvious from these results that Alternatives 3, 4, 5, and 6 are not cost-effective improvements. Compared to Alternative 2, Alternatives 3, 4, and 5 cost more but do not reduce the hazard index. And, of the remaining alternatives, Alternative 6 has the highest cost per injury accident eliminated.

The most cost-effective alternative is Alternative 1, which involved adding a rubrail to the existing guardrail and flaring and safety treating its upstream end. It is the improvement that has the lowest cost per injury, accident eliminated. Thus, from the cost-effectiveness point of view, Alternative 1 is the improvement that should be made. Of course, this is assuming that it is worth $2,120 to eliminate one injury accident. If it is not, then Alternative 7 should be implemented. The following benefit-cost analysis deals more directly with this question of the economic justification of improvement implementation.

Benefit-Cost Analysis

The Benefit-Cost method differs from the Cost-Effectiveness method in that accident costs are taken into consideration. The relationship between impact severity and injury accident costs was discussed earlier (see Figure 9).

Injury Accident Costs

The injury accident cost was computed for each improvement alternative using the following equation:

TABLE 15.

COST-EFFECTIVENESS ANALYSIS

Improvement Alternative	Annual Capital Costs ($/yr)	Annual Collision Maintenance Costs ($/yr)	Total Annual Costs ($/yr)	Hazard Index (Inj. Accid. per yr.)	Cost-Effectiveness Ratios			
					vs. 7	vs. Existing	vs. 1	vs. 2
7	20	0	20	0.085	-	-	-	-
Existing	0	30	30	0.081	$ 2,500	-	-	-
1	65	25	90	0.052	2,120	$ 2,070	-	-
2	175	15	190	0.025	2,830	2,860	$ 3,700	-
3	185	15	200	0.025	3,000	3,040	4,070	Infinite
4	208	10	218	0.025	3,300	3,360	4,740	Infinite
5	218	10	228	0.028	3,650	3,740	5,750	Negative
6	440	50	490	0.023	7,580	7,930	13,790	$175,000

$$C_1 = \frac{E_f D}{5280}\,(CI_1 + CI_2 + CI_3) \qquad \text{---Eq 6}$$

where:

C_1 = injury accident costs for each alternative ($/yr)

CI_1 = accident costs for side impacts

$= P_{(s)} \sum_{\Theta} \sum_{V} \left[(SP)(AC)(L_1) \right]$

CI_2 = accident costs for side impacts in which guardrail bottomed-out on bridge piers

$= P_{(s)} \sum_{\Theta} \sum_{V} \left[(SP)(AC)(L_2) \right]$

CI_3 = accident costs for end type impacts

$= P_{(s+3)} \sum_{\Theta} \sum_{V} \left[(SP)(AC)(L_3) \right]$

AC = accident costs for each alternative

(1) barrier normal impact : refer to Figure 9

(2) guardrail post snagging: Increased SI by 75%

(3) barrier vaulting : SI=2.5

All the remaining terms in Eq 6 have been previously defined in Eq 4.

Evaluation

The benefit-cost ratio of one alternative (A) with respect to another (B) was computed as follows:

$$B/C = \frac{A_B - A_A}{C_A - C_B} \qquad \text{---Eq 7}$$

where:

B/C = benefit-cost ratio of alternative A with respect to alternative B

A_A, A_B = annual accident costs of alternatives A and B

C_A, C_B = total annual costs of alternatives A and B.

The benefit-cost ratio indicates whether or not the additional cost of alternative A results in sufficient accident cost savings to justify the investment. Thus, a benefit-cost ratio greater than 1.0 indicates that the additional investment is justified, and, therefore, A would be preferred to B. A benefit-cost ratio less than 1.0 means that the additional investment in A is not warranted.

The results of the benefit-cost analysis are presented in Table 16. Compared to Alternative 7, removing the existing guardrail and leaving the bridge piers unprotected, all of the other alternatives are economically worthwhile. However, the incremental benefit-cost ratios indicate that Alternative 2 is the best alternative. The additional cost of Alternative 2 with respect to the lower cost improvements is justified by the increased accident cost savings that would be realized by its implementation. Whereas the higher cost improvements do not provide accident cost savings as great as those provided by Alternative 2.

The results of the cost-effectiveness analysis indicate that Alternative 1 is the most cost-effective improvement, and the results of the benefit-cost analysis indicate that Alternative 2 is the most economically worthwhile improvement. The reason that the two methods do not point to the same alternative is that the objectives of the two methods are different. The objective of the cost-effectiveness method is to minimize the

TABLE 16.

BENNEFIT-COST ANALYSIS

IMPROVEMENT ALTERNATIVE	ANNUAL CAPITAL COSTS ($/YR)	ANNUAL COLLISION MAINTENANCE COSTS ($/YR)	TOTAL ANNUAL COSTS ($/YR)	ANNUAL ACCIDENT COSTS ($/YR)	BENEFIT-COST RATIOS			
					VS. 7	VS. EXISTING	VS. 1	VS. 2
7	20	0	20	$15,300	-	-	-	-
EXISTING	0	30	30	7,350	795	-	-	-
1	65	25	90	2,920	177	74	-	-
2	175	15	190	730	86	41	22	-
3	185	15	200	740	81	39	20	NEGATIVE
4	208	10	218	750	73	35	17	NEGATIVE
5	218	10	228	1,110	68	32	13	NEGATIVE
6	440	50	490	890	31	14	5	NEGATIVE

cost of eliminating injury accidents. Whereas the objective of the benefit-cost method is to maximize the investment at the assumed minimum attractive rate of return (i.e., 9%), where the return on the investment is accident cost savings.

Both methods have advocates, and both have been used in the management of roadside safety improvement programs. However, it is beyond the scope of this study to recommend one method or the other.

SUMMARY AND CONCLUSIONS

The University of Nebraska is currently conducting a research project in cooperation with the Nebraska Department of Roads to develop a cost-effective policy for the use of guardrail in Nebraska. One area of concern is the use of guardrail to protect bridge piers in depressed medians on horizontal curves. Because of the nature of the terrain between the traveled way and the guardrail in such locations, it is likely that particular attention should be given to the potential of encroaching vehicles to vault over the guardrail or snag on guardrail posts. The purpose of this study was to select a typical site and investigate the performance of a guardrail of current design protecting bridge piers in a depressed median on a horizontal curve. In addition, improvement alternatives were defined and evaluated.

The results of this study will serve as input to the revision of Nebraska Department of Roads guardrail policy, which is currently underway. Also, the methodology developed in the course of this study will be used to determine cost-effective policies pertinent to other guardrail applications.

Although the results of this study are from an analysis of a specific site, the following more general observations were made during the conduct of the study:

(1) Guardrail protection of bridge piers located in depressed medians on horizontal curves is economically justified.

(2) The standard W-Beam (G4W), with a rub rail, and the Thrie-Beam (G9) are equally cost-effective in protecting bridge piers in depressed medians.

(3) Modified-turned-down-end safety treatment of the upstream end is a very cost-effective improvement.

(4) Providing maximum lateral clearance between the edge of the traveled way and the face of the guardrail, subject to a minimum lateral clearance between the face of the guardrail and the piers of about 2 ft, is a cost-effective design policy; because the increase in hazardousness caused by the relatively infrequent high-speed, high-angle impacts bottomming-out on the piers is less than the decrease in hazardousness due to the decrease in the number of impacts as a result of the increased lateral clearance.

(5) The hazardousness of a traffic barrier is directly proportional to its longitudinal length along the roadway. Therefore, minimizing the length of a guardrail installation is a cost-effective design policy. The results of the benefit-cost analysis conducted in this study indicate that reducing the length of the guardrail installation by 50% and anchoring the downstream end (Alternatives 4 and 5) is an economically justified improvement even though not as cost-effective as simply reducing the guardrail length by 50% (Alternatives 2 and 3). However, it should be noted that only one point of impact was considered in this study and for impacts at this point downstream end anchorage was not required. This may not be the case for other points, therefore the feasibility of the shorter length of guardrail without the downstream anchored is still in question.

(6) Protection of bridge piers in depressed medians with a Fitch Module-Concrete Median Barrier system is not cost-effective.

REFERENCES

1. McHenry, R. R., and Segal, D. J., "Determination of Physical Criteria for Roadside Energy Conversion Systems", Cornell Aeronautical Laboratory Report VJ-2251-V-1, July 1976.

2. McHenry, R. R., and DeLeys, N. J., "Vehicle Dynamics in Single Vehicle Accidents: Validation and Extension of a Computer Simulation", Cornell Aeronautical Laboratory Report VJ-2251-V-3, Dec. 1968.

3. Ross, H. E., and James, J. E., "HVOSM User's Manual", Texas Transportation Institute, Research Report 140-9, Aug. 1974.

4. Ross, H. E., and Post, E. R., "Tentative Criteria for the Design of Safe Sloping Culvert Slopes", HRR 386, pp. 101-10, 1972.

5. Ross, H. E., and Post, E. R., "Full-Scale Embankment Tests and Comparisons with a Computer Simulation", TRB 488, pp. 53-63, 1974.

6. Weaver, G. D., Marquis, E. L., and Olson, R. M., "Selection of Safe Roadside Cross Sections", NCHRP 158, 1975.

7. Powell, G. H., "BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems", Report No. FHWA-RD-73-51, April 1973.

8. Powell, G. H., "Computer Evaluation of Automobile Barrier Systems", Report No. FHWA-RD-73-73, August 1970.

9. AASHTO, "Guide for Selecting, Locating, and Designing Traffic Barriers", 1977.

10. Hirsch, T. J., Buth, C. E., Nixon, J. F., Hustace, D., and Cooner, H., "Eliminating Vehicle Rollovers on Turned-Down Guardrail Terminals", TRB 631, pp. 68-76, 1977.

11. Nebraska Department of Roads, "Road Design Standard Plans", Plan No. 704, p. 5 of 6, 1973.

12. Ross, H. E., and Post, E. R., "Criteria for Guardrail Need and Location on Embankments--Volume One, Development of Criteria", Texas Transportation Institute, Research Report 140-4, April 1972.

13. Calcote, L. R., "Development of Cost-Effectiveness Model for Guardrail Selection", Volume 1. Technical Documentation, Final Report submitted to FHWA, Southwest Research Institute, November 1977.

14. Young, R. D., Post, E. R., and Ross, H. E., "Simulation of Vehicle Impact with Texas Concrete Median Barrier: Test Comparisons and Parameter Study," HRR 460, pp 61-71, 1973.

15. Post, E. R., Ruby, R. J., McCoy, P. T., and Coolidge, D. O., "Cost-Effectiveness of Driveway Slope Improvements", Final Report Submitted to TRB, 57th Annual Meeting, 1978.

16. Weaver, G. D., Post, E. R., and French, D. D., "Cost-Effectiveness Program for Roadside Safety Improvements on Texas Highways", Volume 2: Computer Documentation Manual, Texas Transportation Institute, Research Report 15, August 1974.

17. NHTSA, "Societal Costs of Motor Vehicle Accidents", Preliminary Report, DOT, April 1972.

18. Hutchinson, J. W. and T. W. Kennedy, "Medians of Divided Highways - Frequency and Nature of Vehicle Encroachments," University of Illinois Engineering Experiment Station Bulletin 487, 1966.

19. Ross, H. E., Jr., "Impact Performance and a Selection Criterion for Texas Median Barriers," Texas Transportation Institute Research Report 140-8, April, 1974.

20. Glennon, J. C., "Roadside Safety Improvement Programs on Freeways: A Cost-Effectiveness Priority Approach", NCHRP 148, 1974.

21. Weaver, G. D., Woods, D. L., and Post, E. R., "Cost-Effectiveness Analysis of Roadside Safety Improvements", TRB 543, pp 1-15, 1975.

22. "Safety Improvement Programming for Roadside Obstacles", FHWA, 1977. (Work prepared by: Weaver, G. D., Woods, D. L., and Post, E. R., "Cost-Effectiveness Analysis of Roadside Safety Improvement", TRB 543, 1975.)

A P P E N D I X

A. HVOSM INPUT PROPERTIES

UNL-COST EFFECTIVENESS STUDY ON THE PLACEMENT OF GUARDRAIL ON OUTSIDE HORIZONTAL CURVES. SPEED=50 MPH, ENCROACHMENT ANGLE=10 DEG., (RUN 1A)

INITIAL CONDITIONS

PHIO =	3.857	DEGREES	XCO' =	204.000	INCHES	PO =	0.0	DEG/SEC
THETAO=	0.333	"	YCO' =	1798.800	"	QO =	0.0	"
PSIO =	-10.000	"	ZCO' =	170.769	"	RO =	0.0	"
PHIRO =	0.0	"	DELTA1=	0.0	"	D(PHIR)/DT=	0.0	"
PSIFIO=	0.0	"	DELTA2=	0.0	"	D(PSIF)/DT=	0.0	RAD/SC
			DELTA3=	0.0	"			

UO =	880.000	IN/SEC
VO =	0.0	"
WO =	0.0	"
D(DEL1)/DT=	0.0	"
D(DEL2)/DT=	0.0	"
D(DEL3)/DT=	0.0	"

TIRE DATA / TERRAIN TABLE ARGUMENTS

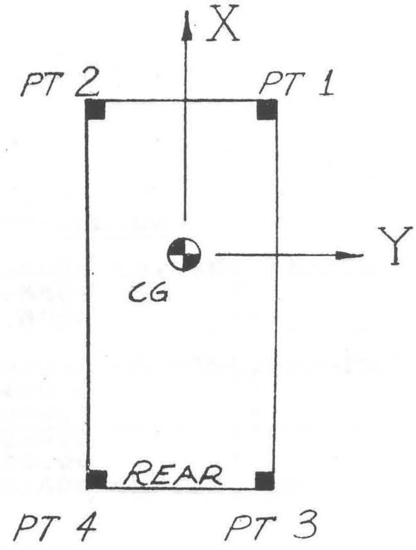
TIRE DATA		TERRAIN TABLE ARGUMENTS
KT	1098.000 LB/IN	
SIGMAT =	3.000	
LAMBDAT =	10.000	
AO	=4400.000	SOIL DAMPING= 0.001 SPI
A1	= 8.276	SOIL FRICT. = 0.250
A2	=2900.000	SSTIFF = 4000. LB/IN
A3	= 1.780	NO.X TEMPS. = 13
A4	=3900.000	NO.Y TEMPS. = 19
AMU	= 0.200	NO. VAR AMU = 48
OMEGT	= 1.000	TABLES

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 (IN.)	Y (IN.)	Z (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



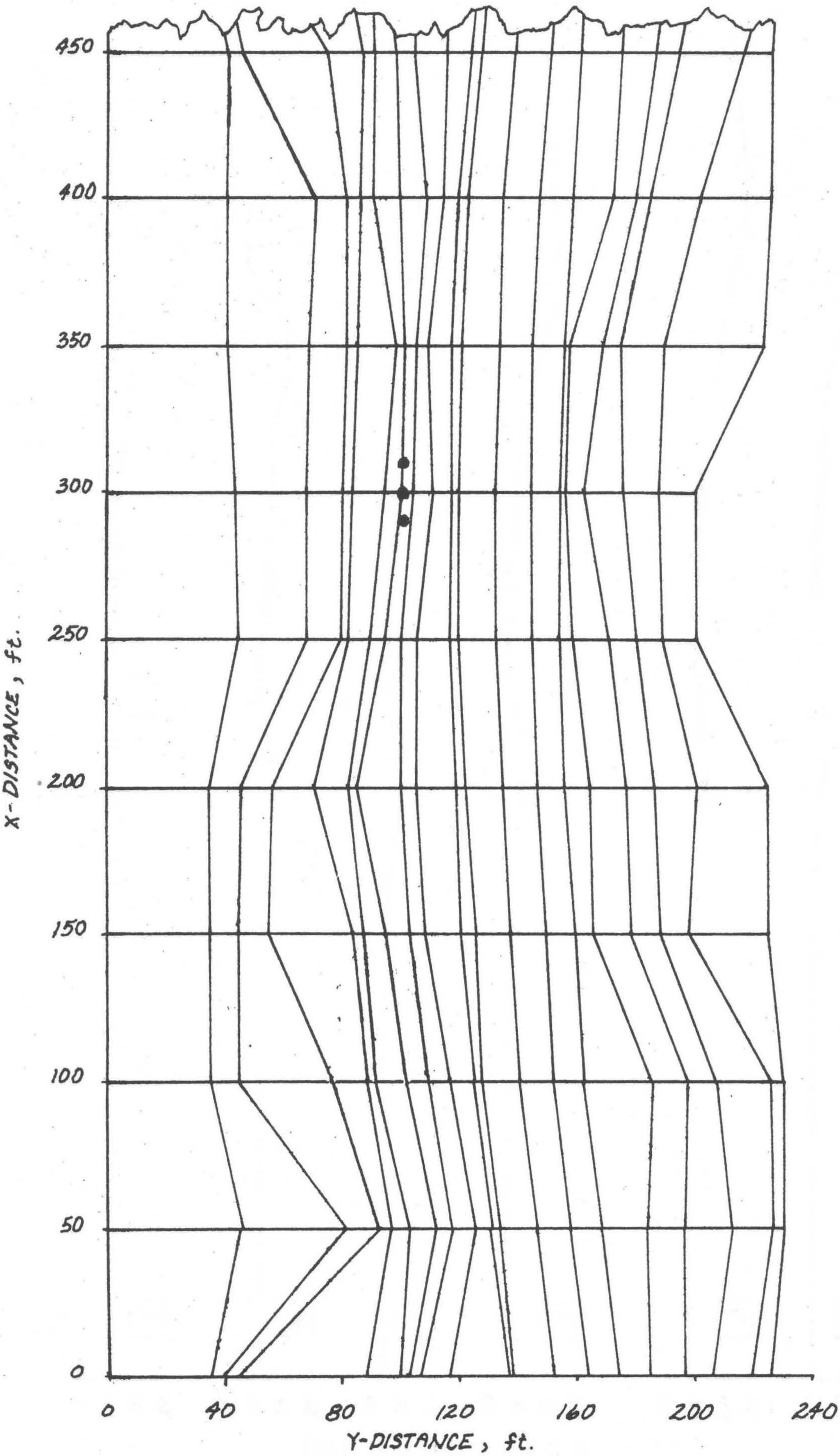
UNL-COST EFFECTIVENESS STUDY ON THE PLACEMENT OF GUARDRAIL CN OUTSIDE HORIZONTAL CURVES. SPEED=50 MPH, ENCROACHMENT ANGLE=10 DEG., (RUN 1A)

```
        PROGRAM CONTROL DATA

START TIME                =   0.0    SEC
END TIME                  =   5.500
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

   LAMBDAF  =     0.500
   LAMBDAR  =     0.500
   OMEGAF   =     3.000 INCHES
   OMEGAR   =     4.000 INCHES
   TS       =    46.500 INCHES
   RR       =  32500.0 LB-IN/RAD
   RF       =  98500.0 LB-IN/RAD
   KRS      =     0.070 ROLL STEER COEFF.

   AKRC     =  300.000 LB/IN
   AKRCP    =    2.000 LB/IN3
   OMEGRC   =   -4.000 IN
   AKRE     =  300.000 LB/IN
   AKREP    =    2.000 LB/IN3
   OMEGRE   =    4.500 IN


                    INERTIAL DATA

          MS   =   8.4402 LB.-SEC.**2/IN
          MUF  =   0.5507        ''
          MUR  =   0.8952        ''

          IX   =   6200.0 LB.-SEC.**2-IN
          IY   =  34400.0        ''
          IZ   =  36000.0        ''
          IXZ  = -192.000        ''
          IR   =   600.00        ''
          G    =  386.400 IN/SEC.**2
```

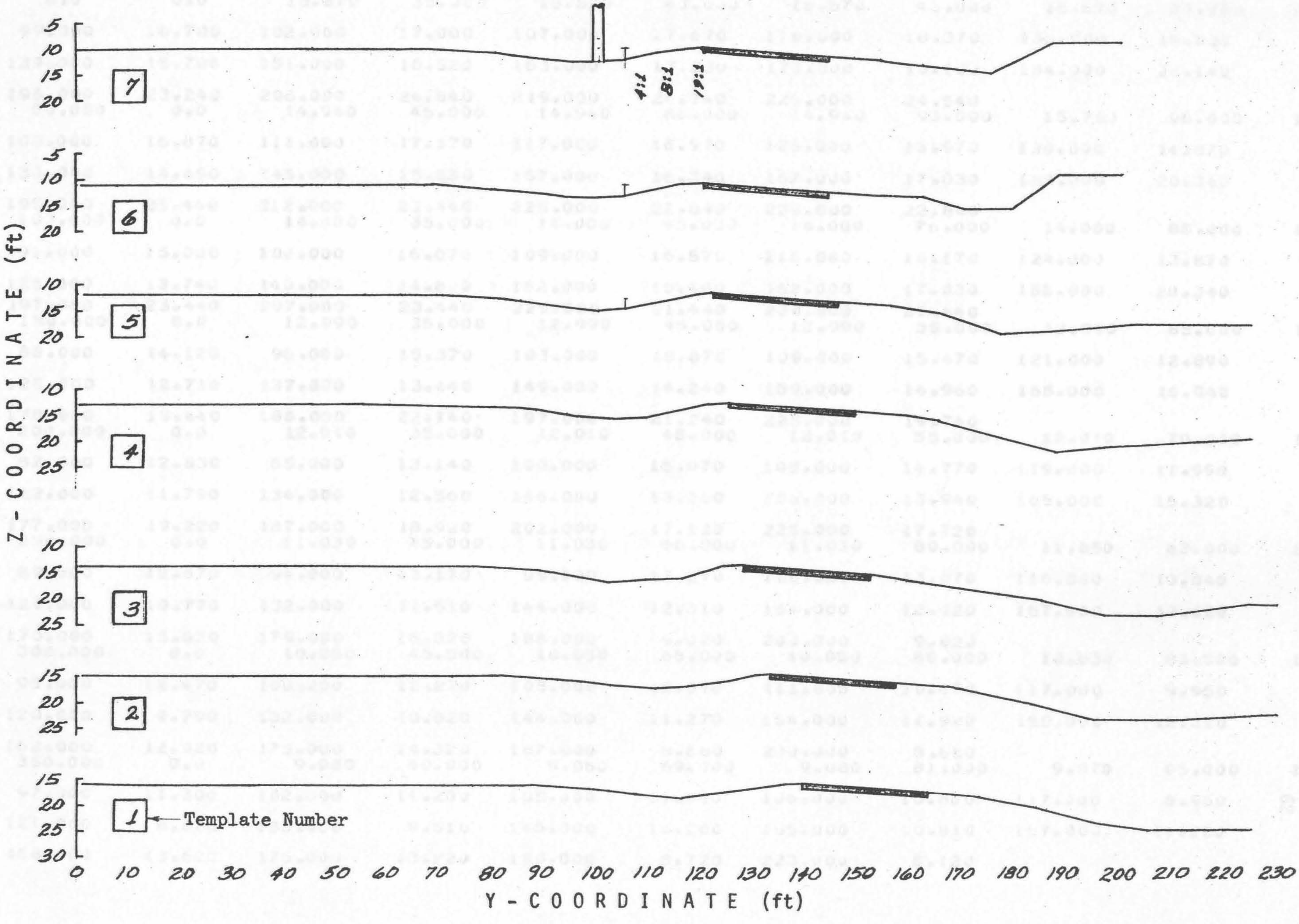
A P P E N D I X

B. TERRAIN DATA

PLAN VIEW OF TERRAIN



TEMPLATE CROSS SECTIONS



```
13.0      19.0      48.0                                                                                   14
GP(I,1),YGP(I,J),ZGP(I,J),I=1,13  J=1,19
    0.0        0.0        15.870     35.000     15.870     40.000     15.870     45.000     15.870     87.000     15.870

  99.000     16.700    102.000     17.000    107.000     17.670    116.000     18.370    136.000     15.830

 139.000     15.700    151.000     16.520    163.000     17.330    173.000     18.100    184.000     20.140

 196.000     23.240    206.000     24.840    219.000     24.740    225.000     24.540
  50.000      0.0       14.940     45.000     14.940     81.000     14.940     93.000     15.780     96.000     16.070

 103.000     16.870    111.000     17.370    117.000     16.970    125.000     15.970    130.000     14.870

 133.000     14.690    145.000     15.530    157.000     16.340    167.000     17.030    183.000     20.340

 195.000     23.440    212.000     23.440    225.000     22.840    230.000     22.840
 100.000      0.0       14.000     35.000     14.000     45.000     14.000     76.000     14.000     88.000     14.790

  91.000     15.080    102.000     16.070    109.000     16.570    116.000     16.170    124.000     13.870

 128.000     13.740    140.000     14.800    152.000     15.400    162.000     17.030    185.000     20.340
 197.000     23.440    207.000     23.440    225.000     21.440    230.000     21.440
 150.000      0.0       12.990     35.000     12.990     45.000     12.990     55.000     12.990     85.000     13.820

  88.000     14.120     96.000     15.370    103.000     15.870    109.000     15.470    121.000     12.890

 125.000     12.710    137.000     13.440    149.000     14.240    159.000     14.960    165.000     16.040

 178.000     19.440    188.000     22.140    197.000     21.240    225.000     19.740
 200.000      0.0       12.010     35.000     12.010     45.000     12.010     55.000     12.010     70.000     12.010

  82.000     12.830     85.000     13.140    100.000     15.070    105.000     14.770    119.000     11.990

 122.000     11.790    134.000     12.560    146.000     13.350    156.000     13.940    165.000     15.320

 177.000     19.220    187.000     18.920    202.000     17.520    225.000     17.720
 250.000      0.0       11.030     45.000     11.030     68.000     11.030     80.000     11.850     83.000     12.110

  89.000     12.670     94.000     13.170     99.000     13.270    105.000     13.070    116.000     10.840

 120.000     10.770    132.000     11.510    144.000     12.310    154.000     12.920    157.000     13.120

 170.000     15.520    179.000     15.320    188.000      9.020    200.000      9.020
 300.000      0.0       10.050     45.000     10.050     68.000     10.050     80.000     10.830     83.000     11.150

  95.000     12.470    100.000     12.270    105.000     12.070    111.000     10.670    117.000      9.950

 120.000      9.790    132.000     10.520    144.000     11.270    154.000     11.920    155.000     12.220

 162.000     12.920    175.000     14.320    187.000      8.680    200.000      8.680
 350.000      0.0        9.080     40.000      9.080     69.000      9.080     81.000      9.870     85.000     10.110

  97.000     11.300    102.000     11.200    105.000     11.000    109.000     10.600    117.000      8.950

 121.000      8.820    133.000      9.510    145.000     10.260    155.000     10.810    157.000     11.220

 168.000     13.620    175.000     13.220    190.000      8.720    223.000      8.120
```

400.000	0.0	8.120	40.000	8.120	70.000	8.120	82.000	8.900	85.000	9.210
90.000	10.100	98.000	10.300	108.000	9.900	114.000	8.600	119.000	8.050	
122.000	7.890	134.000	8.570	146.000	9.320	157.000	10.010	171.000	12.320	
180.000	12.720	185.000	11.520	201.000	11.020	225.000	12.020			
450.000	0.0	7.100	40.000	7.100	45.000	7.100	74.000	7.100	86.000	7.890
90.000	8.150	97.000	9.000	104.000	9.600	115.000	8.300	123.000	7.020	
126.000	6.870	138.000	7.510	150.000	8.240	160.000	8.860	174.000	11.420	
186.000	11.120	194.000	9.820	216.000	9.520	225.000	9.420			
500.000	0.0	6.070	30.000	6.070	35.000	6.070	45.000	6.070	78.000	6.070
90.000	6.860	93.000	7.150	108.000	8.400	122.000	6.400	128.000	5.940	
130.000	5.750	142.000	6.460	154.000	7.170	164.000	7.920	178.000	10.520	
190.000	10.020	201.000	8.420	225.000	8.020	230.000	8.020			
550.000	0.0	5.160	45.000	5.160	83.000	5.160	95.000	5.880	98.000	6.150
106.000	7.000	114.000	7.400	122.000	6.600	129.000	5.100	132.000	4.810	
135.000	4.650	147.000	5.460	159.000	6.230	169.000	6.840	186.000	9.520	
194.000	9.120	204.000	7.120	225.000	6.620	230.000	6.620			
600.000	0.0	4.170	89.000	4.170	101.000	4.960	104.000	5.200	107.000	5.400
113.000	6.200	122.000	6.200	127.000	5.700	133.000	4.400	138.000	3.890	
141.000	3.760	153.000	4.470	165.000	5.270	175.000	5.750	187.000	8.320	
198.000	8.020	210.000	6.020	225.000	5.420	230.000	5.420			

A P P E N D I X

C. BARRIER VII COMPUTER PROGRAM

INPUT DATA: Alternative No. 2

(70 mph/25 deg)

OUTPUT DATA: Interval Time at 280 msec

Note: Last 9 guardrail posts failed completely in the unanchored downstream end (see p. 71). However, the vehicle was still redirected.

BARRIER VII - ANALYSIS OF AUTOMOBILE BARRIERS - U.C. BERKELEY. 1972

****

ALT. NO. 2 (70 mph / 25 deg)

****

CONTROL INFORMATION

NUMBER OF BARRIER NODES	=	46
NUMBER OF CONTROL NODES	=	27
NUMBER OF NODE GENERATIONS	=	1
NUMBER OF INTERFACES	=	1
NUMBER OF MEMBERS	=	61
NUMBER OF MEMBER GENERATIONS	=	5
NUMBER OF DIFFERENT MEMBER SERIES	=	2
NUMBER OF ADDITIONAL WEIGHT SETS	=	0
BASIC TIME STEP (SEC)	=	0.00200
LARGEST ALLOWABLE TIME STEP (SEC)	=	0.10000
MAXIMUM TIME SPECIFIED (SEC)	=	0.80000
MAX. NO. OF STEPS WITH NO CONTACT	=	50
OVERSHOOT INDEX	=	0
ROTATIONAL DAMPING MULTIPLIER	=	1.00
STEP-BY-STEP INTEGRATION TYPE	=	1

OUTPUT FREQUENCIES

AUTOMOBILE DATA	=	5
BARRIER DEFLECTIONS	=	5
BARRIER FORCES	=	10
ENERGY BALANCE	=	20
CONTACT INFORMATION	=	5
PUNCHED JOINT DATA	=	0
PUNCHED TRAJECTORY	=	0

AUTOMOBILE PROPERTIES

WEIGHT (LB)	=	3820.0
MOMENT OF INERTIA (LB.IN.SEC2)	=	36758.0
NO. OF CONTACT POINTS	=	16
NO. OF UNIT STIFFNESSES	=	3
NO. OF WHEELS	=	4
BRAKE CODE (1=ON, 0=OFF)	=	0
NO. OF OUTPUT POINTS	=	1

UNIT STIFFNESSES (K/IN/IN)

NO.	BEFORE BOTTOMING	AFTER BOTTOMING	UNLOADING	BOTTOMING DISTANCE
1	0.500	3.000	4.000	15.00
2	0.875	5.250	7.000	15.00
3	1.250	7.500	10.000	15.00

CONTACT POINT DATA

POINT	R COORD	S COORD	STIFFNESS NO.	TRIBUTARY LENGTH	INTERFACE CONTACTS			
1	-108.00	15.00	1	12.00	1	0	0	0
2	-108.00	27.00	1	12.00	1	0	0	0
3	-108.00	39.00	1	12.00	1	0	0	0
4	-96.00	39.00	1	12.00	1	0	0	0
5	-84.00	39.00	1	12.00	1	0	0	0
6	-72.00	39.00	2	30.00	1	0	0	0
7	-42.00	39.00	3	30.00	1	0	0	0
8	-12.00	39.00	3	30.00	1	0	0	0
9	18.00	39.00	3	30.00	1	0	0	0
10	48.00	39.00	2	12.00	1	0	0	0
11	60.00	39.00	1	12.00	1	0	0	0
12	72.00	39.00	1	12.00	1	0	0	0
13	84.00	39.00	1	12.00	1	0	0	0
14	84.00	27.00	1	12.00	1	0	0	0
15	84.00	15.00	1	12.00	1	0	0	0
16	84.00	3.00	1	12.00	1	0	0	0

WHEEL COORDINATES (IN), STEER ANGLES (DEG), AND DRAG FORCES (LB)

POINT	R-ORD	S-ORD	STEER ANGLE	DRAG FORCE
1	54.00	30.00	0.0	518.00
2	54.00	-30.00	0.0	518.00
3	-65.00	-30.00	0.0	437.00
4	-65.00	30.00	0.0	437.00

BEAM ELEMENTS, 100 SERIES

TYPE NUMBER	=	1	2
M. OF I. (IN4)	=	2.340D 00	2.340D 00
AREA (IN2)	=	2.010D 00	2.010D 00
LENGTH (IN)	=	7.500D 01	1.875D 01
YOUNGS MODULUS (KSI)	=	3.000D 04	3.000D 04
WEIGHT (LB/FT)	=	6.820D 00	6.820D 00
YIELD FORCE (K)	=	1.065D 02	1.065D 02
YIELD MOMENT (K.IN)	=	8.400D 01	8.400D 01
YIELD ACCURACY LIMIT	=	1.000D-01	1.000D-01

POSTS, 300 SERIES

TYPE NUMBER	=	1	2
HEIGHT OF NODE I (IN)	=	2.100D 01	2.100D 01
HEIGHT OF NODE J (IN)	=	0.0	0.0
A AXIS STIFFNESS (K/IN)	=	1.500D 01	2.200D 00
B AXIS STIFFNESS (K/IN)	=	1.660D 00	1.660D 00
EFFECTIVE WEIGHT (LB)	=	6.000D 01	6.000D 01
B AXIS YIELD MOMENT (K.IN)	=	1.000D 04	2.730D 02
A AXIS YIELD MOMENT (K.IN)	=	2.184D 02	2.184D 02
YIELD ACCURACY LIMIT	=	1.000D-01	1.000D-01
A SHEAR AT FAILURE (K)	=	1.000D 04	1.300D 01
B SHEAR AT FAILURE (K)	=	1.040D 01	1.040D 01
A DEFLN AT FAILURE (IN)	=	1.000D 04	7.400D 00
B DEFLN AT FAILURE (IN)	=	7.400D 00	7.400D 00

INITIAL POSITION AND VELOCITIES OF AUTO

SPECIFIED BOUNDARY POINT	=	13
X ORDINATE OF POINT	=	652.20
Y ORDINATE OF POINT	=	1.00
ANGLE FROM X AXIS TO R AXIS (DEG)	=	25.00
VELOCITY IN R DIRECTION (M.P.H)	=	70.00
VELOCITY IN S DIRECTION (M.P.H)	=	0.0
ANGULAR VELOCITY (RAD/SEC)	=	0.0
MINIMUM RESULTANT VELOCITY (M.P.H)	=	5.00
TRANSLATIONAL KINETIC ENERGY (K.IN)	=	7510.47
ROTATIONAL KINETIC ENERGY (K.IN)	=	0.0
TOTAL INITIAL KINETIC ENERGY (K.IN)	=	7510.47

AUTO TRAJECTORY RESULTS

TIME = 0.0 SECS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
1	592.6	-69.8	25.0	63.44	29.58	70.00	-0.00	70.00	25.0	0.0	0.0	0.0	0.0	0.0	0.0

BARRIER DEFLECTIONS, TIME = 0.0 SECS

NODE	X-DEFL	Y-DEFL	X-ORD	Y-ORD
1	0.0	0.0	0.0	39.1
2	0.0	0.0	74.6	31.3
3	0.0	0.0	149.2	23.5
4	0.0	0.0	224.3	20.4
5	0.0	0.0	299.5	17.4
6	0.0	0.0	373.9	14.3
7	0.0	0.0	392.5	13.0
8	0.0	0.0	411.2	11.7
9	0.0	0.0	429.8	10.4
10	0.0	0.0	443.4	9.1
11	0.0	0.0	467.1	7.6
12	0.0	0.0	485.8	6.2
13	0.0	0.0	504.4	4.7
14	0.0	0.0	523.1	3.2
15	0.0	0.0	541.8	3.0
16	0.0	0.0	560.5	2.8
17	0.0	0.0	579.1	2.5
18	0.0	0.0	597.8	2.3
19	0.0	0.0	616.5	1.9
20	0.0	0.0	635.2	1.5
21	0.0	0.0	653.8	1.0
22	0.0	0.0	672.5	0.6
23	0.0	0.0	691.2	0.5
24	0.0	0.0	709.9	0.3
25	0.0	0.0	728.5	0.2
26	0.0	0.0	747.2	0.0
27	0.0	0.0	765.9	0.0
28	0.0	0.0	784.7	0.0
29	0.0	0.0	803.4	0.0
30	0.0	0.0	822.2	0.0
31	0.0	0.0	840.9	0.0
32	0.0	0.0	859.7	0.0
33	0.0	0.0	873.4	0.0
34	0.0	0.0	897.2	0.0
35	0.0	0.0	915.9	0.0
36	0.0	0.0	934.7	0.0
37	0.0	0.0	953.4	0.0
38	0.0	0.0	972.2	0.0
39	0.0	0.0	990.9	0.0
40	0.0	0.0	1009.7	0.0
41	0.0	0.0	1028.4	0.0
42	0.0	0.0	1047.2	0.0
43	0.0	0.0	1065.9	0.0
44	0.0	0.0	1084.7	0.0
45	0.0	0.0	1103.4	0.0
46	0.0	0.0	1122.2	0.0

AUTO TRAJECTORY RESULTS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
TIME = 0.2800 SECS															
1	361.4	8.0	5.1	47.63	6.04	47.98	1.76	48.01	7.2	-1.06	-1.29	-1.17	-1.19	1.67	-129.5

BARRIER DEFLECTIONS, TIME = 0.2800 SECS

NODE	X-DEFL	Y-DEFL	X-ORD	Y-ORD
1	0.12	-0.26	0.1	38.8
2	0.15	-0.00	74.7	31.3
3	0.16	0.09	149.4	23.6
4	0.16	-0.03	224.5	20.4
5	0.15	-0.24	299.7	17.2
6	0.16	-0.11	374.1	14.2
7	0.18	0.17	392.7	13.2
8	0.21	0.64	411.4	12.3
9	0.25	1.35	430.0	11.9
10	0.29	2.38	448.7	11.5
11	0.31	5.13	467.4	12.8
12	0.31	8.09	486.1	14.2
13	0.31	11.07	504.7	15.8
14	0.32	13.94	523.4	17.1
15	0.09	17.15	541.9	20.1
16	-0.10	20.08	560.4	22.8
17	-0.24	22.71	578.9	25.2
18	-0.33	25.07	597.4	27.4
19	-0.63	28.83	615.9	30.7
20	-0.86	32.39	634.3	33.8
21	-1.08	35.82	652.7	36.9
22	-1.15	38.37	671.3	39.0
23	-1.25	40.84	690.0	41.3
24	-1.27	43.23	708.6	43.5
25	-1.16	45.24	727.3	45.4
26	-1.03	47.23	746.2	47.2
27	-1.00	48.98	765.0	49.0
28	-0.95	50.65	783.7	50.6
29	-0.93	52.38	802.5	52.4
30	-0.91	54.16	821.3	54.2
31	-1.01	56.64	839.9	56.6
32	-1.09	59.01	858.6	59.0
33	-1.09	60.54	877.4	60.5
34	-1.03	60.53	896.2	60.5
35	-1.11	58.41	914.8	58.4
36	-1.85	53.11	932.9	53.1
37	-3.05	46.44	950.4	46.4
38	-4.37	39.46	967.8	39.5
39	-5.28	33.63	985.7	33.7
40	-6.23	27.69	1003.5	27.7
41	-7.22	21.63	1021.2	21.6
42	-8.22	15.53	1039.0	15.5
43	-8.49	12.35	1057.5	12.3
44	-8.76	9.13	1075.9	9.2
45	-9.02	6.03	1094.4	6.0
46	-9.29	2.89	1112.9	2.9

Beams (100 Series)

MEMBER FORCES, TIME = 0.2800 SECS

Axial force is tension positive. Bending moments are positive clockwise on member ends.

BEAMS, 100 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	I-MOMENT	J-MOMENT	F-CODE	M-CODE
1	1	2	101	1.72	0.00	2.03	1	1
2	2	3	101	1.94	-2.03	3.46	1	1
3	3	4	101	2.20	-3.46	0.81	1	1
4	4	5	101	2.50	-0.81	0.01	1	1
5	5	6	101	2.36	-0.01	-26.50	1	1
6	6	7	102	3.29	26.50	-37.16	1	1
7	7	8	102	3.29	37.16	-48.79	1	1
8	8	9	102	3.29	48.79	-62.12	1	1
9	9	10	102	3.28	62.12	-78.00	1	3
10	10	11	102	4.12	78.00	-40.33	1	2
11	11	12	102	4.14	40.33	-6.03	1	1
12	12	13	102	4.15	6.03	24.78	1	1
13	13	14	102	4.14	-24.78	53.03	1	1
14	14	15	102	4.26	-53.03	56.68	1	1
15	15	16	102	4.26	-56.68	58.28	1	1
16	16	17	102	4.26	-58.28	58.17	1	1
17	17	18	102	4.27	-58.17	56.88	1	1
18	18	19	102	4.32	-56.88	39.66	1	1
19	19	20	102	4.34	-39.66	21.95	1	1
20	20	21	102	4.36	-21.95	4.01	1	1
21	21	22	102	4.41	-4.01	-10.08	1	1
22	22	23	102	4.52	10.08	-25.51	1	1
23	23	24	102	4.55	25.51	-40.09	1	1
24	24	25	102	4.58	40.09	-52.44	1	1
25	25	26	102	4.60	52.44	-64.19	1	1
26	26	27	102	4.77	64.19	-69.73	1	1
27	27	28	102	4.80	69.73	-73.84	1	1
28	28	29	102	4.82	73.84	-76.79	1	3
29	29	30	102	4.85	76.79	-80.40	1	4
30	30	31	102	5.07	80.40	-76.23	1	2
31	31	32	102	5.10	76.23	-69.14	1	1
32	32	33	102	5.07	69.14	-56.09	1	1
33	33	34	102	4.97	56.08	-34.78	1	1
34	34	35	102	4.73	34.78	13.36	1	1
35	35	36	102	4.06	-13.36	78.38	1	3
36	36	37	102	2.03	-78.38	73.22	1	2
37	37	38	102	1.50	-73.22	50.51	1	1
38	38	39	102	1.04	-50.51	33.28	1	1
39	39	40	102	0.98	-33.28	18.84	1	1
40	40	41	102	0.93	-18.84	6.77	1	1
41	41	42	102	0.87	-6.77	-2.99	1	1
42	42	43	102	0.40	2.99	-4.23	1	1
43	43	44	102	0.36	4.23	-3.86	1	1
44	44	45	102	0.31	3.86	-2.39	1	1
45	45	46	102	0.27	2.39	0.00	1	1

M - Code = flexural state indicator:
1 = elastic;
2 = yielded at i only;
3 = yielded at j only;
4 = yielded at i and j.

F - Code = extensional state indicator:
1 = elastic;
2 = yielded.

POSTS, 300 SERIES

MEMBER	NODE I	NODE J	TYPE	A-SHEAR	B-SHEAR	B-MOMENT	A-MOMENT	CODE
46	1	0	301	1.76	-0.43	37.04	-8.99	1
47	2	0	302	0.32	-0.01	6.77	-0.17	1
48	3	0	302	0.35	0.16	7.37	3.28	1
49	4	0	302	0.35	-0.05	7.26	-1.01	1
50	5	0	302	0.33	-0.40	7.01	-8.45	1
51	6	0	302	0.35	-0.19	7.43	-3.96	1
52	10	0	302	0.64	3.94	13.44	32.80	1
53	14	0	302	0.0	0.0	0.0	0.0	0
54	18	0	302	0.0	0.0	0.0	0.0	0
55	22	0	302	0.0	0.0	0.0	0.0	0
56	26	0	302	0.0	0.0	0.0	0.0	0
57	30	0	302	0.0	0.0	0.0	0.0	0
58	34	0	302	0.0	0.0	0.0	0.0	0
59	38	0	302	0.0	0.0	0.0	0.0	0
60	42	0	302	0.0	0.0	0.0	0.0	0
61	46	0	302	0.0	0.0	0.0	0.0	0

Posts (300 Series)

Shear forces and bending moments are positive for forces on the post in the positive A and B directions.

Code = state indicator:
- 1 = elastic;
- 2 = plastic hinge about A axis only;
- 3 = plastic hinge about B axis only;
- 4 = plastic hinges about both axes;
- negative = in process of failing (e.g -7 indicates third of ten failure steps);
- 0 = failed completely.

ENERGY BALANCE, TIME = 0.2800 SECS

TYPE OF ENERGY		PERCENT OF ORIG AUTO KE
TRANSLATIONAL K.E. OF AUTO	=	47.0
ROTATIONAL K.E. OF AUTO	=	1.2
BARRIER K.E.	=	0.6
ELASTIC ENERGY IN MEMBERS		
BEAMS	=	0.2
POSTS	=	0.1
INELASTIC WORK ON MEMBERS		
BEAMS	=	6.9
POSTS	=	10.9
ELASTIC ENERGY IN AUTO	=	0.0
INELASTIC WORK ON AUTO	=	0.9
DAMPING LOSSES	=	5.6
AUTO-BARRIER FRICTION LOSS	=	26.0
AUTO-PAVEMENT FRICTION LOSS	=	1.5
SUM OF ALL CONTRIBUTIONS	=	101.1

DATA ON AUTO-BARRIER CONTACT, TIME = 0.2800 SECS

AUTO POINT	CONTACT INTERFACE	CONTACT BETWEEN NODE	AND NODE	X COORDINATE	Y COORDINATE	NORMAL FORCE	X FORCE	Y FORCE
13	1	37	36	936.36	51.59	5.77	-4.08	-4.69

AUTO TRAJECTORY RESULTS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
TIME = 0.2900 SECS															
1	869.8	9.0	3.8	47.47	5.85	47.76	2.65	47.83	7.0	-0.33	-0.46	-0.36	-0.44	0.57	-125.5

A P P E N D I X

D. BUMPER HEIGHT COMPUTER PROGRAM

```
$JOB
C
C COMPUTER PROGRAM TO COMPUTE TRAJECTORY OF VEHICLE BUMPER RELATIVE TO TERRAI
C
      DIMENSION XCG(100), YCG(100), ZCG(100), ROLL(100), PITCH(100),
     1 YAW(100), TIME(100), ITEMP(50), XGPP(50), YGP(50,25), ZGP(50,25),
     2 XGP(50,1)
C
C NUMBER OF DATA POINTS, VEHICLE ENCROACHMENT SPEED AND ANGLE
C
      READ(5,100) NBX, NBY, NPT, ISPEED, IANGLE
C
C VEHICLE COORDINATES OF POINT ON VEHICLE BUMPER
C
      READ(5,101) XBUMP, YBUMP, ZBUMP
C
C POSITION AND ATTITUDE OF VEHICLE CENTER OF GRAVITY
C
      DO 10 M=1,NPT
      READ(5,102) TIME(M), XCG(M), YCG(M), ZCG(M), ROLL(M), PITCH(M),
     1 YAW(M)
   10 CONTINUE
C
C TERRAIN COORDINATES
C     NBX = NUMBER OF TEMPLATES ALONG X-AXIS
C     NBY = NUMBER OF Y AND Z COORDINATES ON TEMPLATE
C
      DO 20 I = 1,NBX
      READ(5,104) ITEMP(I), XGP(I,1), (YGP(I,J), ZGP(I,J), J=1,NBY)
   20 CONTINUE
      DO 90 I=1,NBX
      XGP(I,1) = XGP(I,1)*12.0
      DO 90 J=1,NBY
      YGP(I,J) = YGP(I,J)*12.0
      ZGP(I,J) = ZGP(I,J)*12.0
   90  CONTINUE
      WRITE(6,600) ISPEED, IANGLE
      WRITE(6,602)
C
C FIXED AXES COORDINATES OF POINT ON VEHICLE BUMPER
C
      RAD = 3.141592654 / 180.0
      DO 50 M=1,NPT
      R = ROLL(M) * RAD
      P = PITCH(M) * RAD
      H = YAW(M) * RAD
C
      A11 = COS(P)*COS(H)
      A12 = -COS(R)*SIN(H) + SIN(R)*SIN(P)*COS(H)
      A13 = SIN(R)*SIN(H) + COS(R)*SIN(P)*COS(H)
      A21 = COS(P)*SIN(H)
      A22 = COS(R)*COS(H) + SIN(R)*SIN(P)*SIN(H)
      A23 = -COS(H)*SIN(R) + COS(R)*SIN(P)*SIN(H)
      A31 = -SIN(P)
      A32 = COS(P)*SIN(R)
      A33 = COS(P)*COS(R)
C
      X = XCG(M)
      Y = YCG(M)
      Z = ZCG(M)
      XP = XBUMP
      YP = YBUMP
      ZP = ZBUMP
C
      XB = X + A11*XP + A12*YP + A13*ZP
      YB = Y + A21*XP + A22*YP + A23*ZP
      ZB = Z + A31*XP + A32*YP + A33*ZP
C
      II = NBX - 1
      JJ = NBY - 1
      DO 22 I = 1,II
      IF( XB .GT. XGP(I,1) .AND. XB .LE. XGP(I+1,1)) GO TO 30
   22 CONTINUE
   30 CONTINUE
      DO 24 J = 1,JJ
      Y11=YGP(I+1,J)-((((YGP(I,J)-YGP(I+1,J))/(XGP(I,1)-XGP(I+1,1)))*
     * XGP(I+1,1))+((((YGP(I,J)-YGP(I+1,J))/(XGP(I,1)-XGP(I+1,1)))*(XB))
      Y22=YGP(I+1,J+1)-((((YGP(I,J+1)-YGP(I+1,J+1))/(XGP(I,1)-
     * XGP(I+1,1)))*XGP(I+1,1))+((((YGP(I,J+1)-YGP(I+1,J+1))/
     * (XGP(I,1)-XGP(I+1,1)))*(XB))
      IF( YB .GE. Y11 .AND. YB .LE. Y22)  GO TO 32
   24 CONTINUE
   32 CONTINUE
```

```
C
      X1 = XGP(I,1)
      Y1 = YGP(I,J)
      Z1 = ZGP(I,J)
      X2 = XGP(I,1)
      Y2 = YGP(I,J+1)
      Z2 = ZGP(I,J+1)
      X3 = XGP(I+1,1)
      Y3 = YGP(I+1,J)
      Z3 = ZGP(I+1,J)
C
C  EQUATION OF PLANE TERRAIN SURFACE
C
      D = 1.0
      XYD = (X1*Y2*D) + (X3*Y1*D) + (X2*Y3*D) - (X3*Y2*D)
     * - (X1*Y3*D) - (X2*Y1*D)
      A = (Y2*Z1*D) + (Y1*Z3*D) + (Y3*Z2*D) - (Y2*Z3*D)
     * - (Y3*Z1*D) - (Y1*Z2*D)
      B = (X1*Z2*D) + (X3*Z1*D) + (X2*Z3*D) - (X3*Z2*D)
     * - (X2*Z1*D) - (X1*Z3*D)
      C = (X1*Y2*Z3) + (X3*Y1*Z2) + (X2*Y3*Z1) - (X3*Y2*Z1)
     * - (X2*Y1*Z3) - (X1*Y3*Z2)
C
      A = A / XYD
      B = B / XYD
      C = C / XYD
C
      ZGR = (A*XB) + (B*YB) + C
C
C  HEIGHT OF BUMPER ABOVE GROUND
C
      ZBUM = ZGR - ZB
      R = R / RAD
      P = P / RAD
      H = H / RAD
      T = TIME(M)
      WRITE(6,604) T,X,Y,Z,R,P,H,XB,YB,ZB,ZBUM
   50 CONTINUE
C
C  FORMAT STATEMENTS
C
  600  FORMAT(1H1,/////,T42,'TRAJECTORY OF VEHICLE BUMPER ON OUTSIDE OF
     * HORIZONTAL CURVE',/,T62,'SPEED=',T70,I2,T73,'MPH',/,T62,'ANGLE=',
     * T70,I2,T73,'DEG',//)
C
  602  FORMAT(T21,'VEHICLE CENTER OF GRAVITY',T55,'VEHICLE ATTITUDE',
     * T86,'VEHICLE BUMPER',T110,'VEHICLE BUMPER',/,T111,'HEIGHT ABOVE',
     * /,T13,'TIME',T21,'X-COORD',T30,'Y-COORD',T39,'Z-COORD',T52,
     * 'ROLL',T61,'PITCH',T71,'YAW',T81,'X-COORD',T90,'Y-COORD',T99,
     * 'Z-COORD',T114,'GROUND',/,T13,'(SEC)',T23,'(IN)',T32,'(IN)',T41,
     * '(IN)',T52,'(DEG)',T61,'(DEG)',T70,'(DEG)',T83,'(IN)',T92,'(IN)',
     * T101,'(IN)',T115,'(IN)',/)
C
  604  FORMAT(T11,F8.4,T20,F8.2,T29,F8.2,T38,F8.2,T49,F8.2,T58,F8.2,
     * T67,F8.2,T80,F8.2,T89,F8.2,T98,F8.2,T111,F8.2,/)
  100  FORMAT(10I5)
  101  FORMAT(8F10.3)
  102  FORMAT(F10.4,7F10.2)
  104  FORMAT(I3,F7.0,(10F7.0))
       STOP
       END

$ENTRY
```

TRAJECTORY OF VEHICLE BUMPER ON OUTSIDE OF HORIZONTAL CURVE
SPEED= 50 MPH
ANGLE= 10 DEG

VEHICLE CENTER OF GRAVITY			VEHICLE ATTITUDE			VEHICLE BUMPER			VEHICLE BUMPER HEIGHT ABOVE GROUND
X-COORD (IN)	Y-COORD (IN)	Z-COORD (IN)	ROLL (DEG)	PITCH (DEG)	YAW (DEG)	X-COORD (IN)	Y-COORD (IN)	Z-COORD (IN)	(IN)
2140.11	1522.80	125.72	3.21	0.94	-5.49	2217.57	1475.05	134.29	10.55
2353.51	1501.82	121.69	4.52	0.98	-6.02	2430.49	1453.14	129.28	12.16
2396.12	1497.59	120.77	4.58	1.04	-6.16	2472.99	1448.72	128.23	12.36
2438.70	1493.33	119.80	4.52	1.11	-6.28	2515.47	1444.30	127.21	12.53
2481.26	1489.03	118.83	4.40	1.18	-6.37	2557.97	1439.90	126.22	12.66
2523.79	1484.72	117.84	4.22	1.22	-6.42	2600.47	1435.55	125.30	12.72
2566.31	1480.39	116.84	3.94	1.23	-6.24	2643.15	1431.51	124.48	12.66
2608.80	1476.04	115.86	3.53	1.25	-6.42	2685.50	1426.98	123.76	12.54
2651.27	1471.69	114.89	3.08	1.26	-6.35	2728.05	1422.80	123.09	12.34
2693.72	1467.36	113.92	2.60	1.27	-6.23	2770.62	1418.72	122.44	12.11
2736.15	1463.07	112.95	2.10	1.28	-6.06	2813.21	1414.75	121.81	11.86
2778.56	1458.84	111.98	1.58	1.29	-5.85	2855.82	1410.90	121.19	11.59
2820.97	1454.70	111.02	1.07	1.29	-5.60	2898.46	1407.19	120.58	11.29
2863.35	1450.65	110.06	0.59	1.30	-5.31	2941.09	1403.63	119.94	11.02
2905.73	1446.70	109.11	0.17	1.30	-5.02	2983.73	1400.16	119.28	10.76
2948.09	1442.88	108.15	-0.15	1.30	-4.72	3026.34	1396.82	118.54	11.04
2990.44	1439.18	107.21	-0.39	1.29	-4.43	3068.93	1393.56	117.78	11.12
3032.78	1435.61	106.28	-0.57	1.27	-4.16	3111.48	1390.40	117.00	10.78
3075.11	1432.17	105.38	-0.74	1.23	-3.92	3154.00	1387.33	116.27	11.12
3117.43	1428.83	104.49	-0.92	1.19	-3.72	3196.47	1384.31	115.56	11.44
3159.73	1425.59	103.64	-1.16	1.14	-3.56	3238.89	1381.34	114.95	11.65
3202.03	1422.40	102.86	-1.50	1.09	-3.46	3281.27	1378.37	114.47	11.72
3244.31	1419.26	102.14	-1.92	1.01	-3.41	3323.58	1375.40	114.16	11.64

3286.58	1416.11	101.51	-2.44	0.92	-3.40	3365.85	1372.38	114.01	11.40
3328.83	1412.94	100.97	-3.06	0.87	-3.42	3408.09	1369.34	113.96	11.07
3371.07	1409.72	100.49	-3.76	0.82	-3.48	3450.29	1366.21	114.02	10.64
3413.29	1406.43	100.06	-4.51	0.76	-3.59	3492.44	1362.97	114.18	10.14
3455.49	1403.05	99.66	-5.22	0.68	-3.73	3534.53	1359.58	114.37	9.64
3497.63	1399.59	99.29	-5.82	0.60	-3.91	3576.57	1356.04	114.52	9.22
3539.84	1396.05	98.94	-6.26	0.53	-4.13	3618.56	1352.33	114.56	10.95
3581.99	1392.41	98.58	-6.57	0.47	-4.38	3660.51	1348.43	114.49	11.23
3624.12	1388.66	98.20	-6.81	0.42	-4.65	3702.43	1344.38	114.34	11.60
3666.23	1384.81	97.82	-7.03	0.35	-4.93	3744.30	1340.22	114.20	11.98
3708.31	1380.84	97.43	-7.25	0.26	-5.21	3786.15	1335.93	114.09	12.35
3750.38	1376.72	97.07	-7.56	0.19	-5.48	3827.99	1331.54	114.03	12.67
3792.43	1372.45	96.78	-7.98	0.15	-5.74	3869.84	1327.05	114.07	12.91
3834.46	1368.03	96.58	-8.50	0.10	-5.97	3911.69	1322.48	114.28	12.99
3876.48	1363.45	96.48	-9.11	0.04	-6.16	3953.56	1317.84	114.66	9.14
3918.48	1358.71	96.48	-9.78	-0.05	-6.30	3995.44	1313.12	115.22	8.79
3960.46	1353.84	96.63	-10.44	-0.12	-6.42	4037.33	1308.31	115.90	8.34
4002.45	1348.85	96.90	-11.04	-0.20	-6.51	4079.24	1303.41	116.66	7.82
4044.42	1343.74	97.29	-11.55	-0.27	-6.58	4121.15	1298.38	117.47	7.28
4086.39	1338.54	97.78	-11.98	-0.36	-6.62	4163.07	1293.28	118.36	6.69
4128.36	1333.24	98.34	-12.30	-0.44	-6.66	4204.98	1288.04	119.24	9.96
4170.32	1327.84	98.95	-12.52	-0.51	-6.70	4246.90	1282.67	120.09	8.98
4212.27	1322.34	99.54	-12.57	-0.54	-6.76	4288.79	1277.11	120.75	8.20
4254.21	1316.75	100.08	-12.38	-0.54	-6.84	4330.66	1271.34	121.17	7.69
4296.14	1311.05	100.53	-11.95	-0.52	-6.95	4372.50	1265.34	121.32	6.41
4338.05	1305.27	100.86	-11.29	-0.49	-7.10	4414.27	1259.13	121.19	5.98
4463.71	1287.31	101.17	-8.56	-0.30	-7.81	4539.31	1239.34	119.48	6.09