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DEVELOPMENT OF A COST-EFFECTIVENESS MODEL FOR GUARDRAIL SELECTION

Vol. I. Technical Documentation

January 1980

Final Report

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Washington, D. C. 20590

FOREWORD

This report is one of a set of reports documenting the development of a cost-effectiveness model for guardrail selection which includes cost parameters for various guardrail configurations as well as criteria for analysis of system effectiveness under various dynamic impact conditions.

Initially, two computer programs were developed for (1) determining the cost-effectiveness of a specific guardrail type and (2) comparative cost-effectiveness and rankings of eleven guardrail types. It is important to note that in the development and application of this model the guardrail was assumed to be warranted.

A speed distribution reported by Michigan in 1974 was used in the initial model development. Subsequently, another speed distribution developed by Calspan Corporation was used in the model.

The Calspan speed distribution was developed through the reconstruction of single vehicle accidents on two lane rural roads. The Michigan data was obtained from police reports on mostly freeway accidents. Because of differences in accident location and possibly also due to differences in data collection procedures, the Calspan speeds are generally lower than the Michigan speeds. For this reason the Calspan speed distribution data may be more appropriate for use on non-freeway sites while the Michigan speed distribution data may be more indicative of freeway conditions. The use of the lower speed distribution did, as expected, affect the guardrail rankings.

In order to provide flexibility, the speed distribution has been changed to a data input allowing the user to choose between the Michigan produced speed distribution, one developed by the Calspan Corporation or data developed directly by the user.

Two sets of site selection tables were also developed from the models for use in the field in making rough approximations of how the various guardrail types will rank. One set is based on the Michigan data; the other set is based on the Calspan data. In both cases, only the direct costs of the accidents were used. This was done to avoid the controversy surrounding the societel costs of accidents, the major portion of which is the loss of future earnings. This result has little effect on the relative rankings but does effect the site selection tables. The cost variable is also an input variable when using the models. Thus, the user may choose what he considers appropriate values for the costs of accidents.

Sufficient copies of the Executive Summary and the two volume report are being distributed to provide a minimum of one copy to each FHWA regional office and one copy to each FHWA division offices. Copies of the site selection tables based on the Calspan data will be made available to satisfy individual requests.

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Federal Highway Administration

NOTICE

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16. Abstract

This research was conducted to develop a cost-effectiveness model for guardrail selection that includes cost parameters for eleven (11) guardrail configurations and criteria for analysis of system effectiveness under various dynamic impact conditions. Vehicle classes include 2250-lb (1021-kg) and 4500-lb (2041-kg) vehicles. Accident severities were based on extrapolations of full-scale test data and verified by means of guardrail accident reconstruction data. Two computer programs were developed: (1) the SSCOST program for cost-effectiveness values (state cost, societal cost, total cost, and benefit-to-cost ratio) of a single specified guardrail type with given roadway conditions, and (2) the COCOST program for comparative cost-effectiveness values and ranking of the eleven guardrail types with given roadway conditions. Program inputs are simple to prepare, and computer run times are minimal.

This volume includes the data collection and analysis and technical documentation for quantification of the pertinent parameters and development of the computer algorithm. Volume II is a user's manual for applying the computer programs.

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PREFACE

This report, prepared under Contract No. DOT-FH-11-8827, describes the results of work conducted by the Transportation Structural Research Section of the Department of Structural Systems and Fire Technology, Southwest Research Institute. The author acknowledges the technical guidance and constructive report review of the FHWA Contract Manager, Mr. Michael J. McDanold.

Along with Dr. Lee R. Calcote, Principal Investigator, several SwRI staff members assisted in conducting the study. Jarvis D. Michie and M. E. Bronstad served as technical and administrative advisors. Van B. Parr formulated the traffic delay portion of the cost-effectiveness model, and Tom H. Swiercinsky was responsible for the accident reconstruction portion. Ray E. Kirksey expanded the BARRIER VII program and conducted A/D analyses of the pendulum test data. BARRIER VII accident reconstruction simulations were conducted and analyzed by Edwin O. Wiles. Glenn W. Deel assessed full-scale test and extrapolated vehicle damage, and C. E. Kimball, Jr., was responsible for the pendulum testing. Jane E. Baker prepared report manuscripts throughout the program.

Since the completion of this report, a draft final report has been submitted for Contract No. DOT-FH-11-8501, "Methodology for Reducing the Hazardous Effects of Highway Features and Roadside Objects," by Calspan Field Services, Incorporated. This contract involved the collection and analysis of data for 7,972 accidents on both freeway and non-freeway types of roads.

The impact speed distribution obtained from this Calspan study differed significantly from that used in this report (see Figure 6, page 36). Also, a question was raised by FHWA concerning the occupant severity index (see Figure 9, page 51). Consequently, sensitivity analyses were conducted of the speed distribution and severity indices used in the cost-effectiveness model of this study. The conclusions of the analyses were that the model is sensitive (order of preference of guardrail types as well as corresponding values) to both changes in severity and the change in speed distribution.

Details of these sensitivity analyses are shown in the Addendum of Volume II, User's Manual. Because of the sensitivity of these parameters, the computer programs discussed herein have been changed to include user specified input for speed distribution percentages and severity index factors. Further, sensitivity analyses and site selection tables presented herein have been rerun with the Calspan speed distribution.

If the Michigan speed distribution shown in Figure 6 is representative, the user can apply the results of this report directly. If the Calspan distribution is more representative (see Addendum of Volume II), the regenerated results can be obtained from FHWA for use. Finally, if other distributions or modifications of the severity indices (Figure 9) are desired, the user can specify the input values and conduct computer runs to prepare his own set of guardrail selection aids.

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I. INTRODUCTION

Since the late 1960's, extensive investigative efforts have been undertaken to improve highway safety by either eliminating hazardous roadside conditions or by improving traffic barrier systems to protect the motorist from those hazards that cannot be eliminated economically. Numerous reports have been prepared to present updated state-of-the-practice in traffic barrier technology, including warrants, impact performance, and economics. Notable among these have been National Cooperative Highway Research Program (NCHRP) Reports 36 (1967), 54 (1968), and 118 (1971). Current state of knowledge and design guidelines for longitudinal barriers (guardrails and median barriers) and crash cushions are contained in the AASHTO "Guide for Selecting, Locating, and Designing Traffic Barriers," 1977.

This report is concerned with highway guardrails. Figure 1 illustrates the design process graphically. The upper portion of the figure involves the determination of whether or not the guardrail installation is warranted. In the conventional procedures, details of embankments or roadside objects (nontraversable hazards or fixed objects) are compared with available warranting criteria, such as those in the AASHTO guide. Guardrails generally produce a larger target for the motorist than the shielded obstacles and, hence, increase the frequency of impacts. Thus, the warrants are based on the premise that the guardrail should be installed only if it reduces the severity of potential accidents. Note that the probability and associated costs of accidents are not included in this warranting procedure.

Based upon engineering judgment, the probability of run-off-the-road accidents, economic factors, or other decision policies, guardrails are generally constructed in as many warranted sites as funds permit. The AASHTO guide lists deflection, strength and safety, maintenance, compatability, costs, field experience, aesthetics, and promising new designs as selection criteria.

With the problems of ever-increasing highway construction costs and the limited funding available, it has become of critical importance that a cost-effectiveness formulation be included as an aid in the decision-making policy. This is particularly true for the rural, low-volume highway. With such roads, strict adherence to the conventional guardrail warranting and selection procedures could lead to the installation of guardrails of maximum effectiveness at some sites and no installations at other sites because of the lack of available funds. Thus, as shown by the dashed lines in Figure 1, this contract supplies a need for effective criteria for the selection of guardrail types based on a cost-effectiveness analysis. A typical cost-effective procedure of the design process can be used to evaluate the options of (1) removing or reducing the hazard so that the guardrail is no longer warranted, (2) installing the most cost-effective guardrail systems as funds permit, or (3) leaving hazards unshielded at sites where guardrail installation is not cost-effective. This contract focuses principally on the second of these options in that the guardrail is assumed to be warranted. However, option (3) can also be exercised for the included hazard types of fixed objects or embankments. Of course, the value of such a cost-effectiveness decision-making policy need not be limited to low-volume roads and could result in more efficient utilization of available funds for all types of highway systems.

The objective of this program was to develop a cost-effectiveness model for guardrail selection that would include cost parameters for various guardrail configurations as well as criteria for analysis of system effectiveness under various dynamic impact conditions. Two computer programs were developed: (1) the SSCOST program for cost-effectiveness values (state cost, societal cost, total cost, and benefit-to-cost ratio) of a single specified guardrail type with given roadway conditions, and (2) the COCOST program for comparative cost-effectiveness values and ranking of the eleven included guardrail types with given roadway conditions. The following definitions were used with regard to the cost-effectiveness values:

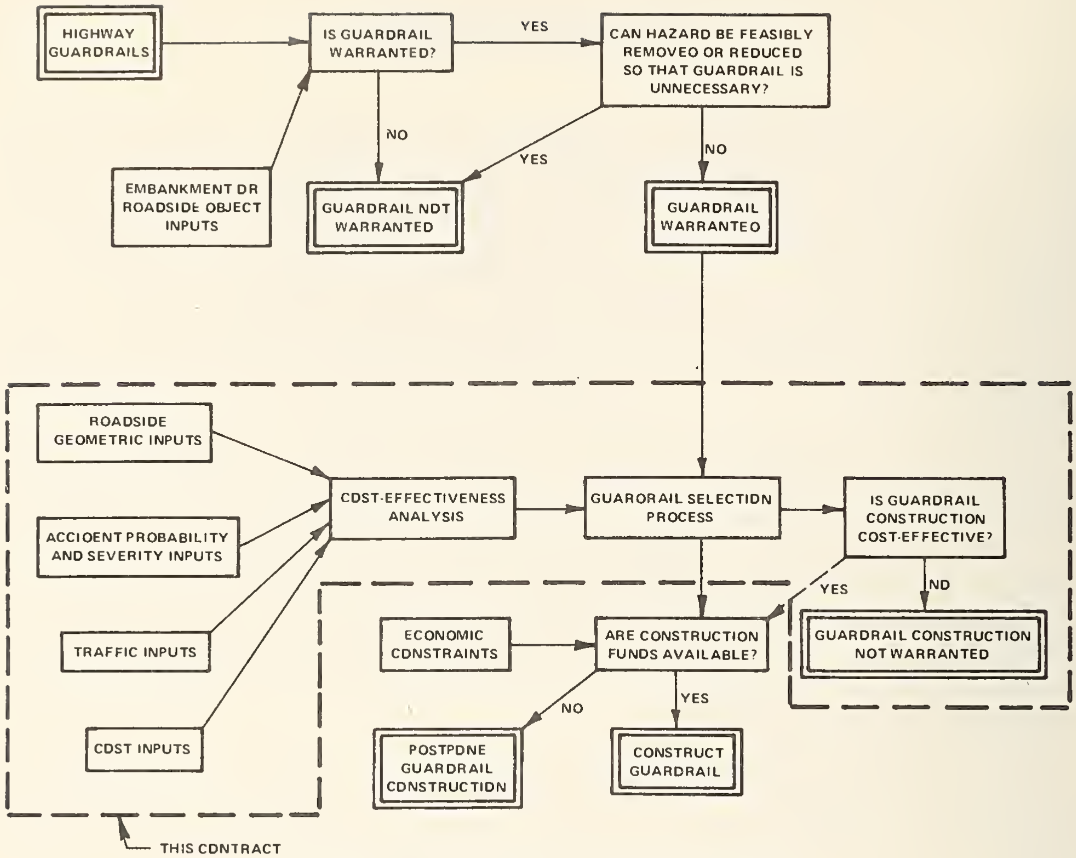


FIGURE 1. GUARDRAIL DESIGN PROCESS

(1) state cost – money spent by the state in installing and maintaining the guardrail.
(2) societal cost – costs associated with accidents, including costs of injuries and fatalities, costs of guardrail and vehicle damage, and cost of traffic delay.
(3) total cost – the sum of state and societal costs.
(4) benefit – the difference between societal cost with no guardrail installation and societal cost with the guardrail installed. Hazard types include fixed objects or embankments.
(5) benefit-to-cost ratio – the ratio of the benefit to the state cost. Thus, to effect a savings in societal costs greater than the state cost of the guardrail installation, a benefit-to-cost ratio greater than unity must be realized.

Specifically, the study involved the following functions:

- Collect and synthesize (a) available guardrail dynamic crash data and (b) cost data for the various guardrail types and impact severities.
- Develop cost-effectiveness model that includes estimates of guardrail performance for various construction combinations and vehicle impact characteristics.
- Collect accident reconstruction data and verify model validity by application of the data.
- Analyze effects of soil condition on guardrail post parameters.
- Prepare final report including (a) technical documentation of the cost-effectiveness model and (b) a user manual for state and local highway engineers.

This volume contains technical documentation and describes the research efforts undertaken to collect and analyze the available data, quantify the pertinent parameters of the cost-effectiveness model, and develop the computer algorithm. Volume II contains the computer program listings and instructions and examples for applying the programs.

II. DISCUSSIONS OF RESEARCH EFFORTS

Chapter 1. Collection and Synthesis of Guardrail Dynamic Crash Data

It was necessary in the cost-effectiveness model development of this study that accident severities (i. e., vehicle accelerations and damage and guardrail damage) be established. For this purpose, the available full-scale vehicle crash test data were selected. Thus, a first effort was to determine the extent of available test data and establish gap areas that would have to be filled by extrapolations.

NCHRP Report 115[1] contains summaries of full-scale guardrail and median barrier crash tests that were performed prior to its publication in 1971. This information was updated to include details of those tests that were either unavailable for inclusion in the report or were conducted subsequent to the publication of the report. The final updated list, containing summaries of several hundred tests, formed the basis for full-scale crash test results.

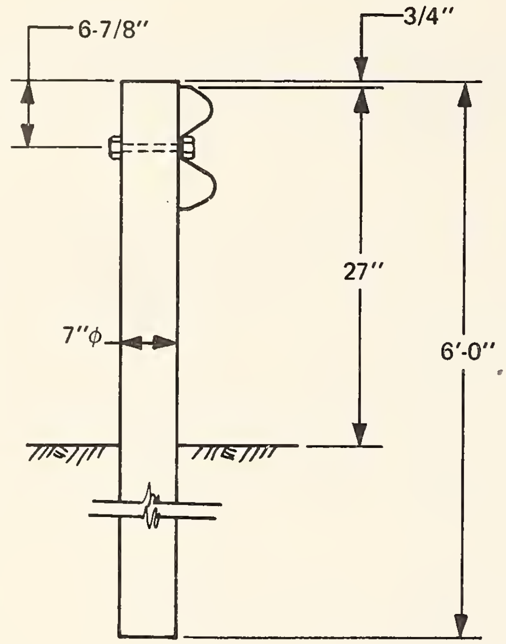
The eleven guardrail types selected for this program are shown in Table 1. Five of the designs (G1, G2, G3, G4S, G4W) were included in NCHRP Report 118. The remaining six systems were arbitrarily selected from commonly used designs and some of the newer designs coming into use. Most of the systems have now been included in the 1977 AASHTO guide. The corresponding system notations follow:

System in This Report	Notation in AASHTO Guide
A	GR2, except for post size
B	G4(1W), except for round rather than square posts
C	Not included
D	G4(2W)
E	G4(2S)
G1	G1
G2	G2
G3	G3
G4S	G4(1S)
G4W	G4(1W)
Thrie	G9

To prepare a full-scale data base, the barrier systems reported in the NCHRP 115 update were compared with the eleven selected guardrail types. Acceptable criteria included (1) identical post material and spacing, (2) identical railing shapes and materials, and (3) railing heights within ±3 inches (76.2 mm). The problems with these hundreds of seemingly applicable full-scale tests soon became apparent. While many of the tests were non-applicable median barrier tests, practically all of them were developmental in nature with very few test results for the final adopted configurations. Thus, the available data were not as directly applicable to this study as anticipated. A major problem was the lack of data for the light 2250-lb (1021-kg) vehicle. Further, most of the tests were directed toward the accepted containment test of a 4500-lb (2041-kg) vehicle/60-mph (96.5-km/hr)/25-degree impact. If satisfactory containment was achieved, tests at other impact conditions were usually not conducted because of the expense involved. From the review of the updated summary, the final matrix of full-scale test results that constitute the data base for this program is shown in Table 2.

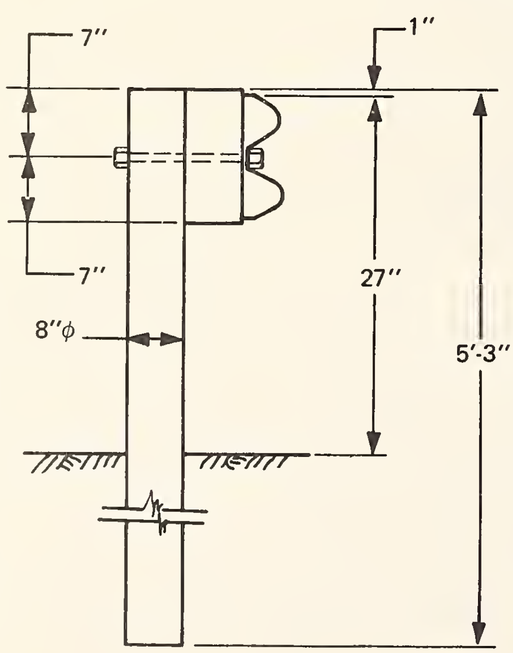
With the limited applicable full-scale data base shown in Table 2, it was necessary to carefully verify the computer simulations before extrapolating the results to other impact conditions. For this purpose, the BARRIER VII computer program[10] was selected because of its capability to

TABLE 1. GUARDRAIL TYPES



DESIGN A

Beam:	12 ga. W
Post:	7-in. dia wood
Post Spacing:	12 ft -6 in.
Bolt:	1/4-in. dia (pipe insert in post)

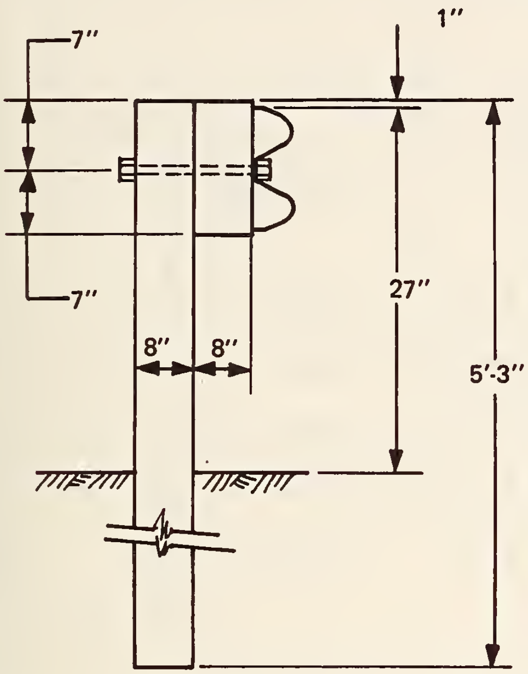
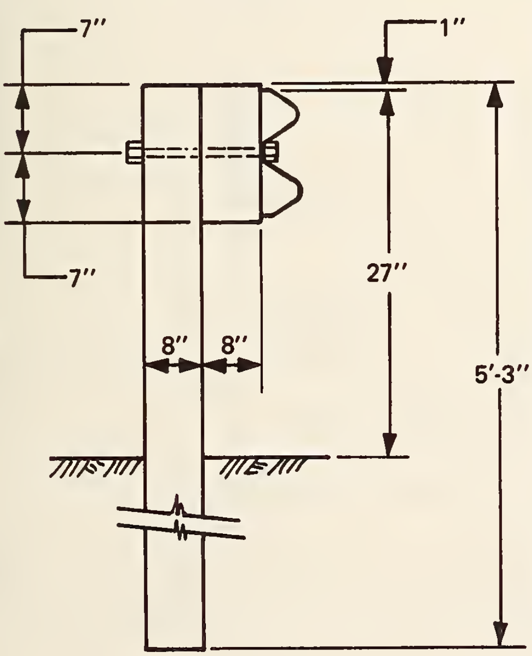


DESIGN B

Beam:	12 ga. W
Blockout:	8 X 8-in. wood
Post:	8-in. dia wood
Post Spacing:	6 ft -3 in.
Bolt:	5/8-in. dia

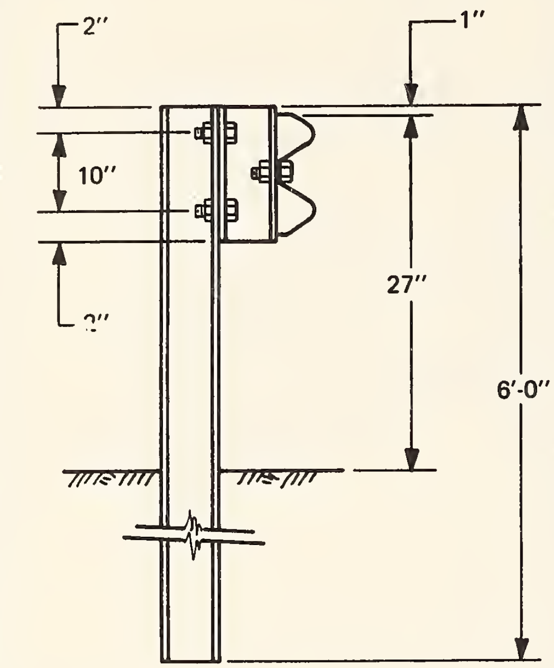
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1. GUARDRAIL TYPES (Cont'd)

	DESIGN C Beam: 12 ga. W Blockout: 8 X 8-in. wood Post: 8 X 8-in. wood Post Spacing: 12 ft -6 in. Bolt: 5/8-in. dia
	DESIGN D Beam: 12 ga. W Blockout: 6 X 8-in. wood Post: 6 X 8-in. wood Post Spacing: 6 ft -3 in. Bolt: 5/8-in. dia

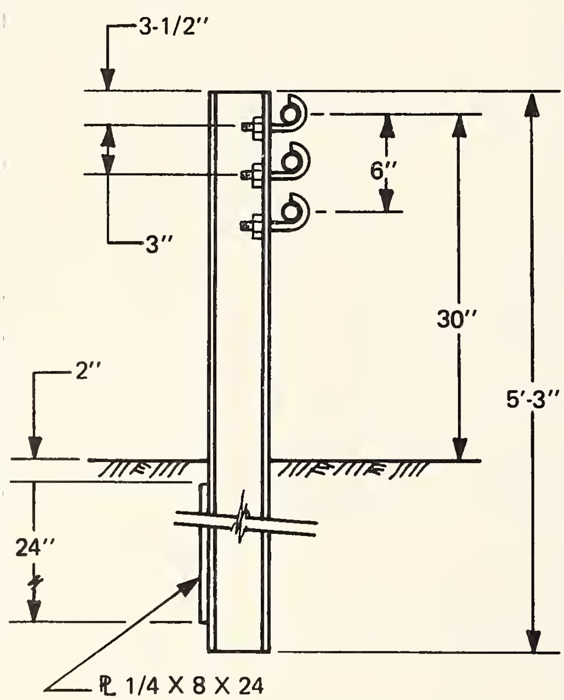
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1. GUARDRAIL TYPES (Cont'd)



DESIGN E

Beam:	12 ga. W
Blockout:	Charley
Post:	Charley
Post Spacing:	6 ft-3 in.
Bolts:	5/8-in. dia

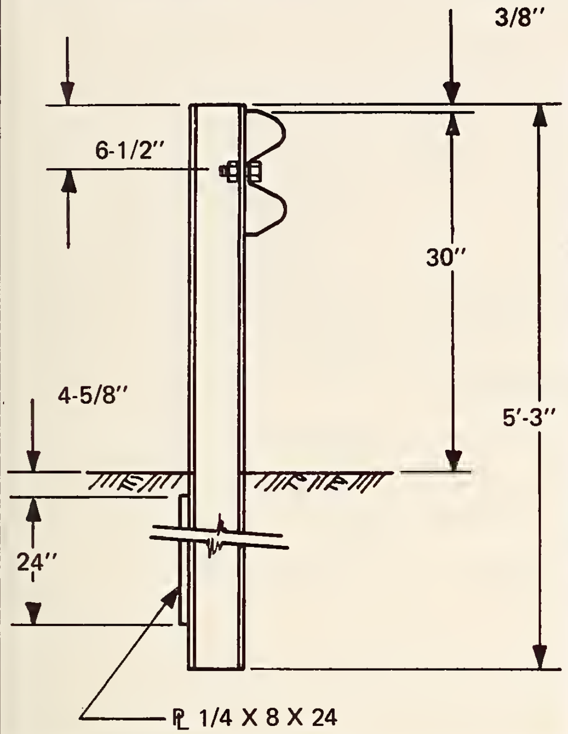


DESIGN G1

Beam:	3-3/4-in. cables
Post:	S3 X 5.7
Post Spacing:	16 ft-0 in.
Hook Bolts:	5/16-in. dia

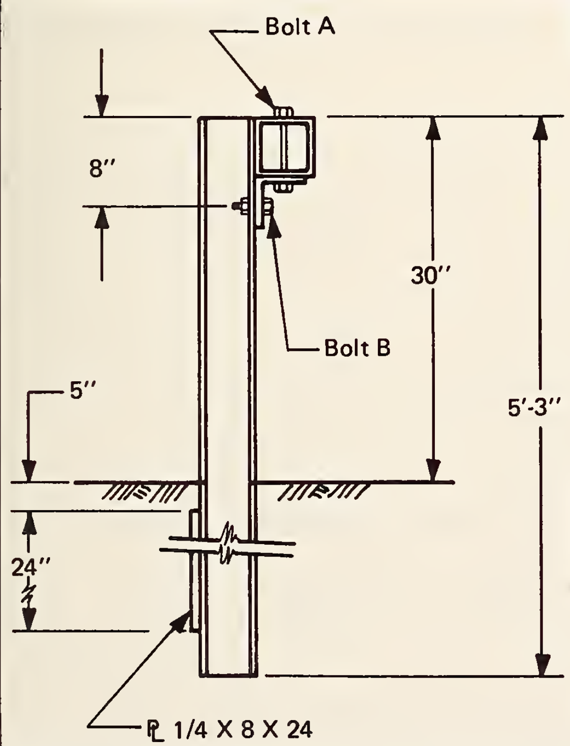
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1. GUARDRAIL TYPES (Cont'd)



DESIGN G2

Beam:	12 ga. W
Post:	S3 X 5.7
Post Spacing:	12 ft-6 in.
Bolt:	5/16-in. dia

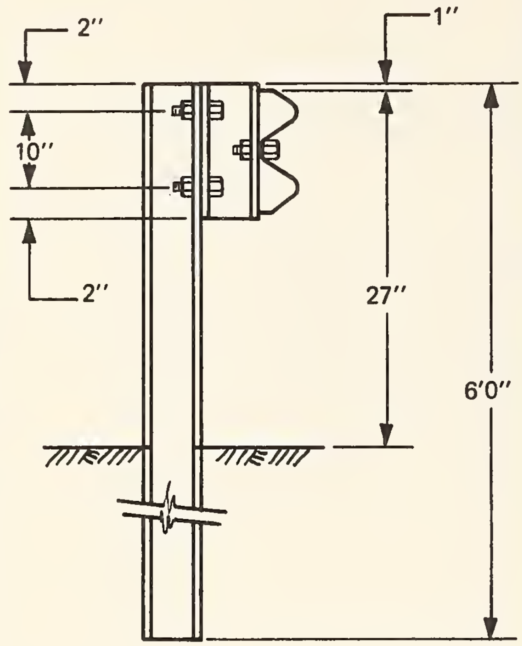
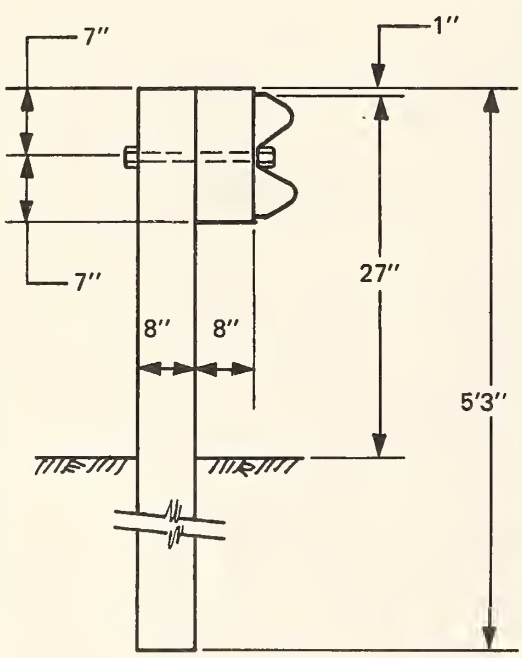


DESIGN G3

Beam:	TS6 X 6 X 0.1875
Post:	S3 X 5.7
Post Spacing:	6 ft-0 in.
Bolt A:	3/8-in. dia
Bolt B:	1/2-in. dia

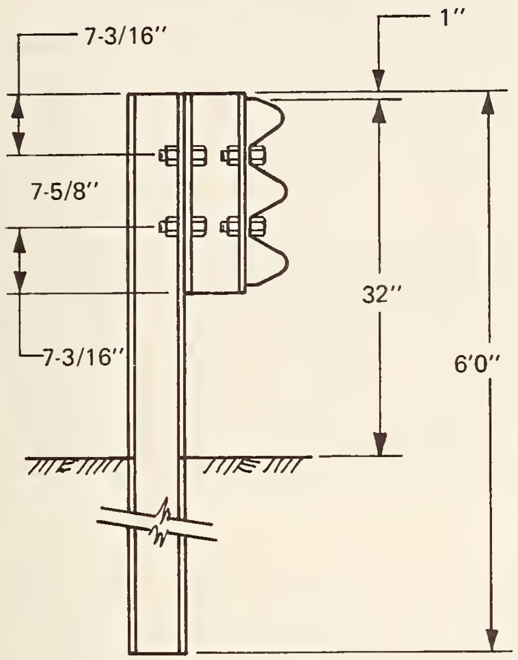
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1. GUARDRAIL TYPES (Cont'd)

	DESIGN G4S Beam: 12 ga. W Blockout: W6 X 8.5 Post: W6 X 8.5 Post Spacing: 6 ft-3 in. Bolts: 5/8-in. dia
	DESIGN G4W Beam: 12 ga. W Blockout: 8 X 8-in. wood Post: 8 X 8-in. wood Post Spacing: 6 ft-3 in. Bolt: 5/8-in. dia

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1. GUARDRAIL TYPES (Cont'd)



DESIGN THRIE

Beam:	12 ga. Thrie
Blockout:	W6 X 8.5
Post:	W6 X 8.5
Post Spacing:	6 ft-3 in.
Bolts:	5/8-in. dia

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

model the geometric variables of the guardrail systems. However, it was necessary for inputs to the program that post, railing, and vehicle inertial properties be specified. Details concerning the determination of these properties are discussed in Appendix A. The geometric configurations of the various guardrail test installations were individually modeled by specification of node locations and member types. Vehicle speeds and impact angles were input as reported.

Details and results of all of the various BARRIER VII correlation runs are discussed in Appendix B. Table 3 is a summary of the test versus simulation comparisons to indicate the degree of correlation that was obtained with the BARRIER VII program. Though not excellent with respect to all of the variables involved, the correlations were considered to be satisfactory. Vehicle impacts with guardrails involve complex mechanisms of crushing metal, high loading rates, and large deformations that defy repeatability. Full-scale tests have demonstrated that seemingly inconsequential changes in construction details can significantly affect the performance of the impacting vehicle. In all likelihood, a duplication of any of the full-scale tests in Table 2, repeated as closely as possible in the field, would not yield results any closer than the indicated BARRIER VII simulations. Consequently, sufficient confidence was established in the simulations to proceed with the extrapolation runs.

The impact conditions selected for this study are shown in Table 4. Vehicle sizes are selected for the specified vehicle classes. Vehicle speeds and angles of impact are selected to cover the ranges of possible values. Category values for use in the extrapolation runs are generally the averages of the corresponding ranges. Since the post shape does not significantly affect the soil response,(17) the guardrail responses of Type B with an 8-inch round post and Type G4W with an 8-inch X 8-inch square post (see Table 1) would be identical. Thus, with 10 distinct guardrail types and the 2 vehicle

TABLE 2. DATA BASE OF FULL-SCALE TESTS

Test No.	Ref.	Design Type	Beam	Post	Block-out	Post Spacing (ft-in.)	Beam Height (in.)	Vehicle Test Conditions			Vehicle Accelerations (g's)*		Maximum Barrier Deflections (ft)		Barrier Damage		Vehicle Damage (% of Total)	Remarks
								Type/Weight (lb)	Speed (mph)	Impact Angle (deg)	Long.	Lat.	Dynamic	Permanent	Beam (ft)	No. of Posts Damaged		
ODH-2	2	A	12 ga. W-beam	4" × 6" SYP	None	12-6	27	1963 Ford Sedan 4404	62.0	25.3	1.2 (200 ms)	2.6 (200 ms)	6.9	5.7	100	10	25	Exit angle 8°
ODH-3	2	A	12 ga. W-beam	7" dia SYP	None	12-6	27	1961 Chevrolet Sedan 4445	62.5	28.7	5.1 (200 ms)	3.5 (200 ms)	4.3	2.2	50	2	100	Vehicle rolled over away from barrier
ODH-4	2	A	12 ga. W-beam	6" dia SYP	None	12-6	27	1960 Chevrolet 4242	63.1	28.3	2.6 (200 ms)	3.4 (200 ms)	6.5	5.2	75	6	35	Exit angle 18°
ODH-5	2	A	12 ga. W-beam	6" × 6" SYP notched	None	12-6	27	1959 Pontiac Sedan 4407	70.8	26.7	2.2 (200 ms)	3.9 (200 ms)	7.2	2.9	112	7	31	Exit angle 7°
105	3	C	12 ga. W-beam	8" × 8" DF	8" × 8" × 1'-2" DF	12-6	24	1962 Chrysler Sedan 4570	58	25	–	–	–	0.42	25	1	10	Vehicle vaulted over barrier
273	4	D	12 ga. W-beam	6" × 8" DF	6" × 8" × 1'-2" DF	6-3	27	1970 Mercury Sedan 4960	68	24	6.75	6.95	–	2.33	31	3	30	Exit angle 14°
AS-7	5	E	12 ga. W-beam	Charley (web facing) traffic)	Charley	6-3	27	1969 Plymouth 4323	62.0	25.0	3.4	5.9	3.5	2.7	37	5	28	Vehicle redirected
AS-8	5	E	12 ga. W-beam	Charley (web opposite traffic)	Charley	6-3	27	1969 Plymouth 4323	59.0	25.0	3.7	6.8	2.9	1.8	25	5	28	Vehicle redirected
20	6	G1	3-3/4" cables	S3 × 5.7	None	8-0	30	1961 Plymouth 3500	55	25	3.9	–	11.0	n/a	56	9	100	Exit angle 23°; vehicle rolled
28	6	G1	3-3/4" cables	S3 × 5.7	None	8-0	30	1961 Plymouth 3500	53	25	3.5	–	8.5	n/a	56	7	–	8° curve, large exit angle
33	6	G1	3-3/4" cables	S3 × 5.7	None	12-0	30	1961 Plymouth 3500	54	25	2.4	–	8.7	n/a	60	6	–	Exit angle 12°; vehicle rolled
36	6	G1	3-3/4" cables	S3 × 5.7	None	12-0	27	1961 Plymouth 3500	43	35	5.2	–	9.3	n/a	72	6	20	Vehicle snagged; no redirection
37	6	G1	3-3/4" cables	S3 × 5.7	None	12-0	30	1961 Plymouth 3500	53	5	0.8	–	1.0	n/a	200	20	15	Vehicle remained in contact with rail
46	6	G1	3-3/4" cables	S3 × 5.7	None	16-0	30	1961 Plymouth 3500	44	25	6.1	–	11.0	n/a	96	6	–	Exit angle 15°
1	7	G1	3-3/4" cables	S3 × 5.7	None	16-0	27	1961 Plymouth 3105	28	90	3.7	–	7.7	n/a	–	6	–	Exit angle 90°
9†	7	G1	3-3/4" cables	S3 × 5.7	None	16-0	27	1961 Plymouth 3300	53	25	6.1	–	8.0	n/a	96	6	–	Exit angle 15°
21	7	G1	3-3/4" cables	S3 × 5.7	None	16-0	27	1957 Anglias 1623	57	25	2.2	–	5.8	n/a	–	–	–	Exit angle 0°
105	8	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1963 Plymouth 4051	60.1	27.8	2.9	3.8	7.30	5.33	25	3	23	Exit angle 9°
38	6	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1961 Plymouth 3500	51	25	8.1	–	10.7	8.0	75	6	30	Vehicle pocketed
39	6	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1961 Plymouth 3500	54	25	2.7	–	6.8	4.0	60	6	20	Exit angle 14°

*50-ms maximum averages unless noted otherwise.
†Revised data for Test 6-46.

Metric conversion: Multiply lb by 0.45 to obtain kg
Multiply ft by 0.305 to obtain m
Multiply mph by 1.609 to obtain km/h

TABLE 2. DATA BASE OF FULL-SCALE TESTS (Cont'd)

Test No.	Ref.	Design Type	Beam	Post	Block-out	Post Spacing (ft-in.)	Beam Height (in.)	Vehicle Test Conditions: Type/Weight (lb)	Vehicle Test Conditions: Speed (mph)	Vehicle Test Conditions: Impact Angle (deg)	Vehicle Accelerations (g's): Long.	Vehicle Accelerations (g's): Lat.	Maximum Barrier Deflections (ft): Dynamic	Maximum Barrier Deflections (ft): Permanent	Barrier Damage: Beam (ft)	Barrier Damage: No. of Posts Damaged	Vehicle Damage (% of Total)	Remarks
40	6	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1961 Plymouth 3500	35	35	2.8	–	9.0	4.0	40	5	25	Vehicle snagged on rail
41	6	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1961 Plymouth 3500	57	6	1.0	–	0.0	0.0	12	2	10	Exit angle 1°
49*	7	G2	12 ga. W-beam	S3 × 5.7	None	12-6	30	1961 Plymouth 3300	58	25	2.7	–	6.0	4.0	60	6	20	Exit angle 14°
25	6	G3	TS6 × 6 × 0.1875	S3 × 5.7	None	6-0	27	1961 Plymouth 3500	50	25	5.5	–	3.0	1.0	24	4	20	Exit angle 11°
34	6	G3	TS6 × 6 × 0.1875	S3 × 5.7	None	6-0	27	1961 Plymouth 3500	49	35	7.2	–	5.1	..	30	9	25	Exit angle 12°
114	8	G3	TS6 × 6 × 0.1875	S3 × 5.7	None	6-0	27	1964 Dodge 4031	57.7	26	3.0	4.1	4.8	2.86	25	8	20	Vehicle remained in contact with rail
2	7	G3	TS6 × 6 × 0.1875	S3 × 5.7	None	6-0	27	1961 Plymouth 3105	29	90	5.4	–	5.9	5.0	48	9	·	Exit angle 90°
19	6	G4S	12 ga. W-beam	W6 × 8.5	W8 × 10	6-3	27	1960 Plymouth 3900	59	25	11.2	–	rail tore and separated		25	5	100	Vehicle pocketed and rolled over away from barrier
120	8	G4S	12 ga. W-beam	W6 × 8.5	W6 × 8.5	6-3	27	1960 Ford 3813	56.8	28.4	4.0	6.7	4.05	2.92	25	5	35	Exit angle 8°
121	8	G4S	12 ga. W-beam	W6 × 8.5	2-W6 × 8.5 members	6-3	27	1963 Ford Station Wagon 4478	56.2	27.4	3.6	6.7	3.10	2.07	37	5	20	Exit angle 9.3°
122	8	G4S	12 ga. W-beam	W6 × 8.5	2-W6 × 8.5 members	6-3	27	1960 Pontiac 4570	62.9	25.3	3.9	7.6	4.9	2.9	37	6	35	Exit angle 9°
274	4	G4S	12 ga. W-beam	W6 × 8.5	W6 × 8.5	6-3	27	1970 Mercury Sedan 4960	63	24	5.80	4.75	–	failed	25	13	100	Anchor failure
276	4	G4S	12 ga. W-beam	W6 × 8.5	W6 × 8.5	6-3	27	1970 Mercury Sedan 4960	66	25	3.78	6.85		1.76	25	3	30	Exit angle 16°
19	9	G4S	12 ga. W-beam	W6 × 8.5	W8 × 10	6-3	27	1960 Plymouth 3900	58.6	25	–	–	–	failed	50	4	35	Vehicle pocketed and rolled over away from barrier
101	8	G4W	12 ga. W-beam	8" × 8" SYP	8" × 8" × 1'-2" SYP	6-3	27	1961 Ford Country Sedan 4042	55.2	30.5	4.6	4.6	4.25	2.6	37	3	35	Exit angle 11.7°
102	8	G4W	12 ga. W-beam	8" × 8" SYP	8" × 8" × 1'-2" SYP	6-3	27	1957 Chevrolet Sedan 3856	54.7	25.2	·	-	2.40	1.50	25	2	30	Exit angle 12.5°
103	8	G4W	12 ga. W-beam	8" × 8" SYP	8" × 8" × 1'-2" SYP	6-3	27	1963 Ford Country Sedan 4123	60.1	22.2	3.1	6.1	2.84	2.40	37	4	25	Exit angle 15°
106	3	G4W	12 ga. W-beam with C6 × 8.2 rub rail	8" × 8" DF	8" × 8" × 1'-2" DF	6-3	30	1962 Chrysler Sedan 4570	60	25	·		--	1.75	37	2	30	Exit angle 13°
107	3	G4W	12 ga. W-beam	8" × 8" DF	8" × 8" × 1'-2" DF	6-3	27	1962 Chrysler Sedan 4570	60	25		-		1.50	37	4	40	Exit angle 17°
108	3	G4W	12 ga. W-beam	8" × 8" DF	8" × 8" × 1'-2" DF	6-3	24	1962 Chrysler Sedan 4570	59	25		–	·	1.50	37	5	35	Exit angle 19°

*Revised data for Test 6-39.

TABLE 2. DATA BASE OF FULL-SCALE TESTS (Cont'd)

Test No.	Ref.	Design Type	Beam	Post	Block-out	Post Spacing (ft-in.)	Beam Height (in.)	Vehicle Test Conditions: Type/Weight (lb)	Speed (mph)	Impact Angle (deg)	Vehicle Accelerations (g's): Long.	Lat.	Maximum Barrier Deflections (ft): Dynamic	Permanent	Barrier Damage: Beam (ft)	No. of Posts Damaged	Vehicle Damage (% of Total)	Remarks
272	4	G4W	12 ga. W-beam	8" × 8" DF	8" × 8" × 1'-2" DF	6-3	27	1970 Mercury Sedan 4960	66	26	5.55	5.45		2.22	37	4	30	Exit angle 6°
AS-2	32	Thrie	12 ga. Thrie	W6 × 8.5	W6 × 8.5	6-3	32	1965 Chevrolet 4000	67.1	28.7	5.9	7.4	3.4	–	25	4	80	Vehicle redirected at large angle
AS-4	32	Thrie	12-ga. Thrie	W6 × 8.5	W6 × 8.5	6-3	32	1965 Pontiac 4500	59.1	15.9	2.9	4.1	0.6	–	12.5	2	20	Redirected vehicle was driveable
AS-5	32	Thrie	10-ga. Thrie	W6 × 8.5	M14 × 17.2	6-3	32	1965 Chevrolet 4000	56.4	25.2	3.9	7.9	1.5		25	3	40	Vehicle redirected
AS-6	5	Thrie	12-ga. Thrie	Charley	Charley	6-3	32	1969 Plymouth 4323	61.3	25	3.6	6.1	2.6	1.8	25	3	35	Vehicle redirected

TABLE 3. SUMMARY OF TEST CORRELATIONS

Test/ Simulation*	Vehicle Accelerations (g's)			Maximum Dynamic Deflection (ft)†	Exit Conditions			Barrier Damage		
	Longitudinal	Lateral	Resultant		Reported Angle	Velocity Vector	Vehicle Heading Angle	Beam (ft)†	No. of Posts Damaged	Railing Model
GUARDRAIL TYPES A AND C										
Test 2-ODH-4	2.6	3.4	–	6.5	18			75	6	
Simulation 7	2.81	3.92	–	6.31		18.1	–3.	50	7	Beam
Test 2-ODH-5	2.2	3.9	–	7.2	7			112.5	7	
Simulation 1	2.62	4.01	–	6.99		13.5	8.8	62.5	9	Beam
GUARDRAIL TYPES B, D, AND G4W										
Test 8-101	4.6	4.6	–	4.25	11.7			37.5	3	
Simulation 8	6.01	4.55	–	3.81		18.6	14.0	25	4	Cable
Test 8-102	–	–	–	2.40	12.5			25	2	
Simulation 3	4.59	6.44	–	3.26		20.1	18.3	25	3	Cable
Test 4-273	6.75	6.95	–	2.33 (perm.)	14			37.5	3	
Simulation 2	3.70	4.52	–	5.33		8.3	4.0	37.5	9	Cable
GUARDRAIL TYPES E AND G4S										
Test 5-AS-7	3.4	5.9	–	3.5	–			37.5	5	
Simulation 4	4.61	5.24	–	6.88		16.2	27.0	37.5	7	Cable
Test 5-AS-8	3.7	6.8	–	2.9	–			25	5	
Simulation 4	4.59	5.17	–	4.51		13.9	14.8	37.5	6	Cable
Test 8-120	4.0	6.7	–	4.05	8			25	5	
Simulation 6	4.60	5.33	–	4.01		17.3	11.4	25	5	Cable
Test 8-122	3.9	7.6	–	4.9	9			37.5	6	
Simulation 1	3.55	5.42	–	5.15		13.7	9.7	37.5	8	Cable
GUARDRAIL TYPE G1										
Test 7-9	–	–	6.1	8.0	15			n.a.	6	
Simulation 1	2.53	3.25	4.12	8.23		10.7	5.5	–	5	Cable
Test 7-1	–	–	3.7	7.7	90			n.a.	6	
Simulation 1	3.93	–	3.93	10.85		90.0	90.0	–	6	Cable
Test 7-21	–	–	2.2	5.8	0			n.a.	not given	
Simulation 1	4.92	4.93	6.97	5.66		10.6	9.0	–	3	Cable
GUARDRAIL TYPE G2										
Test 7-49	–	–	2.7	6.0	14			60	6	
Simulation 2	2.36	4.02	4.66	5.72		10.0	5.7	50	8	Beam
GUARDRAIL TYPE G3										
Test 6-25	–	–	5.5	3.0	11			24	4	
Simulation 4	4.00	4.50	6.02	2.17		8.6	1.5	24	6	Beam
Test 6-34	–	–	7.2	5.1	12			30	9	
Simulation 4	5.91	4.49	7.42	5.80		16.9	4.7	36	10	Beam
Test 7-2	–	–	5.4	5.9	90			–	9	
Simulation 1	8.20	–	8.20	5.92		90.0	90.0	–	9	Beam
THRIE BEAM										
32-AS-2	5.9	7.4	–	3.4	–			25	4	
Simulation 2	6.17	6.49	–	3.65		15.7	–3.9	37.5	8	Beam
32-AS-4	2.9	4.1	–	0.6				12.5	2	
Simulation 2	2.49	4.74	–	1.45		9.4	2.5	25	2	Beam

*See Appendix B.
†Multiply ft by 0.305 to obtain m.

TABLE 4. IMPACT CONDITIONS

Vehicle Size:	Category Weight (lb)
Intermediate and standard-size vehicles	4500
Subcompacts and compacts	2250
Vehicle Speeds:	**Category Speed (mph)**
Less than 40 mph	30
40 to 60 mph	50
Over 60 mph	70
Angles of Impact:	**Category Angle (deg)**
Less than 10°	7
10° to 20°	15
20° to 30°	25
Over 30°	30
Metric conversion: Multiply lb by 0.454 to obtain kg; Multiply mph by 1.609 to obtain km/hr	

classes, 3 speeds, and 4 impact angles shown in Table 4, 240 extrapolation runs of the BARRIER VII program were required. The guardrail configurations and typical vehicle dimensions used in the runs are shown in Appendix B. The guardrail configurations were selected to conform closely to those configurations used in the correlation runs. To eliminate the time-consuming manual plotting of the vehicle deformations, BARRIER VII was modified to yield the two large computer printer plots shown in Figures 2 and 3. With these plots, resolution of the deformations was to the nearest inch, which was considered adequate for estimating the percent of vehicle damage. Details of the estimating procedure are discussed in Appendix C.

The final matrix of extrapolation data is shown in Table 5. In some cases, as shown in this table, vehicle deformation was more extensive for the shallower impacts because of more deformation along the side and rear of the vehicle. Barrier damage estimates include both the length of the railing and the number of posts. However, because of the meager unit repair costs ($/L.F.) that were obtainable in the study, this refinement was not included in the final model. The linear footage of damaged rail was used for guardrail damage.

The BARRIER VII is a two-dimensional program that includes only the yaw rotational motion and hence will not predict the roll motion of the vehicle. Checking for this motion by conducting HVOSM runs for each of the category combinations would have been too expensive. Thus, to determine which of the impact conditions would likely cause the most severe vehicle roll, ENSCO's simplified rollover vaulting algorithm (RVA) was run for the cases shown in Table 6. To obtain bounds, the 27-inch top height and 15-inch bottom height of the average undeformed guardrails were used. From the results shown, it was decided to make HVOSM runs for the 4500-lb vehicle/70 mph/30-degree impact condition, which gives the highest ratio of roll rate to critical roll rate. Table 7 shows the maximum angles of roll predicted by the program as the vehicles passed through the various roll cycles. For example, with the Type A guardrail, the vehicle rolled to 1.52 degrees away from the guardrail, then rolled to 2.19 degrees toward the barrier, slightly righted to 1.63 degrees, and then rolled to 6.71 degrees toward the guardrail. At the end of one second, the vehicle had righted to 3.16 degrees. The high rolls away from the guardrails on Types G1 and G3 were caused when the vehicles suddenly turned back in toward the guardrails. However, since no complete rollover occurred with any of the guardrails, it was concluded that vehicle roll is not a likely problem with the selected guardrail types.

The BARRIER VII program is also limited in its ability to predict vehicle wheel snagging and vehicle pocketing. Both guardrail types A and C with their 12.5-ft (3.81-m) post spacing and strong posts have demonstrated these tendencies. As asserted in the 1977 AASHTO guide, experience also appears to indicate that the longer post spacings may allow a rail to twist into a ramp and thus cause vaulting. However, this could not be supported by study of the test data. Nevertheless, types A and C have undesirable and unpredictable characteristics that should be considered in selecting the final guardrail system.

A final note should be made concerning the BARRIER VII program use for all of the guardrail types. The program will predict barrier failure where an unstable condition arises (e.g., where several of the end posts have failed so that the guard rail end is simply a weak cantilever beam). However,

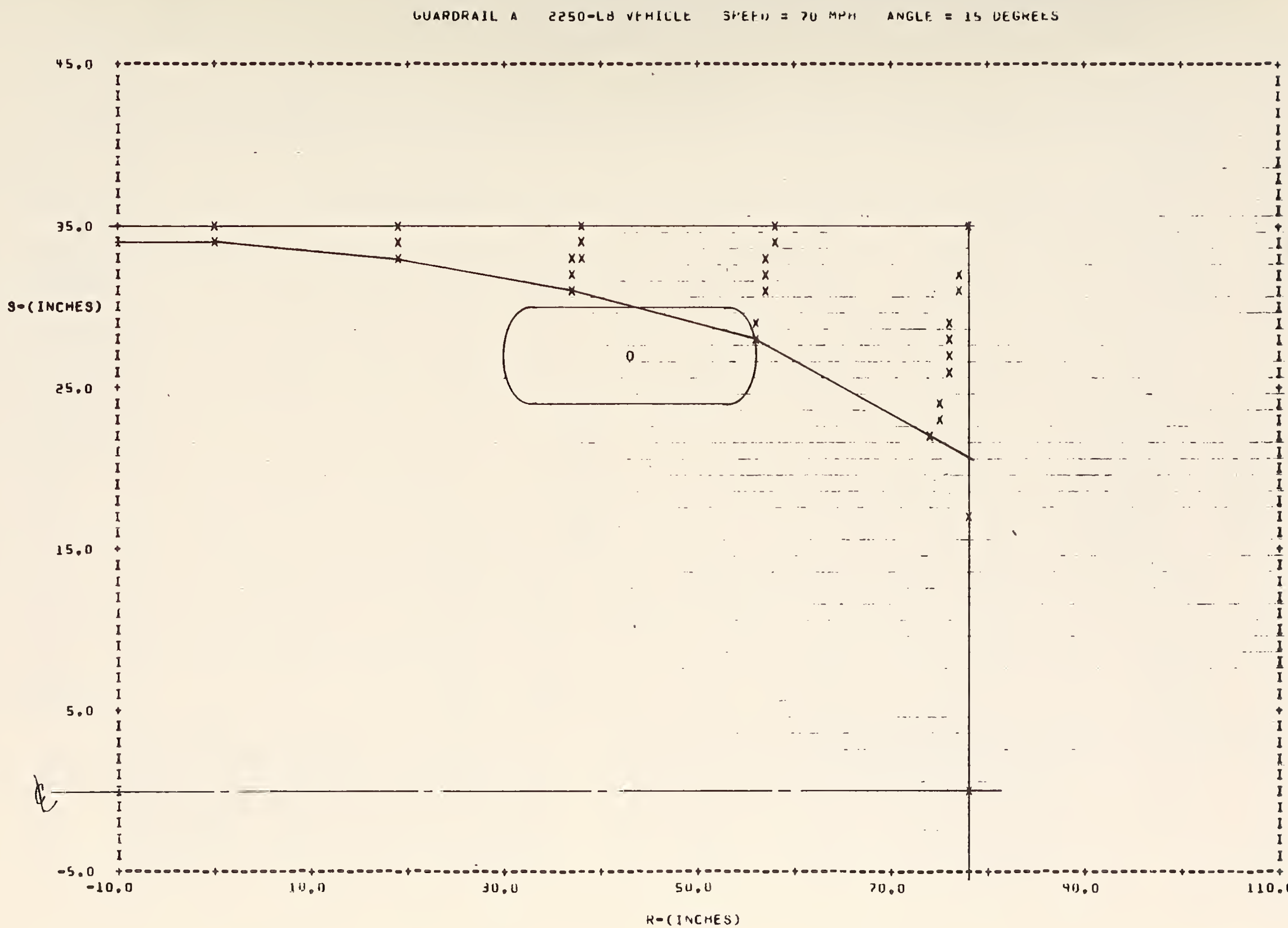


FIGURE 2. VEHICLE DEFORMATION (FRONT HALF)

GUARDRAIL A   2250-LB VEHICLE   SPEED = 70 MPH   ANGLE = 15 DEGREES

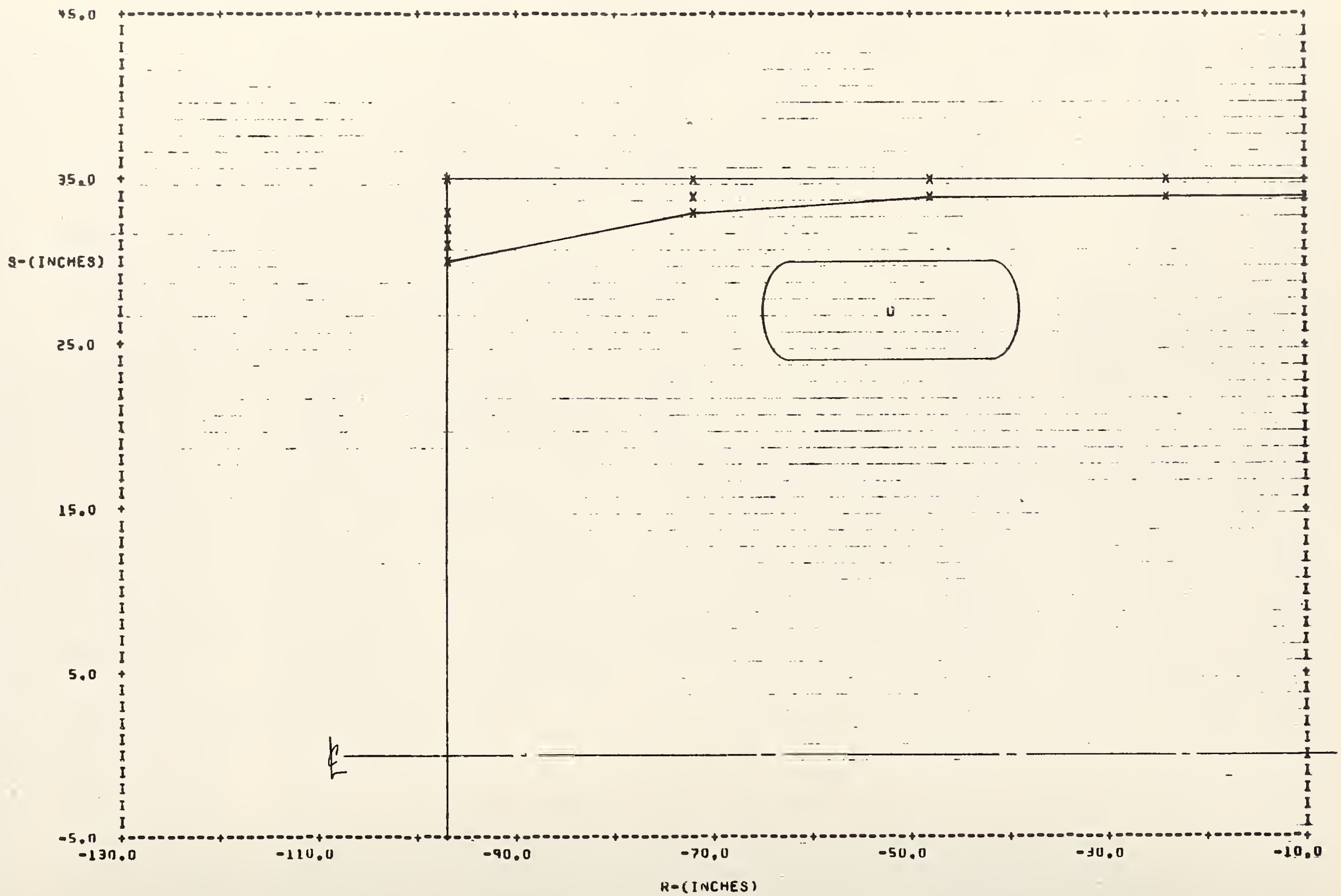


FIGURE 3. VEHICLE DEFORMATION (REAR HALF)

TABLE 5. EXTRAPOLATION DATA

Guardrail Type A								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.42	1.08	37.5	0	10	0.16	2.0° @ 28.4 mph Secondary contact.
30	15	1.22	2.09	37.5	0	15	0.39	5.1° @ 25.9 mph Secondary contact.
30	25	2.91	3.36	37.5	0	25	0.83	12.1° @ 21.6 mph Secondary contact. Rail yields.
30	30	4.58	4.36	37.5	0	25	1.11	19.6° @ 19.1 mph Secondary contact. Rail yields.
50	7	0.84	2.24	37.5	0	15	0.35	3.8° @ 46.9 mph
50	15	2.51	4.29	37.5	0	25	0.82	10.0° @ 42.0 mph
50	25	5.31	5.23	50.0	1	40	1.90	15.0° @ 35.5 mph Rail yields.
50	30	7.04	5.68	50.0	1	40	2.17	14.9° @ 32.6 mph Rail yields.
70	7	1.29	4.14	37.5	0	20	0.45	4.1° @ 65.5 mph
70	15	3.22	7.47	62.5	2	30	2.05	7.5° @ 58.8 mph
70	25	6.41	8.72	62.5	2	40	2.90	13.8° @ 49.9 mph Rail fractures.
70	30	7.85	9.61	62.5	3	40	3.58	17.7° @ 45.6 mph Rail fractures.
Vehicle Weight = 4500 lb								
30	7	0.37	0.81	37.5	0	10	0.22	2.4° @ 28.3 mph
30	15	1.13	1.76	37.5	0	20	0.63	5.1° @ 25.7 mph Secondary impact.
30	25	2.55	2.37	50.0	1	25	1.57	6.4° @ 21.6 mph
30	30	3.31	2.49	37.5	1	30	1.91	9.0° @ 19.4 mph Rail yields.
50	7	0.68	1.85	37.5	0	20	0.42	3.8° @ 46.8 mph
50	15	1.66	3.84	62.5	2	25	2.03	7.1° @ 42.2 mph
50	25	3.15	3.74	62.5	2	30	2.78	12.9° @ 35.4 mph Rail fractures.
50	30	4.12	4.37	62.5	3	30	3.96	19.9° @ 31.5 mph Rail fractures.
70	7	1.09	3.43	50.0	0	30	0.53	4.2° @ 65.5 mph
70	15	2.12	4.57	75.0	4	35	3.08	9.5° @ 57.7 mph Rail yields.
70	25	3.57	6.71	87.5	6	40	5.60	14.8° @ 49.0 mph Rail fractures.
70	30	4.40	5.57	87.5	10	40	7.47	11.9° @ 44.6 mph Secondary impact. Rail fractures.

Metric conversion: Multiply lb by 0.454 to obtain kg
Multiply ft by 0.305 to obtain m
Multiply mph by 1.609 to obtain km/h

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type B/G4W								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.47	1.02	37.5	0	15	0.44	4.0° @ 27.8 mph
30	15	1.35	2.25	37.5	0	20	0.75	8.0° @ 24.7 mph
30	25	3.08	3.28	37.5	0	20	0.82	10.2° @ 21.2 mph
30	30	4.76	4.18	37.5	1	30	1.39	30.4° @ 16.7 mph Secondary impact.
50	7	1.13	2.36	37.5	0	35	0.62	3.1° @ 46.6 mph Secondary impact.
50	15	3.20	5.16	50.0	1	40	1.17	6.0° @ 41.0 mph
50	25	6.31	6.99	50.0	3	35	3.47	23.0° @ 28.4 mph Secondary impact.
50	30	7.76	6.80	50.0	3	35	3.33	40.4° @ 23.2 mph Secondary impact.
70	7	1.71	4.43	50.0	0	35	0.60	3.4° @ 65.2 mph
70	15	3.77	6.95	50.0	2	60	1.27	10.1° @ 56.6 mph Secondary impact.
70	25	6.58	10.29	50.0	4	35	2.79	12.2° @ 49.3 mph
70	30	9.20	7.87	62.5	5	35	4.37	21.9° @ 39.4 mph
Vehicle Weight = 4500 lb								
30	7	0.53	1.02	37.5	0	15	0.56	3.5° @ 27.7 mph
30	15	1.33	1.84	37.5	0	20	0.85	7.3° @ 24.7 mph
30	25	3.01	2.90	50.0	1	25	1.37	7.4° @ 21.0 mph Secondary impact.
30	30	3.84	2.92	50.0	2	35	2.01	9.9° @ 18.5 mph
50	7	0.96	2.11	50.0	0	35	0.80	2.9° @ 46.3 mph Secondary impact.
50	15	2.46	3.06	62.5	3	50	2.23	9.2° @ 37.2 mph Secondary impact.
50	25	3.88	4.46	62.5	5	40	3.77	19.9° @ 30.0 mph Secondary impact.
50	30	4.70	3.62	62.5	5	45	4.13	18.5° @ 29.6 mph Secondary impact.
70	7	1.47	3.45	50.0	0	70	0.74	3.5° @ 65.0 mph
70	15	3.07	5.40	62.5	4	45	2.34	3.4° @ 58.3 mph
70	25	4.16	4.61	75.0	7	50	5.79	9.0° @ 47.7 mph
70	30	5.63	5.69	75.0	9	45	7.21	12.3° @ 43.4 mph Secondary impact.

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type C								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.43	1.10	37.5	0	10	0.15	2.0° @ 28.4 mph Secondary impact.
30	15	1.24	2.12	37.5	0	15	0.38	5.0° @ 25.9 mph Secondary impact.
30	25	2.96	3.42	37.5	0	25	0.81	12.1° @ 21.6 mph Secondary impact. Rail yields.
30	30	4.77	4.60	37.5	0	25	1.07	20.8° @ 19.0 mph Secondary impact.
50	7	0.86	2.22	37.5	0	15	0.34	3.8° @ 46.9 mph
50	15	2.60	4.34	37.5	0	30	0.79	10.3° @ 41.9 mph
50	25	5.83	5.73	50.0	1	35	1.83	14.0° @ 35.6 mph Rail yields.
50	30	7.60	6.13	50.0	1	40	2.07	13.8° @ 32.7 mph Rail yields.
70	7	1.33	4.23	37.5	0	20	0.43	4.2° @ 65.5 mph
70	15	3.43	7.49	50.0	2	30	1.92	7.5° @ 58.8 mph Secondary impact.
70	25	7.16	9.86	50.0	2	40	2.73	12.0° @ 50.1 mph Rail yields.
70	30	8.78	9.17	62.5	3	40	3.22	14.3° @ 46.0 mph Rail yields.
Vehicle Weight = 4500 lb								
30	7	0.38	0.83	37.5	0	10	0.21	2.1° @ 28.3 mph
30	15	1.16	1.79	37.5	0	15	0.61	5.0° @ 25.7 mph Secondary impact.
30	25	2.80	2.61	50.0	1	20	1.55	5.8° @ 21.6 mph
30	30	3.70	2.81	50.0	1	20	1.89	8.2° @ 19.3 mph Rail yields.
50	7	0.71	1.86	37.5	0	15	0.40	3.9° @ 46.8 mph
50	15	1.79	4.08	50.0	2	30	1.88	7.9° @ 42.0 mph
50	25	3.54	3.88	62.5	2	35	2.58	11.3° @ 35.6 mph Rail fractures.
50	30	4.54	4.02	62.5	3	35	3.29	11.8° @ 33.1 mph Rail fractures.
70	7	1.07	3.36	50.0	0	25	0.50	4.0° @ 65.5 mph
70	15	2.28	4.74	75.0	3	35	2.93	8.8° @ 57.9 mph
70	25	3.93	5.12	75.0	6	40	5.02	15.8° @ 48.9 mph Secondary impact. Rail yields.
70	30	4.97	6.37	87.5	8	45	6.99	16.2° @ 44.1 mph Rail fractures.

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type D								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.47	0.97	37.5	0	15	0.47	4.0° @ 27.8 mph
30	15	1.23	1.98	37.5	0	20	0.75	8.3° @ 24.7 mph
30	25	2.79	2.90	37.5	0	25	0.89	12.8° @ 20.9 mph Secondary impact.
30	30	4.53	4.32	37.5	1	20	1.32	13.0° @ 17.9 mph
50	7	1.03	2.24	37.5	0	20	0.63	3.3° @ 46.5 mph Secondary impact.
50	15	2.84	5.19	50.0	1	35	1.25	6.8° @ 40.7 mph Secondary impact.
50	25	5.12	5.74	50.0	2	30	1.87	17.7° @ 34.7 mph
50	30	6.25	5.64	50.0	4	35	3.25	23.2° @ 22.9 mph Secondary impact.
70	7	1.95	4.59	50.0	0	20	0.81	3.9° @ 64.8 mph
70	15	4.73	5.97	62.5	4	35	3.39	4.8° @ 52.5 mph Secondary impact.
70	25	6.04	8.17	62.5	6	35	4.34	14.4° @ 44.0 mph
70	30	8.00	8.21	62.5	8	40	4.02	16.2° @ 44.5 mph
Vehicle Weight = 4500 lb								
30	7	0.47	0.90	37.5	0	15	0.56	3.2° @ 27.8 mph
30	15	1.28	1.73	37.5	0	20	0.91	6.3° @ 24.9 mph
30	25	2.95	2.93	50.0	1	25	1.37	7.1° @ 21.1 mph Secondary impact.
30	30	3.30	2.58	50.0	2	35	2.17	12.6° @ 18.7 mph
50	7	0.98	2.17	50.0	0	25	0.84	3.6° @ 46.2 mph
50	15	1.87	2.88	50.0	2	35	1.35	6.7° @ 41.3 mph Secondary impact.
50	25	3.11	4.45	62.5	5	35	3.54	12.2° @ 34.5 mph Secondary impact.
50	30	3.70	3.66	62.5	6	40	4.66	16.0° @ 30.4 mph
70	7	1.46	3.48	50.0	0	35	0.76	3.4° @ 65.1 mph
70	15	2.51	4.90	75.0	7	50	2.95	12.8° @ 55.2 mph Secondary impact.
70	25	3.54	4.30	75.0	9	40	6.15	9.9° @ 49.1 mph Secondary impact.
70	30	4.61	4.97	75.0	13	35	8.21	9.8° @ 45.0 mph

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type E								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.46	0.99	37.5	0	10	0.47	4.0° @ 27.8 mph
30	15	1.17	2.18	37.5	0	15	0.74	8.2° @ 24.8 mph
30	25	2.71	2.87	37.5	0	25	0.93	13.5° @ 20.8 mph Secondary impact.
30	30	4.39	3.94	37.5	1	20	1.51	28.0° @ 16.9 mph Secondary impact.
50	7	1.05	2.34	50.0	0	20	0.62	3.0° @ 46.6 mph
50	15	3.08	4.75	50.0	1	25	1.28	6.8° @ 40.7 mph Multiple impacts.
50	25	5.70	5.87	50.0	3	35	3.38	17.5° @ 30.2 mph Multiple impacts.
50	30	7.34	6.51	50.0	3	30	3.16	34.1° @ 25.8 mph Multiple impacts.
70	7	1.85	4.40	50.0	0	20	0.85	4.1° @ 64.8 mph
70	15	3.49	6.38	50.0	2	30	1.37	9.1° @ 57.1 mph
70	25	6.60	7.48	62.5	6	80	4.91	26.4° @ 33.3 mph Multiple impacts.
70	30	8.32	9.42	62.5	4	50	3.38	16.0° @ 45.9 mph
Vehicle Weight = 4500 lb								
30	7	0.47	0.91	37.5	0	15	0.59	3.2° @ 27.8 mph
30	15	1.34	1.90	37.5	0	25	0.96	7.0° @ 24.8 mph
30	25	2.83	2.85	50.0	1	30	1.38	7.2° @ 21.2 mph Secondary impact.
30	30	3.87	2.86	50.0	2	35	2.14	12.2° @ 18.0 mph
50	7	1.01	2.26	50.0	0	20	0.86	3.6° @ 46.2 mph
50	15	2.30	3.01	62.5	4	30	2.98	10.3° @ 37.0 mph Multiple impacts.
50	25	3.41	4.26	62.5	4	35	4.06	17.6° @ 32.0 mph Secondary impact.
50	30	4.11	3.76	62.5	4	40	4.16	19.3° @ 30.3 mph Secondary impact.
70	7	1.59	2.99	62.5	1	30	1.47	3.6° @ 63.9 mph
70	15	3.00	5.25	62.5	5	35	3.16	5.8° @ 56.8 mph
70	25	5.03	4.44	87.5	9	70	6.57	17.7° @ 39.8 mph Secondary impact.
70	30	5.07	5.97	87.5	9	50	6.64	14.3° @ 42.6 mph.

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type G1								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail*	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	1.03	1.96	0	0	15	1.85	12.1° @ 26.5 mph
30	15	1.86	2.68	10.0	1	20	2.67	14.0° @ 23.9 mph Contact @ t = 1.0 sec. Multiple impacts.
30	25	2.51	3.06	10.0	1	20	3.33	10.8° @ 20.4 mph Contact @ t = 1.0 sec. Secondary impact.
30	30	2.81	3.12	10.0	1	25	3.58	9.3° @ 18.4 mph Contact @ t = 1.0 sec. Secondary impact.
50	7	1.09	2.41	20.0	2	20	3.29	13.0° @ 44.1 mph Multiple impacts.
50	15	2.32	3.48	30.0	3	15	4.33	7.0° @ 40.8 mph Multiple impacts.
50	25	2.94	4.15	30.0	3	20	5.71	11.2° @ 33.7 mph
50	30	3.00	4.76	40.0	4	25	9.22	14.4° @ 31.5 mph Contact @ t = 1.0 sec.
70	7	1.16	2.96	40.0	4	25	4.62	6.1° @ 63.3 mph Multiple impacts.
70	15	2.92	4.26	40.0	4	20	7.47	6.0° @ 56.6 mph Secondary impact.
70	25	4.51	5.07	70.0	7	20	10.60	9.0° @ 50.3 mph Multiple impacts.
70	30	3.41	3.80	90.0	9	35	15.91	16.2° @ 46.7 mph
Vehicle Weight = 4500 lb								
30	7	0.61	0.95	20.0	2	15	2.27	1.5° @ 27.9 mph Multiple impacts.
30	15	1.08	1.23	20.0	2	20	3.58	2.0° @ 24.8 mph Secondary impact.
30	25	1.36	1.42	20.0	2	25	4.76	3.2° @ 21.1 mph Secondary impact.
30	30	1.74	1.73	30.0	3	30	5.81	8.6° @ 19.3 mph Contact @ t = 1.0 sec.
50	7	0.77	1.38	40.0	4	30	4.09	3.9° @ 46.0 mph Multiple impacts.
50	15	1.40	1.92	40.0	4	25	7.03	6.7° @ 40.5 mph Secondary impact.
50	25	1.56	2.72	50.0	5	25	10.56	8.0° @ 36.3 mph Contact @ t = 1.0 sec.
50	30	1.60	2.56	100.0	10	25	14.60	8.1° @ 34.9 mph Contact @ t = 1.0 sec.
70	7	1.02	2.09	50.0	5	20	6.61	2.9° @ 64.2 mph Multiple impacts.
70	15	1.65	2.33	60.0	6	20	9.36	3.4° @ 59.1 mph Contact @ t = 1.0 sec. Multiple impacts.
70	25	2.17	2.44	130.0	13	35	19.30	0.6° @ 55.4 mph Contact @ t = 1.0 sec.
70	30	1.70	2.22	180.0	18	35	24.50	−0.5° @ 51.8 mph Contact @ t = 1.0 sec.

*Based on 10 feet of damage per damaged post.

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type G2								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.34	0.82	37.5	0	10	0.26	2.4° @ 28.3 mph
30	15	1.03	1.68	37.5	0	15	0.51	5.8° @ 25.8 mph
30	25	2.25	2.41	50.0	1	25	1.38	9.5° @ 21.6 mph
30	30	2.69	2.32	37.5	1	30	1.78	13.1° @ 19.3 mph
50	7	0.57	1.95	100.0	0	15	0.49	−1.5° @ 45.1 mph Secondary impact.
50	15	1.53	3.84	50.0	2	20	1.95	6.8° @ 42.6 mph
50	25	2.88	4.36	62.5	3	30	3.28	17.2° @ 35.0 mph
50	30	3.47	3.86	62.5	4	30	3.94	15.0° @ 32.2 mph
70	7	1.07	3.50	62.5	0	15	0.73	4.3° @ 65.5 mph
70	15	1.85	5.13	75.0	3	20	3.32	10.6° @ 57.7 mph
70	25	3.36	5.73	75.0	7	30	5.37	14.8° @ 49.4 mph
70	30	4.45	5.47	87.5	11	30	7.25	15.8° @ 44.5 mph
Vehicle Weight = 4500 lb								
30	7	0.27	0.66	37.5	0	10	0.35	2.7° @ 28.2 mph
30	15	0.79	1.25	37.5	0	15	0.78	5.2° @ 25.8 mph
30	25	1.32	1.50	62.5	2	20	2.49	8.3° @ 20.7 mph
30	30	1.91	1.74	62.5	3	20	3.04	6.1° @ 18.8 mph Contact @ t = 1.0 sec.
50	7	0.54	1.84	50.0	0	15	0.70	4.0° @ 46.8 mph
50	15	1.03	2.46	75.0	4	20	3.18	8.0° @ 41.6 mph
50	25	1.79	2.89	87.5	7	25	5.62	14.3° @ 34.7 mph
50	30	2.27	3.14	87.5	11	25	7.82	15.0° @ 31.7 mph Contact @ t = 1.0 sec
70	7	0.83	2.13	75.0	2	20	1.36	4.2° @ 65.4 mph
70	15	1.30	2.72	112.5	7	25	5.08	9.8° @ 57.1 mph Contact @ t = 1.0 sec.
70	25	2.21	3.47	112.5	17	25	9.50	7.7° @ 49.9 mph Contact @ t = 1.0 sec.
70	30	2.88	3.60	112.5	24	25	12.14	7.0° @ 46.1 mph

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type G3								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.41	1.17	34.0	0	10	0.11	1.4° @ 28.5 mph Secondary impact.
30	15	1.26	2.16	31.0	0	15	0.23	3.0° @ 26.2 mph Secondary impact.
30	25	3.01	3.55	31.0	0	20	0.43	7.5° @ 22.4 mph Secondary impact.
30	30	4.48	4.46	31.0	0	15	0.58	0.2° @ 21.0 mph
50	7	0.72	2.13	33.0	0	15	0.20	2.2° @ 47.3 mph
50	15	2.16	4.19	34.0	0	20	0.43	5.6° @ 43.2 mph
50	25	5.11	5.97	35.0	2	25	0.93	8.6° @ 37.4 mph
50	30	6.61	6.30	40.0	4	25	1.65	10.3° @ 33.7 mph
70	7	1.22	4.01	41.0	0	20	0.31	2.7° @ 66.0 mph
70	15	3.13	8.35	38.0	0	30	0.64	6.4° @ 60.4 mph
70	25	6.45	7.34	59.0	8	35	3.24	10.0° @ 50.9 mph
70	30	8.53	7.98	64.0	11	40	5.36	13.2° @ 44.4 mph
Vehicle Weight = 4500 lb								
30	7	0.35	0.86	33.0	0	10	0.16	1.7° @ 28.4 mph
30	15	1.04	1.66	33.0	0	20	0.34	2.9° @ 26.0 mph Secondary impact.
30	25	2.52	2.85	34.0	0	25	0.72	8.7° @ 22.2 mph Secondary impact.
30	30	3.21	2.93	35.0	2	25	1.16	8.0° @ 20.2 mph Secondary impact.
50	7	0.62	1.73	37.0	0	15	0.31	2.7° @ 47.1 mph
50	15	1.82	3.43	37.0	0	30	0.63	6.5° @ 43.0 mph
50	25	3.26	3.59	61.0	9	35	3.86	10.9° @ 35.8 mph
50	30	3.94	3.60	68.0	12	35	7.10	16.7° @ 30.4 mph Contact @ 0.98 sec.
70	7	0.98	3.27	46.0	0	20	0.51	3.5° @ 65.8 mph
70	15	2.33	3.90	68.0	8	30	2.74	6.5° @ 59.7 mph
70	25	4.01	4.34	75.0	18	35	12.00	6.4° @ 48.9 mph Secondary impact.
70	30	5.15	4.64	75.0	22	40	16.11	5.2° @ 42.2 mph Secondary impact.

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type G4S								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.47	1.03	37.5	0	15	0.48	4.0° @ 27.8 mph
30	15	1.22	2.20	37.5	0	20	0.78	8.3° @ 24.7 mph
30	25	2.68	2.90	37.5	0	25	0.95	14.1° @ 20.8 mph Secondary impact.
30	30	5.17	4.24	37.5	2	25	1.61	8.6° @ 17.2 mph
50	7	1.01	2.15	50.0	0	25	0.63	2.9° @ 46.6 mph Secondary impact.
50	15	2.86	5.35	50.0	1	30	1.32	8.2° @ 40.4 mph Multiple impacts.
50	25	5.41	5.25	50.0	3	35	3.38	20.5° @ 30.0 mph Secondary impact.
50	30	6.72	6.15	50.0	3	40	3.26	16.4° @ 29.1 mph Multiple impacts.
70	7	1.81	4.24	50.0	0	35	0.90	4.0° @ 64.8 mph
70	15	3.40	6.37	50.0	2	80	1.40	9.9° @ 56.8 mph
70	25	5.95	8.34	75.0	6	80	4.62	17.3° @ 41.3 mph Multiple impacts.
70	30	7.05	10.05	50.0	5	50	4.59	14.3° @ 44.2 mph
Vehicle Weight = 4500 lb								
30	7	0.46	0.87	37.5	0	15	0.60	3.2° @ 27.8 mph
30	15	1.34	1.86	37.5	0	20	0.99	6.8° @ 24.8 mph
30	25	2.83	2.84	50.0	1	25	1.42	7.5° @ 21.0 mph Secondary impact.
30	30	3.27	2.46	50.0	2	35	2.26	14.1° @ 18.2 mph
50	7	0.94	2.05	50.0	0	25	0.90	3.6° @ 46.2 mph
50	15	2.26	3.03	62.5	5	40	2.49	4.5° @ 38.8 mph Multiple impacts.
50	25	3.13	4.04	62.5	6	45	3.74	15.1° @ 32.8 mph
50	30	3.83	3.58	62.5	6	35	4.54	15.3° @ 30.5 mph
70	7	1.42	2.74	62.5	2	35	1.97	2.9° @ 64.0 mph Secondary impact.
70	15	2.61	4.74	62.5	6	35	3.75	3.3° @ 57.9 mph
70	25	3.81	5.00	87.5	10	50	6.05	12.0° @ 46.4 mph Secondary impact.
70	30	4.92	4.90	87.5	13	40	8.38	13.1° @ 42.9 mph

TABLE 5. EXTRAPOLATION DATA (Cont'd)

Guardrail Type Thrie								
Speed (mph)	Impact Angle (deg)	Accelerations (g's)		Barrier Damage		Vehicle Damage %	Max. Dynamic Deflection (ft)	Exit Angle/ Remarks
		Long.	Lateral	Ft. of Rail	No. of Posts			
Vehicle Weight = 2250 lb								
30	7	0.44	1.30	12.5	0	5	0.13	1.8° @ 28.4 mph Secondary impact.
30	15	1.33	2.33	12.5	0	15	0.23	4.2° @ 26.0 mph Secondary impact.
30	25	3.00	3.58	12.5	0	15	0.46	9.1° @ 22.3 mph Secondary impact.
30	30	4.49	4.54	12.5	0	15	0.64	0.8° @ 20.8 mph
50	7	0.81	2.31	12.5	0	10	0.21	3.0° @ 47.1 mph
50	15	2.34	4.36	12.5	0	20	0.50	7.0° @ 43.0 mph
50	25	4.97	5.45	12.5	2	25	1.35	11.3° @ 36.4 mph
50	30	6.67	5.89	12.5	2	25	1.68	15.0° @ 32.7 mph
70	7	1.36	4.46	12.5	0	10	0.32	3.7° @ 65.7 mph
70	15	3.69	6.80	25.0	1	25	0.88	7.6° @ 59.9 mph
70	25	6.81	9.99	25.0	4	30	2.20	15.7° @ 49.5 mph
70	30	9.13	9.94	25.0	6	35	2.72	15.0° @ 45.1 mph
Vehicle Weight = 4500 lb								
30	7	0.36	1.08	12.5	0	5	0.18	2.2° @ 28.4 mph Secondary impact.
30	15	1.02	1.89	12.5	0	15	0.38	4.6° @ 25.9 mph Secondary impact.
30	25	2.38	2.66	12.5	1	20	0.93	8.5° @ 22.0 mph Secondary impact.
30	30	3.13	2.61	12.5	2	20	1.43	9.7° @ 19.5 mph Secondary impact.
50	7	0.68	2.01	12.5	0	15	0.29	3.5° @ 46.9 mph
50	15	2.00	3.57	25.0	1	20	0.83	6.7° @ 42.7 mph
50	25	3.37	4.52	25.0	4	20	2.10	13.3° @ 35.5 mph
50	30	4.67	4.00	25.0	5	20	2.76	14.7° @ 32.4 mph
70	7	1.25	3.95	25.0	0	20	0.45	4.4° @ 65.5 mph
70	15	2.43	4.95	37.5	4	25	1.87	9.4° @ 58.6 mph
70	25	4.77	5.77	50.0	11	25	4.18	13.2° @ 48.9 mph
70	30	6.22	6.96	50.0	13	30	4.93	15.0° @ 44.5 mph

failures in which the vehicle breaks through the guardrail cannot be reliably predicted. Such railing fractures shown in Table 5 were noted when sufficient railing hinges were formed to effect a local mechanism. In all of the cases, however, the railing returned to the elastic state on subsequently unloading. In short, BARRIER VII, as all other computer simulations, is inadequate for predicting some of the guardrail failure modes, and the guardrail performance extrapolations are based on essentially successful guardrail tests.

Chapter 2. Collection and Synthesis of Cost Data

In developing the cost-effectiveness model, an important consideration was the ability of the user to input his own local unit costs. However, to illustrate the application of the program and to generate guardrail selection tables, representative mid-1975 costs were developed. The methods used in developing these costs are discussed in this section.

Injury and Fatality Costs

A difficulty with available accident cost data is that only a single value is usually given for fatal, injury, or PDO accidents, with no breakdown of the various costs. Such fatal and injury costs include the property damage, which was independently determined in this study by estimating vehicle and barrier damage costs. Thus, definitive fatality and injury costs were required that exclude property damage.

A direct cost approach was selected for this program. It is defined as follows:(11)

"The money value of damage to property, ambulance use, hospital and treatment services, doctor and dentist services, loss of use of vehicle, value of work time lost, legal and court fees, damage awards and settlements, and other miscellaneous items. . . . Such items as loss of future earnings of persons killed or permanently injured in accidents were excluded from the direct cost phase of the studies, except to the extent that damage awards or settlements made either in or out of court might have compensated for such losses. Expenditures also excluded from

TABLE 6. RVA PROGRAM RESULTS

Ratio of Roll Rate to Critical Roll Rate

Vehicle Weight (lb)	Speed (mph)	Angle of Impact (deg)	Rail Height (in.)	Ratio
4500	70	7	27	–0.1
4500	70	15	27	–0.2
4500	70	25	27	–0.5
4500	70	30	27	–0.7
4500	70	7	15	0.2
4500	70	15	15	0.9
4500	70	25	15	2.8
4500	70	30	15	4.8
2250	70	7	27	–0.2
2250	70	15	27	–0.7
2250	70	25	27	–1.5
2250	70	30	27	–2.0
2250	70	7	15	0.1
2250	70	15	15	0.4
2250	70	25	15	1.3
2250	70	30	15	1.9

Metric conversion:
Multiply lb by 0.454 to obtain kg
Multiply mph by 1.609 to obtain km/hr
Multiply in. by 0.0254 to obtain m

TABLE 7. VEHICLE ROLL ANGLE CYCLES

(4500-lb vehicle, 70-mph, 30-degree impact)

	A	B/G4W	C	D	E	G1	G2	G3	G4S
Max. roll angles (degrees)*:	0.00 –1.52 2.19 1.63 6.71 3.16	0.00 –1.01 6.82 –3.03	0.00 –2.20 6.07 1.37	0.00 –1.56 2.14 1.99 6.46 3.22	0.00 –1.51 6.04 2.50	0.00 –2.25 5.82 –12.81 –0.86	0.00 –0.83 6.49 –3.15	0.00 –3.19 7.23 –12.71 3.97	0.00 –1.44 6.09 2.60

*(Plus/minus) angle = roll (toward/away from) guardrail. Starting angle is at t = 0 sec. Final angle is at t = 1.0 sec.

TABLE 8. SOCIETAL COST COMPONENTS FOR FATALITIES, 1972 NHTSA STUDY

Component	1971 Costs
Future Productivity Losses	
Direct	$132,000
Indirect	41,300
Medical Costs	
Hospital	700
Other	425
Property Damage	1,500
Insurance Administration	4,700
Legal and Court	3,000
Employer Losses	1,000
Victim's Pain and Suffering	10,000
Funeral	900
Assets (Lost Consumption)	5,000
Miscellaneous Accident Cost	200
Total Per Fatality	$200,725
Cost Excluding Productivity, Property Damage, and Funeral Costs	$ 25,025

Ref: U.S. Department of Transportation, National Highway Traffic Safety Administration, *Societal Costs of Motor Vehicle Accidents, Preliminary Report,* May 1972.

the direct cost phase of the studies were those made by public and private agencies in the interest of accident prevention or to mitigate the economic burden of accidents and the overhead cost of automobile and certain other types of insurance. Incidentally, funeral costs are not considered as an element of direct cost as it is reasoned that death is inevitable, and that an accident merely fixes the time of death. The idea of direct costs might be summarized as measuring "out-of-pocket" costs.

The direct cost approach avoids some rather difficult philosophical questions on whether anticipated future earnings are really a loss to society in general. Direct costs provide a reasonable, conservative estimate of the cost to highway users of traffic accidents."

Table 8 shows the 1971 cost components for a fatality.(12) Excluding future productivity, property damage, and funeral costs gives $25,025 for the 1971 cost. The consumer price indexes for medical care were 128.4 for 1971 and 169.8 for July 1975. Thus, by simple ratio, the estimated 1975 cost for a fatality is

$$25025\left(\frac{169.8}{128.4}\right) = \$33,100$$

TABLE 9. INJURY SEVERITY CLASSES IN THE 1972 SOCIETAL COST STUDY

Item	Permanent Total Disability	Permanent Partial Disability & Permanent Disfigurement	No Permanent Disability
Percent Distribution of Injuries	0.2	6.5	93.3
Costs			
Productivity	$191,000	$48,000	$ 350
Medical	7,800	2,800	315
Property Damage	1,000	900	700
Legal and Court	3,000	1,000	150
Insurance Administration	4,300	4,300	800
Pain and Suffering	50,000	10,000	100
All Other	3,200	100	50
Total Cost per Injury	$260,300	$67,100	$2,465
Cost Excluding Productivity and Property Damage	$ 68,300	$18,200	$1,415

Ref: U.S. Department of Transportation, *Automobile Insurance and Compensation Study,* "Automobile Personal Injury Claims, Vol. 1," July 1970.

Table 9 shows the 1971 cost components and severities for injuries.(12) It is considered that the gradations of injury severities shown in the table cannot be satisfactorily predicted from vehicle accelerations. Thus, a weighted average of the severity levels is presented. Again excluding productivity and property damage, the estimated 1975 cost for an injury is

$$\left[0.002\,(68300) + 0.065\,(18200) + 0.933\,(1415)\right]\frac{169.8}{128.4} = \$3,500$$

Vehicle Prices

Table 10 contains the 1975 sticker prices for the various domestic automobile models. Refinements could be made in establishing typical prices by including in the

TABLE 10. 1975 AUTOMOBILE PRICES

SMALL CARS
Subcompacts

Pinto 2-dr.	$ 2,769
Vega 2-dr.	2,786
Gremlin 2-dr.	2,798
Astre S 2-dr.	2,841
Bobcat 2-dr.	3,189
Vega 2-dr. Wagon	3,016
Astre S 2-dr. Wagon	3,071
Pinto 2-dr. Wagon	3,153
Bobcat 2-dr. Wagon	3,481

COMPACTS
(6-cyl., 2-dr. Sedan)

Maverick	$ 3,025
Hornet	3,074
Nova S	3,099
Comet	3,113
Ventura S	3,162
Omega F-85	3,203
Nova	3,205
Apollo/Skylark S	3,234
Valiant Duster	3,243
Ventura	3,293
Dart Sport	3,297
Omega	3,422
Apollo/Skylark	3,463
Camaro	3,540
Firebird	3,713

LUXURY SMALL
(Lowest-priced 2-dr.)

Pacer 6	$ 3,299
Mustang II 4	3,529
Monza S 4	3,648
Granada 6	3,698
Monarch 6	3,764
Skyhawk S V-6	3,860
Starfire S V-6	3,873

INTERMEDIATES
(V-8, 2-dr. models)

Matador	$ 3,545
Chevelle	3,657
Fury	3,672
Coronet	3,719
LeMans	3,720
Cutlass	3,821
Torino	3,954
Century	3,972
Montego	4,092
Monte Carlo	4,249
Elite	4,767
Charger SE	4,903
Cordoba	5,072

INTERMEDIATES (Cont'd)
(V-8, 2-dr. models)

Cougar	5,218
Grand Prix	5,296

INTERMEDIATE WAGONS
(V-8, 2-Seat)

Matador	$ 3,943
Fury	4,309
Chevelle	4,318
Torino	4,336
Coronet	4,358
LeMans	4,555
Century	4,636
Cutlass	4,665
Montego	4,674

STANDARD-SIZE
(V-8; 4-dr. models unless otherwise noted)

Low Standard

Chevrolet Impala	$ 4,548
Ford LTD	4,712
Plym. Gran Fury Cus.	4,761

High Standard

Pontiac Catalina	$ 4,612
Buick LeSabre	4,771
Oldsmobile Delta 88	4,774
Dodge Royal Monaco	4,848
Chrysler Newport	4,854
Mercury Marquis	5,115
Riviera (2-dr.)	6,420
Toronado (2-dr.)	6,523
Thunderbird (2-dr.)	7,701

Luxury Standard

Cadillac deVille	$ 8,801
Imperial LeBaron	8,844
Lincoln Continental	9,656
Eldorado (2-dr.)	9,935
Mark IV (2-dr.)	11,082

STANDARD SIZE WAGONS
(V-8, 2-Seat)

Chevrolet Impala	$ 5,001
Pontiac Safari	5,149
Ford LTD	5,158
Plym. Gran Fury Cus.	5,176
Dodge Royal Monaco	5,292
Mercury Marquis	5,411
Olds. Cus. Cruiser	5,413
Buick Estate Wagon	5,447
Chrys. Twn. & Ctry	6,099

Ref: "Automotive News, 1975 Almanac Issue," August 23, 1975.

averaging process the number of units produced for each of the models. However, the various prices are not considered to differ sufficiently enough to warrant this. Further, less than 10 percent of the automobiles on the road are less than one year old and the average age is about 6 years.[13] While this average vehicle is obviously not worth the new vehicle price, it could be argued that, excluding total losses, the cost of repair of the older car will probably be as much as the new car. The principal factor of labor costs would be essentially the same for both cases, and if new replacement parts are used, material costs would not be significantly different. Thus, a simple average of the 1975 sticker prices was used for vehicle prices. Using the subcompact and compact categories in Table 10 results in an average of

$$\frac{76190}{24} = \$3{,}200$$

for the 2250-lb vehicle class of the study. The standard-size categories, excluding the luxury standards, give

$$\frac{111785}{21} = \$5{,}300$$

for the 4500-lb class.

Guardrail Installation and Repair Costs

Several states were contacted by mail and telephone to determine unit prices for guardrail installation and repair costs. Most of the installation information received was in the form of bid summaries. It was noted that the prices varied considerably and were generally higher than estimates made by the guardrail material suppliers (e.g., Syro Steel Company and Anderson "Safeway" Guard Rail Corporation). Feeling that the varying state prices might not be representative for comparison purposes, it was decided to contact the guardrail erectors for installation estimates. Letters were sent to 44 erectors. Unfortunately, nearly all of them quoted labor costs only, and it was necessary to estimate and add material costs. The results that have been obtained from both the states and the erectors are shown by FHWA region in Table 11.

As shown in Table 12, the guardrail repair costs also vary considerably, ranging from 30 to 130 percent of the corresponding installation costs. Some of these responses were estimates for installing new materials. Others were actual costs of cases where damaged material was reused or salvaged material was used. Because of the resulting wide variation, it was decided to simply use the installation cost for the repair cost. An interesting point in this portion of the work was that several states bill the responsible party for the guardrail repair. Thus, the flexibility to enter such costs as either societal or government/state costs is included in the final model.

State responses have been that normal maintenance is negligible with galvanized and treated wood materials. Thus, representative maintenance costs are not included. If similar maintenance costs are assumed for each of the guardrail types, the omission should not affect the selection process. Again, however, the model is of such flexibility that a particular agency can insert its own maintenance costs if it so desires.

Vehicle Delay Costs

Several figures appear in the literature for the cost of vehicle delay.[14,15,16] These figures range from $3 per vehicle hour up to $15 per vehicle hour, depending on the type of vehicle and other assumptions in arriving at the cost, such as average number of travelers per vehicle, value of time, etc. An average value of $10 per hour was used for illustrative purposes.

TABLE 11. TYPICAL GUARDRAIL INSTALLATION COSTS ($/L.F.)

FHWA Region	Guardrail Type									
	A		B		C		D		E	
	States	Erectors	States	Erectors	States	Erectors	States	Erectors	States	Erectors
1		3.66		5.23		4.15		5.39		5.83
		4.35						6.38		6.43
								6.00		
2								5.30	6.20*	8.57
										5.90
3		3.73		5.17		4.03		5.03	6.92*	5.73
4						6.65				7.68
5		4.13		16.20	9.35	4.52		6.63		6.63
				6.37						
6	7.90	4.70	9.25	5.64		5.19		6.05		6.13
		4.28		6.22		4.82		6.38		
7		3.88		5.34		4.20	9.93	5.57		5.80
8	5.45	5.00		6.75	6.04	5.40		5.05		8.40
		7.50		8.00		6.50		8.00		
9			12.00	6.27	6.87	5.27		7.73		
						5.97				

*Contractor has option of W6 X 8.5 or wood posts.

FHWA Region	Guardrail Type										
	G1		G2		G3		G4S		G4W		Thrie
	States	Erectors	States	Erectors	States	Erectors	States	Erectors	States	Erectors	Erectors
1	5.00	2.90	6.25	4.60	14.00	14.17		5.84			7.50
		2.90				13.67		6.55			
		3.55				14.67		6.80			
								6.00			
2	5.75		6.65	5.47			5.50*	8.30	5.50†		
							6.20*	6.40			
3				3.75			6.92*	5.85	6.92†	5.49	
							5.60*	5.60	5.60†		
4							12.00	7.80			
								8.00			
5		6.70		4.80		13.67	10.76	6.75	10.50	6.69	
		3.30									
6		3.05		4.35		13.47	11.75	6.52		6.21	
								6.25		6.54	
7		2.75		3.82		12.77	23.13	6.37	9.93	5.66	
		2.75		3.82		12.77		6.37		5.66	
8		4.70		4.85		10.50		8.00	4.91	7.25	
		4.00								8.00	
9	5.00				16.50		6.63	7.55	8.25	6.59	10.50
								8.30	12.00	8.04	

*Contractor has option of Charley or wood posts.
†Contractor has option of steel posts.

Chapter 3. Development of Cost-Effectiveness Model

Figure 4 focuses on the cost-effectiveness portion of the total guardrail design process that was shown in Figure 1. The six most common analytical methods used in economic analyses to compare the various alternative treatments are:[16]

- Equivalent uniform annual cost
- Present worth of costs

TABLE 12. TYPICAL GUARDRAIL REPAIR COSTS ($/L.F.)

Agency	Guardrail Type									
	A	B	C	D	E	G1	G2	G3	G4S	G4W
Texas	11.10 (129)[1]									
California				5.36 (54)						5.36 (54)
New York						2.25 (45)	4.90 (78)	8.80 (63)		
New Mexico		3.60 (30)								3.60 (30)
Georgia				6.10 (88)						6.10 (88)
Pennsylvania									7.00 (54)	
Missouri									8.56 (80)	
Minnesota			5.72 (61)							
Colorado										
Oregon										5.02 (102)
Ohio									4.41 (80)	4.41 (80)

[1] Percent of installation cost.

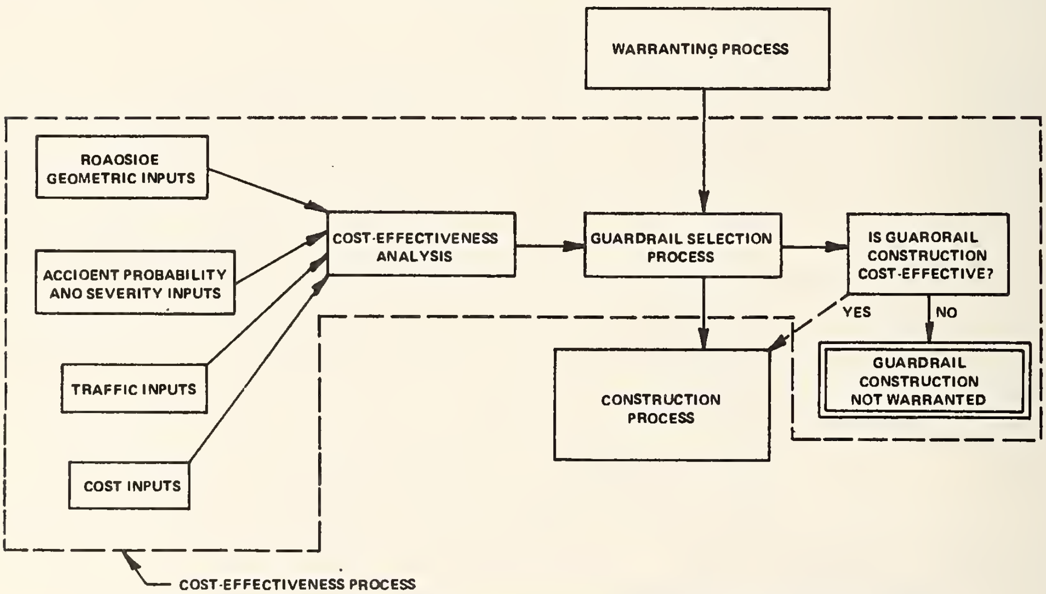


FIGURE 4. COST-EFFECTIVENESS PROCESS IN GUARDRAIL DESIGN

- Equivalent uniform annual net return
- Net present value
- Benefit/cost ratio
- Rate of return

Selected for use in the development of the cost-effectiveness model for this study was the present worth of costs method. This method combines the guardrail installation cost and all annual maintenance and accident costs into a single equivalent sum at zero time. Of the various alternatives compared, the one with the lowest present worth is the most economical. To give the user a choice in his selection process, the present worths are used to calculate state costs, societal costs, total costs, and benefit/cost ratios, as defined previously in Section I.

With the present-worth formulation, the total government or state present-worth cost is given by

$$C_G = C_I + (C_{YM} + C_{YR}) \times k_A - C_{FS} \times k_P \tag{1}$$

and the total societal present-worth cost by

$$C_S = (C_{YS} + C_{YD}) \times k_A \tag{2}$$

where

C_I = cost of installation

C_{YM} = yearly cost of maintenance

C_{YR} = yearly cost of repair

C_{FS} = future salvage value

C_{YS} = yearly severity cost (fatalities, injuries, guardrail and vehicle damage)

C_{YD} = yearly traffic delay cost

k_P = economic factor—present value of future dollar

k_A = economic factor—present value of yearly annuity

For illustrative purposes, the economic factor k_P and k_A were based on a guardrail service life of 15 years with an 8-percent interest rate.

The most difficult factors to quantify in equations (1) and (2) were the yearly severity cost C_{YS} and traffic delay cost C_{YD}. For example, consider a point of impact on a guardrail with given roadside and category impact conditions [e.g., a 2250-lb (1021-kg) vehicle impact at 50 mph (80.5 km/hr) and an angle of 25 degrees]. Required quantities include the severities of the hit (expected number of fatalities or injuries and guardrail and vehicle damage) and the probability of the impact. Factors affecting the probability include the number of expected encroachments, the percentage of the traffic for the selected vehicle class, the probability of traveling at the selected speed, the probability of the out-of-control vehicle traversing the distance to the guardrail, and the probability of hitting the guardrail at the selected angle of impact. Traffic delay must be estimated for the periods immediately following the accident and during guardrail repair. The cost of the accident then becomes

$$\begin{aligned} C_{ACC} = {} & ENC \times (P_{traffic} \times P_{speed} \times P_{offset} \times P_{angle}) \\ & \times [C_{GD}(GD) + C_{VD}(VD) + C_{INJ}(INJ) + C_{FAT}(FAT) + C_{TD}(TD)] \end{aligned} \tag{3}$$

where

ENC = number of yearly encroachments

P_i = probability for indicated factor i

GD, C_{GD} = guardrail damage and unit cost

VD, C_{VD} = vehicle damage and unit cost

INJ, C_{INJ} = number of injuries and cost of each

FAT, C_{FAT} = number of fatalities and cost of each

TD, C_{TD} = traffic delay and unit cost

Finally, for each of the n impact category combinations, equation (3) is applied and the results are summed to yield

$$C_{YS} + C_{YD} = \sum_{i=1}^{n} (C_{ACC})_i \tag{4}$$

for the estimated yearly societal cost of the selected guardrail type.

Discussions of the methods used to quantify these various parameters follow.

Vehicle Distributions

Various degrees of refinement could have been attempted in establishing the distribution of traffic for use in this study. If the distribution of the vehicles on the road could have been determined according to model, age, and geographic location, such factors could have been included in the probability portion of the model. However, on reviewing the available statistics, it was found that even the required coarse distribution of passenger car registrations according to the light 2250-lb (1021-kg) vehicle and the heavy 4500-lb (2041-kg) vehicle classes would be impossible to ascertain. Telecons with the Motor Vehicle Manufacturers Association and the R. L. Polk Company were unfruitful. A telecon with the Motor Vehicles Division of the Texas State Highway Department revealed that such distributions might be obtained from the states. Thus, letters were prepared and sent to all of the states in an attempt to get this information. The response from the states was good, but most of them did not have the data available. Table 13 is a summary of the usable results.

TABLE 13. TRAFFIC MIX DISTRIBUTION BY WEIGHT

State	Percent of Compacts/ Subcompacts (< 3000 lb)
New Mexico	35
New Hampshire	38
Washington	~~46~~
South Carolina	28
D.C.	29
New Jersey	22
Florida	16
Arkansas	20
North Dakota	25
South Dakota	19
Michigan	26
Maine	15
Texas	21
Rhode Island	~~6~~
Colorado	38
Mississippi	23
Average	25

Conclusion: Assume traffic mix is 25% for 2250-lb vehicles and 75% for 4500-lb vehicles.

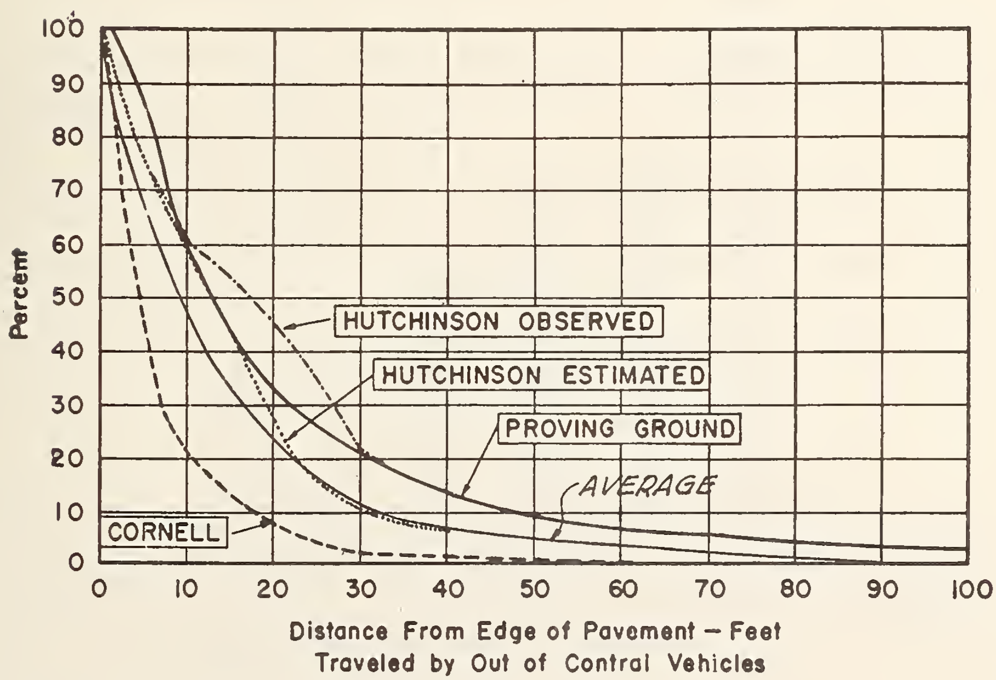
Since trucks and buses are not included in this study, the traffic mix was assumed to consist of 25% for 2250-lb (1021-kg) class vehicles and 75% for 4500-lb (2041-kg) class vehicles, as shown in Table 13. Encroachment frequencies were multiplied by these percentages to determine the corresponding estimated number of encroachments by vehicle class.

Impact Probabilities

Up to the start of this investigation, the only available encroachment frequency data was the Hutchinson and Kennedy data on median encroachments.[18,19,20] During the study, a report by Glennon was received.[21] This report contains "order of magnitude" encroachment frequency estimates for several highway types. Glennon's rates were estimated by multiplying accident rates of the various highway types by the ratio of freeway encroachment rate (twice the median rate of Hutchinson and Kennedy) to freeway accident rates (measured in his study). A resulting ratio of 5.23 was used, which may be a bit too high. However, in the absence of better data, the

TABLE 14. ENCROACHMENT RATE TABLE

Type of Highway	Description of Collision Direction	Encroachment Rate (events/mile/year)
Narrow Two-lane Rural Highway	1. Both directions 2. One direction only–right side 3. One direction only–left side	0.00060 ADT 0.00030 ADT 0.00030 ADT
Wide two-lane or Undivided Four-lane Rural Highway	1. Both directions 2. One direction only–right side 3. One direction only–left side	0.00037 ADT 0.00019 ADT 0.00019 ADT
Multilane Divided Rural Highway	One direction for each side, each direction separately for median	0.00015 ADT
Freeway	One direction for each side, each direction separately for median	0.00023 ADT
Ref: J. C. Glennon and C. J. Wilton, "Roadside Encroachment Parameters for Non-Freeway Facilities," presented at the 55th Annual Meeting of the TRB, January 1976.		

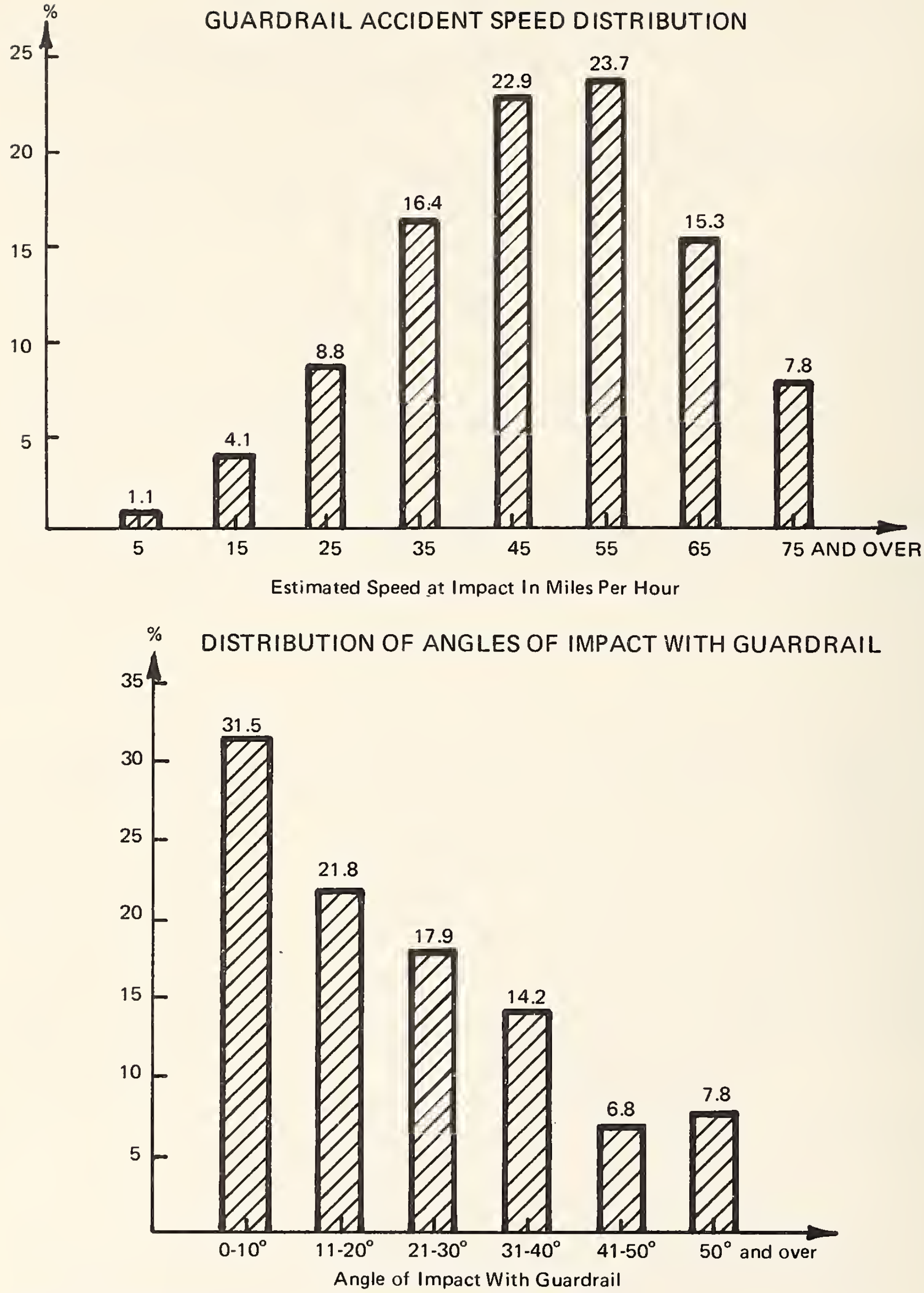


Metric conversion: Multiply ft by 0.3048 to obtain m

FIGURE 5. DISTRIBUTION OF LATERAL DISPLACEMENTS(22)

Glennon estimates were selected for this study. Table 14 shows the encroachment rates that were used.

The distribution of lateral displacements was estimated from the average curve in Figure 5. The distribution of impacts for the category values of vehicle speeds and impact angles was first



Metric conversion: Multiply mph by 1.609 to obtain km/hr

FIGURE 6. DISTRIBUTION OF VEHICLE SPEEDS AND IMPACT ANGLES[23]

estimated on the basis of the historical data generated by Lampela and Yang.[23] This study involved approximately 1400 single-vehicle and 200 multiple-vehicle guardrail accidents in Michigan. The distributions of vehicle speeds and impact angles from this reference are shown in Figure 6. The assumption that these two distributions were completely independent resulted in the combined distribution of speeds and angles shown in Table 15. Some of the resulting high-speed, high-angle impacts were simply not considered possible. The values shown in parentheses, calculated by using the point mass approach discussed in Appendix D, represent distributions for a guardrail

TABLE 15. DISTRIBUTION OF SPEEDS AND ANGLES

Speed (mph)	Impact Angle (degrees): 5 (31.5%)	15 (21.8%)	25 (17.9%)	35 (14.2%)	45 (6.8%)	55 (7.8%)
15 (5.1%)	1.61 (0.69)	1.11 (0.79)	0.91 (1.07)	0.72 (1.07)	0.35 (0.79)	0.40 (0.69)
25 (8.8%)	2.77 (2.32)	1.92 (3.42)	1.57 (2.37)	1.25 (0.63)	0.60 (0.06)	0.69 (0.00)
35 (16.4%)	5.17 (7.04)	3.57 (7.72)	2.94 (1.59)	2.33 (0.05)	1.11 (0.00)	1.28 (0.00)
45 (22.9%)	7.21 (13.81)	4.99 (8.75)	4.10 (0.34)	3.25 (0.00)	1.56 (0.00)	1.79 (0.00)
55 (23.7%)	7.47 (17.90)	5.17 (5.78)	4.24 (0.02)	3.36 (0.00)	1.61 (0.00)	1.85 (0.00)
65 (15.3%)	4.82 (13.30)	3.34 (2.00)	2.74 (0.00)	2.17 (0.00)	1.04 (0.00)	1.19 (0.00)
75 (7.8%)	2.46 (7.32)	1.70 (0.48)	1.39 (0.00)	1.11 (0.00)	0.53 (0.00)	0.61 (0.00)

Metric conversion Multiply mph by 1.609 to obtain km/hr.

about 3 feet from the edge of the pavement. These values appear much more realistic in that the probability of high impact angles at high speeds is reduced. Thus, it was decided to formulate combined probabilities by using the following:

(1) the average curve for distribution of lateral displacements from Figure 5;
(2) the distribution of impact speeds from Figure 6;
(3) the point mass approach with a coefficient of friction of unity for determination of the 95 percentile impact angle (see Appendix D);
(4) an angle of zero degrees for the 0 percentile impact angle;
(5) a normal distribution of impact angles using the two values determined in steps (3) and (4).

Details of this formulation are discussed in Appendix D.

Traffic Delay Time

A modified version of the shock wave method for queuing in uninterrupted flow was used to formulate traffic delay time estimates for accident blockage and guardrail repair congestion. Traffic queuing and assumed average vehicle speeds for one-half mile site lengths of 20 mph (32.2 km/hr) during the accident blockage and 35 mph (56.3 km/hr) during repair are included. An average speed of 30 mph (48.3 km/hr) is assumed for the "gawkers" traveling in the opposite direction during the accident blockage. Details of the formulation are discussed in Appendix E. For each case of specified geometric and traffic conditions, total travel delay times are computed in program subroutines for input values of the times to remove the damaged vehicle and to repair the damaged guardrail, both in hours. For illustrative purposes, one hour to remove the vehicle and ten hours to repair the guardrail were used.

Exposure Lengths

In order to estimate the probable number of impacts at a site with and without the guardrail installation, it is necessary to determine the exposure length of the obstacle and the guardrail length of need. Assuming a vehicle speed of 70 mph (112.6 km/hr), a coefficient of tire-to-pavement friction of 0.50, and using the point mass approach yield a radius of vehicle turn that can be used with the site geometry to calculate these exposure lengths. Details of the formulation are discussed in Appendix G. The resulting exposure lengths are shorter than those of previous recommendations and, hence, might warrant some discretion in their use. Since the lengths must be specified as inputs to the program, a table for selecting the values is presented in Volume II, along with a discussion of its use and the previous recommended practice.

Computer Programs

With the formulations discussed above, two computer programs were developed to establish ranking criteria of state cost, societal cost, total cost, and benefit-to-cost ratio. The SSCOST program computes these values for a single specified guardrail type with given roadway conditions. A comparative cost program COCOST requires only the roadway conditions for input and then checks and ranks all of the eleven guardrail types of Table 1 internally. Both CDC and IBM versions of the programs have been developed. Descriptions of the programs are given in Section VII of Volume II, User's Manual.

Required inputs for the SSCOST and COCOST programs are illustrated in Figures 7 and 8. Though the inputs are quite simple to prepare and in a format familiar to engineers, it can be seen that several variables are involved to provide the desired flexibility of the programs. These variables correspond to the cost-effectiveness inputs that were shown in Figure 1. To aid in assessing the relative significance of these variables and, hence, to illustrate the need for care that must be exercised in specifying some of the values, a series of sensitivity analyses were performed. Discussions of these analyses follow.

Input parameters of guardrail installation, repair, and maintenance costs and local vehicle prices will be the most easily defined quantities by a particular state agency. Typical service life and current rate of interest should also be well defined. However, injury and fatality costs will probably be less well defined. Using the representative costs discussed above, an analysis was made to check the effects of varying fatality/injury costs. Tables 16 through 18 show the effects on societal costs, total costs, and benefit/cost ratios, respectively. The low fatality/injury costs are the direct cost estimates of this study. The middle and high values were taken from References 33 and 34, respectively. All of the results are for a straight 2-lane rural road with 6-foot shoulder, 500-foot guardrail length, 400-foot obstacle length, AADT of 5000 vehicles, and the various guardrail-to-obstacle distances shown. It can be seen that the most significant changes in ranking occur for the flexible G2 system in societal and total costs where severities increase when the dynamic deflections exceed the distance specified behind the guardrail. However, the system ranks high from a benefit-to-cost standpoint. Notice also that the G1 system ranks high from a benefit-to-cost standpoint when the guardrail-to-obstacle distance is increased to 8 feet. Changes in ranking for the other systems do not appear significant. The slight increases in ranking of the stiffer systems and corresponding decreases of the more flexible systems with increasing fatality/injury costs are to be expected because of the increased severities explained above. An important point from this analysis is that care should be exercised in selecting the injury and fatality costs. If the higher values are used, the cheaper, flexible systems may be excluded from consideration, particularly with limited space behind the guardrail.

Again using the representative costs discussed previously for program inputs, Tables 19 through 21 were generated. For the conditions shown, these tables show the probable optimum distance behind the guardrail and the probable rank by benefit-to-cost ratio for the eleven selected guardrail types of this study. Note that the optimum distance shown for each type is the distance which yields the highest benefit-to-cost ratio. Notable in these tables are the poor rankings of the more rigid G3 and G4W systems. Of course, if the relative costs of the systems are different from

Column	10	20	30	40	50	60	70	80
Card 1 Format (10A8):								
Title	2- Lane	Road, AADT=5,000,	Guardrail Type	A, Low	Fatality Cost			
Card 2 Format (8F10.0):								
	2.0 Highway type	1.0 Guardrail type	500.0 Guardrail length	5000. AADT	0.25 Fraction of traffic for 2250-lb vehicles	0.75 Fraction of traffic for 4500-lb vehicles	0.0 Highway division	6.0 FHWA region
Card 3 Format (5F10.0):								
	24.0 Left offset distance	12.0 Right offset distance	0.0 Degree of curve	4.0 Guardrail-to-obstacle distance	400.0 Obstacle length			
Card 4 Format (2F10.0):								
	1.0 Time to remove damaged vehicle	10.0 Time to repair damaged guard-rail						
Card 5 Format (8F10.0):								
	3500.00 Cost of injury	33100.00 Cost of fatality	4.50 Cost of installation	4.50 Cost of repair	0.00 Cost of maintenance	3200.00 2250-lb vehicle cost	5300.00 4500-lb vehicle cost	10.00 Cost of traffic delay
Card 6 Format (4F10.0):								
	15.0 Service life	8.0 Interest rate	500.0 Total salvage value	0.0 Print flag				

FIGURE 7. SSCOST INPUT WORKSHEET

Column	10	20	30	40	50	60	70	80

Card 1 Format (10A8):

2-Lane Rural Road, AADT = 5000, I = $3500 and F = $33,100

Title

Card 2 Format (5I5). Flag card for changes in preset input values.

Use blank card for no changes in present input values X
Enter 1 in Column 5 for changes in traffic mix
Enter 1 in Column 10 for changes in guardrail costs
Enter 1 in Column 15 for changes in travel delay
Enter 1 in Column 20 for changes in injury, fatality, or vehicle costs
Enter 1 in Column 25 for changes in service life or interest rate

Card 2a Format (2F10.0). Include if 1 is punched in Column 5 of Card 2.

Fraction of traffic for 2250-lb vehicles	Fraction of traffic for 4500-lb vehicles

Cards 2b Format (8F10.0). Include if 1 is punched in Column 10 of Card 2.

Unit cost of guardrail A	Unit cost of guardrail B	Unit cost of guardrail C	Unit cost of guardrail D	Unit cost of guardrail E	Unit cost of guardrail G1	Unit cost of guardrail G2	Unit cost of guardrail G3
Unit cost of guardrail G4S	Unit cost of guardrail G4W	Unit cost of guardrail Thrie	Unit yearly maintenance cost	Unit salvage value			

Card 2c Format (3F10.0). Include if 1 is punched in Column 15 of Card 2.

Time to remove damaged vehicle	Time to repair damaged guard-rail	Unit cost of traffic delay

Card 2d Format (4F10.0). Include if 1 is punched in Column 20 of Card 2.

Cost of injury	Cost of fatality	2250-lb vehicle cost	4500-lb vehicle cost

Card 2e Format (2F10.0). Include if 1 is punched in column 25 of Card 2.

Service life	Interest rate

Card 3 Format (7F10.0):

2.0	0.0	24.0	12.0	0.0	4.0	6.0
Highway type	Highway division	Left offset distance	Right offset distance	Degree of curve	Guardrail-to-obstacle distance	Pavement-to-guardrail distance

Card 4 Format (4F10.0):

500.0	400.0	5000.	0.0
Guardrail length	Obstacle length	AADT	Final degree of curve

FIGURE 8. COCOST INPUT WORKSHEET

TABLE 16. EFFECT OF FATALITY/INJURY COSTS ON SOCIETAL COSTS

Guardrail Type	Low Values*		Middle Values†		High Values‡	
	Cost	Rank	Cost	Rank	Cost	Rank
Guardrail-to-Obstacle Distance = 4 ft (1.22 m)						
A	$ 3,303	4	$ 6,079	3	$ 8,526	3
B	4,394	9	8,070	9	11,991	8
C	3,802	7	7,450	8	11,314	7
D	3,214	3	4,972	2	4,853	2
E	3,912	8	7,396	7	10,913	6
G1	12,172	11	32,864	11	72,289	11
G2	2,967	1	6,498	5	12,573	10
G3	3,668	6	6,654	6	9,120	5
G4S	3,050	2	4,607	1	4,530	1
G4W	4,404	10	8,079	10	12,000	9
Thrie	3,310	5	6,268	4	8,677	4
Guardrail-to-Obstacle Distance = 0 ft (Embankment)						
A	$ 3,303	5	$ 6,080	4	$ 8,526	5
B	4,382	9	8,030	9	11,893	8
C	3,802	8	7,450	8	11,314	7
D	3,208	3	4,953	2	4,808	2
E	3,420	6	5,856	3	7,165	3
G1	8,804	11	22,949	11	49,339	11
G2	2,967	1	6,498	6	12,573	10
G3	3,668	7	6,653	7	9,120	6
G4S	3,045	2	4,589	1	4,485	1
G4W	4,391	10	8,040	10	11,903	9
Thrie	3,289	4	6,201	5	8,515	4
Guardrail-to-Obstacle Distance = 8 ft (2.44 m)						
A	$ 3,323	6	$ 6,144	5	$ 8,686	6
B	4,362	10	7,965	10	11,733	9
C	3,781	9	7,385	9	11,153	8
D	3,187	4	4,887	3	4,648	3
E	3,401	7	5,792	4	7,007	4
G1	3,153	3	6,782	8	12,857	11
G2	1,367	1	1,837	1	1,844	1
G3	3,655	8	6,613	7	9,022	7
G4S	3,025	2	4,524	2	4,325	2
G4W	4,371	11	7,974	11	11,743	10
Thrie	3,289	5	6,201	6	8,515	5

Roadside conditions:
- 2-lane rural road with 6-ft (1.82-m) shoulder
- Guardrail length = 500 ft (152.4 m)
- Obstacle length = 400 ft (121.9 m)
- AADT = 5000

*Fatality = $33,100 and Injury = $3,500.
†Fatality = $102,460 and Injury = $6,500.
‡Fatality = $241,600 and Injury = $5,880.

TABLE 17. EFFECT OF FATALITY/INJURY COSTS ON TOTAL COSTS

Guardrail Type	Low Values*		Middle Values†		High Values‡	
	Cost	Rank	Cost	Rank	Cost	Rank
Guardrail-to-Obstacle Distance = 4 ft (1.22 m)						
A	$ 5,396	2	$ 8,172	3	$10,619	3
B	7,236	8	10,912	8	14,833	8
C	6,145	4	9,792	5	13,656	5
D	6,182	5	7,939	2	7,820	2
E	6,805	6	10,289	7	13,805	6
G1	13,564	11	34,257	11	73,682	11
G2	4,984	1	8,516	4	14,590	7
G3	10,261	10	13,246	10	15,713	10
G4S	6,143	3	7,699	1	7,622	1
G4W	7,496	9	11,172	9	15,093	9
Thrie	6,903	7	9,861	6	12,270	4
Guardrail-to-Obstacle Distance = 0 ft (Embankment)						
A	$ 5,396	2	$ 8,172	3	$10,619	4
B	7,224	8	10,872	8	14,736	8
C	6,145	4	9,793	6	13,656	6
D	6,175	5	7,921	2	7,776	2
E	6,312	6	8,748	5	10,058	3
G1	10,196	10	24,341	11	50,731	11
G2	4,984	1	8,516	4	14,590	7
G3	10,260	11	13,246	10	15,712	10
G4S	6,137	3	7,681	1	7,578	1
G4W	7,484	9	11,132	9	14,995	9
Thrie	6,881	7	9,794	7	12,108	5
Guardrail-to-Obstacle Distance = 8 ft (2.44 m)						
A	$ 5,415	3	$ 8,237	5	$10,778	5
B	7,204	9	10,807	9	14,576	9
C	6,124	5	9,727	7	13,495	7
D	6,155	6	7,855	3	7,615	3
E	6,294	7	8,684	6	9,899	4
G1	4,545	2	8,174	4	14,250	8
G2	3,385	1	3,855	1	3,862	1
G3	10,248	11	13,206	11	15,615	11
G4S	6,117	4	7,616	2	7,418	2
G4W	7,464	10	11,067	10	14,835	10
Thrie	6,881	8	9,794	8	12,108	6

Roadside conditions:
- 2-lane rural road with 6-ft (1.82-m) shoulder
- Guardrail length = 500 ft (152.4 m)
- Obstacle length = 400 ft (121.9 m)
- AADT = 5000

*Fatality = $33,100 and Injury = $3,500.
†Fatality = $102,460 and Injury = $6,500.
‡Fatality = $241,600 and Injury = $5,880.

TABLE 18. EFFECT OF FATALITY/INJURY COSTS ON BENEFIT/COST RATIOS

Guardrail Type	Low Values*		Middle Values†		High Values‡	
	B/C	Rank	B/C	Rank	B/C	Rank
Guardrail-to Obstacle Distance = 4 ft (1.22 m)						
A	3.18	2	9.30	2	22.38	1
B	1.96	7	6.14	7	15.25	7
C	2.63	3	7.72	3	18.80	3
D	2.27	4	6.93	4	17.02	4
E	2.09	6	6.27	6	15.36	6
G1	−1.59	11	−5.27	11	−12.17	11
G2	3.47	1	9.44	1	21.20	2
G3	0.95	10	2.86	10	7.01	10
G4S	2.23	5	6.77	5	16.43	5
G4W	1.80	9	5.64	8	14.02	8
Thrie	1.85	8	5.36	9	12.99	9
Guardrail-to-Obstacle Distance = 0 ft (Embankment)						
A	0.67	2	0.70	3	1.35	4
B	0.12	9	−0.17	10	−0.19	9
C	0.39	7	0.04	8	0.01	7
D	0.51	4	0.88	2	2.20	2
E	0.45	5	0.59	4	1.45	3
G1	−2.94	11	−11.06	11	−27.28	11
G2	0.86	1	0.52	5	−0.61	10
G3	0.16	8	0.14	7	0.34	6
G4S	0.54	3	0.96	1	2.22	1
G4W	0.10	10	−0.16	9	−0.18	8
Thrie	0.40	6	0.38	6	0.79	5
Guardrail-to-Obstacle Distance = 8 ft (2.44 m)						
A	2.04	3	6.38	3	16.03	3
B	1.14	9	4.05	8	10.73	8
C	1.63	4	5.17	4	13.27	4
D	1.49	5	4.92	5	12.67	5
E	1.45	7	4.73	7	12.18	7
G1	3.19	1	9.12	1	21.10	1
G2	3.09	2	8.75	2	20.02	2
G3	0.60	11	1.95	11	5.04	11
G4S	1.48	6	4.84	6	12.26	6
G4W	1.04	10	3.72	9	9.86	9
Thrie	1.20	8	3.70	10	9.39	10

Roadside conditions:
- 2-lane rural road with 6-ft (1.82-m) shoulder
- Guardrail length = 500 ft (152.4 m)
- Obstacle length = 400 ft (121.9 m)
- AADT = 5000

*Fatality = $33,100 and Injury = $3,500.
†Fatality = $102,460 and Injury = $6,500.
‡Fatality = $241,600 and Injury = $5,880.

TABLE 19. OPTIMUM GUARDRAIL-TO-OBSTACLE DISTANCE –2-LANE RURAL ROAD WITH 4-FT SHOULDER

Guardrail-to-Obstacle Distance / Guardrail Type	2	3	4	5	6	7	8	10	12	14	16	Optimum* Distance	Probable Rank
	Benefit/Cost Ratio (Rank)												
A	3.03 (2)	3.97 (1)	3.90 (2)	3.52 (2)	3.17 (2)	2.86 (2)	2.56 (3)	2.05 (3)	1.61 (3)	1.24 (3)	0.92 (3)	3	1
B	1.76 (8)	2.67 (5)	2.48 (7)	2.21 (7)	1.96 (7)	1.72 (8)	1.51 (9)	1.13 (9)	0.80 (9)	0.53 (9)	0.30 (9)	3	5
C	3.59 (1)	3.68 (2)	3.32 (3)	2.98 (3)	2.68 (3)	2.40 (3)	2.14 (4)	1.67 (4)	1.28 (4)	0.95 (4)	0.67 (5)	3	2
D	2.77 (3)	2.82 (3)	2.76 (4)	2.49 (5)	2.25 (4)	2.03 (6)	1.83 (6)	1.46 (6)	1.15 (6)	0.89 (6)	0.67 (6)	3	3
E	1.99 (6)	2.72 (4)	2.62 (6)	2.50 (4)	2.25 (5)	2.02 (7)	1.81 (7)	1.44 (7)	1.12 (7)	0.85 (7)	0.62 (7)	3	4
G1	–2.83 (11)	–2.85 (11)	–1.20 (11)	1.18 (10)	1.13 (10)	2.04 (4)	4.09 (1)	3.95 (1)	3.69 (1)	3.13 (1)	2.66 (1)	8	1
G2	2.68 (4)	2.66 (6)	4.30 (1)	3.92 (1)	4.22 (1)	3.89 (1)	3.59 (2)	3.06 (2)	2.60 (2)	2.22 (2)	1.89 (2)	4	1
G3	1.29 (10)	1.25 (10)	1.19 (10)	1.07 (11)	0.96 (11)	0.86 (11)	0.77 (11)	0.61 (11)	0.47 (11)	0.35 (11)	0.25 (11)	2	10
G4S	1.95 (7)	2.60 (7)	2.73 (5)	2.48 (6)	2.24 (6)	2.03 (5)	1.83 (5)	1.48 (5)	1.19 (5)	0.94 (5)	0.72 (4)	4	5
G4W	1.62 (9)	2.45 (9)	2.28 (9)	2.03 (9)	1.80 (9)	1.58 (10)	1.38 (10)	1.03 (10)	0.74 (10)	0.49 (10)	0.27 (10)	3	9
Thrie	2.65 (5)	2.53 (8)	2.29 (8)	2.08 (8)	1.88 (8)	1.69 (9)	1.52 (8)	1.22 (8)	0.96 (8)	0.75 (8)	0.56 (8)	2	5
	AADT = 5,000		Guardrail Length = 500 ft			Obstacle Length = 400 ft							

*Distance which yields highest value of benefit/cost ratio. Distances shown are in feet. Multiply by 0.3048 to obtain m.

TABLE 20. OPTIMUM GUARDRAIL-TO-OBSTACLE DISTANCE–4-LANE RURAL ROAD WITH 8-FT SHOULDER

Guardrail-to-Obstacle Distance / Guardrail Type	2	3	4	5	6	7	8	10	12	14	16	Optimum* Distance	Probable Rank
	Benefit/Cost Ratio (Rank)												
A	1.59 (4)	2.46 (1)	2.61 (2)	2.34 (2)	2.03 (2)	1.80 (2)	1.58 (3)	1.19 (3)	0.86 (3)	0.58 (3)	0.34 (4)	4	2
B	0.78 (9)	1.74 (5)	1.55 (7)	1.42 (7)	1.26 (7)	1.09 (7)	0.93 (9)	0.65 (9)	0.40 (9)	0.20 (9)	0.02 (10)	3	5
C	2.26 (1)	2.36 (2)	2.17 (3)	1.93 (3)	1.74 (3)	1.53 (3)	1.33 (4)	0.98 (4)	0.69 (6)	0.44 (7)	0.23 (8)	3	2
D	1.74 (3)	1.87 (3)	1.80 (4)	1.66 (5)	1.48 (5)	1.35 (5)	1.19 (6)	0.92 (6)	0.69 (5)	0.49 (5)	0.32 (5)	3	3
E	0.99 (5)	1.74 (4)	1.74 (6)	1.68 (4)	1.49 (4)	1.36 (4)	1.20 (5)	0.92 (7)	0.68 (7)	0.48 (6)	0.30 (6)	3	4
G1	–2.14 (11)	–2.36 (11)	–1.61 (11)	0.15 (11)	0.13 (11)	0.51 (10)	2.60 (2)	2.76 (1)	2.50 (1)	2.08 (1)	1.91 (1)	10	1
G2	0.93 (7)	1.26 (9)	2.94 (1)	2.65 (1)	3.00 (1)	2.75 (1)	2.63 (1)	2.28 (2)	1.94 (2)	1.65 (2)	1.40 (2)	6	1
G3	0.79 (8)	0.81 (10)	0.74 (10)	0.66 (10)	0.57 (10)	0.50 (11)	0.46 (11)	0.34 (11)	0.25 (11)	0.16 (11)	0.08 (9)	3	10
G4S	0.97 (6)	1.65 (7)	1.77 (5)	1.63 (6)	1.46 (6)	1.33 (6)	1.18 (7)	0.92 (5)	0.70 (4)	0.51 (4)	0.35 (3)	4	5
G4W	0.72 (10)	1.60 (8)	1.42 (9)	1.30 (9)	1.16 (9)	1.00 (9)	0.85 (10)	0.59 (10)	0.37 (10)	0.18 (10)	0.02 (11)	3	8
Thrie	1.75 (2)	1.68 (6)	1.51 (8)	1.37 (8)	1.22 (8)	1.09 (8)	0.96 (8)	0.73 (8)	0.54 (8)	0.38 (8)	0.24 (7)	2	2

AADT = 10,000   Guardrail Length = 500 ft   Obstacle Length = 400 ft

*Distance which yields highest value of benefit/cost ratio. Distances shown are in feet. Multiply by 0.3048 to obtain m.

TABLE 21. OPTIMUM GUARDRAIL-TO-OBSTACLE DISTANCE–DIVIDED HIGHWAY WITH 10-FT SHOULDER

Guardrail-to-Obstacle Distance / Guardrail Type	2	3	4	5	6	7	8	10	12	14	16	Optimum* Distance	Probable Rank
	Benefit/Cost Ratio (Rank)												
A	1.29 (4)	2.23 (1)	2.39 (2)	2.13 (2)	1.89 (2)	1.67 (2)	1.47 (3)	1.11 (3)	0.81 (3)	0.56 (3)	0.35 (3)	4	2
B	0.58 (8)	1.62 (4)	1.46 (7)	1.27 (7)	1.09 (7)	0.93 (8)	0.78 (9)	0.52 (9)	0.30 (9)	0.11 (10)	−0.04 (11)	3	4
C	2.00 (1)	2.22 (2)	1.96 (3)	1.73 (3)	1.51 (3)	1.32 (3)	1.14 (4)	0.82 (6)	0.55 (7)	0.33 (7)	0.14 (8)	3	2
D	1.58 (3)	1.75 (3)	1.72 (4)	1.54 (5)	1.37 (5)	1.22 (5)	1.07 (6)	0.82 (5)	0.61 (5)	0.43 (5)	0.28 (5)	3	3
E	0.81 (5)	1.58 (5)	1.68 (6)	1.56 (4)	1.39 (4)	1.23 (4)	1.08 (5)	0.83 (4)	0.61 (6)	0.43 (6)	0.27 (6)	4	6
G1	−2.03 (11)	−2.30 (11)	−1.77 (11)	−0.02 (11)	−0.09 (11)	0.14 (11)	2.39 (2)	2.70 (1)	2.45 (1)	2.07 (1)	1.75 (1)	10	1
G2	0.55 (9)	0.99 (9)	2.68 (1)	2.41 (1)	2.85 (1)	2.62 (1)	2.41 (1)	2.04 (2)	1.73 (2)	1.47 (2)	1.25 (2)	6	1
G3	0.71 (7)	0.76 (10)	0.70 (10)	0.62 (10)	0.54 (10)	0.47 (10)	0.41 (11)	0.29 (11)	0.20 (11)	0.12 (9)	0.05 (9)	3	10
G4S	0.79 (6)	1.48 (7)	1.68 (5)	1.51 (6)	1.34 (6)	1.20 (6)	1.06 (7)	0.82 (7)	0.61 (4)	0.44 (4)	0.30 (4)	4	5
G4W	0.53 (10)	1.48 (8)	1.34 (9)	1.16 (9)	1.00 (9)	0.85 (9)	0.72 (10)	0.47 (10)	0.27 (10)	0.10 (11)	−0.04 (10)	3	8
Thrie	1.64 (2)	1.53 (6)	1.36 (8)	1.21 (8)	1.07 (8)	0.94 (7)	0.82 (8)	0.62 (8)	0.44 (8)	0.30 (8)	0.17 (7)	2	2
	AADT = 10,000			Guardrail Length = 500 ft				Obstacle Length = 400 ft					

*Distance which yields highest value of benefit/cost ratio. Distances shown are in feet. Multiply by 0.3048 to obtain m.

TABLE 22. EFFECT OF REDUCING INSTALLATION COST ON BENEFIT/COST RATIOS

Guardrail Type	Guardrail-to Obstacle Distance (ft)	Percent of Illustrative Cost						Controlling Guardrail Type	B/C Ratio
		100	90	80	70	60	50		
		Benefit/Cost Ratio (Rank)							
B	3	2.67 (5)	2.99 (3)	3.40 (3)	3.93 (2)	4.66 (1)	5.71 (1)	A	3.97
C	3	3.68 (2)	4.12 (1)	4.68 (1)	5.42 (1)	6.44 (1)	7.92 (1)	A	3.97
D	3	2.82 (3)	3.16 (3)	3.58 (3)	4.14 (1)	4.90 (1)	6.01 (1)	A	3.97
E	3	2.72 (4)	3.04 (3)	3.45 (3)	3.99 (1)	4.73 (1)	5.79 (1)	A	3.97
G3	2	1.29 (10)	1.44 (10)	1.63 (9)	1.87 (8)	2.21 (6)	2.68 (5)	C	3.59
G4S	4	2.73 (5)	3.05 (4)	3.47 (3)	4.01 (2)	4.74 (1)	5.80 (1)	G2	4.30
G4W	3	2.45 (9)	2.75 (4)	3.12 (3)	3.60 (3)	4.27 (1)	5.22 (1)	A	3.97
Thrie	2	2.65 (5)	2.96 (3)	3.36 (2)	3.87 (1)	4.57 (1)	5.58 (1)	C	3.59

Roadside conditions:
2-lane rural road with 4-ft (1.22-m) shoulder
Guardrail length = 500 ft (152.4 m)
Obstacle length = 400 ft (121.9 m)
AADT = 5000

those used, these trends could change. Some indication of this is shown in Table 22. It was of interest to see what relative reduction in installation costs would increase the ranking of the poorer systems in Table 19 at their optimum distances. The illustrative costs used in these sensitivity analyses were the following average Region 6 values from Table 11:

Type A	$4.50/L.F.
B	6.00
C	5.00
D	6.25
E	6.10
G1	3.10
G2	4.35
G3	13.50
G4S	6.50
G4W	6.50
Thrie	7.50

Holding all of these values constant except for the guardrail of interest produced the results shown in Table 22. For example, the optimum distance for guardrail B from Table 19 is 3 feet and the controlling guardrail at this distance is Type A with a B/C ratio of 3.97. As shown in Table 22, Type B becomes essentially as cost-effective as Type A if it can be installed for 0.70 (6.00) = $4.20/L.F., which is slightly less than the $4.50/L.F. value for Type A. Note in Table 22 that the G3 system will still rank only 5th if the installation cost is cut in half. However, the increase in rank of all of the other types indicates the importance of carefully selecting the installation costs.

The effect of traffic mix on B/C ratios is shown in Table 23, again for the typical 2-lane rural road indicated. Note in the table that the rankings are not significantly affected. With increasing small car percentages, the B/C ratios of the less flexible systems go down because of the greater severities of the small car impacts.

Table 24 illustrates the effect of encroachment rate on B/C ratios. An inspection of this table reveals that all of the B/C ratios vary directly with encroachment rate so that no changes occur in the rankings. This was to be expected since the number of impacts, and hence the societal cost, are linear functions of encroachment rate, as well as the ADT. Of course, state costs will not change.

TABLE 23. EFFECT OF TRAFFIC MIX ON BENEFIT/COST RATIOS

Percent 2250-lb Vehicles	10	20	30	40	50	60	70	80	90
Percent 4500-lb Vehicles	90	80	70	60	50	40	30	20	10
Guardrail Type	Benefit/Cost Ratio (Rank)								
A	3.39 (2)	3.25 (2)	3.11 (2)	2.97 (2)	2.83 (2)	2.69 (2)	2.55 (2)	2.41 (2)	2.28 (2)
B	2.14 (6)	2.02 (7)	1.90 (7)	1.77 (7)	1.65 (8)	1.53 (8)	1.40 (8)	1.28 (8)	1.16 (8)
C	2.88 (3)	2.71 (3)	2.54 (3)	2.38 (3)	2.21 (4)	2.04 (5)	1.87 (6)	1.70 (6)	1.54 (6)
D	2.29 (4)	2.28 (4)	2.27 (4)	2.26 (4)	2.25 (3)	2.24 (3)	2.23 (3)	2.22 (3)	2.21 (3)
E	2.14 (7)	2.11 (6)	2.08 (6)	2.05 (6)	2.01 (6)	1.98 (6)	1.95 (5)	1.92 (5)	1.89 (5)
G1	−1.90 (11)	−1.69 (11)	−1.48 (11)	−1.28 (11)	−1.07 (11)	−0.86 (11)	−0.65 (11)	−0.44 (11)	−0.23 (11)
G2	3.45 (1)	3.46 (1)	3.47 (1)	3.48 (1)	3.49 (1)	3.50 (1)	3.51 (1)	3.52 (1)	3.53 (1)
G3	1.01 (10)	0.97 (10)	0.93 (10)	0.90 (10)	0.86 (10)	0.82 (10)	0.78 (10)	0.74 (10)	0.70 (10)
G4S	2.27 (5)	2.25 (5)	2.22 (5)	2.20 (5)	2.18 (5)	2.16 (4)	2.13 (4)	2.11 (4)	2.09 (4)
G4W	1.97 (8)	1.85 (9)	1.74 (9)	1.63 (9)	1.51 (9)	1.40 (9)	1.29 (9)	1.17 (9)	1.06 (9)
Thrie	1.97 (9)	1.89 (8)	1.81 (8)	1.74 (8)	1.66 (7)	1.58 (7)	1.51 (7)	1.43 (7)	1.35 (7)

Roadside conditions:
2-lane rural road with 6-ft (1.82-m) shoulder
Guardrail-to-obstacle distance = 4 ft (1.22 m)
Guardrail length = 500 ft (152.4 m)
Obstacle length = 400 ft (121.9 m)
AADT = 5000

Thus, if the cost-effectiveness values are known for a particular encroachment rate and ADT, values for other encroachment rates or ADT's can be determined as follows:

$$(\text{State Cost})_{\text{new}} = (\text{State Cost})_{\text{old}}$$

$$(\text{Societal Cost})_{\text{new}} = (\text{Societal Cost})_{\text{old}} \times \frac{(\text{ADT})_{\text{new}}}{(\text{ADT})_{\text{old}}} \times \frac{(\text{Encroachment Rate})_{\text{new}}}{(\text{Encroachment Rate})_{\text{old}}}$$

$$(\text{Total Cost})_{\text{new}} = (\text{State Cost})_{\text{new}} + (\text{Societal Cost})_{\text{new}}$$

$$(\text{B/C})_{\text{new}} = (\text{B/C})_{\text{old}} \times \frac{(\text{ADT})_{\text{new}}}{(\text{ADT})_{\text{old}}} \times \frac{(\text{Encroachment Rate})_{\text{new}}}{(\text{Encroachment Rate})_{\text{old}}}$$

A difficulty in this study in conducting meaningful sensitivity analyses has been the multiplicity of roadside variables and the wide variations of regional costs. However, the analyses discussed above indicate trends that should be helpful in selecting representative values for specification of input values to be used in the cost-effectiveness program.

Chapter 4. Collection of Reconstructed Accident Data and Verification of Model Validity

Accident severities for the various category impact conditions, including measures of occupant injury and vehicle and guardrail damage, were required in developing the cost-effectiveness model.

TABLE 24. EFFECT OF ENCROACHMENT RATE ON BENEFIT/COST RATIOS

Guardrail Type	Encroachment Rate (Events/mile/year/ADT)										
	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011	0.0012
	Benefit/Cost Ratio (Rank)										
A	2.12 (2)	3.18 (2)	4.24 (2)	5.30 (2)	6.36 (2)	7.42 (2)	8.48 (2)	9.54 (2)	10.60 (2)	11.67 (2)	12.73 (2)
B	1.31 (7)	1.96 (7)	2.61 (7)	3.26 (7)	3.92 (7)	4.57 (7)	5.22 (7)	5.87 (7)	6.53 (7)	7.18 (7)	7.83 (7)
C	1.75 (3)	2.63 (3)	3.51 (3)	4.38 (3)	5.26 (3)	6.13 (3)	7.01 (3)	7.89 (3)	8.76 (3)	9.64 (3)	10.52 (3)
D	1.52 (4)	2.27 (4)	3.03 (4)	3.79 (4)	4.55 (4)	5.30 (4)	6.06 (4)	6.82 (4)	7.58 (4)	8.34 (4)	9.09 (4)
E	1.39 (6)	2.09 (6)	2.79 (6)	3.48 (6)	4.18 (6)	4.88 (6)	5.58 (6)	6.27 (6)	6.97 (6)	7.67 (6)	8.36 (6)
G1	−1.06 (11)	−1.59 (11)	−2.12 (11)	−2.65 (11)	−3.18 (11)	−3.71 (11)	−4.24 (11)	−4.77 (11)	−5.29 (11)	−5.82 (11)	−6.35 (11)
G2	2.31 (1)	3.47 (1)	4.62 (1)	5.78 (1)	6.93 (1)	8.09 (1)	9.24 (1)	10.40 (1)	11.55 (1)	12.71 (1)	13.87 (1)
G3	0.64 (10)	0.95 (10)	1.27 (10)	1.59 (10)	1.91 (10)	2.23 (10)	2.54 (10)	2.86 (10)	3.18 (10)	3.50 (10)	3.82 (10)
G4S	1.49 (5)	2.23 (5)	2.98 (5)	3.72 (5)	4.47 (5)	5.21 (5)	5.96 (5)	6.70 (5)	7.45 (5)	8.19 (5)	8.94 (5)
G4W	1.20 (9)	1.80 (9)	2.40 (9)	2.99 (9)	3.59 (9)	4.19 (9)	4.79 (9)	5.39 (9)	5.99 (9)	6.59 (9)	7.19 (9)
Thrie	1.23 (8)	1.85 (8)	2.47 (8)	3.08 (8)	3.70 (8)	4.32 (8)	4.94 (8)	5.55 (8)	6.17 (8)	6.79 (8)	7.40 (8)

Roadside conditions:
2-lane rural road with 6-ft (1.82-m) shoulder
Guardrail-to-obstacle distance = 4 ft (1.22 m)
Guardrail length = 500 ft (152.4 m)
Obstacle length = 400 ft (121.9 m)
AADT = 5000

These quantities were based on the extrapolation results of the BARRIER VII program. In an effort to validate these predictions, a series of accident reconstructions were undertaken in the study. The proposed methodology was to simulate the reported accident data with BARRIER VII in exactly the same manner as that used in simulating the full-scale tests and to compare the results of the simulation with the reported accident results. However, principally because of the problems associated with estimating the accident impact conditions, the validation effort was unsuccessful in that no definitive conclusion could be drawn that the model is valid. Conversely, the conclusion could not be made that the model is not valid. Details of the effort and discussions of these problem areas follow.

The instructions and accident reconstruction forms that were used in the study, along with a list of the six accident investigation teams, are shown in Appendix F. Though 100 accidents were anticipated during the scheduled year for the task, only 32 reports were accepted, and only 24 of these were of usable value for two reasons. First, several of the early reports involved accidents with classic guardrail installation blunders (e.g., penetration hits near the ends of unanchored systems, hits on extremely short and ineffective installations around bridge piers, and guardrail/high curb combinations in which most of the vehicle redirection was caused by the curb rather than the guardrail). Second, the quality of a few of the reports was so poor that computer simulations of the accidents were not possible from the reported data. Remedial measures included telecons requesting corrected data and memoranda increasing the number of investigation criteria that had to be met before reporting the accident.

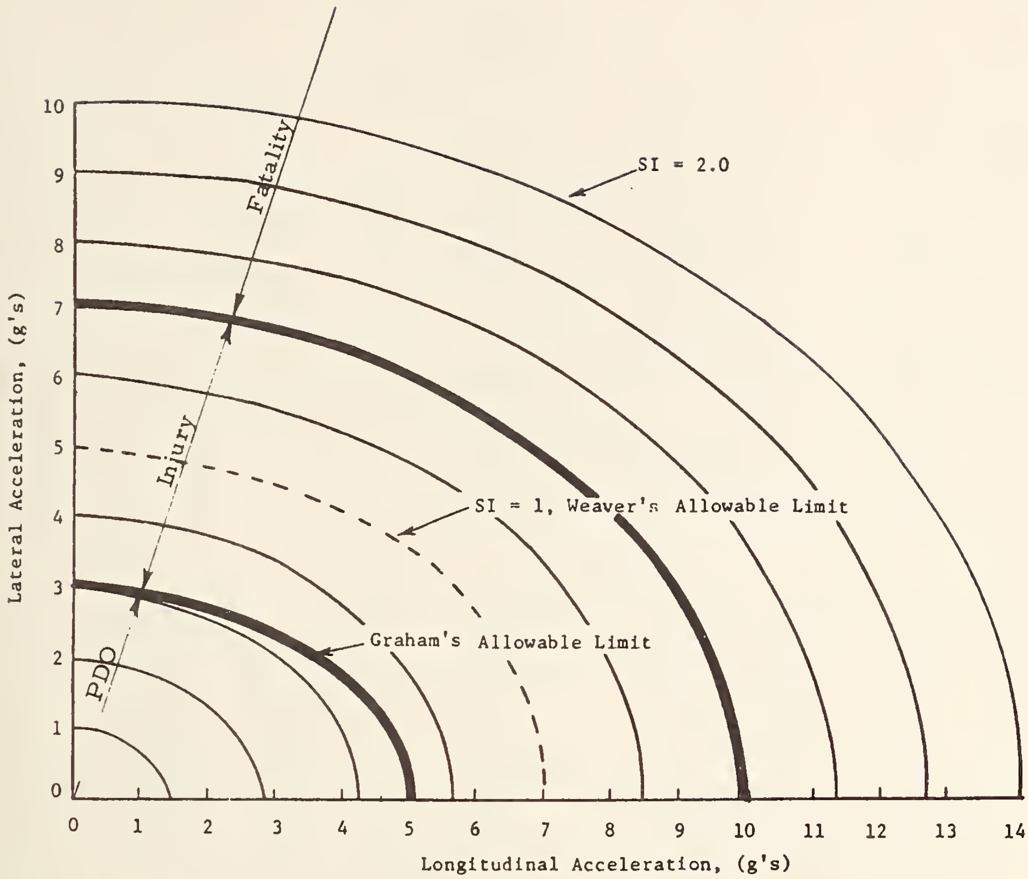
The list of accident investigation criteria restricted the accident teams and reduced the number of reported accidents because of the predominantly large number of guardrail hits that are freakish in nature. Impacts with terminal sections or near the guardrail ends were excluded, and most of the usable impacts involved skidding vehicles. In such cases, proper computer simulation required specification of vehicle heading angle, resultant velocity angle, and vehicle angular speed at impact. Field teams estimated the first two of these quantities but were not requested to estimate the angular speed. This quantity was assumed to be zero in the computer simulations. Because of these necessary guesses, computer correlation with accident results could certainly not be expected to be as good as that with the controlled full-scale crash test results.

A principal purpose of the reconstructed accident data was to help establish the interfaces between PDO, injury, and fatality accelerations in the guardrail severity indicator shown in Figure 9. With the reduction in accident reports that were received, along with the inevitable scatter in such data, it was considered necessary to judiciously assume the interfaces and check the assumption with the data that was received. The allowable limits shown in Figure 9 are based on a severity index as defined by

$$SI = \sqrt{\frac{G^2_{long.}}{G^2_{XL}} + \frac{G^2_{lat.}}{G^2_{YL}}}$$

where G_{XL} and G_{YL} are the maximum tolerable accelerations in the longitudinal and lateral directions. Graham's allowables are 5 and 3 g's, respectively, while Weaver's allowables are 7 and 5 g's. Graham's limit would appear to be a reasonable interface between PDO and injury accidents. Weaver's limit probably approximates the division between minor and severe injuries. Thus, the SI = 1.4 line based on Weaver's limit was assumed as a reasonable interface location between injury and fatality accidents. Though tenuous and certainly not completely accurate, Figure 9 qualifies as current state-of-the-art and is considered the best available data.

As mentioned above, the approach used for verification of the model validity was much the same as that used in the correlation portion of the study. The pertinent input data from the reconstructed accident reports was punched, including (1) node locations and member types to correspond to the reported guardrail geometry, (2) post and railing properties, (3) vehicle plus



Ref: R.M. Olson, P.L. Ivey, E.R. Post, R.H. Gunderson, and A. Cetiner, "Bridge Rail Design: Factors, Trends, and Guidelines," NCHRP Report 149, 1974.

FIGURE 9. GUARDRAIL SEVERITY LEVEL INDICATOR

occupant weight and inertial properties, and (4) reported vehicle heading, velocity vector, and speed at impact. Member and vehicle properties were determined by the methods discussed in Appendix A. BARRIER VII simulation runs were then made for the various severity predictions to compare with the reported accident severity data. Table 25 shows the comparisons for the 24 usable accident reports. The most obvious discrepancies are in the barrier deflections. Maximum dynamic deflections are shown in the simulations and should be higher than the permanent deflections reported by the teams. The remaining severity correlations (guardrail and vehicle damage and occupant injury) are not too bad. The notable exception for occupant severity is the PDO accident 04-03, in which a fatality was predicted. However, as noted in the table footnote, the occupant was wearing both lap and torso belts at the time of the accident. Other occupant severity correlations were close enough that changes in the assumed interfaces in Figure 9 were not considered necessary. From the remarks in Table 25 that briefly describe the accidents, it becomes clear why correlations are not better. With a skidding and spinning vehicle that has moved from some distance out and has gone through several gyrations before impact, the estimates of vehicle heading angle, velocity vector, speed, and angular velocity at impact, all required for adequate simulation, are educated guesses at best with low reliability.

Chapter 5. Analysis of Effects of Soil Condition on Post Parameters

With high loading rates and post/soil interaction problems, it was not considered that the required BARRIER VII post properties could be adequately determined by available analytical

TABLE 25. COMPARISON OF SIMULATED AND REPORTED ACCIDENTS

Item	Team No.–Case No.											
Guardrail Type	01-01 A	01-03 A	02-02 B	02-03 B	03-11 C*	03-13 C*	03-19 C*	04-01 G4S	04-02 G4S	04-03 G4S	04-04 G4S	04-05 G4S
Barrier Deflections (in.)												
BARRIER VII	6.5	0.7	11.6	0.2	24.7	104.8	35.4	13.8	30.3	9.3	17.5	4.7
Reported†	not given	11.0	2.0	31.0	24.0	61.0	21.0	8.0	10.0	15.5	4.0	7.0
No. of Posts Damaged												
BARRIER VII	0	0	0	5	2	14	3	1	2	2	1	0
Reported	0	0	0	6	2	11	3	1	1	2	0	0
Length of Railing Damaged (ft)												
BARRIER VII	12.5	12.5	37.5	37.5	25	12.5	25	25	12.5	12.5	12.5	25
Reported	0	12.5	12.5	50	25	62.5	25	25	50	50	25	25
Vehicle Damage (percent)												
Estimated from computer print	10	15	80	20	35	20	25	20	20	25	20	10
Estimated from report photographs	60‡	10	60‡	25	20**	20**	30**	25	25	40	10	5
Reported	50	10	not given	not given	major	major	moderate	15	10	60	10	5
Maximum 50-ms Accelerations (g's)												
Longitudinal	0.78	2.53	2.36	4.12	4.25	9.23	7.31	3.53	5.08	8.95	3.92	2.27
Lateral	1.26	1.58	4.54	3.60	3.86	1.81	8.31	3.23	2.10	5.16	1.27	0.50
Predicted Severity	PDO	PDO	I	I	I	I	F	I	I	F	PDO	PDO
Reported Severity	I	PDO	I	I	PDO	PDO	F	PDO	I	PDO††	PDO	PDO

Remarks:
01-01 Vehicle skidded into and mounted guardrail, rebounded onto roadway, and overturned.
01-03 Vehicle was sliding to right and spinning at impact, contacted left front, and spun completely around during impact.
02-02 Vehicle slid to left, contacted left rear, rebounded, yawing clockwise, and overturned.
02-03 Vehicle was spinning, hit right front almost headon, snagged a post with left front, and spun over half a turn after impact.
03-11 Vehicle veered right, passed over swale, contacted right front, and was redirected back onto roadway.
03-13 Vehicle swerved to right from 3 lanes out, contacted guardrail at 60-degree angle, and was redirected.
03-19 Vehicle impacted guardrail at 30-degree angle from 4 lanes out, was redirected, and spun into second vehicle.
04-01 Vehicle hit at 25-degree angle from 2 lanes out, was redirected back to original lane.
04-02 Vehicle swerved right onto shoulder, then back across 2 lanes, contacted left front at 48 degrees, and was redirected adjacent to guardrail.
04-03 Vehicle swerved left onto median, then to right across 5 lanes, contacted left front, and spun almost half a turn.
04-04 Vehicle skidded to right and was spinning clockwise at impact, contacted right front, and spun almost half a turn.
04-05 Vehicle spun several times, hit right guardrail with left rear contact, was redirected and stopped in opposite direction of travel.

*With 6'-3" post spacing.
†Permanent deflection.
‡Vehicle rolled.
**Vehicle photo not given–estimated from given VDI.
††Occupant was wearing lap and upper torso belts.

TABLE 25. COMPARISON OF SIMULATED AND REPORTED ACCIDENTS (Cont'd)

Item Guardrail Type	Team No.–Case No. 04-06 G4S	04-07 G4S	05-01 G4S	05-02 G2	05-03 G2*	05-04 G2*	06-01 G3	06-02 G3	06-03 G3	06-04 G1	06-05 G3†	06-06 G3‡
Barrier Deflections (in.)												
BARRIER VII	2.4	3.0	55.6	47.7	4.4	3.8	79.9	1.2	7.8	63.8	41.0	1.9
Reported**	4.0	0.0	2.8	21	7.5	15.3	5.0	0	0	12.0	25.0	2.0
No. of Posts Damaged												
BARRIER VII	1	0	7	5	0	2	10	3	0	5	9	0
Reported	0	0	3	7	0	2	0	1	0	11	10	0
Length of Railing Damaged (ft)												
BARRIER VII	12.5	12.5	37.5	62.5	25	12.5	24	12	12	54††	24	6
Reported	25	0	25	75	25	12.5	0	0	0	192	24	0
Vehicle Damage (percent)												
Estimated from computer print	20	5	40	30	15	20	20	15	30	10	25	5
Estimated from report photographs	80‡‡	10	80	80***	10	15	20	25	20	20	80	10
Reported	total	10	50	80	15	20	50	55	10	total	55	minor
Maximum 50-ms Accelerations (g's)												
Longitudinal	7.94	0.16	4.57	2.76	0.57	4.24	8.44	3.70	2.59	0.87	6.42	0.44
Lateral	6.52	0.18	5.74	5.81	1.99	4.22	1.76	4.72	3.66	1.81	3.98	0.63
Predicted Severity	F	PDO	I	I	PDO	I	I	I	I	PDO	I	PDO
Reported Severity	I	PDO	I	I	I	PDO	PDO	PDO	PDO	PDO	I	PDO

Remarks:

04-06 Vehicle drifted left, overcorrected, skidded right and spun, crossed 3 lanes, contacted left front, rolled onto left side, and slid back onto roadway.
04-07 Vehicle impacted from first lane, contacted right front, was redirected but spun clockwise to opposite direction.
05-01 Vehicle moved to right on shoulder, back to opposing lane, and then across 2 lanes to right front impact, redirected onto shoulder but spun one complete turn.
05-02 Vehicle impacted right front from two lanes out, mounted the guardrail, vaulted, and flipped end over end.
05-03 Vehicle moved right, made a right front contact, was redirected, hit a second time, was redirected, continued to move, struck embankment, and rolled on its side.
05-04 Vehicle slid to left and rotated across two lanes, grass median, and then 2 lanes to right front impact, was redirected but spun to opposite direction.
06-01 Vehicle slid left and rotated from first lane into left front impact, was redirected but continued spin to original direction.
06-02 Vehicle slid left and rotated from two lanes out, hit with right front, and was redirected with continued spin to opposite direction.
06-03 Vehicle drifted right to right front impact, was redirected along guardrail.
06-04 Vehicle drifted right, contacted cables with right front, started clockwise spinning, and was redirected to opposite lane in original direction.
06-05 Vehicle moved right to right front impact, redirected across 4 lanes to contact opposite guardrail and overpass pillar, was redirected back to original lane with no spin.
06-06 Vehicle moved left to left front contact, was redirected with slight rotation back onto roadway.

*With W6 × 8.5 posts.
†With 4'-0" post spacing.
‡With 6'-0" post spacing.
**Permanent deflection.
††Vehicle/guardrail contact length.
‡‡Vehicle rolled.
***Vehicle penetrated guardrail.

techniques. Consequently, as discussed in Appendix A, a representative soil was selected that had been characterized by a series of pendulum tests. Because of difficulties encountered in correlating some of the full-scale tests (see Appendix B), it was decided to conduct a series of pendulum tests in this study. The purpose of the tests was to determine the ultimate effect of soil conditions on barrier performance, with an interim determination of post performance variations as a function of soil conditions. Two post types (W6 X 8.5 steel and 6-in. X 8-in. Douglas fir) were tested about the major and minor axes with five different base supports (sandy loam, saturated clay, stiff clay, base material, and fixed supports). Details of the testing program are discussed in Appendix H.

Tests 4-273 from Table B.2 and 8-120 from Table B.7 in Appendix B were selected for conducting BARRIER VII runs to determine the effects of various soil types on the Douglas Fir and steel posts, respectively. With lengths of 75 and 112.5 feet (22.9 and 34.3 m), both of these test guardrail installations were shorter than the usual minimum test length of 150 feet (45.7 m). Further, Test 4-273 was quite severe [4960-lb (2250-kg) vehicle/68 mph (109.4-km/hr)/24-degree impact], and the Test 8-120 impact point was so far down the guardrail that only the last two posts show unnoticeable permanent deformation in the test photographs. However, the correlation for Test 4-273 was of some concern in the study, and these tests were selected in spite of their shortcomings.

With the post properties from Table H.4 as inputs, the BARRIER VII runs shown in Tables 26 and 27 were conducted. In Table 26, it can be seen that vehicle redirection is not predicted with the poorer soil types (negative velocity vectors). Using fixed support properties for the end posts does not improve the situation. The lesser severity with the fixed supports over the fixed properties of simulation 4 was probably caused by the poorer quality wood used in the tests of this program. Four static tests of the full-size posts were conducted,and horizontal shear failures occurred at an average of 530 psi (3654 kPa) shearing stress, as compared to a 1140-psi (7860-kPa) book value. Four static tests were then conducted on 2 X 2-in. (5.1 X 5.1-cm) specimens milled from the posts. These tests produced flexural failures with an average modulus of rupture of 8,530 psi (58,800 kPa) as compared to the 11,700-psi (80,700-kPa) book value. Thus, the posts used in the pendulum tests were not of the best quality. Nonetheless, the results of Table 26 clearly indicate that such 75-ft (22.9-m) installations can be expected to fail with the severe impacts unless the posts are of good quality and are sufficiently anchored in the soil to cause the post strength to control the failure mechanism.

The longer length of guardrail installation and less severe impact [3813-lb (1730-kg) vehicle/56.8-mph (91.4-km/hr)/28.4-degree] in Test 8-120 produced the results in Table 27. Again, with the poor clay and sand support, the vehicle is not predicted to redirect. However, by using the fixed support properties for the end posts, redirection is achieved before the lateral failures of the downstream anchor posts occur. Thus, if an installation of this length were to be constructed in poorer soils, a concrete footing should be used on the end posts so that the post strength will control the lateral failure.

The guardrail configuration of Figure B.3 in Appendix B with a length of 150 feet (45.7 m) was finally used to show the post and soil effects on vehicle performance. Impact conditions were 4500-lb (2041-kg) vehicle/60 mph (96.5 km/hr)/25 degrees to correspond with the accepted containment standard. The results are shown in Table 28. Note that fixed lateral post properties were again used on the three poorer soils. Vehicles were redirected in all cases (positive velocity vectors) but were not turned completely around with the three poor soils (negative heading angles). It can be seen that the post properties used in this program development represent those of a better soil type. However, with the wide bands of severity classification in Figure 9, the differences in predicted severities are not too significant. Unless the guardrail-to-obstacle distances were greater than ten feet, the cost-effectiveness program would override and increase the PDO predictions of the saturated clay runs because of the excessive dynamic deflections. Thus, it is considered that the order of ranking of the guardrail types would not be materially affected if a poorer soil type had

TABLE 26. COMPARISON OF SOIL SUPPORTS FOR 6-IN. × 8-IN. DOUGLAS FIR POSTS

Test/Simulation	50-ms Vehicle Accelerations (g's)		Severity Prediction	Maximum Dynamic Deflection (ft)	Exit Conditions			Barrier Damage		Remarks
	Longitudinal	Lateral			Reported Angle (deg)	Velocity Vector (deg)	Vehicle Heading Angle (deg)	Beam (ft)	No. of Posts Damaged	
Test 4-273	6.75	6.95	F	2.33 (1.6) = 3.7	14			37.5	3	
Simulation 2	3.70	4.52	I	5.33		8.3	4.0	37.5	9	
Simulation 4	4.42	6.39	F	4.07		8.8	10.7	37.5	7	Fixed support properties from Ref. 37.
Fixed Supports	4.27	5.01	I	4.80		8.9	9.9	37.5	7	
Stiff Clay Support	2.31	2.32	F*	7.80 @ 0.30 sec		–17.0	–8.5	–	10	Lateral failure of upstream anchor post.
Sandy Loam Support	2.32	2.42	F*	8.00 @ 0.30 sec		–17.1	–8.4	–	10	Lateral failure of upstream anchor post.
Stiff Clay with Fixed End Posts	2.31	3.40	F*	18.15 @ 0.65 sec		–6.8	24.4	–	12	Lateral failure of downstream anchor post.
Sandy Loam with Fixed End Posts	2.32	3.18	F*	17.18 @ 0.62 sec		–7.2	23.5	–	12	Lateral failure of downstream anchor post.
Base Material Support	2.92	4.27	F*	10.47 @ 0.55 sec		–2.0	13.3	–	12	Lateral failure of downstream anchor post.
Saturated Clay with Fixed End Posts	1.96	2.48	F*	19.02 @ 0.59 sec		–10.0	19.2	–	12	Lateral failure of downstream anchor post.

Metric conversion: Multiply ft by 0.3048 to obtain m.

*Assumed fatality with failure of guardrail.

TABLE 27. COMPARISON/OF SOIL SUPPORTS FOR W6 X 8.5 STEEL POSTS

Test/Simulation	50-ms Vehicle Accelerations (g's)		Severity Prediction	Maximum Dynamic Deflection (ft)	Exit Conditions			Barrier Damage		Remarks
	Longitudinal	Lateral			Reported Angle (deg)	Velocity Vector (deg)	Vehicle Heading Angle (deg)	Beam (ft)	No. of Posts Damaged	
Test 8-120	4.0	6.7	F	4.05	8			25	5	
Simulation 6	4.60	5.33	I	4.01		17.3	11.4	25	5	
Fixed Supports	5.25	6.03	F	4.47		14.2	16.5	37.5	6	
Stiff Clay Support	3.41	2.87	F*	22.17 @ 0.80 sec		–4.5	34.9	–	11	Lateral failure of downstream anchor post.
Sandy Loam Support	3.61	3.02	F*	20.85 @ 0.79 sec		–3.7	31.7	–	11	Lateral failure of downstream anchor post.
Stiff Clay with Fixed End Posts	3.41	6.32	F*	6.91 @ 0.44 sec		8.3	5.6	–	13	No change–numerical instability at 0.57 sec.
Sandy Loam with Fixed End Posts	3.61	6.32	F*	7.17 @ 0.45 sec		7.9	5.3	–	13	No change–numerical instability at 0.58 sec.
Base Material Support	4.54	5.12	I	4.42		15.9	7.0	37.5	7	
Saturated Clay with Fixed End Posts	3.04	5.60	F*	20.07 @ 0.80 sec		5.3	46.7	–	18	Lateral failure of downstream anchor post.

Metric conversion: Multiply ft by 0.3048 to obtain m.

*Assumed fatality with failure of guardrail.

TABLE 28. POST AND SOIL EFFECTS ON VEHICLE PERFORMANCE

Condition	50-ms Vehicle Accelerations (g's)		Severity Prediction	Maximum Dynamic Deflection (ft)	Exit Conditions		Barrier Damage	
	Longitudinal	Lateral			Velocity Vector (deg)	Vehicle Heading Angle (deg)	Beam (ft)	No. of Posts Damaged
6-in. × 8-in. Douglas Fir Posts								
Program Support Values	3.38	5.78	I	5.25	13.5	11.9	50.0	8
Fixed Supports	4.32	5.95	I	4.49	13.8	10.8	37.5	6
Base Material Support	2.70	3.43	I	7.07	10.1	0.6	62.5	12
Stiff Clay Support*	1.97	2.82	I	9.54	2.2	−5.8	62.5	20
Saturated Clay Support*	1.81	2.39	PDO	10.09	8.0	−9.0	62.5	23
Sandy Loam Support*	2.06	2.95	I	8.72	2.5	−6.4	62.5	20
W6 × 8.5 Steel Posts								
Program Support Values	3.78	5.44	I	4.89	15.1	9.7	37.5	6
Fixed Supports	4.84	5.68	I	5.69	14.1	8.8	50.0	8
Base Material Support	3.29	4.33	I	6.27	11.7	0.5	62.5	9
Stiff Clay Support*	2.45	3.19	I	8.04	6.5	−1.5	62.5	15
Saturated Clay Support*	1.91	2.46	PDO	10.13	9.5	−7.5	62.5	23
Sandy Loam Support*	2.57	3.28	I	7.88	6.1	−1.6	62.5	15

Metric conversion: Multiply ft by 0.3048 to obtain m.

*Fixed support properties used for end posts.

been used. Of course, it is obvious from Table 28 that guardrail deflections will increase with the poorer soils. Partial compensation for the effect could be accomplished by decreasing the actual guardrail-to-obstacle distance in the cost-effectiveness program input.

It is indicated in Appendix B that soil conditions were usually exceptionally good for satisfactory tests on guardrails of less than 150-ft (45.7-m) length. The results discussed above also indicate that failure problems can be expected for severe impacts on short installations with the poorer soil types. Thus, it is recommended that guardrail lengths be not less than 150 feet (45.7 m) unless precautions are taken to ensure post integrity, particularly if the available space behind the guardrail is limited. These precautions include the use of concrete footings or greater embedment depths for the posts.

Chapter 6. Preparation of User's Manual

On formulating the cost-effectiveness model and developing the computer algorithm, a user's manual was prepared. Program listings, instructions and examples for their use, and selection criteria tables generated with the programs are contained in Volume II of this report.

III. CONCLUSIONS

A cost-effectiveness model for guardrail selection has been developed that includes estimates of performance for eleven guardrail types with various vehicle impact characteristics. A probabilistic present-worth approach for the model development was selected, and it has been shown how the various pertinent parameters have been quantified on the basis of historical data and analytical extrapolations thereof. Hazard types include fixed objects and embankments, and eleven commonly used guardrail designs are included.

Two cost-effectiveness computer programs were developed: (1) the SSCOST program for cost-effectiveness values (state cost, societal cost, total cost, and benefit-to-cost ratio) of a single specified guardrail type with given roadway conditions, and (2) the COCOST program for comparative cost-effectiveness values and ranking of the eleven guardrail types with given roadway conditions.

Program inputs, simple to prepare in a format familiar to engineers, include such items as the following:

- Highway type, horizontal curvature, and guardrail type
- AADT and traffic mix
- Guardrail and obstacle lengths
- Guardrail distance from traffic lanes and guardrail-to-obstacle distance
- Guardrail installation, maintenance, and repair costs
- Estimated times to remove damaged vehicle and to repair damaged guardrail
- Estimates of vehicle, injury, fatality, and travel delay costs
- Service life of guardrail, current interest rate, and future salvage value

The user has the option of either using preselected representative values for most of these inputs or inserting his own local values.

Both CDC and IBM versions of the programs are available so that adaptation to the user's computer will not be difficult. Computer run times for both versions are minimal. Outputs include a repeat of the geometric and traffic inputs and a ranking of the eleven included guardrail types, along with the corresponding values, according to present-worth state costs, societal costs, total costs, and benefit/cost ratios.

Outputs of the computer programs can be applied for (1) selection at a particular site of the most cost-effective guardrail system of the eleven included types, (2) guardrail placement at a site for the optimum location and guardrail type, and (3) priority ranking of several site locations for appropriation of available funds. Thus, in addition to the usual uses of cost-effectiveness analyses, the program provides the user with a design basis for choosing and placing a guardrail system at the most optimum location on the roadway shoulder.

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APPENDIX A

DETERMINATION OF POST, RAILING, AND VEHICLE PROPERTIES

For inputs to the BARRIER VII program, the post, railing, and vehicle properties must be specified. Such properties, particularly for the posts and vehicles, are difficult to determine. The methods used to estimate the properties are discussed in this appendix.

Since BARRIER VII inputs must be in English units, such units are used in this appendix without the metric equivalents. The following are factors that can be used for metric conversion:

Multiply	By	To Obtain
in.	2.540 E–02	m
ft	3.048 E–01	m
lbm	4.536 E–01	kg
kip (1000 lbf)	4.448 E+03	N
in.^{2}	6.451 E–04	m^2
in.^{3}	1.639 E–05	m^3
in.^{4}	4.162 E–07	m^4
in.-k	1.130 E–04	Nm
lb/ft	1.459 E+01	N/m
psi	6.894 E+03	Pa
ksi	6.895 E+06	Pa
in.-lb-sec^2	1.152 E–02	m-kg-sec^2

Post Properties

Post properties were estimated by means of pendulum test results of previous SwRI projects.[25,26,27] Two types of soil were used in the tests. The first was a uniformly graded sand commonly used in the production of concrete, and the second was a well-graded gravel specified as a base material by the Texas Highway Department. The second type was considered the more representative. A typical impulse diagram is shown in view (a) of Figure A.1. By approximating the trace with the dashed triangular distribution shown, it was possible to construct the acceleration-time and velocity-time diagrams shown in views (b) and (c).

From the first curve,

$$1/2\ (t_{tot})(F_{max}) = \text{Total Impulse} \qquad (A.1)$$

The total impulse was reported in the references. Thus the value of F_{max} at yield of the soil can be computed directly from this equation. From the v-t diagram, which is a second degree parabola, the deflection Δ at time t_1 becomes

$$\Delta = v_f(t) + 2/3\ (v_i - v_f)(t_1)$$

$$= 1/3\ (2v_i + v_f)(t_1) \text{ in feet} \qquad (A.2)$$

$$= 4\ (2v_i + v_f)(t_1) \text{ in inches}$$

The value of v_i was given in the reports. To obtain the value of v_f, the impulse equation

$$I = 1/2\ (t_1)(F_{max}) = m(v_f - v_i) \qquad (A.3)$$

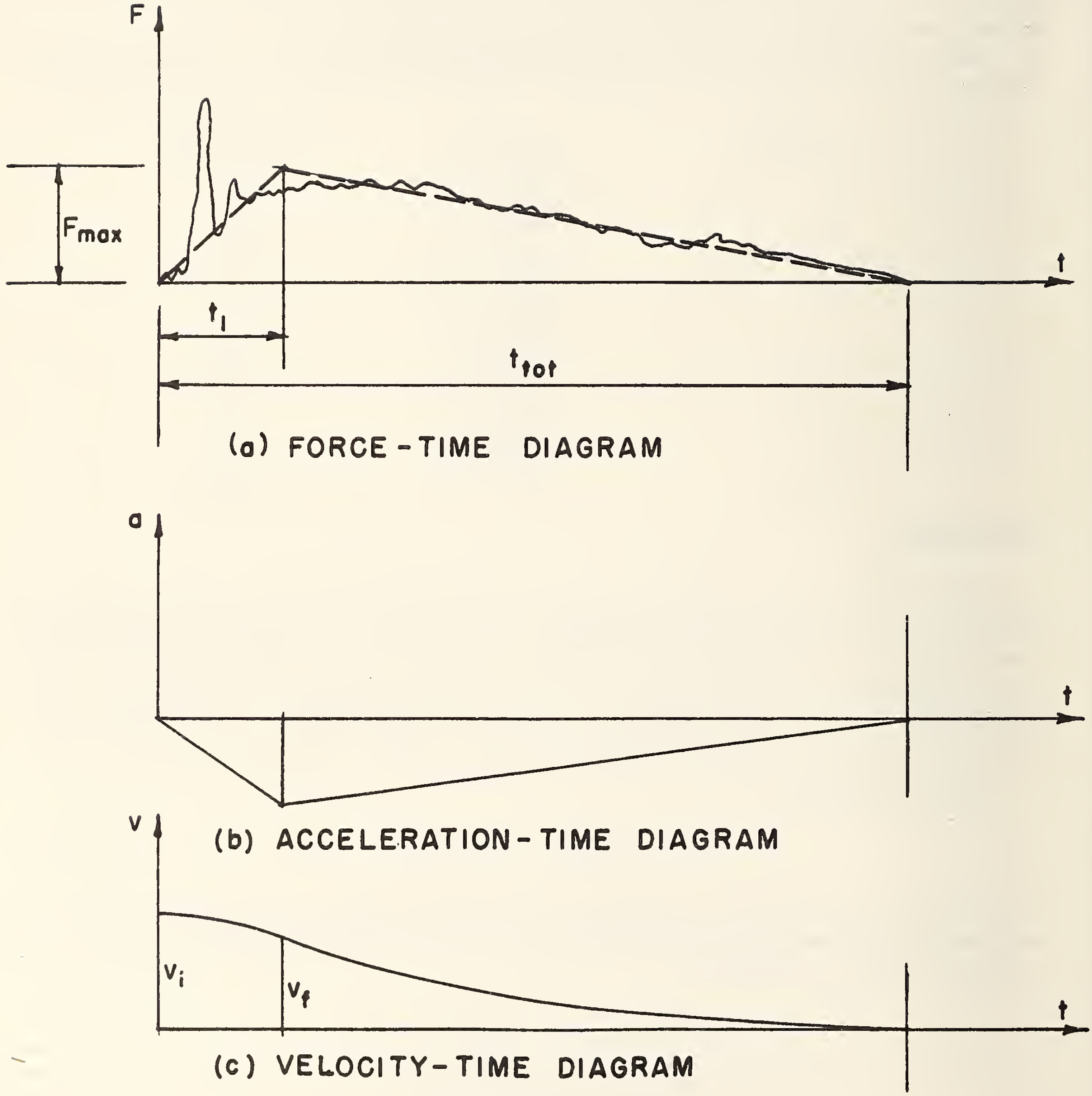


FIGURE A.1. DETERMINATION OF POST PROPERTIES was used. With a 4000-lb pendulum, this gave

$$v_f = v_i - \frac{t_1 F_{max}(32.2)}{8000} \qquad (A.4)$$

From the results of several tests, the post stiffnesses (F_{max}/Δ), maximum resisting forces F_{max}, and post deflections Δ were computed and plotted. The results, used for estimating the post properties based on the soil, are shown in Figures A.2, A.3, and A.4. With an assumed impact allowance of 2.0, the moduli of rupture for the wooden posts were 2.0 (11,700) = 23,400 psi for Douglas Fir and 2.0 (14,700) = 29,400 psi for Southern Yellow Pine.[28] For an applied load at 24-inch height, these values all produced resistive loads that were much higher than the soil yield loads. Thus, the soil values shown in Figures A.2, A.3, and A.4 were assumed to control for all of the wooden posts.

An impact allowance of 1.5 was assumed for the high strain rates on the steel posts to produce a yield stress of 1.5 (36) = 54 ksi. The following are material values that were compared with the soil values to determine the controlling quantities:

Post Type	Plastic Moduli (in.^{3})		Plastic Moments (in.-k)	
	Major Axis	Minor Axis	Major Axis	Minor Axis
W6 X 8.5	5.71	1.55	308.3	83.7
S3 X 5.7	1.95	0.653	105.3	35.3
Charley (8.56 lb/ft)	5.77	3.43	311.6	185.1

These values were used in the absence of test data when the values were less than those at yield of the soil for similar post widths. In those cases where the exact post configurations were tested with the pendulum, the results were used directly. The final selected post properties for the various guardrail types are shown in Appendix B.

Railing Properties

An impact allowance of 1.5 was again used for the high strain rates to produce a yield stress of 1.5 (36) = 54 ksi. The pertinent values follow:

Cable System (three 3/4 inch cables)

Area = 0.714 in.^{2}
Modulus of elasticity = 12,000 ksi[6]
Weight = 2.55 lb/ft
Yield force = 100 k

12 gauge W-beam

Area = 1.99 in.^{2}
Moment of inertia = 2.31 in.^{4}
Section modulus = 1.37 in.^{3}
Estimated form factor = 1.20
Modulus of elasticity = 30,000 ksi

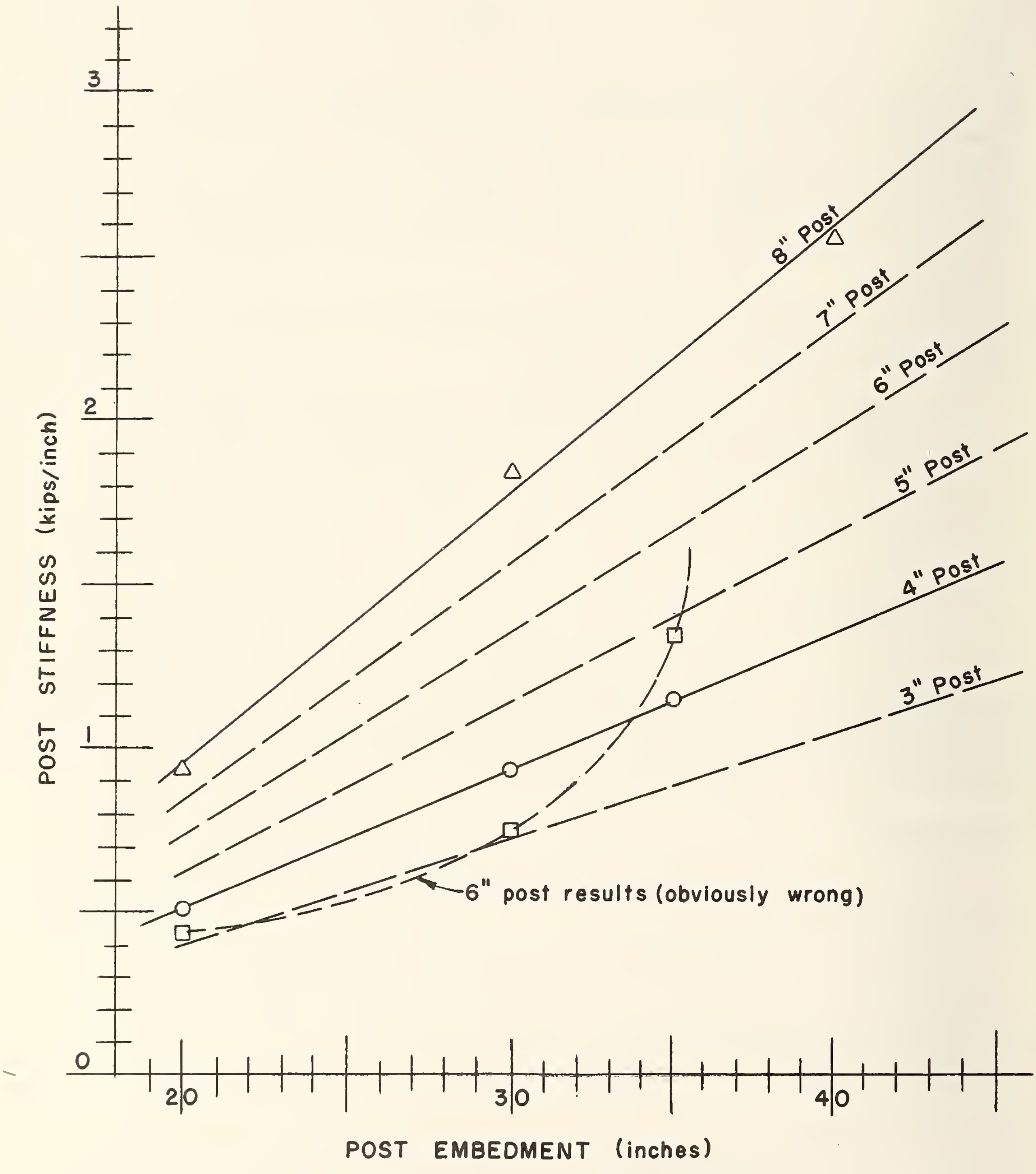


FIGURE A.2. POST STIFFNESSES

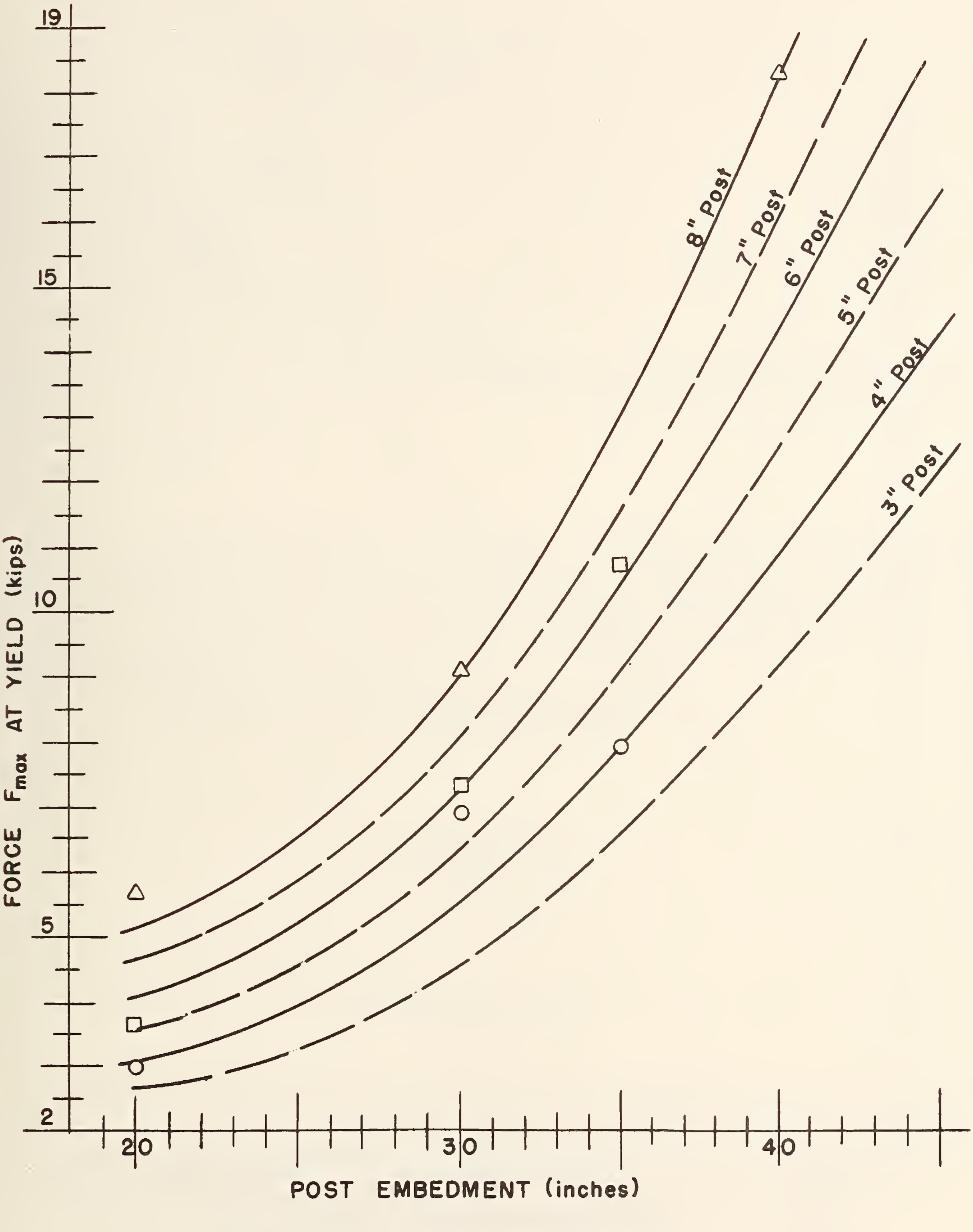


FIGURE A.3. POST FORCES AT YIELD OF SOIL

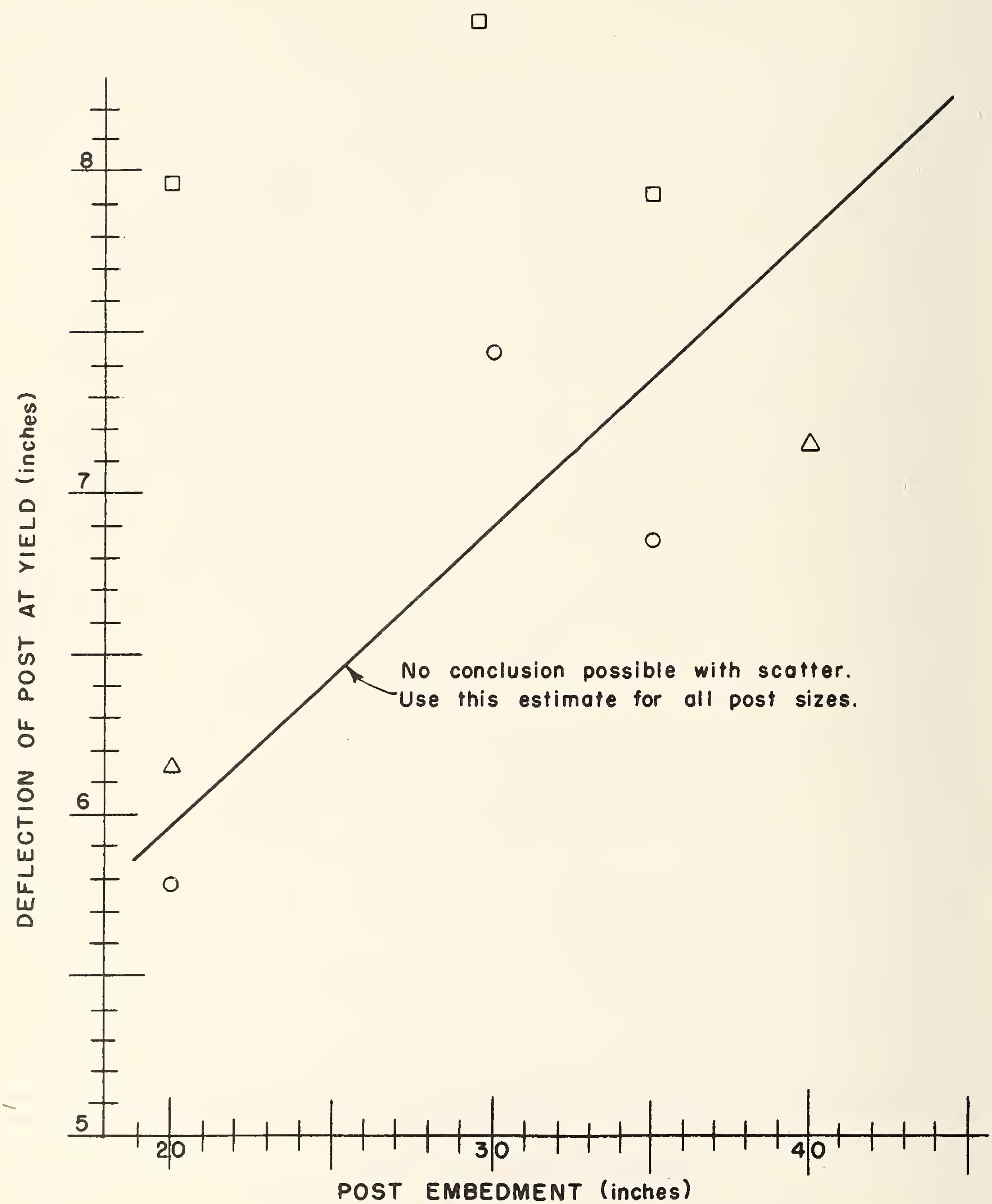


FIGURE A.4. DEFLECTIONS OF POSTS AT YIELD OF SOIL

Weight = 6.77 lb/ft
Yield force = 1.99 (54) = 107.5 k
Plastic moment = 1.20 (1.37)(54) = 88.8 in.-k

Box Beam System (TS 6 X 6 X 6 X 0.1875)

Area = 4.24 in.^{2}
Moment of inertia = 23.5 in.^{4}
Section modulus = 7.83 in.^{3}
Estimated form factor = 1.18
Modulus of elasticity = 30,000 ksi
Weight = 14.41 lb/ft
Yield force = 4.24 (54) = 229 k
Plastic moment = 1.18 (7.83)(54) = 499 in.-k

On comparing the above values with those in Reference 6, it was found that they are lower because of the higher reported yield stresses. However, the discrepancies were not considered significant, and the values above were used.

Vehicle Properties

Vehicle dimensions were obtained principally from "Parking Dimensions" pamphlets published by the Motor Vehicle Manufacturers Association for the years 1958 through 1975. The "Consumer Reports" magazines were also used for some dimensions. The distribution of vehicle weights on the front and rear axles were taken from these magazines to determine the center of gravity locations. Total yaw mass moments of inertia for the vehicles were estimated by formulas in References 29 and 30. From Reference 29, the equation is

$$I = [1.26\,(wt) - 1750]\,(12) \qquad \text{(A.5)}$$

Reference 30 contains the equations

$$I = \frac{0.225\,(wt)^{1.572}\,(12)}{32.2} \qquad \text{(A.6)}$$

and

$$I = \frac{0.103\,(wt)^{1.67}\,(12)}{32.2} \qquad \text{(A.7)}$$

A comparison of these predictions with two previous SwRI torsional pendulum tests follows:

Vehicle weight (lb)	2173	4159
Values of I (in.-lb-sec^2):		
SwRI test	14,901	49,826
Equation (A.5)	11,860	41,880
Equation (A.6)	14,770	40,980
Equation (A.7)	14,400	42,450

From this comparison, as well as comparisons with the minimal information that could be obtained from the automobile manufacturers, it was decided to use equation (A.6) for the light 2250-lb vehicle class and equation (A.5) for the heavy 4500-lb vehicle class. The application of these equations for the typical vehicles is shown in Appendix B.

APPENDIX B

CORRELATION RUN RESULTS AND GUARDRAIL AND VEHICLE CONFIGURATIONS FOR EXTRAPOLATION RUNS

This appendix discusses the results of the BARRIER VII correlation runs and shows the various guardrail configurations and vehicle models that were used in the extrapolation runs.

Since BARRIER VII inputs must be in English units, such units are used in this appendix without the metric equivalents. The following are factors that can be used for metric conversion:

Multiply	By	To Obtain
in.	2.540 E–02	m
ft	3.048 E–01	m
lbm	4.536 E–01	kg
kip (1000 lbf)	4.448 E+03	N
in.^{2}	6.451 E–04	m^2
in.^{3}	1.639 E–05	m^3
in.^{4}	4.162 E–07	m^4
in.-k	1.130 E–04	Nm
lb/ft	1.459 E+01	N/M
psi	6.894 E+03	Pa
ksi	6.895 E+06	Pa
in.-lb-sec^2	1.152 E–02	m-kg-sec^2

Tests selected from Table 2 for the correlation runs were modeled as closely as possible for the various fixed parameters of guardrail geometry, post type, size, embedment, vehicle weight and speed, and impact angle. However, there were certain modeling parameters that could be varied in the BARRIER VII program to obtain the best correlation possible. For example, since the W-section railing is weak in flexure and principally a tension member, it could be modeled as a cable as well as a beam. Various values of initial slack in the railings could be used to simulate the take-up of slotted holes used in W-beam installation. Thus, these and other modeling techniques were tried for the various simulations to determine the modeling characteristic that would produce the best correlation.

The results of all of the BARRIER VII correlation runs are shown in Tables B.1 through B.9. Note that the lower sections of these tables show values of the modeling parameters that were used in the various simulations. Changes in these values from simulation to simulation were made either to check the variable parameters mentioned above or to use better post properties as determined from subsequent study of other pendulum test results. Definitions of the indicated parameters follow:

- Railing type – the W-section railing was modeled as a beam in some simulations and as a cable in others.
- Prestress – various values of initial slack in the railings were used to simulate the take-up of slotted holes used in W-beam installation.
- k_A, k_B – stiffnesses in kips/inch for post elastic horizontal deflections at the railing height in the longitudinal and transverse directions of the guardrail, respectively.
- M_{PA}, M_{PB} – base moments in inch-kips about the longitudinal and transverse axes, respectively, at which the post yields.
- F_{PA}, F_{PB} – shear forces in kips in the longitudinal and transverse directions, respectively, that cause failure of the posts.

TABLE B.1. GUARDRAIL TYPE A CORRELATIONS

Item	Test 2-ODH-3*	Run 1	Test 2-ODH-4	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Test 2-ODH-5	Run 1
Vehicle Accelerations†												
Longitudinal (200-ms)	5.1	4.60	2.6	4.47	3.33	3.37	2.83	2.89	2.55	2.81	2.2	2.62
Lateral (200-ms)	3.5	3.97	3.4	3.29	4.06	3.72	3.46	3.55	3.80	3.92	3.9	4.01
Barrier Deflection (ft)	4.3	4.24	6.5	4.90	4.75	5.17	7.42	7.00	7.80	6.31	7.2	6.99
No. of Posts	2	4	6	6	6	7	7	7	8	7	7	9
Exit Angle	vehicle rolled	17.0	18	16.5	12.6	14.6	18.4	16.8	10.7	18.1	7	13.5 (8.8)
Simulation Conditions												
Railing:												
Type		Beam		Beam	Beam	Beam	Cable	Cable	Cable	Beam		Beam
Prestress		None		None	None	None	1/4" slack	1/8" slack	None	None		None
Post:												
k_A (k/in.)		1.93		1.66	1.66	1.66	1.66	1.66	1.66	1.66		1.66
k_B (k/in.)		1.93		1.66	1.66	1.66	1.66	1.66	1.66	1.66		1.66
M_{PA} (in.-k)		245.7		218.4	218.4	218.4	218.4	218.4	218.4	218.4		218.4
M_{PB} (in.-k)		245.7		218.4	218.4	218.4	218.4	218.4	218.4	218.4		218.4
F_{PA} (k)		11.7		10.4	10.4	10.4	10.4	10.4	10.4	10.4		10.4
F_{PB} (k)		11.7		10.4	10.4	10.4	10.4	10.4	10.4	10.4		10.4
δ_A (in.)		7.36		7.36	7.36	7.36	7.36	7.36	7.36	7.36		7.36
δ_B (in.)		7.36		7.36	7.36	7.36	7.36	7.36	7.36	7.36		7.36
Coefficient of Friction		0.50		0.50	0.30	0.30	0.30	0.30	0.30	0.30		0.30
Rotational Damping Multiplier		10.0		10.0	10.0	10.0	10.0	10.0	1.0	1.0		1.0
Anchor Post k_A (k/in.)		50.0		50.0	50.0	50.0	50.0	50.0	15.0	15.0		15.0
						15° steer angle	0° steer angle					

*Test nos. shown as ref. no.–test no. (e.g., Test ODH-3 from Ref. 2)
†50-ms maximum averages unless otherwise noted.

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

Use

Use

TABLE B.2. GUARDRAIL TYPE D CORRELATIONS

Item	Test 4-273	Run 1	Run 2	Run 3
Vehicle Accelerations				
Longitudinal	6.75	4.16	3.70	4.20
Lateral	6.95	5.14	4.52	5.07
Barrier Deflection (ft)	2.33 (permanent)*	3.99	5.33	5.77
No. of Posts	3	7	9	9
Exit Angle	14	12.0	8.3 (4.0)	13.1
Simulation Conditions				
Railing:				
Type		Beam	Cable	Beam
Prestress		None	None	None
Post:				
k_A (k/in.)		2.28	2.28	2.28
k_B (k/in.)		1.72	1.72	1.72
M_{PA} (in.-k)		235.2	235.2	235.2
M_{PB} (in.-k)		294.0	294.0	294.0
F_{PA} (k)		14.0	14.0	14.0
F_{PB} (k)		11.2	11.2	11.2
δ_A (in.)		7.50	7.50	7.50
δ_B (in.)		7.50	7.50	7.50
Rotational Damping Multiplier		1.0	1.0	1.0
Anchor Post k_A (k/in.)		15.0	40.0	40.0
			Use	No good. End anchor post failed.

*2.33 (1.6) = 3.7 assumed maximum dynamic deflection.

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

- δ_A, δ_B – deflections in inches at the railing height that cause failure of the posts in the longitudinal and transverse directions.
- Coefficient of friction – the coefficient of friction between the vehicle and the railing.
- Rotational damping multiplier – stabilizing factor to introduce viscous damping that constrains rigid body rotations of the model members.

Those railing and post properties indicated by the arrows in Tables B.1 through B.9 were considered best and were selected for subsequent extrapolation runs. Where two or more arrows are shown in a table, the same properties were used to correlate the corresponding two or more tests shown. The apparent discrepancies in properties of the two selected simulations in Table B.9 were caused by the fact that post embedments were different for the two tests. Of course, each simulation was tailored to fit the impact conditions of the corresponding test, and the subsequent extrapolation runs were made with the final recommended post embedments.

TABLE B.3. GUARDRAIL TYPE E CORRELATIONS

Item	Test 5-AS-7	Run 1	Run 2	Run 3	Run 4	Test 5-AS-8	Run 1	Run 2	Run 3	Run 4
Vehicle Accelerations										
Longitudinal	3.4	5.28	4.37	4.11	4.61	3.7	4.40	4.35	4.59	4.59
Lateral	5.9	6.37	6.37	6.08	5.24	6.8	5.44	4.84	5.14	5.17
Barrier Deflection (ft)	3.5	2.41	2.88	5.16	6.88	2.9	2.71	5.18	3.69	4.51
No. of Posts	5	3	4	7	7	5	4	6	3	6
Exit Angle	not given	16.3	18.2	14.5	16.2 (27.0)	not given	16.7	17.6 (21.4)	−2.2*	13.9 (14.8)
Simulation Conditions										
Railing:										
Type		Beam	Beam	Cable	Cable		Beam	Cable	Cable	Cable
Prestress		None	None	None	None		None	None	None	None
Post:										
k_A (k/in.)		2.20	2.20	2.20	2.20		2.20	2.20	2.20	2.20
k_B (k/in.)		1.50	1.50	1.50	1.50		1.50	1.50	1.50	1.50
M_{PA} (in.-k)		311.6	311.6	311.6	285.6		311.6	311.6	311.6	285.6
M_{PB} (in.-k)		185.1	185.1	185.1	185.1		185.1	185.1	185.1	185.1
F_{PA} (k)		8.80	8.80	8.80	8.80		8.80	8.80	8.80	8.80
F_{PB} (k)		13.6	13.6	13.6	13.6		13.6	13.6	13.6	13.6
δ_A (in.)		8.20	8.20	8.20	8.20		8.20	8.20	8.20	8.20
δ_B (in.)		8.20	8.20	8.20	9.10		8.20	8.20	9.10	9.10
Rotational Damping Multiplier		10.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0
Anchor Post k_A (k/in.)		15.0	15.0	15.0	15.0		15.0	40.0	15.0	15.0

*Numerical instability at t = 0.29 sec.

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

Use

Use

Some difficulties were encountered with the runs shown in the correlation tables. For example, the use of a rotational damping multiplier of 10.0 to try to prevent numerical instability was thought to be satisfactory from an inspection of the computed damping losses. However, reducing the value to 1.0 significantly affected the results. As shown in Table B.5, further reduction to 0.0 (no damping) was not significant. Therefore, a multiplier of 1.0 was selected for predominant use. However, as shown in Table B.6, it was felt necessary to retain the 10.0 value for the strong-beam G3 system.

From the standpoint of direct use, as opposed to a simple indication of trends, certain of the results shown in Tables B.3, B.4, B.5, and B.8 were of no value and are crossed out. In Tables B.3 and B.8, the input data were checked when numerical instability diagnostics were encountered. In Table B.3, the only error that could be found was the specification of M_{PA} = 311.6 in.-kips for the yield moment of the post rather than the 285.6 in.-kip value for the soil. The change produced successful runs. In Table B.8, the inspection revealed a coding error in the member inputs that called for nodes beyond the specified member. Previously, such errors usually resulted in machine aborts when indefinite or infinite arguments were picked up at these extraneous node addresses.

TABLE B.4. GUARDRAIL TYPE G1 CORRELATIONS

Item	Test 6-46	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Test 7-9	Run 1	Test 7-1	Run 1	Test 7-2	Run 1
Vehicle Accelerations														
Longitudinal	6.1	1.28	1.73	1.40	1.31	1.83	0.68	1.87	6.1	2.53	3.7	3.93	2.2	4.92
Lateral		2.70	2.39	2.48	1.94	2.50	1.46	2.89		3.25 (4.12)				4.93
Barrier Deflection (ft)	11.0	5.45	7.15	7.77	8.23	7.93	9.93	7.26	8.0	8.23	7.7	10.85	5.8	5.66
No. of Posts	6	8	4	4	5	4	8	4	6	5	6	6	not given	3
Exit Angle	15	8.0	7.4	11.7	10.5	11.0	0.5	8.7	15	10.7	90	90.0	0	10.6 (9.0)
Simulation Conditions														
Railing:														
Type		Cable	Cable	Cable	Cable	Cable	Cable	Cable		Cable		Cable		Cable
Prestress		3.0^{k} pretension	None	None	None	None	None	None		None		None		None
Post:														
k_A (k/in.)		50.0	0.001	0.001	0.001	0.001	0.001	0.001		0.001		0.001		0.001
k_B (k/in.)		1.38	1.38	1.38	1.38	0.62	1.00	0.62		0.62		0.62		0.62
M_{PA} (in.-k)		105.3	105.3	105.3	105.3	141.6	141.6	141.6		141.6		141.6		141.6
M_{PB} (in.-k)		10000.0	10000.0	10000.0	10000.0	10000.0	76.8	76.8		76.8		76.8		76.8
F_{PA} (k)		10000.0	10000.0	10000.0	10000.0	3.20	3.20	3.20		3.20		3.20		3.20
F_{PB} (k)		3.90	3.90	3.90	3.90	5.90	5.90	5.90		5.90		5.90		5.90
δ_A (in.)		10000.0	10000.0	10000.0	10000.0	14.32	6.00	14.32		14.32		14.32		14.32
δ_B (in.)		3.00	6.70	4.00	3.00	9.45	6.00	9.45		9.45		9.45		9.45
Rotational Damping Multiplier		10.0	10.0	10.0	10.0	1.0	1.0	0.0		1.0		1.0		1.0
Anchor Post k_A (k/in.)		50.0	50.0	50.0	50.0	15.0	15.0	15.0		15.0		15.0		15.0
							Revised posts- don't use	Corrected post heights from 27" to 24"	Revised data for Test 6-46					Light car test
										Use		Use		Use

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

TABLE B.5. GUARDRAIL TYPE G2 CORRELATIONS

Item	Test 8-105	Run 1	Run 2	Test 6-39	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Test 7-49	Run 1	Run 2
Vehicle Accelerations														
Longitudinal	2.9	3.12	2.41	2.7	1.87	1.81	2.28	2.43	2.13	2.20	2.06	2.7	2.13	2.36
Lateral	3.8	2.31	3.90		2.26	2.78	3.93	3.40	3.79	3.64	3.66		4.04	4.02
Barrier Deflection (ft)	7.30	6.82*	8.43	6.8	8.06	6.56	4.46	5.76	7.08	5.26	5.34	6.0	5.57	5.72
No. of Posts	3	6	7	6	16	18	7	8	7	6	7	6	8	8
Exit Angle	9	−18.5	7.2	14	3.1	6.1	9.6	7.2	10.1	14.5	13.4	14	9.6	10.0
Simulation Conditions														
Railing:														
Type		Cable	Beam		Cable	Beam	Beam	Cable	Cable	Beam	Beam		Beam	Beam
Prestress		1/4" slack	None		None	None	None	None	None	None	None		None	None
Post:														
k_A (k/in.)		0.83	0.22		0.72	0.72	0.72	0.72	0.22	0.22	0.22		0.22	0.22
k_B (k/in.)		2.03	0.62		1.80	1.80	1.80	1.80	0.62	0.62	0.62		0.62	0.62
M_{PA} (in.-k)		105.3	141.6		105.3	105.3	105.3	105.3	141.6	141.6	141.6		141.6	141.6
M_{PB} (in.-k)		35.3	76.8		35.3	35.3	10000.0	10000.0	76.8	76.8	76.8		76.8	76.8
F_{PA} (k)		1.50	3.20		10000.0	10000.0	10000.0	10000.0	3.20	3.20	3.20		3.20	3.20
F_{PB} (k)		4.40	5.90		3.90	3.90	4.40	4.40	5.89	5.90	5.90		5.90	5.90
δ_A (in.)		12.0	14.32		12.0	12.0	10000.0	10000.0	14.32	14.32	14.32		14.32	14.32
δ_B (in.)		7.20	9.45		6.90	6.90	6.90	6.90	9.45	9.45	9.45		9.45	9.49
Rotational Damping Multiplier		10.0	1.0		10.0	10.0	10.0	10.0	1.0	1.0	0.0		0.0	1.0
Anchor Post k_A (k/in.)		50.0	15.0		50.0	50.0	50.0	50.0	15.0	15.0	15.0		15.0	15.0
		Short installation. All 6 of the last posts failed – no good.	Data still no good. End post deflects excessively.								Change not significant	Revised data for Test 6-39		Use

*At loss of contact

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

TABLE B.6. GUARDRAIL TYPE G3 CORRELATIONS

Item	Test 6-25	Run 1	Run 2	Run 3	Run 4	Test 6-34	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Test 7-2	Run 1
Vehicle Accelerations														
Longitudinal	5.5	4.44	4.41	4.29	4.00	7.2	5.99	5.96	5.98	5.91	4.58	4.79	5.4	8.20
Lateral		4.98	4.94	4.73	4.50 (6.02)		4.89	4.90	4.71	4.49 (7.42)	3.68	4.95		
Barrier Deflection (ft)	3.0	1.64	1.72	1.78	2.17	5.1	3.79	4.17	3.79	5.80	8.85	4.74	5.9	5.92
No. of Posts	4	5	5	4	6	9	11	14	10	10	12	14	9	9
Exit Angle	11	8.0	8.3	8.8	8.6	12	15.9	13.8	16.4	16.9	29.8 (8.3)	17.9	90	90.0
Simulation Conditions														
Railing:														
Type		Beam	Beam	Beam with 36 ksi yield	Beam with A = 0.01		Beam	Beam	Beam	Beam with A = 0.01	Beam with A = 0.01	Beam with full area		Beam with A = 0.01
Prestress		None	None	None	None		None	None	None	None	None	None		None
Post:														
k_A (k/in.)		1.00	1.00	1.00	0.22		1.00	1.00	0.22	0.22	0.22	0.22		0.22
k_B (k/in.)		2.50	2.50	2.50	0.62		2.50	1.40	0.62	0.62	0.62	0.62		0.62
M_{PA} (in.-k)		105.3	105.3	105.3	141.6		105.3	105.3	141.6	141.6	141.6	141.6		141.6
M_{PB} (in.-k)		35.3	10000.0	10000.0	76.8		10000.0	10000.0	76.8	76.8	76.8	76.8		76.8
F_{PA} (k)		10000.0	10000.0	10000.0	3.20		10000.0	10000.0	3.20	3.20	3.20	3.20		3.20
F_{PB} (k)		4.40	4.40	4.40	5.90		4.40	4.40	5.90	5.90	5.90	5.90		5.90
δ_A (in.)		12.0	10000.0	10000.0	14.32		10000.0	10000.0	14.32	14.32	14.32	14.32		14.32
δ_B (in.)		7.70	7.70	7.70	9.45		7.70	6.40	9.45	9.45	9.45	9.45		9.45
Rotational Damping Multiplier		10.0	10.0	10.0	10.0		10.0	10.0	10.0	10.0	1.0	1.0		10.0
Anchor Post k_A (k/in.)		50.0	15.0	15.0	15.0		15.0	10.0	15.0	15.0	15.0	15.0		15.0
					Use			Post properties reduced to those of 24" plate	New post properties based on pendulum tests of actual posts	Use				Use

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

TABLE B.7. GUARDRAIL TYPE G4S CORRELATIONS

Item	Test 8-120	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Test 4-276	Run 1	Run 2	Test 8-122	Run 1
Vehicle Accelerations														
Longitudinal	4.0	6.22	3.49	6.04	5.41	4.79	4.60	4.84	5.16	3.78	3.67	4.60	3.9	3.55
Lateral	6.7	5.53	4.82	5.39	4.53	5.38	5.33	5.17	5.02	6.85	6.59	5.12	7.6	5.42
Barrier Deflection (ft)	4.05	2.07	8.08	2.33	3.50	4.59	4.01	3.81	2.81	1.76* (permanent)	5.67	3.43	4.9	5.15
No. of Posts	5	3	15	4	4	5	5	4	5	3	8	6	6	8
Exit Angle	8.0	11.2	16.5	14.1	16.3	21.5	17.3 (11.4)	17.7 (10.9)	14.5 (3.3)	16	8.5	15.6	9	13.7 (9.7)
Simulation Conditions														
Railing:														
Type		Beam	Cable	Beam	Cable	Cable	Cable	Cable	Beam		Cable	Beam		Cable
Prestress		None	1/4" slack	None	None	1/4" slack	None	None	None		None	None		None
Post:														
k_A (k/in.)		2.09	2.09	2.03	2.03	2.03	2.03	2.03	2.03		2.20	2.20		2.03
k_B (k/in.)		1.50	1.50	1.40	1.40	1.40	1.40	1.40	1.40		1.52	1.52		1.40
M_{PA} (in.-k)		252.0	252.0	241.5	241.5	241.5	241.5	241.5	241.5		285.6	285.6		241.5
M_{PB} (in.-k)		84.0	84.0	83.7	83.7	83.7	83.7	83.7	83.7		83.7	83.7		83.7
F_{PA} (k)		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0	4.0		4.0
F_{PB} (k)		12.0	12.0	11.5	11.5	11.5	11.5	11.5	11.5		13.6	13.6		11.5
δ_A (in.)		2.00	2.00	7.90	7.90	7.90	7.90	7.90	7.90		8.20	8.20		7.90
δ_B (in.)		8.00	8.00	7.90	7.90	7.90	7.90	7.90	7.90		8.20	8.20		7.90
Rotational Damping Multiplier		10.0	10.0	10.0	10.0	10.0	1.0	1.0	1.0		1.0	1.0		1.0
Anchor Post k_A (k/in.)		50.0	50.0	50.0	50.0	50.0	15.0	40.0	15.0		40.0	40.0		15.0
							Use							Use

*1.76 (1.4) = 2.5 assumed dynamic deflection

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

TABLE B.8. GUARDRAIL TYPE G4W CORRELATIONS

Item	Test 8-101	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Test 8-102	Run 1	Run 2	Run 3	Run 4
Vehicle Accelerations														
Longitudinal	4.6	7.08	6.47	6.44	7.59	5.85	6.02	6.23	6.01	–	4.90	4.54	4.59	4.97
Lateral	4.6	5.79	4.66	4.40	5.25	5.21	4.70	4.88	4.55	–	5.63	5.99	6.44	5.45
Barrier Deflection (ft)	4.25	2.02	3.28	4.18	3.93	4.56	3.78	2.67	3.81	2.40	1.82	2.96	3.26	1.78
No. of Posts	3	3	4	5	3	5	4	3	4	2	2	3	3	2
Exit Angle	11.7	12.0	15.4	21.4 (12.2)	27.7	18.4 (17.1)	19.2 (13.1)	16.4 (9.1)	18.6 (14.0)	12.5	12.3 (6.5)	17.3* (16.8)	20.1 (18.3)	11.9 (6.1)
Simulation Conditions														
Railing:														
Type		Beam	Cable	Cable	Cable	Cable	Cable	Beam	Cable		Beam	Cable	Cable	Beam
Prestress		None	None	1/4" slack	1/4" slack	None	None	None	None		None	None	None	None
Post:														
k_A (k/in.)		2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30		2.30	2.30	2.30	2.30
k_B (k/in.)		2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30		2.30	2.30	2.30	2.30
M_{PA} (in.-k)		294.0	294.0	294.0	294.0	294.0	294.0	294.0	294.0		294.0	294.0	294.0	294.0
M_{PB} (in.-k)		294.0	294.0	294.0	294.0	294.0	294.0	294.0	294.0		294.0	294.0	294.0	294.0
F_{PA} (k)		14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
F_{PB} (k)		14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0		14.0	14.0	14.0	14.0
δ_A (in.)		7.50	7.50	7.50	15.0	7.50	7.50	7.50	7.50		7.50	7.50	7.50	7.50
δ_B (in.)		7.50	7.50	7.50	15.0	7.50	7.50	7.50	7.50		7.50	7.50	7.50	7.50
Rotational Damping Multiplier		10.0	10.0	10.0	10.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0
Anchor Post k_A (k/in.)		50.0	50.0	50.0	50.0	15.0	40.0	15.0	15.0		15.0	15.0	15.0	15.0
									Use				Use	

*Numerical instability at t = 0.60–found coding error–all previous runs voided

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

TABLE B.9. THRIE BEAM CORRELATIONS

Item	Test 32-AS-2	Run 1	Run 2	Test 32-AS-4	Run 1	Run 2	Test 5-AS-6	Run 1
Vehicle Accelerations (g's)								
Longitudinal	5.9	5.79	6.17	2.9	2.36	2.49	3.6	4.80
Lateral	7.4	6.31	6.49	4.1	4.84	4.74	6.1	5.91
Barrier Deflection (ft)	3.4	4.30	3.65	0.6	1.57	1.45	2.6	2.60
No. of Posts	4	8	8	2	2	2	3	4
Barrier Damage (ft)	25	37.5	37.5	12.5	25	25	25	37.5
Simulation:								
Railing:								
Type		Beam	Beam		Beam	Beam		Beam
Post:								
k_A (k/in.)		2.10	2.10		2.50	2.50		2.50
k_B (k/in.)		1.50	1.50		1.70	1.70		1.70
M_{PA} (in.-k)		268.4	268.4		308.3	308.3		311.6
M_{PB} (in.-k)		83.7	83.7		83.7	83.7		185.1
F_{PA} (k)		3.8	3.8		3.8	3.8		8.4
F_{PB} (k)		12.2	12.2		14.0	14.0		14.2
δ_A (in.)		8.0	8.0		8.5	8.5		8.5
δ_B (in.)		8.0	8.0		8.5	8.5		8.5
Rotational Damping Multiplier		1.00	1.00		1.00	1.00		1.00
Anchor Post k_A (k/in.)		15.0	50.0		15.0	50.0		15.0
			Use			Use		

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m
Multiply k by 4,448.2 to obtain N

Unfortunately, such was not the case with the Table B.8 runs, and the error was not found until the numerical instability occurred.

The deleted results in Tables B.4 and B.5 were caused by a reanalysis of the original 1965 test data reported in Reference 6. For example, on inspecting Reference 7 that was received from the contract manager during the course of the study, it was found for Table B.4 that the vehicle weight was changed from 3500 lb to 3300 lb, the impact speed from 44 mph to 53 mph, and the reported barrier deflection from 11 ft to 8.0 ft. Similar changes were found for the test of Table B.5. Reasons for the changes could not be found in Reference 7, but the correlations with the new data were much better.

A difficult problem was encountered in the correlation work in using the same modeling for similar guardrail systems. For example, guardrail Types A, C, and G2 are similar except for the posts. Though only one unsatisfactory test was available for Type C, the railing model as a beam rather than a cable was fortunately the more satisfactory for both Types A and G2. Such was not the case, however, for Type E with a Charley post and the similar Type G4S with a W6 X 8.5 post. As shown in Table B.3, a beam model for the railing might be more satisfactory for Type E, but, as shown in Table B.7, it is too stiff for the G4S. Since these two post types are so similar, it did not make sense to use a beam for one system and a cable for the other. Further, the cable model was more satisfactory for Type G4W with stronger posts but with similar 6'-3" post spacing. Thus, while it was not considered objectionable for beam modeling of the W-section for 12'-6" post spacing and cable modeling for the 6'-3" spacing, it was considered desirable to use the cable for all of the systems with the same 6'-3" post spacing.

One explanation for the stiffer test results of the Type E system in Table B.3 could be the manner in which the posts were installed. This was the only test series at SwRI in which the posts were driven into the ground rather than being placed in holes and then backfilled. Correlation troubles were also experienced with the California series of tests (4-273 in Table B.2 and 4-276 in Table B.7). The test site soil for these tests was extremely stiff, and the posts were also driven into smaller predrilled pilot holes. Further, the test installation length of 75 ft was quite short. These installation details were not considered to be as representative as those of the other reported tests. Consequently, only a minimal correlation effort was made for the California tests, and the results were not too good.

The state-of-the-art of relating soil properties to the dynamic response characteristics of guardrail posts is considered to be far from adequate. Consequently, a representative soil was selected for this study that had been characterized by means of a series of pendulum tests so that some rational basis could be established for determining the required post properties. The soil selected was a well-graded gravel specified as a base material by the Texas Highway Department. Details of the post characterizations are discussed in Appendix A. Except for bending about the major axes of the W6 X 8.5 and Charley posts, all of the steel post properties were controlled by the posts themselves rather than by the selected soil. All of the wood post properties were controlled by the soil. As discussed above, wood posts and, to a lesser extent, W6 X 8.5 and Charley posts in very stiff or frozen soils will probably produce greater accident severities than those predicted by this model. Loose or soft soils will probably produce lesser severities. However, the relative severities of the various guardrail types at a particular site should not likely be significantly affected. Thus, in the interest of eliminating this complex variable from the model, along with the lack of available characterizing data, the single soil discussed in Appendix A was selected as a representative.

To avoid the undesirable specification of prestress slack in the cable railing models, softer longitudinal anchor post stiffnesses of 15.0 kips/in. were used for most of the correlation runs. No unreasonable anchor shear forces or post deflections were observed with the installation lengths of 150 ft or longer. In most of the runs, the longitudinal railing forces were transmitted to the interior posts, and insignificant forces remained for the end anchors. Since satisfactory results were obtained without it, no attempt was made to reduce longitudinal post stiffnesses because of the block-outs.

Tests 7-1 of Table B.4 and 7-2 of Table B.6 were 90-degree impacts run by New York to verify deflections in their computer model for the cable and box-beam systems. Note that the simulated deceleration in Test 7-2 is high but the deflection correlation is excellent. Reference 7 shows a kinetic energy at impact of 87 ft-kips and a measured area of 84.9 ft-kips under the force-deflection curve for this test. In Test 7-1, the decelerations are excellent but the simulated deflection is high. In Reference 7, a significant and unresolved conflict was found for this test between the calculated kinetic energy of 81 ft-kips and measured area under the force-deflection curve of 65.6 ft-kips. A quick force deflection plot from the BARRIER VII results and calculation of the area gave much closer results of 77.2 ft-kips.

Test 7-21 of Table B.4 is the single light car test that could be found for the correlation study. As shown, the deflection check is good but the decelerations are high.

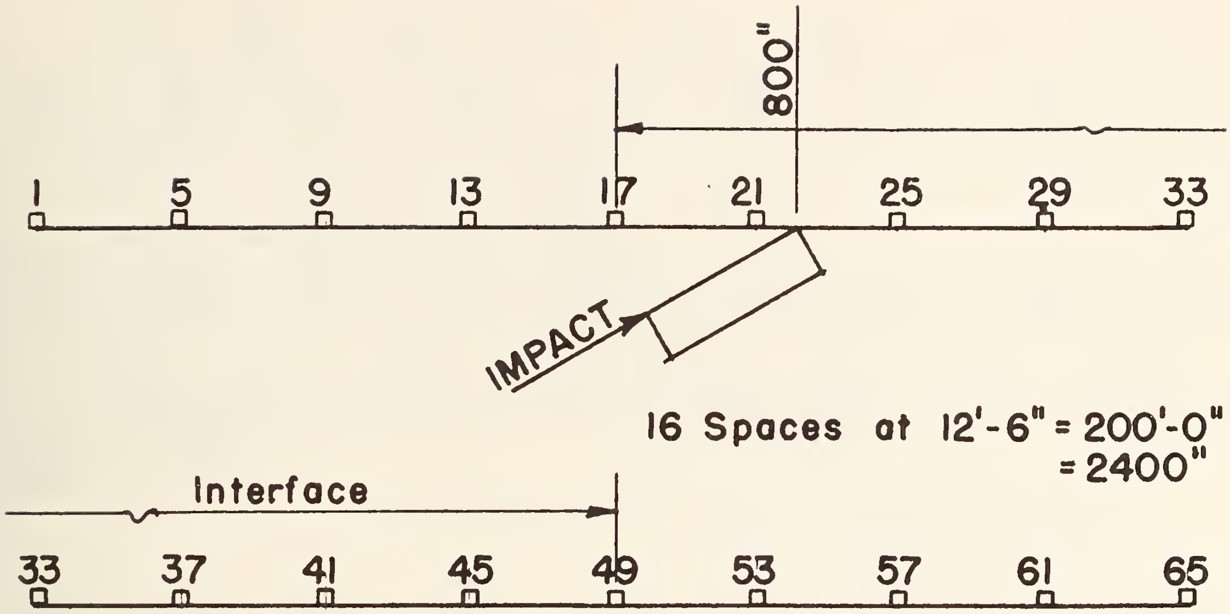
For the BARRIER VII extrapolation runs, the various guardrail configurations were selected to conform closely to those configurations finally selected in the test correlation runs. The guardrail models and post properties used for the extrapolations are shown in Figures B.1 through B.6 and Table B.10. The post properties were estimated as discussed in Appendix A.

Figure B.7 shows the vehicle properties that were used in the extrapolation runs for the 4500-lb vehicle class. Figure B.8 shows the properties used for the 2250-lb vehicle class. In computing the wheel drag forces shown, a coefficient of friction of 0.50 was assumed between the tires and the pavement.

TABLE B.10. POST PROPERTIES (GUARDRAIL TYPES G1, G2, AND G3)

Post Properties	Guardrail		
	Type G1	Type G2	Type G3
Size	S3 × 5.7	S3 × 5.7	S3 × 5.7
Embedment (in.)	32	32	32
Height (in.)	27	24	27
k_A (k/in.)	0.001	0.22	0.22
k_B (k/in.)	0.62	0.62	0.62
M_{PA} (in.-k)	141.6	141.6	141.6
M_{PB} (in.-k)	76.8	76.8	76.8
F_{PA} (k)	3.20	3.20	3.20
F_{PB} (k)	5.90	5.90	5.90
δ_A (in.)	14.32	14.32	14.32
δ_B (in.)	9.45	9.45	9.45

Note: Use anchor post k_A = 15.0 k/in. for all guardrail types.



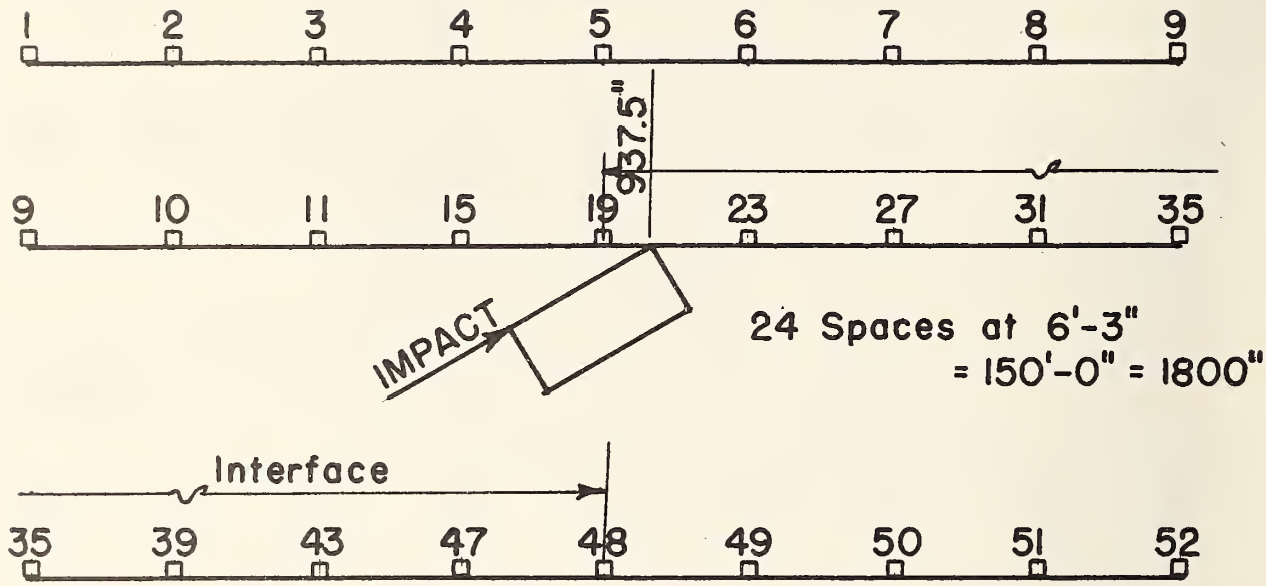
Control Nodes	
No.	X
1	0
65	2400

65 Nodes
64 Beams
17 Posts

81 Members

Post properties:	Guardrail	
	Type A	Type C
Size	7" round	8" x 8"
Embedment (in.)	35	35
Railing height (in.)	21	21
k_A (k/in.)	1.92	2.20
k_B (k/in.)	1.92	2.20
M_{PA} (in.-k)	243.6	273.0
M_{PB} (in.-k)	243.6	273.0
F_{PA} (k)	11.6	13.0
F_{PB} (k)	11.6	13.0
δ_A (in.)	7.40	7.40
δ_B (in.)	7.40	7.40

FIGURE B. 1 GUARDRAIL TYPES A AND C CONFIGURATION



Control Nodes

No.	X
1	0
11	750
47	1425
52	1800

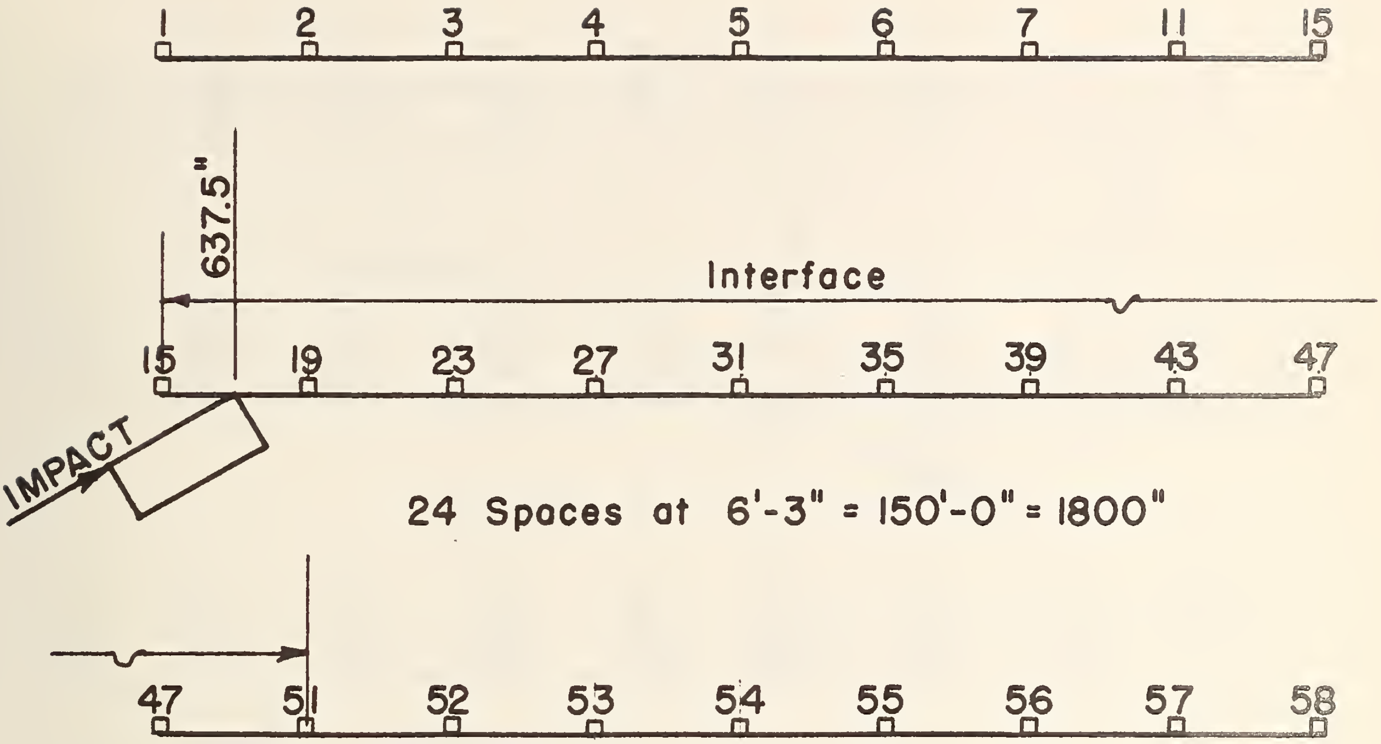
52 Nodes
51 Cables
25 Posts

76 Members

Post Properties:

	Guardrail		
	Type B	Type D	Type G4W
Size	8″ x 8″	6″ x 8″	8″ x 8″
Embedment (in.)	35	35	35
Height (in.)	21	21	21
k_A (k/in.)	2.20	2.20	2.20
k_B (k/in.)	2.20	1.66	2.20
M_{PA} (in.-k)	273.0	218.4	273.0
M_{PB} (in.-k)	273.0	273.0	273.0
F_{PA} (k)	13.0	13.0	13.0
F_{PB} (k)	13.0	10.4	13.0
δ_A (in.)	7.40	7.40	7.40
δ_B (in.)	7.40	7.40	7.40

FIGURE B. 2 GUARDRAIL TYPES B, D AND G4W CONFIGURATION



Control Nodes

No.	X
1	0
7	450
51	1275
58	1800

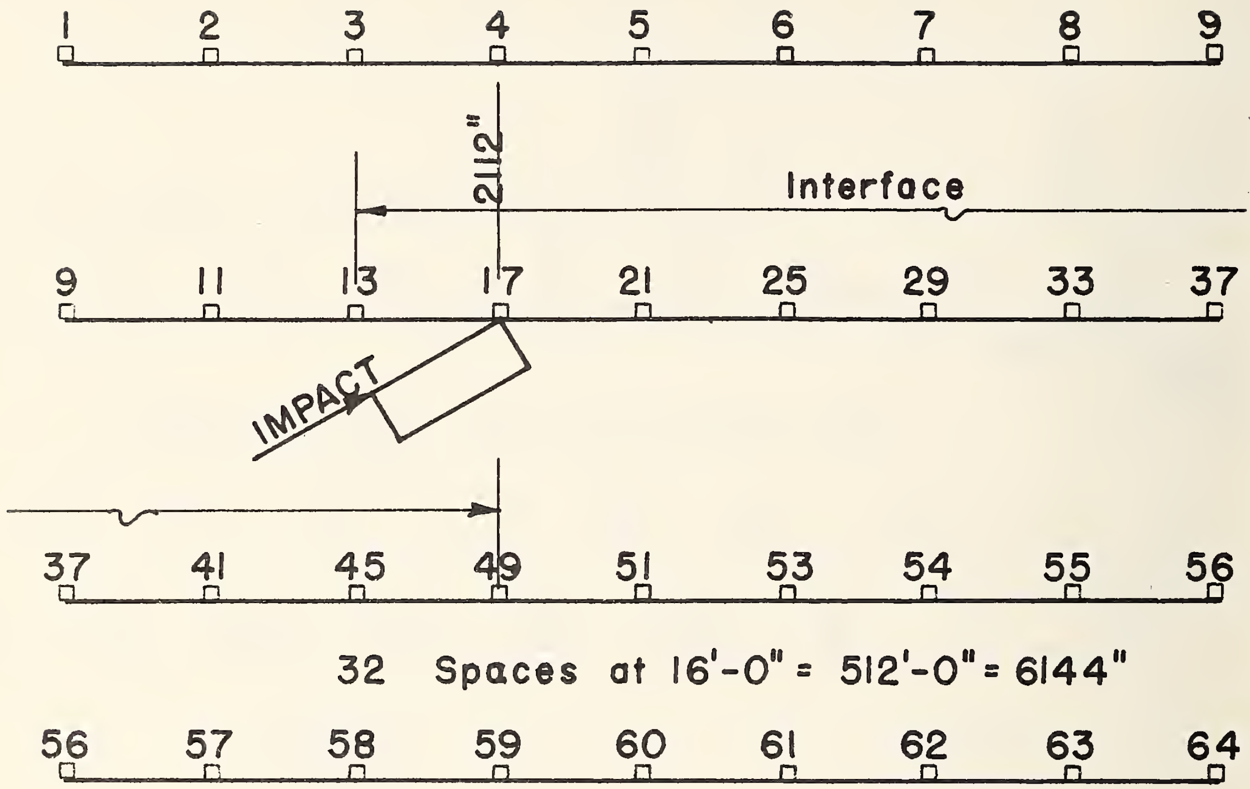
58 Nodes
57 Cables
25 Posts

82 Members

Post Properties:

	Guardrail		
	Type E	Type G4S	Thrie
Size	Charley	W6 x 8.5	W6 x 8.5
Embedment (in.)	44	44	39
Height (in.)	21	21	22
k_A (k/in.)	2.20	2.03	1.90
k_B (k/in.)	1.50	1.40	1.30
M_{PA} (in.-k)	285.6	241.5	297.0
M_{PB} (in.-k)	185.1	83.7	83.7
F_{PA} (k)	8.8	4.0	3.80
F_{PB} (k)	13.6	11.5	13.5
δ_A (in.)	8.20	7.90	7.70
δ_B (in.)	9.10	8.20	7.70

FIGURE B. 3 GUARDRAIL TYPES E, G4S, AND THRIE CONFIGURATION



Control Nodes

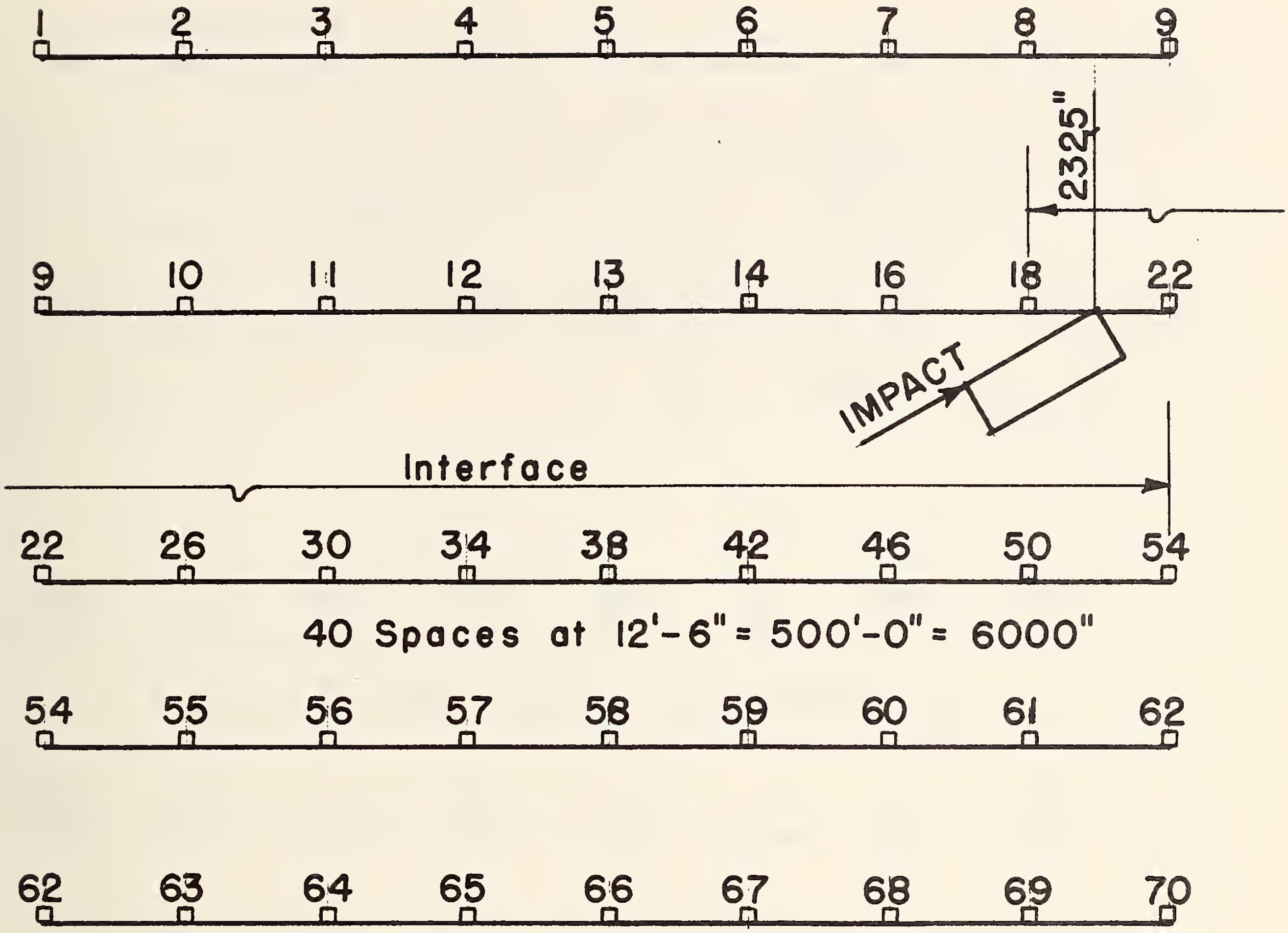
No.	X
1	0
9	1536
13	1920
49	3648
53	4032
64	6144

64 Nodes
63 Cables
33 Posts

96 Members

Post Properties: (see Table B. 10)

FIGURE B. 4 GUARDRAIL TYPE G1 CONFIGURATION



Control Nodes

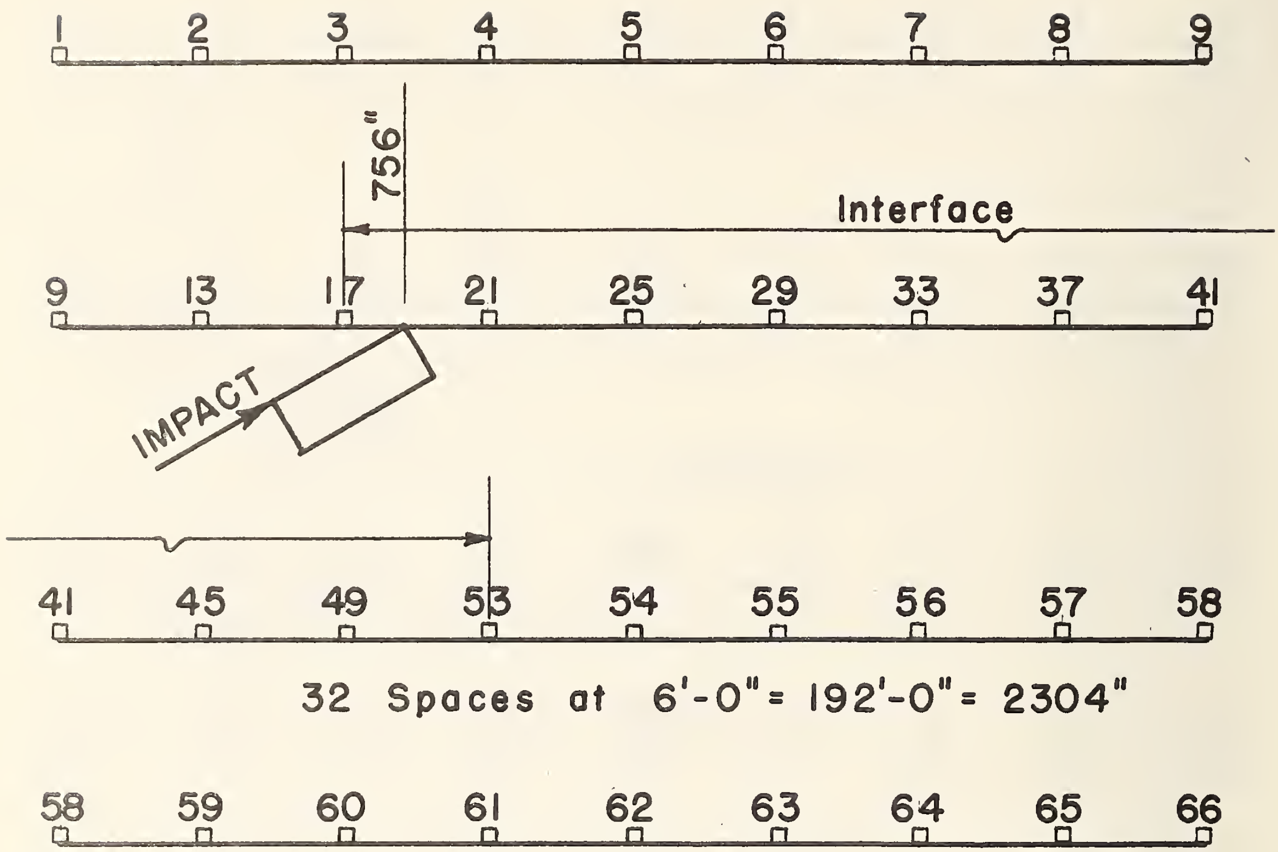
No.	X
1	0
14	1950
18	2250
54	3600
70	6000

70 Nodes
69 Beams
41 Posts

110 Members

Post Properties: (see Table B. 10)

FIGURE B. 5 GUARDRAIL TYPE G2 CONFIGURATION



Control Nodes

No.	X
1	0
9	576
53	1368
66	2304

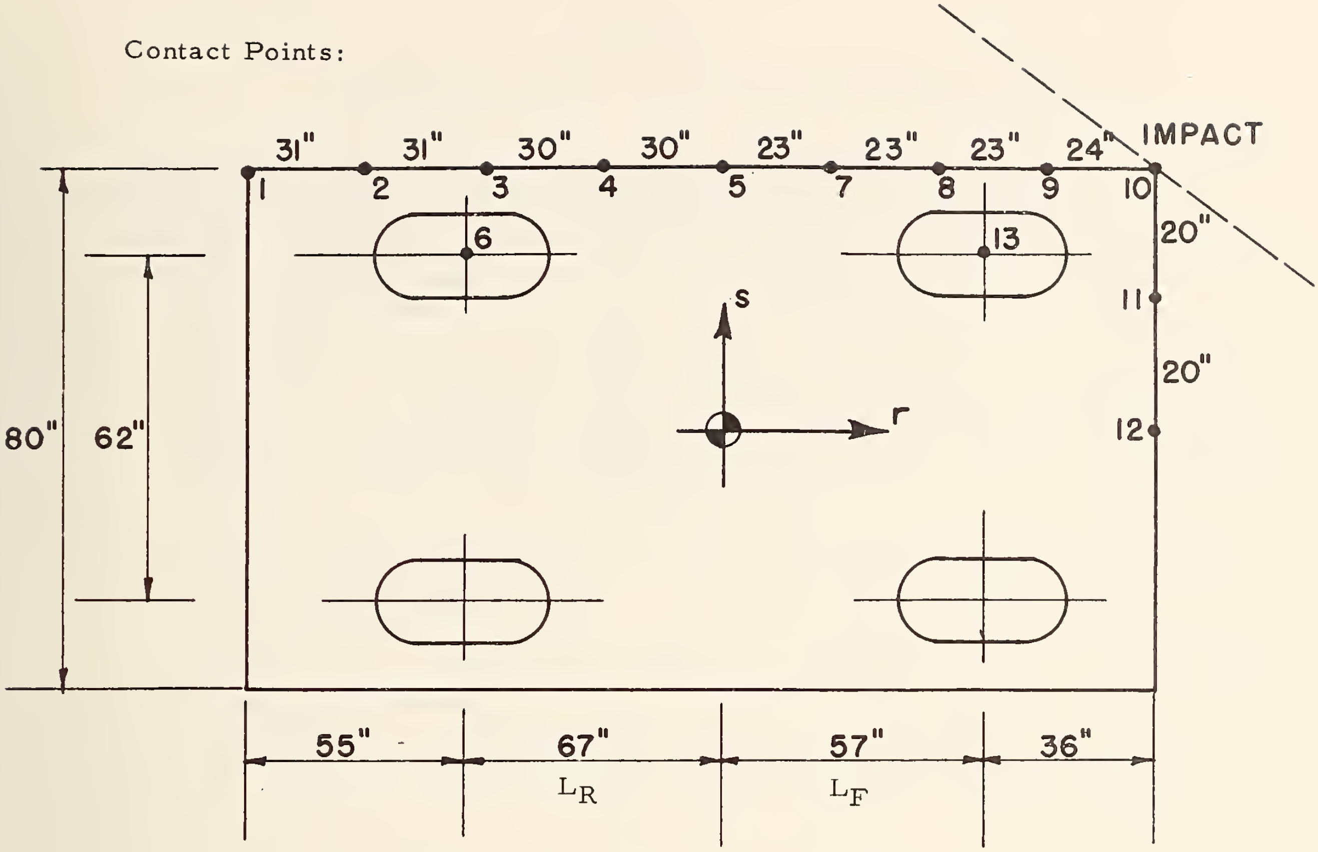
66 Nodes
65 Beams
33 Posts

98 Members

Post Properties: (see Table B.10)

FIGURE B. 6 GUARDRAIL TYPE G3 CONFIGURATION

Contact Points:



Weight = 4500 lb From equation (A.5),

$$I = [1.26\,(Wt) - 1750]\,(12) = [1.26(4500) - 1750]\,(12)$$

$$= 47{,}000 \text{ lb-in.-sec}^2$$

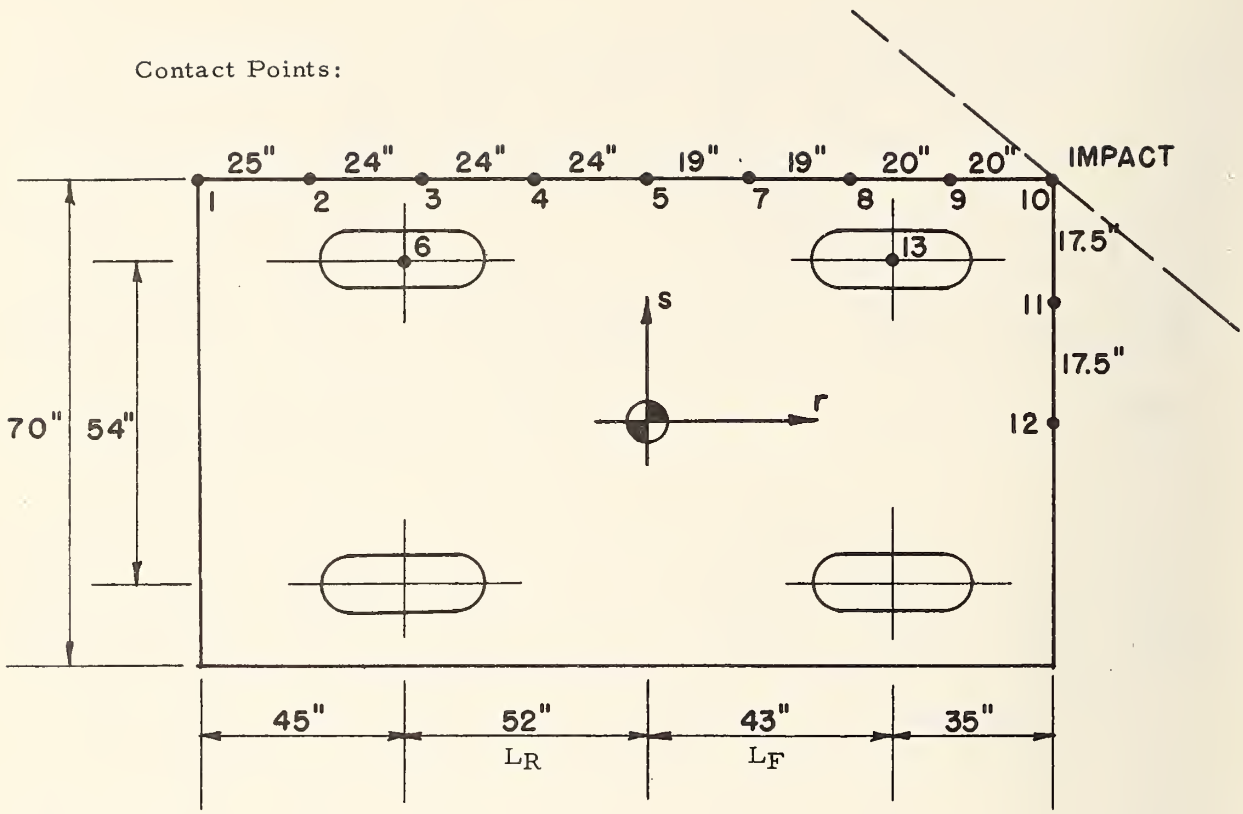
Drag forces:

$$\text{Front wheels} = \frac{Wt(L_R)\mu}{(L_F + L_R)2} = \frac{4500(67)(0.50)}{124(2)} = 608 \text{ lb}$$

$$\text{Rear wheels} = \frac{Wt(L_F)\mu}{(L_F + L_R)2} = \frac{4500(57)(0.50)}{124(2)} = 517 \text{ lb}$$

FIGURE B. 7 TYPICAL 4500-LB VEHICLE PROPERTIES

Contact Points:



Weight = 2250 lb From equation (A.6),

$$I = \frac{0.225(Wt)^{1.572}(12)}{g} = \frac{0.225(2250)^{1.572}(12)}{32.2}$$

$$= 15{,}600 \text{ lb-in.-sec}^2$$

Drag forces:

$$\text{Front wheels} = \frac{Wt(L_R)\mu}{(L_F + L_R)2} = \frac{2250(52)(0.50)}{95(2)} = 308 \text{ lb}$$

$$\text{Rear wheels} = \frac{Wt(L_F)\mu}{(L_F + L_R)2} = \frac{2250(43)(0.50)}{95(2)} = 255 \text{ lb}$$

FIGURE B. 8 TYPICAL 2250-LB VEHICLE PROPERTIES

APPENDIX C

BASIS FOR ESTIMATING VEHICLE DAMAGE

To estimate the percent of vehicle damage from the computer printer plots of the vehicle deformation as shown in Figures 1 and 2, the following procedure was used:

1. *Sheet Metal Damage.* For minor deformations that involved only the sheet metal of the vehicle, an estimate was simply made of the cost of repair or replacement, body work, touch-up paint, etc.
2. *Wheel Snagging.* From past SwRI experience of approximately 150 full-scale vehicle/guardrail tests, it has been found that A-frame damage is usually caused by vehicle wheel snagging of the posts. Thus, estimates of the dynamic deflection necessary for wheel snagging were made for each of the guardrail types. If the dynamic deflections predicted by the extrapolation runs exceeded these estimates, the loss of the A-frame was assumed and 10 percent additional vehicle damage was estimated.
3. *Windshield Damage.* The windshield of the vehicle was assumed to require replacement if the deformation in the area reached 6 inches.
4. *Body Frame Damage.* The A-pillar of the vehicle was assumed to be damaged if the deformation in the area reached 8 inches. An additional damage of 10 percent was estimated if this occurred.
5. *Radiator Damage.* The vehicle radiator was assumed to be damaged if the deformation of the left front side of the vehicle reached 20 inches. An additional 5 percent damage was used for this case.
6. *Total Damage.* Total vehicle damage was set at 80 percent. It was assumed that 20 percent of the vehicle price could be recovered in the salvage value.

APPENDIX D

DETERMINATION OF PROBABILITIES

To determine the probabilities of the various impact conditions, the average curve for distribution of lateral displacements from Figure 5 and the distribution of impact speeds from Figure 6 were first assumed. It then became necessary to determine the distributions of vehicle speeds and impact angles corresponding to the selected category values.

To determine the angle of impact with the minimum radius of turn of the vehicle (i.e., with saturation of the side force capabilities of the front tires), the point mass approach investigated by Ross(24) was used. Ross found that the point mass model predicted the impact angle quite accurately, at least for the extreme steering maneuvers and for lateral distances up to about 40 feet. For the model, the maximum available side force is $F_f = \mu W$, where μ is the coefficient of friction and W is the weight of the vehicle. As the point mass corners in a circular turn with no pavement superelevation, the centrifugal force $F_c = ma = [W/g(v^2/r]$, where v is the vehicle velocity and r is the radius of turn. Setting the two forces equal and solving for the minimum radius of turn yields

$$r_{\min} = \frac{v^2}{g\mu} \tag{D.1}$$

As done by Ross, a coefficient of friction of 1.0 was selected to represent a limiting value.

In using the point mass model, it was possible to easily extend the considerations to include horizontal curves. Figure D.1 illustrates the conditions for a straight section of highway. From simple geometric considerations,

$$\begin{aligned} r &= \sqrt{\left(r_{\min} - \frac{w}{2}\right)^2 + a^2} \\ \sin D &= \frac{a}{r} \\ \cos B &= \frac{r_{\min} - L_T}{r} \\ \theta &= C = B - D \end{aligned} \tag{D.2}$$

For the positive degree of curve shown in Figure D.2, values of r and D given in equation (D.2) still apply. From the geometric relationships

$$\begin{aligned} R \sin A &= r \sin B \\ R \cos A + r \cos B &= R - L_T + r_{\min} \end{aligned} \tag{D.3}$$

the values of angles A and D and the impact angle θ are computed as

$$\begin{aligned} \sin A &= \frac{r \sin B}{R} \\ \cos B &= \frac{(R - L_T + r_{\min})^2 - R^2 + r^2}{2(R - L_T + r_{\min})r} \end{aligned} \tag{D.4}$$

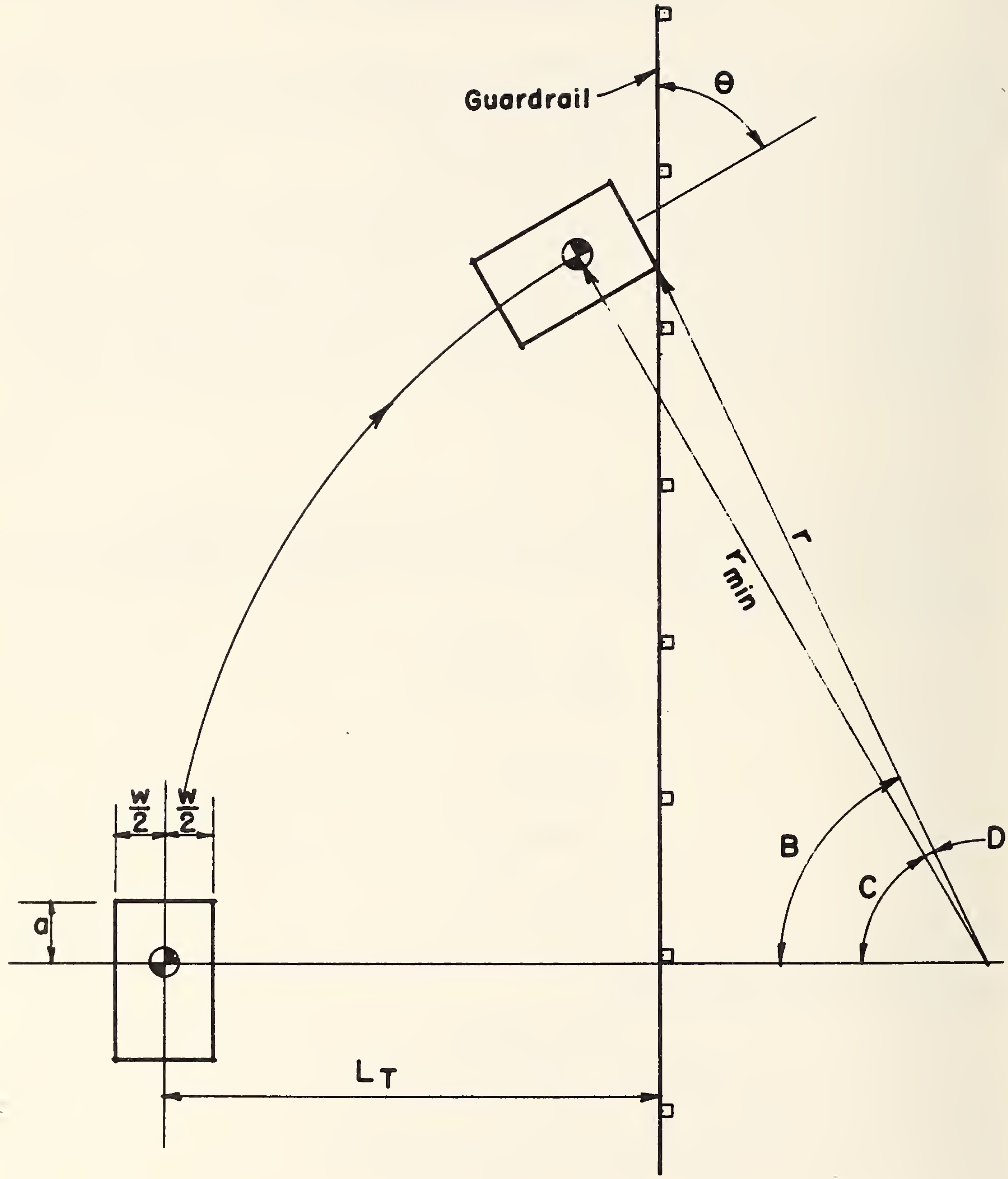


FIGURE D.1. POINT MASS CONDITIONS FOR STRAIGHT ROAD

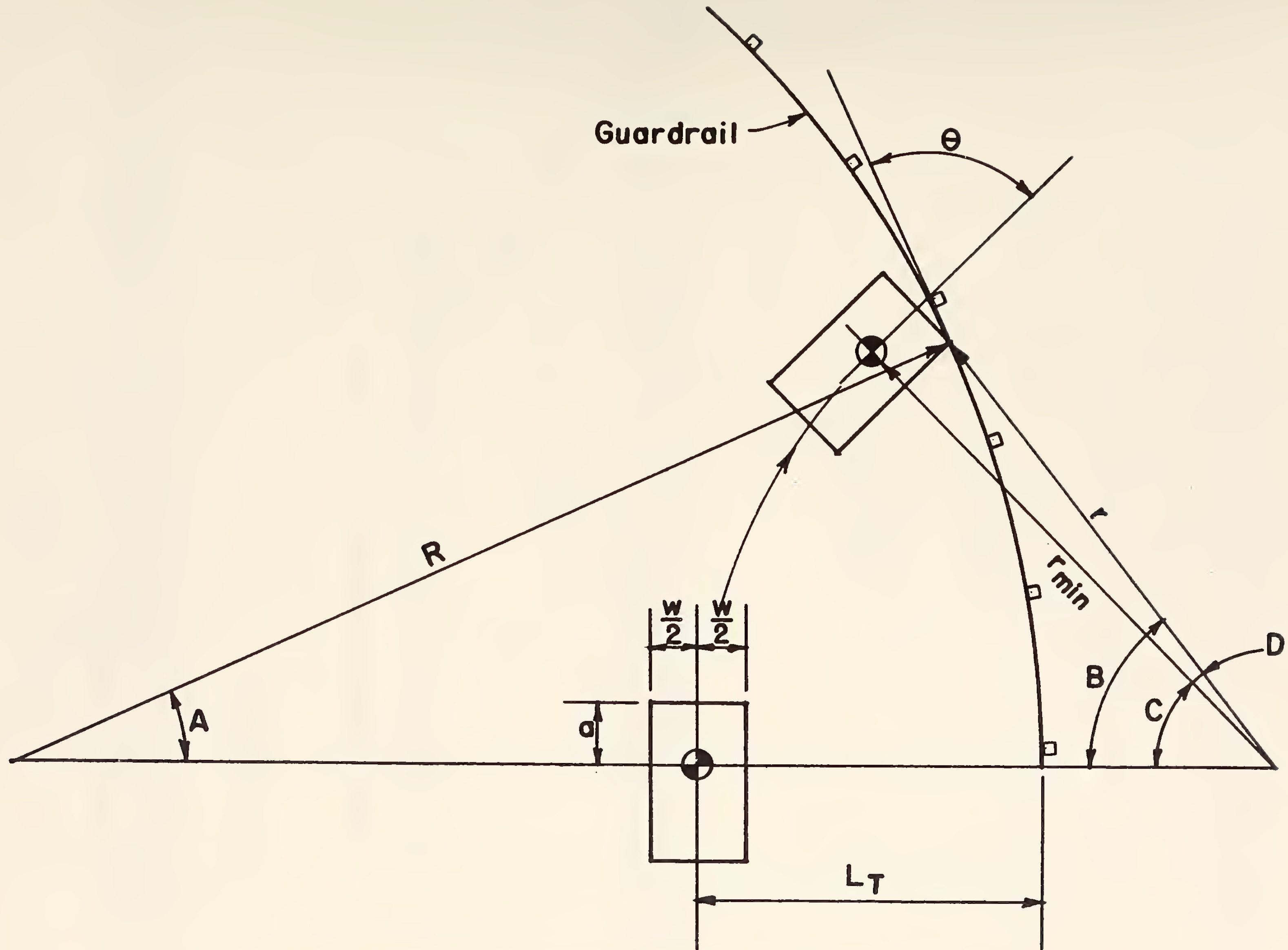


FIGURE D.2. POINT MASS CONDITIONS FOR POSITIVE DEGREE OF CURVE and

$$\theta = A + C = A + B - D$$

Similarly, from Figure D.3 for a negative degree of curve, the conditions

$$R \sin A = r \sin B$$

$$R \cos A - r \cos B = R + L_T - r_{\min} \tag{D.5}$$

yield

$$\sin A = \frac{r \sin B}{R}$$

$$\cos B = \frac{R^2 - (R + L_T - r_{\min})^2 - r^2}{2(R + L_T - r_{\min})r} \tag{D.6}$$

and

$$\theta = C - A = B - D - A$$

Based on 135 field observations, Ross concluded that the distribution of impact angles for median encroachments could be approximated by a normal distribution.[24] It was assumed that a normal distribution would also be applicable for this study. For this distribution,

$$\theta_P = \sigma X_P + \beta \tag{D.7}$$

where

θ_P = impact angle for equal to or less than cumulative probability P

σ = standard deviation

X_P = parameter such that area under normal curve from $-\infty$ to $X_P = P$

and

β = mean of distribution.

The angles θ discussed above, as determined from the offset distance L_T to the center of lane 1, were assumed to be the 95 percentile value of the impact angle, and zero degrees was assumed near the zero percentile value. From the normal distribution tables, corresponding values of X are X_0 = -4.00 and X_{95} = 1.65. Then, from equation (D.7), $\theta_0 = 0 = -4.00\,\sigma + \beta$, which yields

$$\sigma = \frac{\beta}{4.00} \tag{D.8}$$

Also, $\theta_{95} = \theta = 1.65\,\sigma + \beta$, which, when combined with equation (D.8), gives

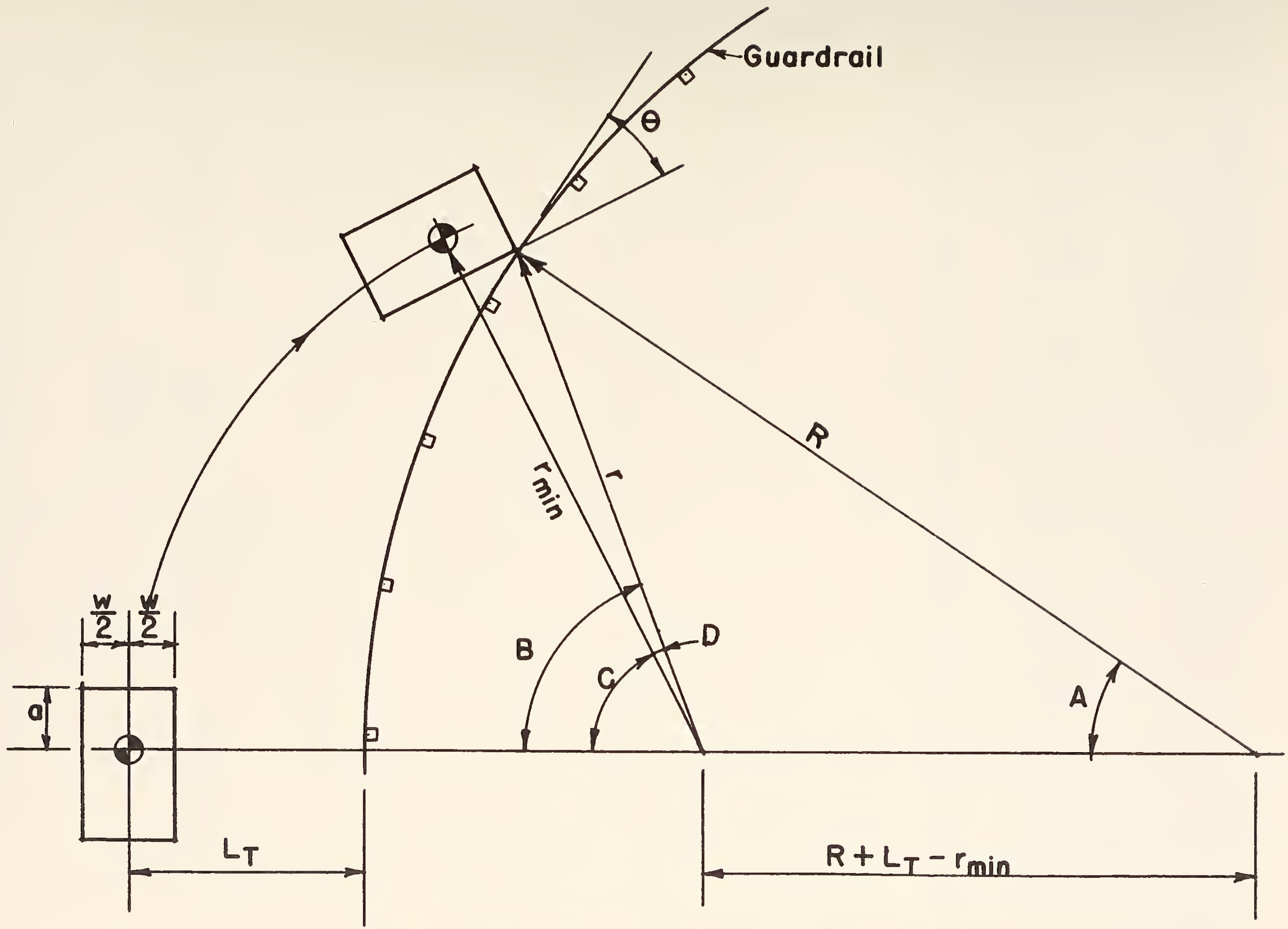


FIGURE D.3. POINT MASS CONDITIONS FOR NEGATIVE DEGREE OF CURVE

$$\beta = \frac{\theta}{1.4125} \qquad \text{(D.9)}$$

The various distributions of vehicle speed, offset distance, and impact angle were finally multiplied together to yield the combined probabilities. In the program, vehicle dimensions of a = 7 feet and w = 6 feet were used, and values of X were computed by a fifth degree polynomial approximation.

APPENDIX E

TRAFFIC DELAY TIME

The estimation of traffic delay time (vehicle hours) due to traffic congestion caused by guardrail accidents and repair involves queuing theory. A modified version of the shock wave method for queuing in uninterrupted flow, as described by Curry,[14] was assumed to provide a reasonable estimate of the delay time for various road types and partial lane blockage durations. In addition to queuing delay, it was assumed that traffic speed would be reduced to 20 mph and that "gawkers" from the opposite direction would slow to 30 mph for an average length of one-half mile while the lane was blocked by the damaged vehicle. A speed of 35 mph for the half-mile section in one direction only was assumed during the guardrail repair. The steps used in the formulation were as follows:

(1) Determine highway capacity of each section. Figure E.1 is a diagram of the highway situation. The capacity of each section was computed by[31]

$$C = 2000\ NWT$$

where

N = number of lanes

W = width factor (1.0 was used)

and

T = truck factor (0.88 was used corresponding to 14 percent trucks[14].

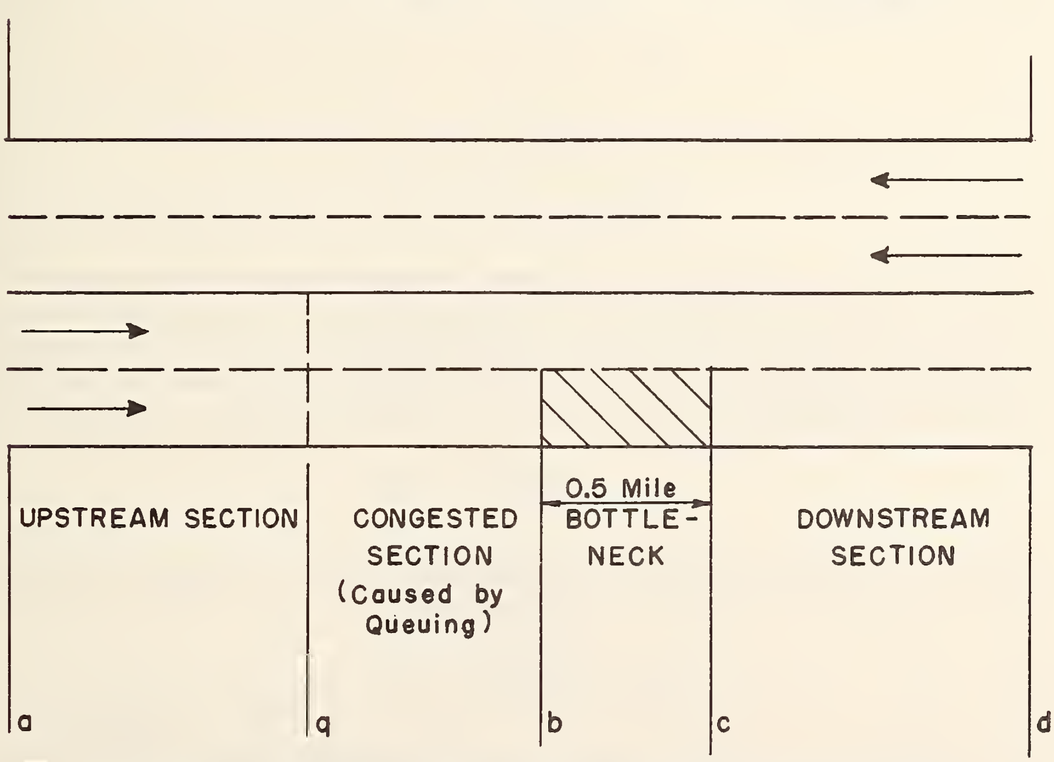


FIGURE E.1. DIAGRAM OF HIGHWAY UNDER QUEUING CONDITIONS

The resulting one-way capacities were as follows:

Road Type	Capacities (vehicles/hour) Section ab	Section bc
2-lane rural	880	220
3-lane rural	1760	880
4-lane rural and freeway	3520	1760
6-lane freeway	5280	3520
8-lane freeway	7040	5280

(2) Determine hourly traffic demand *AHT*. On omitting 8 hours of light night traffic, 16 hours were used instead of 24 to average out peak traffic amounts. Thus, the average hourly traffic demand was estimated by

$$AHT = AADT/16 \tag{E.2}$$

(3) Determine demand/capacity D/C ratios and check for queuing. The demand/capacity for each section was computed by

$$D/C = AHT/C \tag{E.3}$$

If D/C_{bc} was greater than 1, service condition F existed during blockage and queuing occurred in section qb of Figure E.1.

(4) Determine volume/capacity V/C for each section. The values of V/C were set equal to the corresponding values of D/C if no queuing occurred. For the case of queuing, the values were computed by

$$\begin{aligned} V/C_{aq} &= D/C_{aq} \\ V/C_{qb} &= C_{bc}/C_{ab} \\ V/C_{bc} &= 1.00 \end{aligned} \tag{E.4}$$

(5) Calculate average speed S for each section. These values were computed from the curves shown in Figure E.2. The 60-mph curve was assumed for freeways and the 50-mph curve for rural roads. The Level F curve was used for the speed in section qb if queuing occurred.

(6) Check for queuing caused by reduced speeds. For the reduced speeds at the accident site, the capacity was determined by

$$C_r = C_{aq}(S_r)/S_{aq} \tag{E.5}$$

where S_r = 20 mph and 30 mph for the accident and S_r = 35 mph for the repair. The demand/capacity at the site was computed by

$$D/C_{bc} = AHT/C_r \tag{E.6}$$

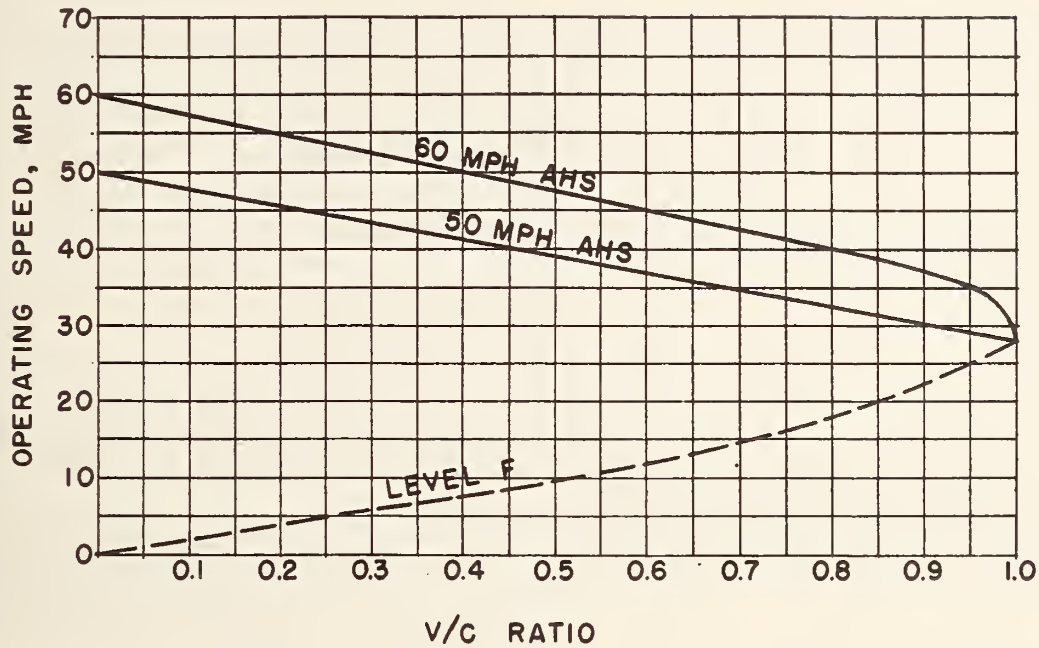
which indicated no queuing for $D/C_{bc} \leqslant 1$ and queuing for $D/C_{bc} > 1$. For queuing, the V/C ratios were computed by

$$V/C_{qb} = C_r/C_{qb}$$

and (E.7)

$$V_{bc} = V/C_r = 1.00$$

and the speed S_{qb} was computed from the Level F curve of Figure E.2.



Ref: HCM

FIGURE E.2. FREEWAY RUNNING SPEEDS OF PASSENGER CARS

The next four steps apply only for the queuing condition.

(7) Determine the rate of queuing R_q in vehicles per hour by

$$R_q = AHT - C_{bc} \tag{E.8}$$

(8) Determine the density of vehicles dV in vehicles per mile for each section by

$$dV_{aq} = AHT/S_{aq}$$

$$dV_{qb} = C_{bc}/S_{qb} \tag{E.9}$$

$$dV_{bc} = AHT/S_{bc}$$

(9) Determine the change in density dd in vehicles per mile from upstream to congested section by

$$dd = dV_{qb} - dV_{aq} \tag{E.10}$$

(10) Determine the average queue length L_q in miles by

$$L_q = T(R_q)/2(dd) \tag{E.11}$$

where T is the estimated time in hours to remove the damaged vehicle or to repair the guardrail. For no queuing,

$$L_q = 0.$$

(11) The total delay time (vehicle hours) caused by blockage of the damaged vehicle was computed by

$$T_b = C_{bc}T\left[L_q\left(\frac{1}{S_{qb}} - \frac{1}{S_{aq}}\right) + L_{bc}\left(\frac{1}{S_{bc}} - \frac{1}{S_{aq}}\right)\right] \tag{E.12}$$

Similarly, the delay caused by repair of the guardrail was computed by

$$T_m = C_{bc}T_r\left[L_q\left(\frac{1}{S_{qb}} - \frac{1}{S_{aq}}\right) + L_{bc}\left(\frac{1}{S_r} - \frac{1}{S_{aq}}\right)\right] \quad . \tag{E.13}$$

Note that $L_q = 0$ in these equations when no queuing occurred. Further, when the assumed site speed S_r became greater than the operating speed S_{aq} at the higher values of *AADT*, no delay time was assumed.

In order to estimate the societal costs due to these traffic delays, it was necessary to estimate the percentage of vehicles that deflected back on to the roadway after a guardrail hit. The historical data generated by Lampela,[23] who derived a table of these percentages as a function of impact angle, was used for this purpose. Table E.1 shows the data extracted from this reference, with the ranges of impact angles reduced to the four category values used in this study.

TABLE E.1. PERCENTAGE OF VEHICLES REDIRECTED TO ROADWAY AS A FUNCTION OF THE IMPACT ANGLE

Range (deg)	Category Value (deg)	Percent of Redirected Vehicles
0 to 10	7	32
11 to 20	15	22
21 to 30	25	18
30 and over	30	14

APPENDIX F

INSTRUCTIONS TO ACCIDENT INVESTIGATION TEAMS

"The Development of a Cost-Effectiveness Model for Guardrail Selection," Federal Highway Administration Contract No. DOT-FH-11-8827

1. Task Objective and Scope

The objective of this contract is to develop a cost-effectiveness model for guardrail selection that will include cost parameters for various guardrail configurations as well as criteria for analysis of system effectiveness under various dynamic impact conditions. The effectiveness of the selected guardrail systems for the various impact conditions will be performed at SwRI and will be based on available full-scale test data and extrapolations thereof. The purpose of your work will be to collect reconstructed data on actual accident situations that can then be used to check the predicted effectiveness and verify the model validity. As such, SwRI is primarily interested in the impact conditions, the guardrail details, and an indication of the accident severity (i.e., property damage only, injuries, or fatalities). Detailed analyses of the injuries are not required, and specific injuries sustained by occupants need not be identified. Rather, your emphasis should be placed on specifying the geometric and environmental factors associated with the accident, assessing the damage to the vehicle and guardrail, and supplying basic occupant data.

Your reconstructions should take the form of on-site investigations of the actual accidents whenever possible, but may be obtained in part through the use of supplemental police reports and contact with your local highway engineers. In any event, of course, police cooperation is an important and critical aspect of this task.

A completed case will consist of the following:

(1) A legible copy of the accident report
(2) A completed copy of the vehicle description field form
(3) A completed copy of the occupant description field form
(4) A completed copy of the environmental description field form
(5) Photographs that adequately describe the environmental and vehicular post crash conditions.

2. General Comments

Accident reconstruction is scheduled to begin on October 15, 1975, and extend to October 1, 1976. During this time period a project total of approximately 100 cases are to be completed. The expected distribution of guardrail types between the teams is shown in Table F.1. General details of the various types are shown in Table F.2. At the start, there is no restriction on the type of guardrail on which you may report as long as it is one of the 11 types shown in Table F.2.

Certain critical periods will exist during the data collection. In the early stages, it may be necessary to make certain changes in the report form or instructions in order to maintain a level of report consistency between the various teams. In the latter stages of the data collection, it will be necessary for SwRI to promptly inform all teams that a representative number of reports have been received for a particular guardrail type and that no more reports are to be made for that type. To help alleviate this latter problem, the teams collecting data will be asked to contact SwRI for an assigned case number for each individual case that is to be reported. SwRI will then know the exact number of cases reported or to be reported on each type of guardrail. Send the completed cases to SwRI as quickly as possible, preferably within two weeks after notification.

TABLE F.1. SUMMARY OF GUARDRAIL SYSTEMS BY ACCIDENT INVESTIGATION TEAM

Accident Investigation Team	Guardrail Design	Beam[a]	Height to Top of Beam (in.)	Post[b]	Post Spacing (ft-in.)
1. Southwest Research Institute San Antonio, Texas	A	W-beam	27	7" dia (W)	12'-6"
	G4S	W-beam (B.O.)	27	W6 X 8.5 (S)	6'-3"
2. University of New Mexico Albuquerque, New Mexico	B	W-beam (B.O.)	27	8" dia (W)	6'-3"
3. University of Southern California Los Angeles, California	C	W-beam (B.O.)	27	8 X 8 (W)	12'-6"
	G4W	W-beam (B.O.)	27	8 X 8 (W)	6'-3"
	D	W-beam (B.O.)	27	6 X 8 (W)	6'-3"
4. University of Miami Miami, Florida	G2	W-beam	30	S3 X 5.7 (S)	12'-6"
	G4S	W-beam (B.O.)	27	W6 X 8.5 (S)	6'-3"
5. Pennsylvania Team University Park, Pennsylvania	G3	Box beam	30	S3 X 5.7 (S)	6'-0"
	E	W-beam (B.O.)	27	Charley	6'-3"
6. Calspan Corporation Buffalo, New York	G1	3-3/4" cables	30	S3 X 5.7 (S)	16'-0"
	G3	Box beam	30	S3 X 5.7 (S)	6'-0"

[a](B.O.)–beam blocked-out from post.
[b]Post material code–(C)–concrete, (S)–steel, (W)–wood.

Send the completed reports to:

Tom Swiercinsky, Dept. 11
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78284

If problem areas exist, contact:

Tom Swiercinsky (512) 684-5111, ext. 2631
Lee R. Calcote (512) 684-5111, ext. 2408

Send your statement with the completed report. In submitting these statements, please show your cost breakdown (salary, travel, supplies, overhead, etc.).

Refer to SwRI Project No. 03-4309-003.

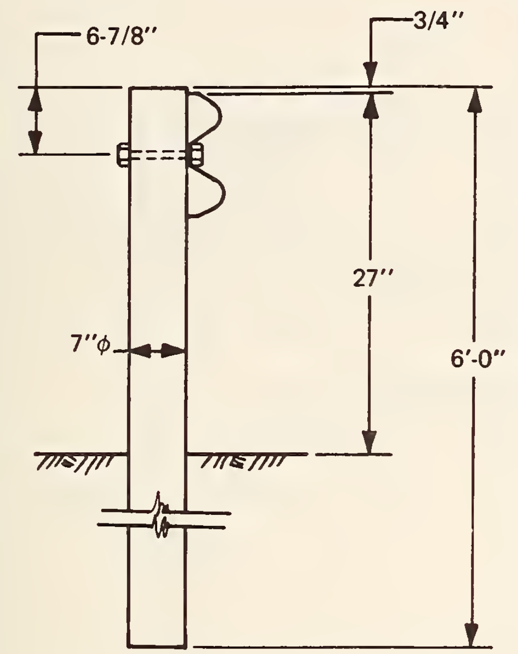
3. Investigation Criteria

The primary interest in this contract is passenger vehicle impact on the main sections of selected guardrail systems without curbs. Thus, on investigating a particular accident, report ONLY those accidents that meet the following criteria:

Environment

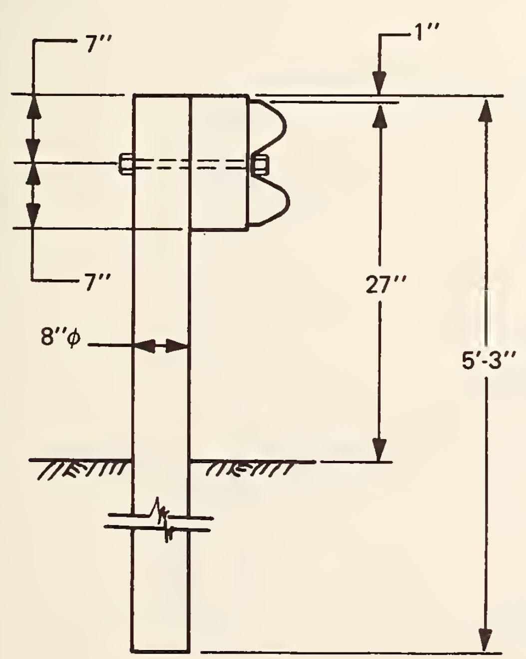
(1) The guardrail type must be one of those identified in Tables F.1 and F.2.
(2) There can be no curbs between the guardrail and the edge of the pavement.
(3) The guardrail beam heights must not vary from the nominal heights shown in Table 2 by more than plus or minus 3 inches.

TABLE F.2. GUARDRAIL TYPES



DESIGN A

Beam:	12 ga. W
Post:	7-in. dia wood
Post Spacing:	12 ft -6 in.
Bolt:	1/4-in. dia (pipe insert in post)

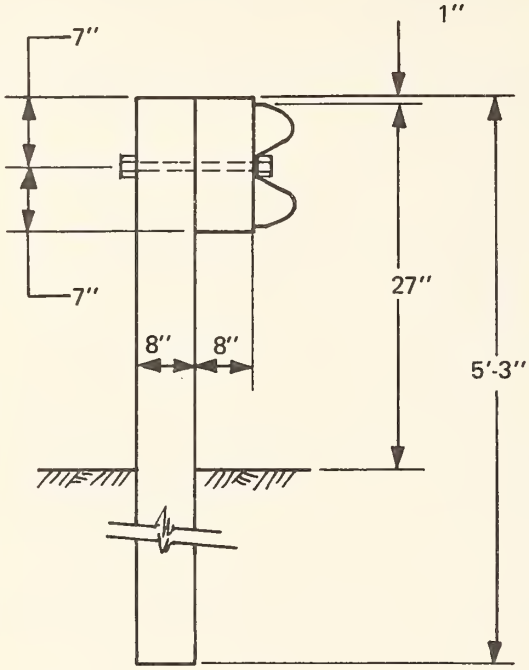


DESIGN B

Beam:	12 ga. W
Blockout:	8 X 8-in. wood
Post:	8-in. dia wood
Post Spacing:	6 ft -3 in.
Bolt:	5/8-in. dia

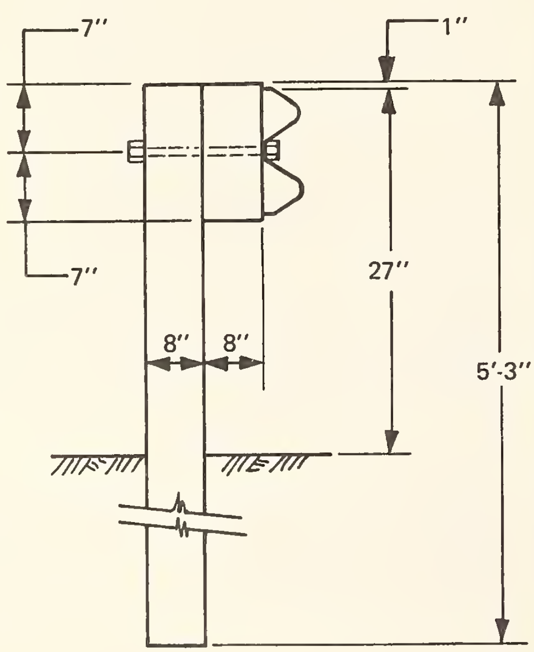
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE F.2. GUARDRAIL TYPES (Cont'd)



DESIGN C

Beam:	12 ga. W
Blockout:	8 X 8-in. wood
Post:	8 X 8-in. wood
Post Spacing:	12 ft -6 in.
Bolt:	5/8-in. dia

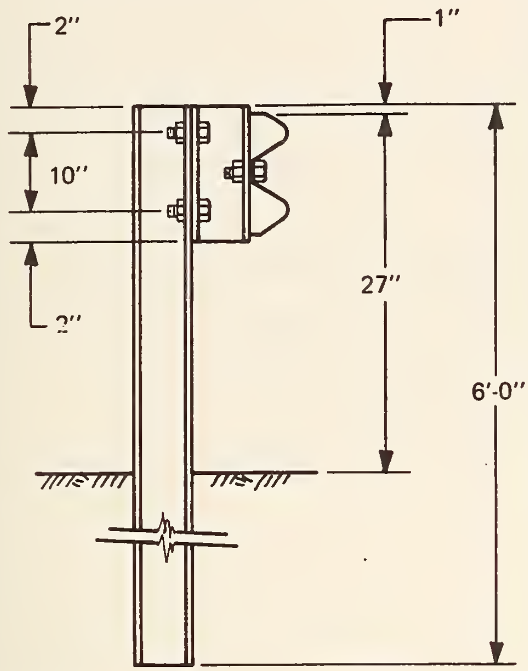
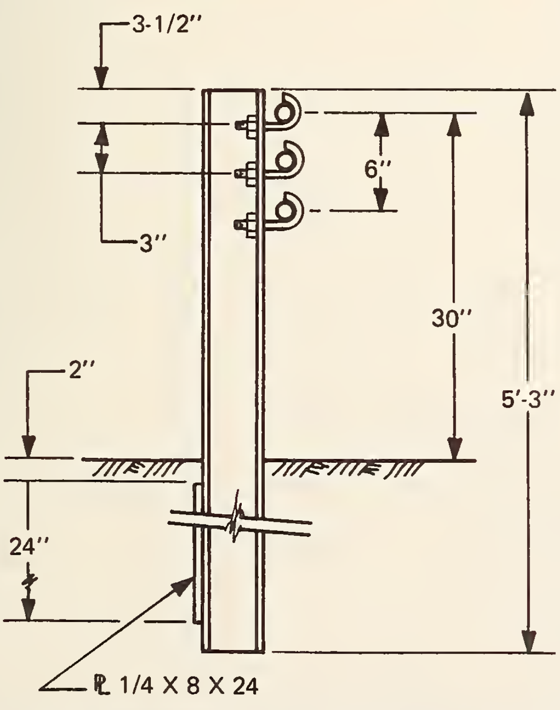


DESIGN D

Beam:	12 ga. W
Blockout:	6 X 8-in. wood
Post:	6 X 8-in. wood
Post Spacing:	6 ft -3 in.
Bolt:	5/8-in. dia

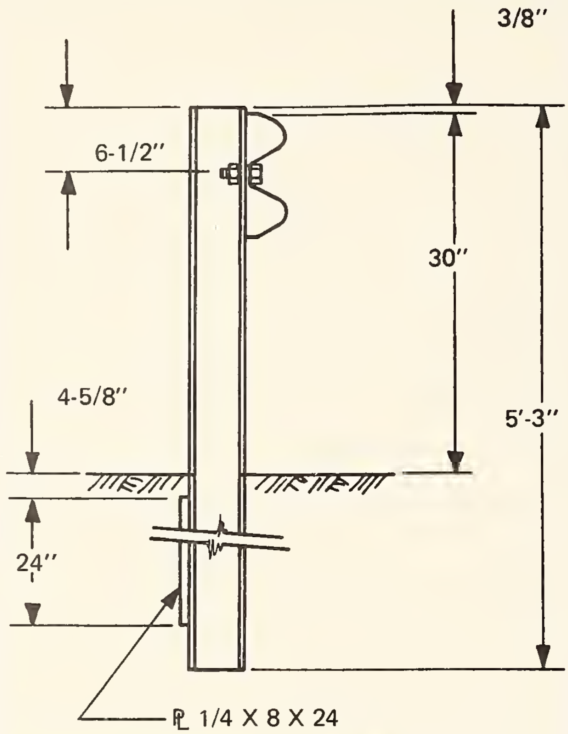
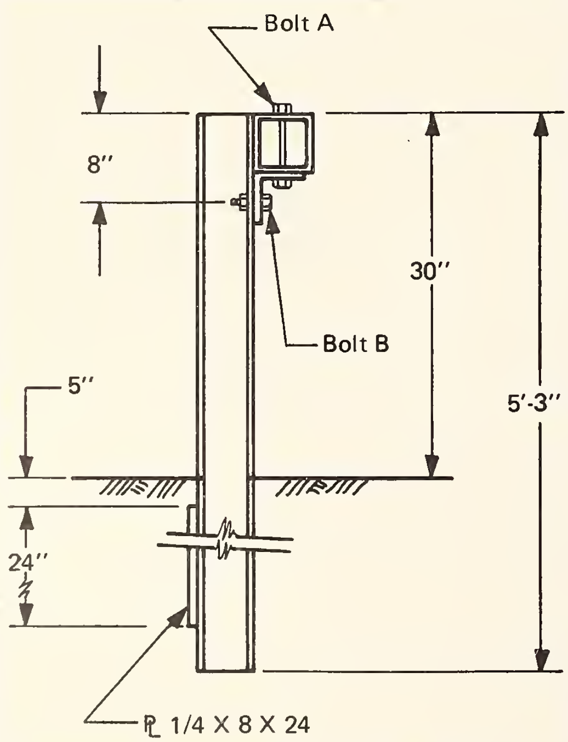
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE F.2. GUARDRAIL TYPES (Cont'd)

	DESIGN E Beam: 12 ga. W Blockout: Charley Post: Charley Post Spacing: 6 ft-3 in. Bolts: 5/8-in. dia
	DESIGN G1 Beam: 3-3/4-in. cables Post: S3 X 5.7 Post Spacing: 16 ft-0 in. Hook Bolts: 5/16-in. dia

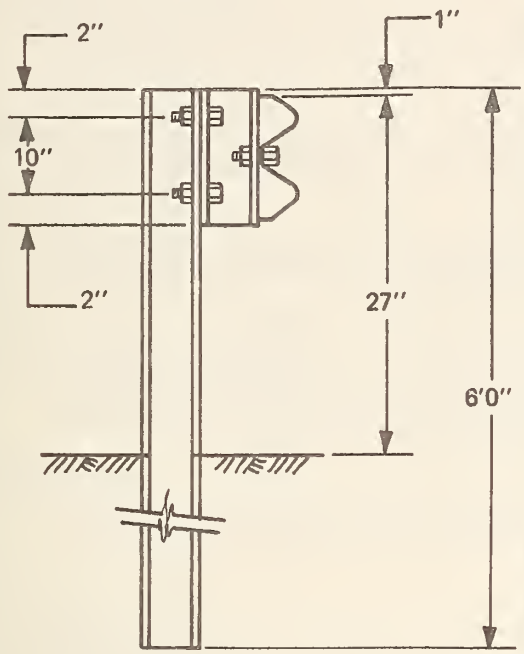
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE F.2. GUARDRAIL TYPES (Cont'd)

	DESIGN G2 Beam: 12 ga. W Post: S3 X 5.7 Post Spacing: 12 ft-6 in. Bolt: 5/16-in. dia
	DESIGN G3 Beam: TS6 X 6 X 0.1875 Post: S3 X 5.7 Post Spacing: 6 ft-0 in. Bolt A: 3/8-in. dia Bolt B: 1/2-in. dia

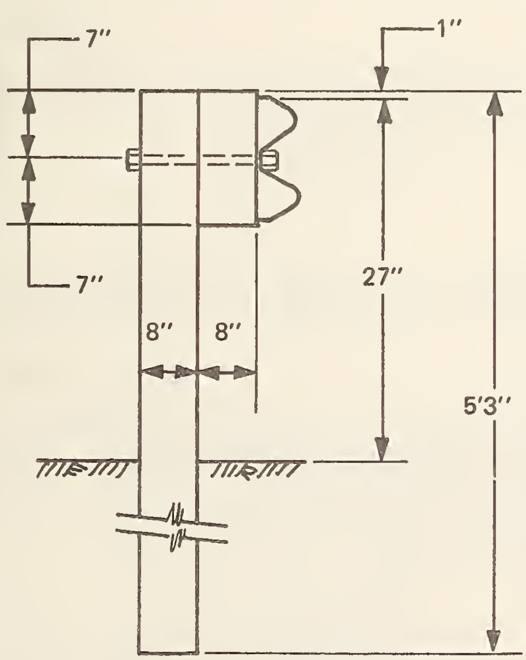
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE F.2. GUARDRAIL TYPES (Cont'd)



DESIGN G4S

Beam:	12 ga. W
Blockout:	W6 X 8.5
Post:	W6 X 8.5
Post Spacing:	6 ft-3 in.
Bolts:	5/8-in. dia

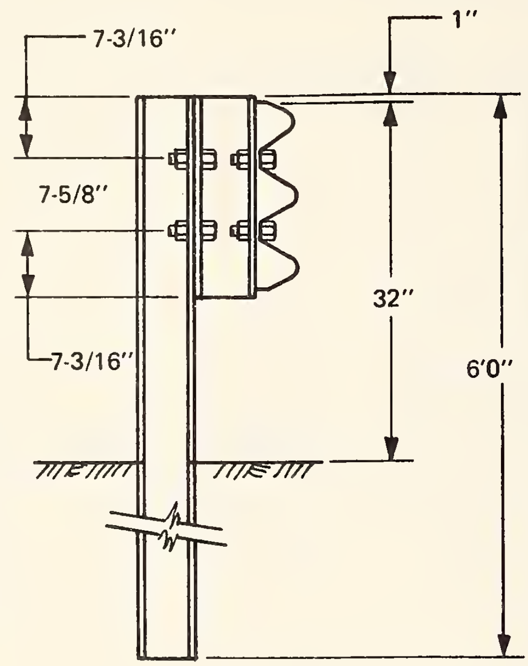


DESIGN G4W

Beam:	12 ga. W
Blockout:	8 X 8-in. wood
Post:	8 X 8-in. wood
Post Spacing:	6 ft-3 in.
Bolt:	5/8-in. dia

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE F.2. GUARDRAIL TYPES (Cont'd)



DESIGN THRIE

Beam:	12 ga. Thrie
Blockout:	W6 X 8.5
Post:	W6 X 8.5
Post Spacing:	6 ft-3 in.
Bolts:	5/8-in. dia

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

(4) Impacts must occur in the main sections of the guardrail. Accidents involving impacts on end or transition sections of the guardrail are not to be reported.

Vehicle

(5) The vehicle must be a passenger automobile. From the vehicle code contained in this transmittal, the last two digits of the vehicle five digit code must be 01 through 10, 17, 18, or 19.
(6) The vehicle must not be towing a trailer.
(7) The first impact of the case vehicle must be with the appropriate main section of the guardrail. Consequently, multiple-vehicle accidents are not to be reported unless the secondary vehicle was involved as a result of the primary vehicle's trajectory after impact with the guardrail.

4. Accident Report Forms

The accident report forms are attached. A portion of the required information pertains to highway, guardrail, and vehicle features that are not provided by law enforcement traffic accident reports. Thus, several field measurements, an interview with a vehicle occupant, and possible contact with the investigating police officer and state highway engineers will be required.

Instructions and comments for completing the accident forms follow.

INSTRUCTIONS FOR COMPLETION OF THE FIELD FORM – ENVIRONMENTAL DESCRIPTION

- Accident Report No.:
  The number of the accident report that was assigned by the investigating officer, if appropriate.

- Date of Accident:
  Record month, day, and year of accident as recorded on accident report.

- Time of Accident:
  Use the 24-hour clock to record approximate time of case accident.

- Highway Type and No.:
  Identify the highway type (IS = interstate, SH = state highway, FM = farm-to-market road, etc.) and number where the accident occurred.

- Speed Limit:
  The speed limit for the section of the roadway where the accident occurred, either posted or unposted.

- Accident Area:
  Code (1) – urban
  (2) – rural
  (3) – unknown

- Locality:
  Code (1) – manufacturing or industrial
  (2) – shopping or business
  (3) – apartments
  (4) – school or playground
  (5) – residential
  (6) – farm
  (7) – undeveloped
  (0) – unknown

- Roadway Type:
  Code (01) – 2-way, expressway, divided
  (02) – 2-way, expressway, not divided
  (03) – 2-way, multilane, divided
  (04) – 2-way, multilane, not divided
  (05) – 2-way, single lane (each way)
  (06) – 1-way, multilane
  (07) – 1-way, single lane
  (08) – entrance or exit ramp
  (98) – not applicable
  (99) – other____________________
  (00) – unknown

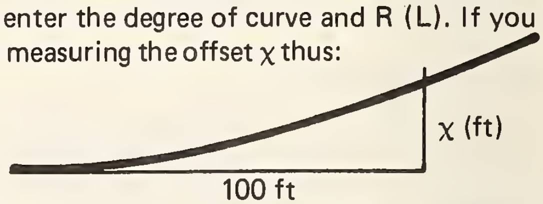
- Type of Road Surface:
  - Code (1) – asphalt, bituminous concrete
  - (2) – concrete
  - (3) – gravel
  - (4) – more than one type
  - (5) – other____________________
  - (0) – unknown

- Road Surface Condition:
  - Code (01) – dry
    - water:
      - (02) – damp
      - (03) – wet
      - (04) – puddled
      - (05) – unknown amount
    - snow:
      - (06) – loose
      - (07) – packed
      - (08) – condition unknown
  - (09) – ice
  - (10) – slush
  - (11) – spilled gravel
  - (12) – other
  - (00) – unknown

General Site Conditions

- Number of traffic lanes: Record the actual number of traffic lanes in the direction of traffic. On a typical two-lane rural highway, enter 1.
- Average lane width: Record in feet-inches the average width of the traffic lanes.
- Lane in which case vehicle was traveling: Record the lane number starting with right outside lane as No. 1.
- Distance from edge of pavement to barrier: Record the distance in feet-inches from the right edge of Lane No. 1 to the face of the guardrail.
- Horizontal curve: Indicate degree of curve and direction at point of impact. If curve bends to right (left) in the direction of traffic, enter the degree of curve and R (L). If you desire, you can determine the degree of curve by measuring the offset χ thus:

$$\text{Degree of Curve } D = \frac{2\chi(5729.58)}{\chi^2 + 10{,}000}$$



- Grade: Enter percent of grade at point of impact and + (–) if roadway elevation is increasing (decreasing) in the direction of traffic. If appropriate, indicate "crest" or "dip".
- Roadway cross-section: In the space provided, prepare a detailed sketch of the roadway cross-section at the point of impact. Show horizontal distances and slopes of pavement, shoulders, ditches, etc. Show the vertical distance from the edge of the pavement to the ground at the guardrail.

Guardrail Design Information

- Guardrail type: Enter the guardrail design shown in Tables 1 and 2.

- Guardrail length: If the guardrail is greater than 200 feet long, enter 200+. If not, indicate the measured length in feet-inches.
- Post spacing: Record the center-to-center spacing of the guardrail posts in feet-inches at an undamaged portion of the guardrail.
- Distance to top of railing: Record in inches the vertical measured distance from the top of the guardrail railing to the ground at an undamaged portion of the guardrail.
- Post and block-out descriptions: Record type of material and shape (square, round, rolled section). Consider width dimension parallel and depth dimension perpendicular to roadway. If possible, record post length by measuring post that has pulled out of the ground.
- Railing description: Enter as W-section, box beam (TS6 X 6), or Thrie beam. Record gauge or material thickness.

Impact Conditions

- Estimated impact speed and angle: These measurements are essential as inputs for the computer simulation of the impact. Do your best through inspection of the site and discussions with the driver and/or inspecting police officer to estimate these quantities as accurately as possible.
- Distance from initial impact point to upstream end of guardrail: Consider "upstream" as opposed to the direction of traffic. If the impact point is greater than 50 feet from the upstream end of the guardrail, enter 50+. If not, record the actual distance in feet-inches.
- Distance from initial impact point to first upstream post: Record in feet-inches the distance from the initial impact point to the original location of the first upstream post.

Guardrail Damage

- Maximum permanent guardrail deflection: Measure and record in inches the maximum permanent deflection of the guardrail caused by the impact. If the railing ruptured or the guardrail was pushed over by the impact, so state.
- Location of maximum deflection: Record the distance in feet-inches from the initial impact point to the point of maximum guardrail deflection.
- Length of rail damaged: Measure and record the length of damaged railing that will probably require replacement by the maintenance crews.
- Number of posts damaged: Inspect the damaged guardrail and indicate the condition of the posts. For example, an upstream entry of 4L-2R would indicate 4 leaning posts that might be reusable by pushing them back to the vertical position, followed by 2 posts that are ruptured or completely pulled out of the soil and would require replacement. Describe downstream posts in a similar manner.

Guardrail Performance Appraisal

These are general yes-no types of questions that will indicate the general effectiveness of the guardrail system.

Desired Photographic Coverage

Because of their value in supplementing the reported data, plan to include several photographs with your reports. Keep in mind that SwRI is interested in appraising guardrail and vehicle damage, and photographs that clearly depict damage details will greatly enhance the completeness of the reports. Include general shots showing the broad area of the accident site. Take close-up views showing damage to the guardrail railing and posts.

Cost Effectiveness
Guardrail Selection

FIELD FORM
Environmental Description

Team No. ______

Case No. ______

- Accident Report No. ______
- Date of Accident ______
- Time of Accident ______
- Highway Type and No. ______
- Speed Limit ______

- Accident Area ______
  Locality ______
- Roadway Type ______
- Type of Road Surface ______
- Road Surface Condition ______

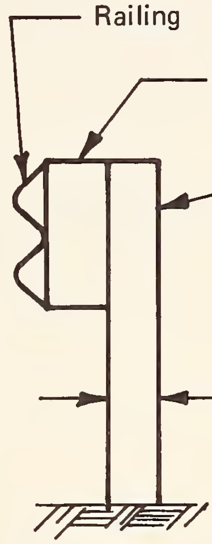
General Site Conditions

- Number of traffic lanes ______
- Average lane width (ft. -in.) ______
- Lane in which case vehicle was traveling (counting from edge of pavement) ______
- Distance from edge of pavement to barrier (ft.-in.) ______
- Horizontal curve (degrees) ______
- Grade (percent) ______
- Sketch of roadway cross-section:

Cost Effectiveness Guardrail Selection	**FIELD FORM** **Environmental Description**	Team No. ____	Case No. ____

Guardrail Design Information

- Guardrail type
- Guardrail length (if less than 200 ft.)
- Post spacing (ft.-in.)
- Distance to top of railing (in.)
- Post Description:
  - Material ____
  - Shape ____
  - Width (in.) ____
  - Depth (in.) ____
  - Length (in.) ____
- Block-out description:
  - Material ____
  - Shape ____
  - Length (in.) ____
  - Width (in.) ____
  - Depth (in.) ____
- Railing description:
  - Shape ____
  - Gauge ____



Impact Conditions

- * Estimated Heading Angle (deg) ____
- Estimated impact speed (mph) ____
- Estimated impact angle (deg) ____
- Distance from initial impact point to upstream end of guardrail (if less than 50 ft) ____
- Distance from initial impact point to first upstream post (ft.-in.) ____

Guardrail Damage

- Maximum permanent guardrail deflection (in.) ____
- Location of maximum deflection (ft.-in.) ____
- Length of rail damaged (ft) ____
- Number of posts damaged:
  - Upstream ____
  - Downstream ____

*Added 6/11/76

Cost Effectiveness Guardrail Selection	**FIELD FORM** **Environmental Description**	Team No. ______	Case No. ______

Guardrail Performance Appraisal

- Did guardrail railing rupture? If yes, describe failure briefly. ______
- Did vehicle travel on top of the guardrail? ______
- Was vehicle pocketed or snagged by the guardrail? ______
- Was vehicle redirected? If so, what was the approximate exit angle? ______
- Did vehicle roll over? If so, did it roll toward or away from the barrier? ______
- Did vehicle spin? ______

- Sketch the accident scene illustrating the precrash, crash, and post crash position of the vehicle and significant objects contacted by the case vehicle. A short narrative describing vehicle dynamics will assist SwRI to reconstruct the accident.

Narrative: ______

______

______

______

INSTRUCTIONS FOR COMPLETION OF THE FIELD FORM – OCCUPANT DESCRIPTION

One of the occupants (preferably the driver) of the case vehicle should be contacted for the following information:

- Team No.:
  - Code (01) – SwRI
  - (02) – University of New Mexico
  - (03) – University of Southern California
  - (04) – University of Miami
  - (05) – Pennsylvania
  - (06) – Calspan Corporation

- Case No:
  Two digit number assigned by SwRI upon team notification.

- Age:
  Record actual/estimated age of occupants in years.

- Weight
  Record approximate weight of individual occupants in pounds.

- Height:
  Record approximate height in inches.

- Occupant Ejection:
  Interviewer's opinion of actual ejection of the occupants after assessment of factors from vehicle inspection, interview, accident report, injuries, restraint usage, etc.

  - Code (0) – Unknown
  - (1) – Partial Ejection
  - (2) – Total Ejection
  - (3) – Not Ejected

- Occupant Injured:
  - Code (0) – Unknown if injured
  - (1) – No Injuries PIC = 0
  - (2) – Injured PIC = A, B, C
  - (3) – Fatal PIC = K
  - (4) – Injured, Severity Unknown

- Occupant Treatment:
  - Code (00) – Unknown
  - (01) – Not Injured
  - (02) – Injured but not treated
  - (03) – Taken to hospital emergency room for treatment and released
  - (04) – Admitted to hospital
  - (05) – Other

- Restraints Worn:

  This is the interviewer's assessment of restraint system usage. Factors to be considered should include but not be limited to:

  1. Restraint condition from vehicle description form
  2. Vehicle investigator's opinion of restraint usage
  3. Comments from occupant interviewer
  4. Reliability of interview
  5. Information from accident report
  6. Evidence of occupant ejection
  7. Injury pattern of the occupants
  8. Vehicle dynamics

  Code (0) — Unknown
  (1) — Lap and upper torso
  (2) — Lap belt only
  (3) — Diagonal belt only
  (4) — Passive system only
  (5) — Child restraint
  (6) — Held in lap
  (7) — None used or not applicable
  (8) — Other

  Note: When SwRI evaluates the completed case, this coded response will override information on the vehicle form, accident report, etc., if there is a contradiction.

- Traffic Conditions:

  Have person being interviewed describe traffic conditions at time of accident and record on space provided. Review of the individual cases might indicate that these accidents occur during periods of light traffic flow, etc.

- Accident Description:

  Information supplied by the driver/occupant may assist the accident reconstructionist in determining the vehicle dynamics, etc., vehicle rotation, roll over, evasive maneuvers, brake application, etc.

- Interviewer's Comments:

  The interviewer should note any unusual circumstances not covered on the accident report, vehicle form or occupant form that would affect the analysis of the case.

Cost Effectiveness
Guardrail Selection

FIELD FORM

Occupant Description

Team No. ________

Case No. ________

Seat Location	LF	CF	RF	LR	CR	RR	Other
• Age (yrs.)	____	____	____	____	____	____	________
• Weight (lb.)	____	____	____	____	____	____	________
• Height (in.)	____	____	____	____	____	____	________
• Occupant Ejection	____	____	____	____	____	____	________
• Occupant Injured	____	____	____	____	____	____	________
• Occupant Treatment	____	____	____	____	____	____	________
• Restraints Worn	____	____	____	____	____	____	________

• Traffic Conditions ____

• Accident Description (Vehicle Dynamics): ____

____

____

____

____

____

____

____

• Interviewer's Comments: ____

____

____

____

INSTRUCTIONS FOR COMPLETION OF THE FIELD FORM – VIEHICLE DESCRIPTION

- Team No.:
  Code (01) – SwRI
  (02) – University of New Mexico
  (03) – University of Southern California
  (04) – University of Miami
  (05) – Pennsylvania

- Case No.:
  Two digit number assigned by SwRI upon team notification.

- Vehicle No.:
  The number of the case vehicle as shown on the accident report.

- Vehicle Identification No.:
  Unique number for each vehicle. Variations exist in VIN locations and VIN systems used. The VIN will be used to obtain additional data on the vehicle (e.g., vehicle curb weight, etc.).

- Vehicle Make:
  Buick, Chevrolet, Ford, etc.

- Vehicle Model:
  Apollo, Impala, Mustang, etc.

- Vehicle 5 Digit Code:
  Enter number from attached vehicle code.

- Cargo Carried by Vehicle:
  Include only cargo carried in the vehicle. Do not include weight of occupants.

  Code (00) – Unknown
  (01) – 1-300 lbs
  (02) – 300-600 lbs
  (03) – 600-900 lbs
  (04) – 900-1200 lbs
  (05) – 1200-1500 lbs
  (06) – Over 1500 lbs
  (09) – Not applicable; no cargo

- Location of Cargo:

  Code (0) – Unknown
  (1) – In occupant compartment
  (2) – In trunk or rear of occupant compartment
  (3) – In front of occupant compartment
  (4) – On roof
  (9) – Not applicable

- Occupant Ejection:

  From inspection of the vehicle or from the accident report, is there indication that one of the occupants was ejected from the vehicle, either partially or completely?

  Code (0) — Unknown
  (1) — Yes
  (2) — No

- Occupant Compartment Reduced in Size:

  Code (0) — Unknown
  (1) — Yes
  (2) — No
  (3) — Not applicable

- Type Restraints:

  Code (0) — Unknown
  (1) — Active restraints
  (2) — Passive restraints
  (3) — Passive and active
  (4) — No restraints installed

- Restraints Used:

  This column indicates the investigator's opinion of restraints used for each occupant in the vehicle. From the accident report, it is not always possible to determine the number of occupants in the vehicle or the seated position of the occupants. However, from an inspection of the vehicle, factors such as restraint condition or occupant contact points can assist the investigator to determine if an occupant was present and/or if the restraint system was in use. If, after examination, the investigator determines that there was no occupant for the seated position, then Code (7) should be recorded.

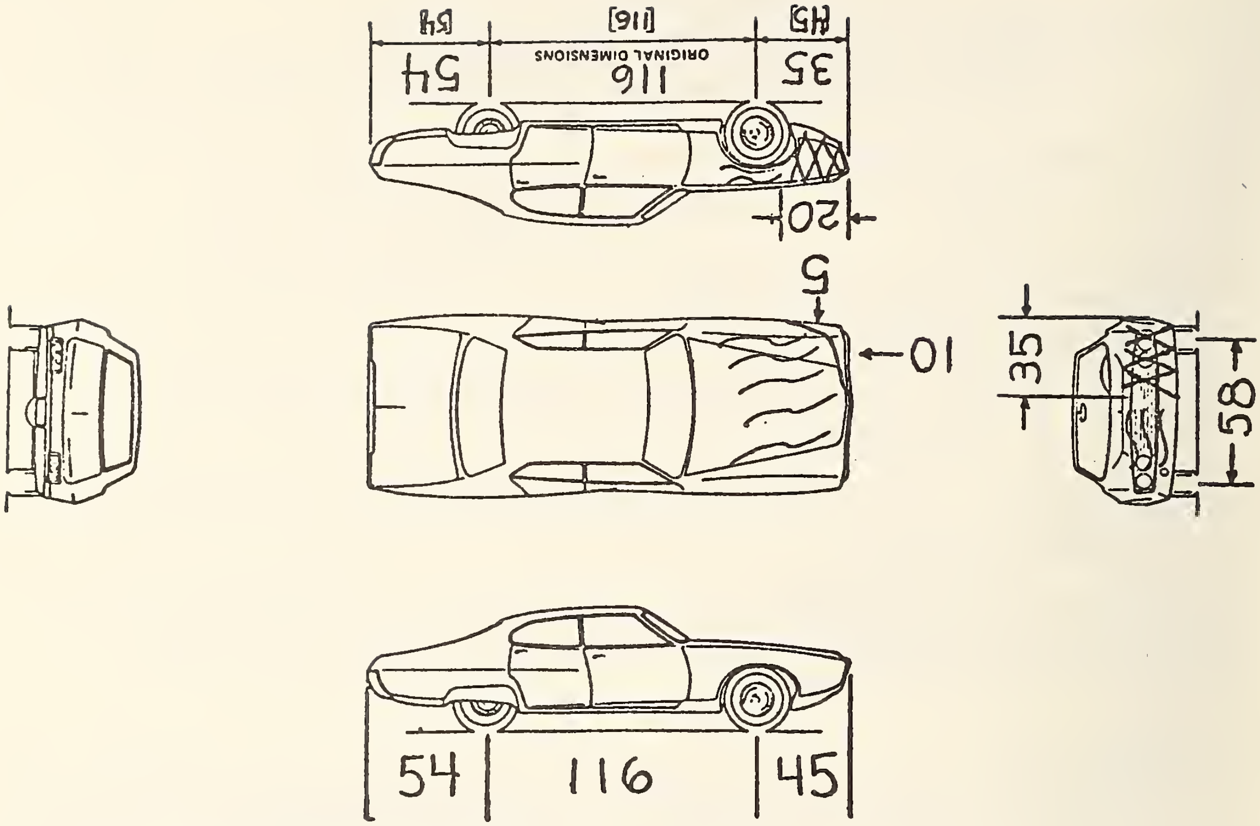
  Code (0) — Unknown if used
  (1) — Not used
  (3) — Lap only used
  (4) — Shoulder only used
  (5) — Child seat used
  (6) — Other
  (7) — No occupant for seated position
  (8) — Lap and shoulder used
  (9) — Not applicable; no belts for this position

- Interior Occupant Contact Points:

  Mark only those areas which indicate possible occupant contact. Do not show induced damage.

- Damage Sketch:

  Indicate damaged area(s) by outlining new perimeter of vehicle. Indicate direct impact damage by a series of X's and induced damage by a wavy line (~). Indicate the amount of crush in inches. The damaged areas must correspond with the assigned VDI. Also indicate the original dimensions for the wheel base, front overhang, and rear overhang for the case vehicle. The following is an example:



- Vehicle Repair/Replacement Cost:
  If this information is available from the repair garage, insurance company, or the driver, record the information. The investigator should not estimate the repair/replacement cost unless he is a qualified estimator.

- Frame Damage:
  From inspection of the vehicle, determine if the frame sustained damage from the collision.

  Code (0) — Unknown
  (1) — Yes
  (2) — No

- Objects Contacted:
  Code the appropriate objects contacted from the attached list.

- VDI:
  Use SAE Standard J224a to assign appropriate VDI.

- Inches Crush:
  The amount of crush in inches should correspond to the value shown in the damage sketch.

- Desired Photographic Coverage:
  Head-on, side view, perspective, and, if possible, overhead views of vehicle showing vehicle damage.

MAKE/MODEL CODES FOR VEHICLES

Code consists of 5 digits that identify:

1. Country of manufacture
2 & 3. Manufacturer
4 & 5. Model type

COUNTRY, CORPORATION, DIVISION (abc)

1	USA
11	General Motors Corp.
111	Buick
112	Cadillac
113	Chevrolet
114	Oldsmobile
115	Pontiac
116	GMC Truck and Coach
117	GMC Electromotive
12	Ford Motor Co.
121	Ford
122	Lincoln-Mercury
13	Chrysler Corp.
131	Chrysler
132	Dodge
133	Imperial
134	Plymouth
135	DeSoto
14	American Motors Corp.
141	American Motors
15	Other USA Corporations
151	Checker
152	Kaiser-Jeep
153	International
154	Studebaker/Avanti
155	Harley-Davidson
156	General Vehicles Corp. (Bricklin)
16	USA Truck Corp.
160	USA Truck Corp. Unknown
161	Brockway
162	Diamond-Reo
163	FWD
164	Kenworth
165	Mack
166	Peterbilt
167	White (Autocar, Freight Liner)
168	Other USA Truck Corp.
170	Unknown/Other USA Manufacturer of Special Purpose Vehicle
171	Flexible
172	Freuhauf
191	Male Pedestrian/Bicyclist
192	Female Pedestrian/Bicyclist
2	Canada
21	GM Canada*
213	Chevrolet*
214	Oldsmobile*
215	Pontiac*
22	Ford Canada*
222	Lincoln-Mercury*
3	Australia
311	GM (Holden)*

4	England
419	GM Vauxhall*
42	Ford England*
434	Plymouth (Cricket)*
45	British Leyland
451	Austin
452	Austin Healy
453	MG
454	Morris
455	Jaguar
456	Triumph
46	Rootes
482	Lotus Elan
484	Rolls Royce
488	Rover
5	France
531	Chrysler (Simca)*
551	Citroen
561	Renault
571	Peugeot
6	Germany
618	GM (Opel)*
622	Ford (Capri)*
651	Mercedes Benz
661	Volkswagon
662	Porsche
671	BMW
681	Audi
7	Italy
722	Ford of Italy*
751	Alfa-Romeo
761	Fiat
771	Ferrari
8	Japan
813	Chevrolet-Isuzu (LUV Pickup)*
832	Dodge-Mitsubishi (Colt)*
851	Toyo (Mazda)
861	Nissan (Datsun)
871	Toyota
881	Honda
882	Fuji Heavy Ind. (Subaru)
883	Suzuki
884	Kawasaki
885	Yamaha
9	Other Foreign
951	Saab (Sweden)
952	Volvo (Sweden)
000	Unknown, Missing Data

* Corporation codes 1-4 (b) are always the same from country to country, e.g., 12 = USA/Ford and 42 = England/Ford. Codes 5-9 have different definitions in each country.

MODEL TYPE (de)

Passenger Cars

01	Intermediate (GM A Body)
02	Standard/Full Size (B Body)
03	Luxury (C Body) or Limousine (D Body)
04	Mini Specialty (Mustang II)
05	Personal Luxury (E Body)
06	Specialty/Pony (F Body)
07	Specialty Intermediate (A SF Body)
08	Compact (X Body & Y Body)
09	Sub-compact/Mini-Imported (VW)
10	Super Sport (Corvette)
17	Pickup-Car (Ranchero)
18	Sub-compact/Mini-USA (H Body)
19	Foreign Sports Cars (MG)
20	Unknown Automobile Body

Size	Standard	Specialty	Sports
Mini	09, 18	04	19
Compact	08	06	10
Intermediate	01, 17	07	--
Standard	02	05	--
Luxury/Limo	03	--	--

Multipurpose Passenger Vehicle

14	Utility (Jeep, Bronco)
15	Carryall/Panel Truck
16	Pickup Truck w. Canopy/Shell Cover
17	Pickup-Car (Ranchero)
17	Pickup-Car w. Canopy/Shell Cover
21	Motor Home
22	Pickup Truck w. Slide-in Camper
23	Pickup-Car w. Slide-in Camper
31	Chassis-Mounted Camper

Trucks

11	Small Van (Econoline)
12	Pickup
13	Unknown Light Truck (<1-1/2 Ton)
15	Carryall/Panel Truck
16	Pickup Truck w. Canopy/Shell Cover
22	Pickup Truck w. Slide-in Camper
30	Unknown Truck Type
31	Chassis-Mounted Camper
33	Delivery Van (Walk-in)
34	Straight Truck
35	Truck-Tractor
36	Chassis-Cab
37	Unknown Heavy Truck (>1-1/2 Ton)
38	Tractor + Semi-Trailer (Semi)
39	Truck (or Semi) + Full Trailer(s)

Buses

40	Unknown Bus Type
41	School Bus
42	Inter City (between)
43	Intra City (within)
44	Streetcar (on tracks)

Motorcycles

50	Unknown Motorcycle Type
51	1-75cc
52	76-125cc
53	126-250cc
54	251-500cc
55	501-750cc
56	751+cc
57	3-wheels (or with Sidecar)

Special Purpose Vehicles

60	Unknown/Other Special Vehicle
61	Snowmobile
62	ATV, All Terrain Vehicles
63	Amphibious Vehicle
64	Farm Vehicles
65	Construction Vehicles
66	Trailer-Private (camper)
67	Trailer-Commercial (cargo)
68	Train (Cars)
69	Locomotive, Switcher

Miscellaneous Model Types

70	Pedestrian
71	Bicyclist, Other Pedalcycle
72	Pedestrian Conveyance (e.g. Person riding animal or in cart)
98	Other Model Type
00	Unknown Model Type

VEHICLE MAKE MODEL (ABCDF): (4/75)

AMERICAN MOTORS*

14101 Classic, Rebel, Matador
14102 Ambassador (-74)
14104 Pacer (75-)
14106 Marlin, Javelin (-74), Javelin AMX (71-74)
14108 American, Hornet
14110 AMX (to 70)
14118 Gremlin
*See Also Kaiser Motors (152--)

CHRYSLER CORPORATION (1960 to-date)

Chrysler
13102 Newport, Chrysler 300, New Yorker, Town & Country (66-)
Windsor (60,61), Saratoga (60)
13107 Cordoba

Dodge
13201 Coronet (65-), Super Bee (67-69), Charger (71-74)
Dart (62), Polara (62-64)
13202 Polara (60,61,65-74), Monaco (65-), 880 (62-65),
Dart (60,61), Matador (60)
13206 Charger (66-70), Challenger (70-74), R/T
13207 Charger SE (Special Edition) (75-)
13208 Dart (63-), GTS, Swinger (69-), Custom (69), Demon,
Lancer (61,62)
13211 Van, Sportsman Wagon, Tradesman
13212 Pickup, D100, D200, D300, Club Cab, Crew Cab,
Utiline,-Sweptline
13214 Ramcharger
13215 Carryall
13233 Van Walk-in, Kary Van
13234 Straight Truck
13235 Truck Tractor
13238 Tractor-Trailer Combination (Semi)
(83209) Colt

Imperial
13303 Imperial, LeBaron, Crown, Custom (60-63)

Plymouth
13401 Fury (62-64,75-), Savoy (62-64), Belvedere (62-),
Satellite (65-74), Sebring,
Road Runner, GTX (67-)
13402 Fury (-61) (65-74), Suburban (68-), VIP (66-69),
Belvedere (60,61), Grand Fury (75-)
13406 Barracuda (67-74), Grand Coupe (70-)
13409 Valiant, Barracuda (64-66), Signet (62-69)
Duster (70-), Scamp (72-)
13411 Van, Voyager
13414 Trail Duster
(43409) Cricket

DeSoto
13502 DeSoto (61), Fireflite (60), Adventurer (60)

FORD MOTOR COMPANY

Ford
12101 Fairlane, Torino, Cobra, Falcon (70 1/2-)
12102 Custom (-74), Galaxie (-74), XL, LTD, Country Squire,
Ranch Wagon
12104 Mustang II, Ghia, Mach I (74-)
12105 Thunderbird, Landau
12106 Mustang (-73), Mach I (-73), Grande, Boss, Granada
12107 Elite
12108 Falcon (to 70), Maverick, Futura, Grabber
12111 Econoline, E100, E200, E300, Station Bus, Club Wagon
12112 Pickup, F100 to F350, Courier
12114 Bronco
12117 Ranchero
12118 Pinto
12133 Van Walk-in (P Series), Parcel Delivery
12134 Straight Truck (C,F, L Series 500 and over)
12135 Truck-Tractor (C Series, L Series, W Series)
12138 Tractor-Trailer Combinations (Semi)
12141 School Bus (B Series)

Lincoln-Mercury
12201 Comet (67-69) Caliente (67-68)
Montego (68-), Voyager, Villager, Cyclone (67-)
12202 Mercury Monterey, Montclair, Park Lane, Marauder,
Marquis, Colony Park
12203 Lincoln, Continental
12205 Continental Mark III, Mark IV (72-)
12206 Cougar (67-73), Monarch
12207 Cougar (74-)
12208 Comet (65, 66, 71-)
12218 Bobcat (75-)
(62209) Capri (Germany)

FORD OF CANADA, LTD.

Lincoln-Mercury
22202 Meteor
22218 Mercury Bobcat (-74)

GENERAL MOTORS CORPORATION

Buick
11101 Special (64-), Skylark (-74), GS, Sportwagon, Century,
Century 350, Regal
11102 LeSabre, Wildcat, Centurion
11103 Electra 225, Estate Wagon
11104 Skyhawk
11105 Riviera
11108 Special (to 63), Apollo, Skylark (75-)
(61809) Opel Kadett, 1900, Rallye
(61819) Opel GT

Cadillac
11203 Calais, DeVille, Fleetwood 60 Special, Brougham
Fleetwood 75, Limousine
11205 Eldorado
11207 Seville

Chevrolet
11301 Chevelle, Malibu, Nomad, Greenbrier, Laguna, Laguna S-3 (74-)
11302 Biscayne, Bel Air, Impala, Caprice, Brookwood, Townsman, Kingswood, Chevrolet Wagon
11304 Monza 2+2 (75-), Monza Town Coupe (75-)
11306 Camaro
11307 Monte Carlo
11308 Chevy II, Nova, Corvair, Monza (-69), Nova Cabriolet (75-)
11310 Corvette, Sting Ray
11311 Van, Sport Van, Beauville
11312 Pickup, Cheyenne
11314 Blazer
11315 Carryall, Suburban
11317 El Camino
11318 Vega, Cosworth Vega
11333 Van Walk-in, Step-Van, High Cube Van
11334 Straight Truck
11335 Truck-Tractor
11338 Tractor-Trailer Combination (Semi)
(81312) Chevrolet-Isuzu LUV Pickup

Oldsmobile
11401 F-85 (64-), Cutlass, Vista-Cruiser, 442
11402 Delmont 88, Delta 88, Starfire, Rocket 88, 88, Jetstar Dynamic 88, Jetstar 88, Royal
11403 98, Custom Cruiser
11404 StarFire
11405 Toronado, Toronado Brougham (74-)
11408 F-85 (to 63), Omega

Pontiac
11501 Tempest (64-), LeMans, GTO (-74), Safari (to 69), Grand Am
11502 Catalina, Ventura, Executive, Bonneville, GrandVille Grand Prix (to 68), Brougham, Star Chief
11503 Safari (71-)
11506 Firebird, Esprit, Formula, Trans Am
11507 Grand Prix (69-)
11508 Tempest (to 63), Ventura, Ventura GTO (74)
11518 Astre

GMC Truck and Coach
11611 Sportvan, Vandura
11612 Pick-up, Crew Cab
11614 Jimmy
11615 Carryall, Suburban
11617 GMC Sprint
11621 GMC Motor Home
11633 Van Walk-in, Value-Van
11634 Straight Truck
11635 Truck-Tractor
11638 Tractor-Trailer Combination (Semi)

GENERAL MOTORS OF CANADA LTD

Chevrolet
21301 Chevelle, Chevrolet, Acadian
21302 Biscayne, Bel Air

Oldsmobile
21401 Oldsmobile

Pontiac
21501 Beaumont
21502 Pontiac, Parisienne (-70), Grand Parisienne (to 69), Parisienne Brougham (71-), Laurentian
21503 Safari
21518 Astre

KAISER MOTORS (JEEP)

15201 Wagoneer, J-100
15214 Jeep, Jeepster, CJ-5, CJ-6, Cherokee, Commando
15212 Pickup

CHECKER

15102 Checker, Marathon

INTERNATIONAL HARVESTER

15312 Pickup, Travelette
15314 Scout
15315 Travelall
15333 Van Walk-in
15334 Straight Truck
15335 Truck-Tractor
15338 Tractor-Trailer Combination (Semi)
15341 School Bus

STUDEBAKER

15405 Avanti II
15408 Lark

HARLEY-DAVIDSON

1555- Motorcycle

GENERAL VEHICLES CORPORATION

15610 Bricklin

IMPORTED VEHICLES - BY NAME (4/75)

75108 Alfa Romeo 1750 Berlina, Guila
75110 Alfa Romeo Montreal
75119 Alfa Romeo 1750 & 1600 GTV, Spyder
48110 Aston Martin DB5, DB6, DBS
68108 Audi 100LS, 100GL, Fox, Super 90
68119 Audi 100 Coupe
45219 Austin Healy Sprite
45219 Austin Healy 3000
45108 Austin Maxi, A60, 1800
45109 Austin Mini, Mini Cooper, America, 1300, Marina
15405 Avanti II

67108 BMW 2500/2800/3000 sedans, Bavaria, 3.3L, 525
67109 BMW 1600, 2002, 1800, 1602, 2002tii, Turbo 2002
67110 BMW 2800cs, 2800ca, 3000cs, 3000ca

62209 Capri, Ford
81312 Chevrolet-Isuzu LUV Pickup
55101 Citroen 21, ID20, DS21
55108 Citroen GS
55109 Citroen 2CV, Dyane, Ami
55110 Citroen SM
83209 Colt, Dodge-Mitsubishi
43409 Cricket, Plymouth

86108 Datsun 200L, Laurel
86109 Datsun 1000, Sunny, 1200(-73), PL510, PL610, B-210(74), Datsun 100A, 120A, Cherry
86112 Datsun PL620 Pickup
86119 Datsun 1600, 2000, 240Z, 260Z
72210 DeTomaso Mangusta, Pantera, Deauville
83209 Dodge-Mitsubishi Colt

77110 Ferrari
76109 Fiat 500, 650, 850, 124,128,131 sedans
76110 Fiat Dino
76119 Fiat 850, 124, 128, Coupe and Spyder, 1500 Spyder
42209 Ford Anglia, Cortina, Escort
62209 Ford Capri
42401 Ford Zephyr

46109 Hillman Imp, Avenger
31708 Holden
8815- Honda (motorcycle)
88109 Honda, Civic, 600, S800
45503 Jaguar 420, XJ-6, XJ-12, V-12
45510 Jaguar E type (XKE)
48610 Jensen, Healey, Interceptor
66119 Karmann Ghia, VW
8845- Kawasaki (motorcycle)

78410 Lamborghini
78208 Lancia Berlina 4 door
78219 Lancia 2 door
48814 Land Rover
48219 Lotus Elan, Elite, +2s, Super 7, Europa
81312 LUV Pickup, Chevrolet-Isuzu

78110 Maserati
85109 Mazda (except Cosmo)
85112 Mazda Pickup
85119 Mazda Cosmo
65101 Mercedes Benz 200, 190, 220, 230, 250, 280(-73) 300 except SL, 450 SE
65103 Mercedes 600 (limo)
65110 Mercedes Benz 280 SL, 250 SL, 300SL(-73), 190 SL, 350 SL, 450SL
45319 MGA, MGB, MGC, MG, Midget MGB/GT, MGC/GT
45409 Morris Mini
48319 Morgan

4895- Norton Motorcycle
68309 NSU 1000, 1200
68301 NSU Ro80
61809 Opel Kadett, 1900, Rallye, Manta
61819 Opel GT

57108 Peugeot 504
57109 Peugeot 204, 304, 404, 403
43409 Plymouth Cricket
66210 Porsche 911, 914-6
66219 Porsche 912, 914

56108 Renault 16
56109 Renault 8, 10, 12, 15, 17
48403 Rolls Royce (shadow), Rolls Royce (limo)
49508 Rover
95108 Saab 95, 96, 99
95119 Saab Sonnett
53109 Simca 1204, GLS
46209 Singer (automobile)
88209 Subaru
46319 Sunbeam Alpine, Tiger, Rapier
88309 Suzuki (automobile)
8835- Suzuki (motorcycle)

45609 Triumph Herald
45608 Triumph 2000
45619 Triumph Spitfire, GT6, TR3, TR4, TR250, TR6, GT6+, Stag
87108 Toyota Corona, Crown, MarkII
87109 Toyota Corolla, Sprinter, Celica, Carina
87110 Toyota 2000GT
87112 Toyota Hi-Lux Pickup
87114 Toyota Land Cruiser

41908 Vauxhall
95208 Volvo 122, 142, 144, 145, 164, 522
95219 Volvo P1800
66108 VW 411, 412, VW Dasher
66109 VW 1300, 1302, 1303, 1500, 1600, "Beetle", Rabbit(75-), LaGrande Bug(75-), Scirocco(75-)
66111 VW Van, Campmobile, "Bus"
66119 VW Karmann Ghia
66120 VW Thing
8855- Yamaha (motorcycle)

IMPORTED VEHICLES - BY CODE (4/75)

Australia

31708	Holden

England

41908	Vauxhall
42209	Ford Anglia, Cortina, Escort
42401	Ford Zephyr
43409	Plymouth Cricket
45---	British Leyland
45108	Austin Maxi, A60, 1800
45109	Austin Mini, Mini Cooper, America, 1300, Marina
45219	Austin Healy Sprite, 300
45319	MGA, MGB, MGC, MG, Midget, MGT/GT, MGC/GT
45409	Morris Mini
45503	Jaguar 420, XJ-6, XJ-12, V-12
45510	Jaguar E type (XKE)
45608	Triumph 2000
45609	Triumph Herald
45619	Triumph Spitfire, GT6, TR3, TR4, TR250, TR6, GT6+, Stag
46---	Rootes
46109	Hillman Imp, Avenger
46209	Singer
46319	Sunbeam Alpine, Tiger, Rapier
48110	Aston Martin DB5, DB6, DBS
48219	Lotus Elan, Elite, +2s, Super 7, Europa
48319	Morgan
48403	Rolls Royce (shadow), Rolls Royce (limo)
48610	Jensen, Healey, Interceptor
48814	Land Rover
4899-	Norton (motorcycle)

France

53109	Simca 1204, GLS
55101	Citroen 21, ID20, DS21
55108	Citroen GS
55109	Citroen 2CV, Dyane, Ami
55110	Citroen SM
56108	Renault 16
56109	Renault 9, 10, 12, 15, 17
57108	Peugeot 504
57109	Peugeot 204, 304, 404, 403
58---	Other French

Germany

61809	Opel Kadett, 1900, Rallye, Manta
61819	Opel GT
62209	Ford Capri
65101	Mercedes Benz 200, 190, 220, 230, 250, 280(-73) 300 except SL, 450 SE
65103	Mercedes 600 (limo)
65110	Mercedes Benz 230 SL, 250SL, 300SL(-73), 190SL, 350SL, 450SL
66108	VW 411, 412, VW Dasher
66109	VW 1300, 1302, 1303, 1500, 1600, "Beetle", Rabbit(75-), LaGrande Bug(75-), Scirocco(75-)
66111	VW Van, Campmobile, "Bus"
66119	Karmann-Ghia
66120	VW Thing
66210	Porsche 911, 914-6
66219	Porsche 912, 914, 355B, 356B, 1600s
67108	BMW2500/2800/3000 sedans, Bavaria, 3.3L, 525
67109	BMW 1600,2002, 1800, 2002tii, 1602, Turbo 2002
67110	BMW 2800cs, 2800 ca, 3000 cs, 3000 ca
6715-	BMW Motorcycle
68109	Audi 100LS, 100GL, Fox, Super 90
68119	Audi 100 Coupe
68309	NSU 1000, 1200
68301	NSU Ro80

Italy

72210	De Tomaso Mangusta, Pantera, Deauville
75108	Alfa Romeo 1750 Berlina, Guila
75110	Alfa Romeo Montreal
75119	Alfa Romeo 1750 & 1600 GTV, Spyder
76109	Fiat 500, 650, 850, 124,128,131 sedans
76110	Fiat Dino
76119	Fiat 850, 124, 128, Coupe and Spyder, 1500 Spyder
77110	Ferrari
78110	Maserati
78208	Lancia Berlina 4 door
78219	Lancia 2 door
78410	Lamborghini

Japan

81312	Chevrolet-Isuzu LUV Pickup
83209	Dodge-Mitsubishi Colt
85109	Mazda (except Cosmo)
85110	Mazda Cosmo
85112	Mazda Pickup
86108	Datsun 200L, Laurel
86109	Datsun 1000, Sunny, 1200(-73), PL510, PL610, B-210(74), Datsun 100A, 120A, Cherry
86112	Datsun PL620 Pickup
86119	Datsun 1600, 2000, 240Z, 260Z
87108	Toyota Corona, Crown, MarkII
87109	Toyota Corolla, Sprinter, Celica, Carina
87110	Toyota 2000GT
87112	Toyota Hi-Lux Pickup
87114	Toyota Land Cruiser
8815-	Honda (motorcycle)
88109	Honda, Civic, 600, S800
88209	Subaru
8835-	Suzuki (motorcycle)
88309	Suzuki (automobile)
8845-	Kawasaki (motorcycle)
8855-	Yamaha (motorcycle)

Other (Sweden)

95108	Saab 95, 96, 99
95119	Saab Sonnett
95208	Volvo 122, 142, 144, 145, 164, 572
95219	Volvo P1800

VEHICLES/OBJECTS CONTACTED

01-39 Autos and Trucks
40-69 Other Vehicles
70-76 Pedestrians and On-Roadway Objects
80-97 Off-Roadway Objects
98 Other: ____________
99 No Object
00 Unknown

Vehicles

01 Intermediate (GM A Body)
02 Standard/Full Size (B Body)
03 Luxury (C Body) or Limousine (D Body)
04 Mini Specialty (Mustang II)
05 Personal Luxury (E Body)
06 Specialty/Pony (F Body)
07 Grand Prix (A-SP Body)
08 Compact (X Body & Y Body)
09 Sub-compact/Mini-Imported (VW)
10 Super Sport (Corvette)
17 Pickup-Car (Ranchero)
13 Sub-compact/Mini-USA (H Body)
19 European Sports Cars (MG)
20 Unknown Automobile Body

Size	Standard	Specialty	Sports
Mini	09,13	04	19
Compact	08	06	10
Intermediate	01,17	07	--
Standard	02	05	--
Luxury/Limo	03	--	--

Multipurpose Passenger Vehicle

14 Utility (Jeep, Bronco)
15 Carryall/Panel Truck
16 Pickup Truck w. Canopy/Shell Cover
17 Pickup Car w. Canopy/Shell cover
21 Motor Home
22 Pickup Truck with Slide-in Camper
23 Pickup-Car w. Slide-in Camper
31 Chassis-Mounted Camper

Truck

11 Small Van (Econoline)
12 Pickup
13 Unknown Light Truck (<$1\frac{1}{2}$ Ton)
15 Carryall/Panel Truck
16 Pickup-Camper (Canopy, Shell)
22 Slide-in Camper
30 Unknown Truck Type
31 Chassis-Mounted Camper
33 Delivery Van (Walk-in)
34 Straight Truck
35 Truck-Tractor
36 Chassis-Cab
37 Unknown Heavy Truck (>$1\frac{1}{2}$ Ton)
38 Tractor + Semi-Trailer (Semi)
39 Truck (or Semi) + Full Trailer(s)

Bus

40 Unknown Bus Type
41 School Bus
42 Inter City (between)
43 Intra City (within)
44 Streetcar (on tracks)

Motorcycles

50 Unknown Motorcycle Type
51 1-75cc
52 76-125cc
53 126-250cc
54 251-500cc
55 501-750cc
56 751+cc
57 3-wheels (or with Sidecar)

Special Purpose Vehicles

60 Unknown/Other Special Vehicle
61 Snowmobile
62 ATV, All Terrain Vehicles
63 Amphibious Vehicle
64 Farm Vehicles
65 Construction Vehicles
66 Trailer-Private (camper)
67 Trailer-Commercial (cargo)
68 Train (Cars)
69 Locomotive, Switcher

Objects

70 Pedestrian
71 Bicyclist, Other Pedalcycle
72 Pedestrian Conveyance
(e.g. Person Riding Animal, Cart, etc.)
73 Large Animal
74 Fallen Objects such as Objects Dislodged from Other Vehicles, Fallen Trees, Rocks, etc.
75 Traffic Cones, Barrels, Construction Barriers
76 Construction or Emergency Equipment
77 Sign Posts, Utility Pole, Tree
78 Ditch
79 Embankment, Snowbank
80 Ground (Rollover Only)
81 Curb (Damage Producing Impacts Only)
82 Culvert
83 Fence
84 Hydrants, Short Posts, Stumps
85 Small Posts/Trees, Rural Mail Boxes, Delineators, Mile Markers
86 Building
87 Pier, Pillar (e.g. Bridge Support)
88 Abutment, Retaining Wall
89 Bridge Rail
90 Guard Rail, Leading Section
91 Guard Rail, Middle or Unknown Section
92 Guard Rail, Trailing Section
93 Guard Posts (Timber, Metal, Concrete)
94 Cable, Fence Barrier
95 Concrete Barrier (Median)
96 Impact Attenuator
97 Breakaway Fixtures

FIELD FORM

Vehicle Description

Cost Effectiveness
Guardrail Selection

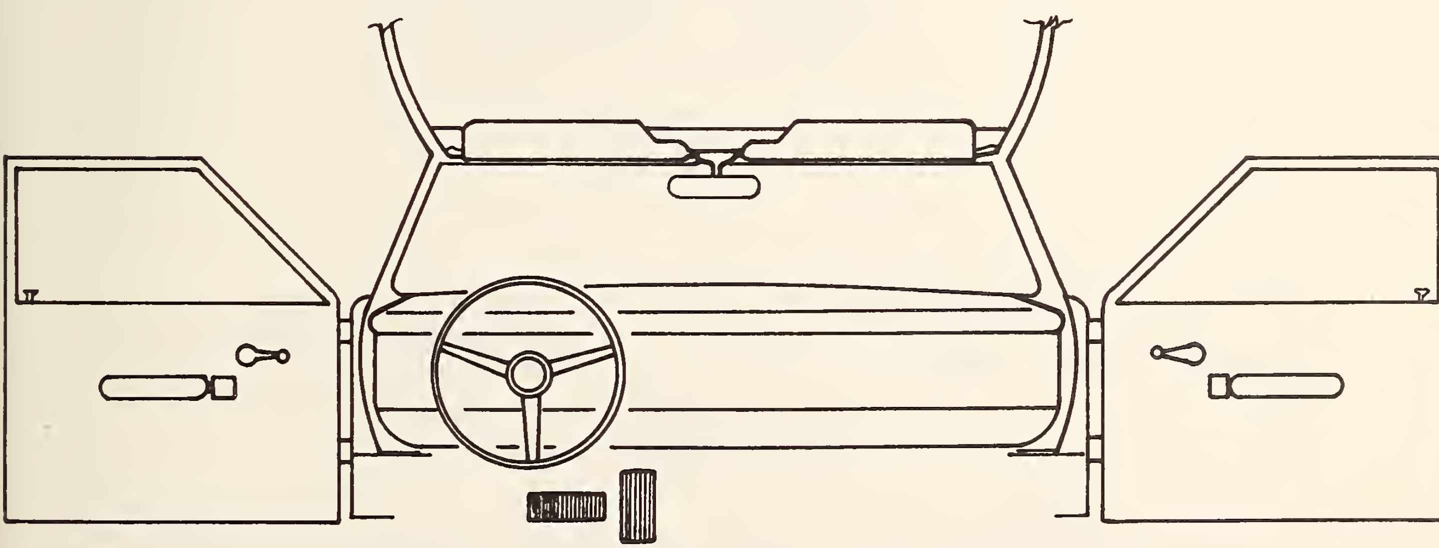
Team No. ____________ Case No. ____________

- Vehicle No. ____________
- Vehicle Identification No. ____________
- Vehicle Make ____________
- Vehicle Model ____________
- Vehicle Model Year ____________
- Vehicle 5 Digit Code ____________
- Cargo Carried ____________
- Location of Cargo ____________
- Occupant Ejection ____________
- Occupant Compartment Reduced in Size ____________

Seat Position	LF	CF	RF	LR	CR	RR	Other
• Type Restraints							
• Restraints Used							

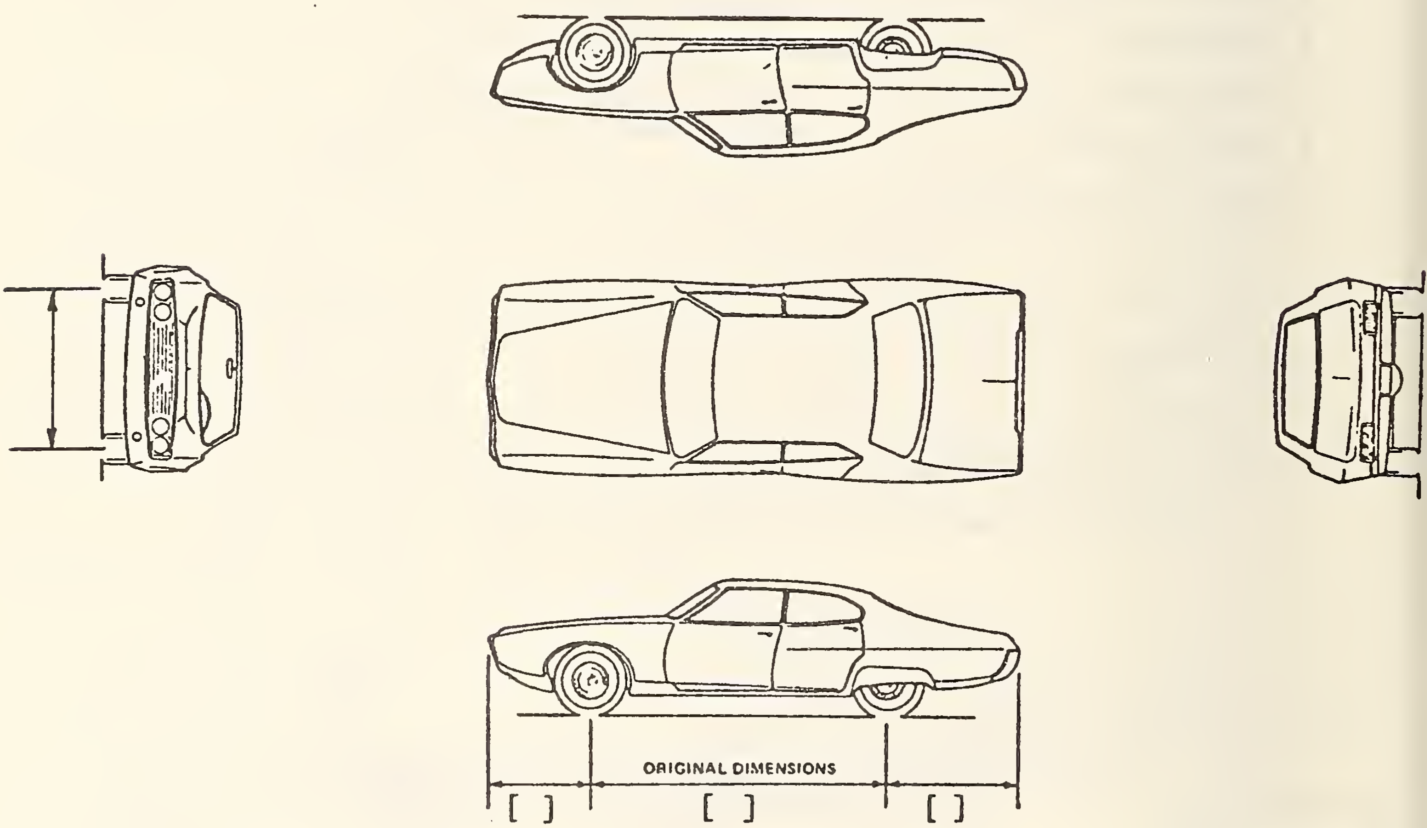
- Interior Occupant Contact Area:

If there is no indication of occupant contact, so indicate.



- Damage Sketch:

  Indicate damaged areas by outlining new perimeter of vehicle.
  Indicate direct impact damage by a series of X's and induced damage by a wavy line (~).
  Indicate the amount of crush in inches.



Vehicle repair/replacement cost:____________________ Frame damage:____________________

Objects Contacted – VDI

	Object Contacted	VDI	In. Crush
Event No. 1	____ ____	____ ____–____ ____ ____ ____–____	____ ____
Event No. 2	____ ____	____ ____–____ ____ ____ ____–____	____ ____
Event No. 3	____ ____	____ ____–____ ____ ____ ____–____	____ ____
Event No. 4	____ ____	____ ____–____ ____ ____ ____–____	____ ____

APPENDIX G

DETERMINATION OF EXPOSURE LENGTH

As input for the COCOST program, it is necessary to specify the obstacle length and the guardrail length of need. Methods for determining the guardrail length of need are shown in NCHRP Report 118[35] and its update.[36] However, these references produce lengths that are considered to be somewhat conservative with current economic constraints, particularly on low volume rural roads. A method is presented here that produces shorter lengths, and hence less protection, but should be adequate for most installations. Further, the method can be used to determine the obstacle length of exposure.

As shown in Figure G.1, an automobile turns into an obstacle of width W. The problem is to determine the offset distance X that must be added to the obstacle length to determine the total length of exposure. From the figure, the relationships

$$D = R - R\cos A + a\sin A + b\cos A$$

$$D + W = R - R\cos B + a\sin B - b\cos B$$

and (G.1)

$$X + R\sin A + a\cos A - b\sin A$$

$$= R\sin B + a\cos B + b\sin B$$

can be established. For the typical 4500-lb vehicle in Figure B.7,

$$a = \frac{57 + 36}{12} = 7.75 \text{ ft}$$

and (G.2)

$$b = \frac{40}{12} = 3.33 \text{ ft}$$

Assuming a vehicle speed of 70 mph (102.67 fps), a coefficient of tire-to-pavement friction of 0.50, and using the point mass approach yields

$$R = \frac{v^2}{g\mu} = \frac{(102.67)^2}{32.2(0.50)} = 655 \text{ ft} \qquad \text{(G.3)}$$

for the radius of turn.

The relationships (G.1) were programmed in a small XDIST program to generate tables of X values for various values of D and $D+W$. These tables, along with the explanation of their use, are included in the user's manual, Volume II of this report.

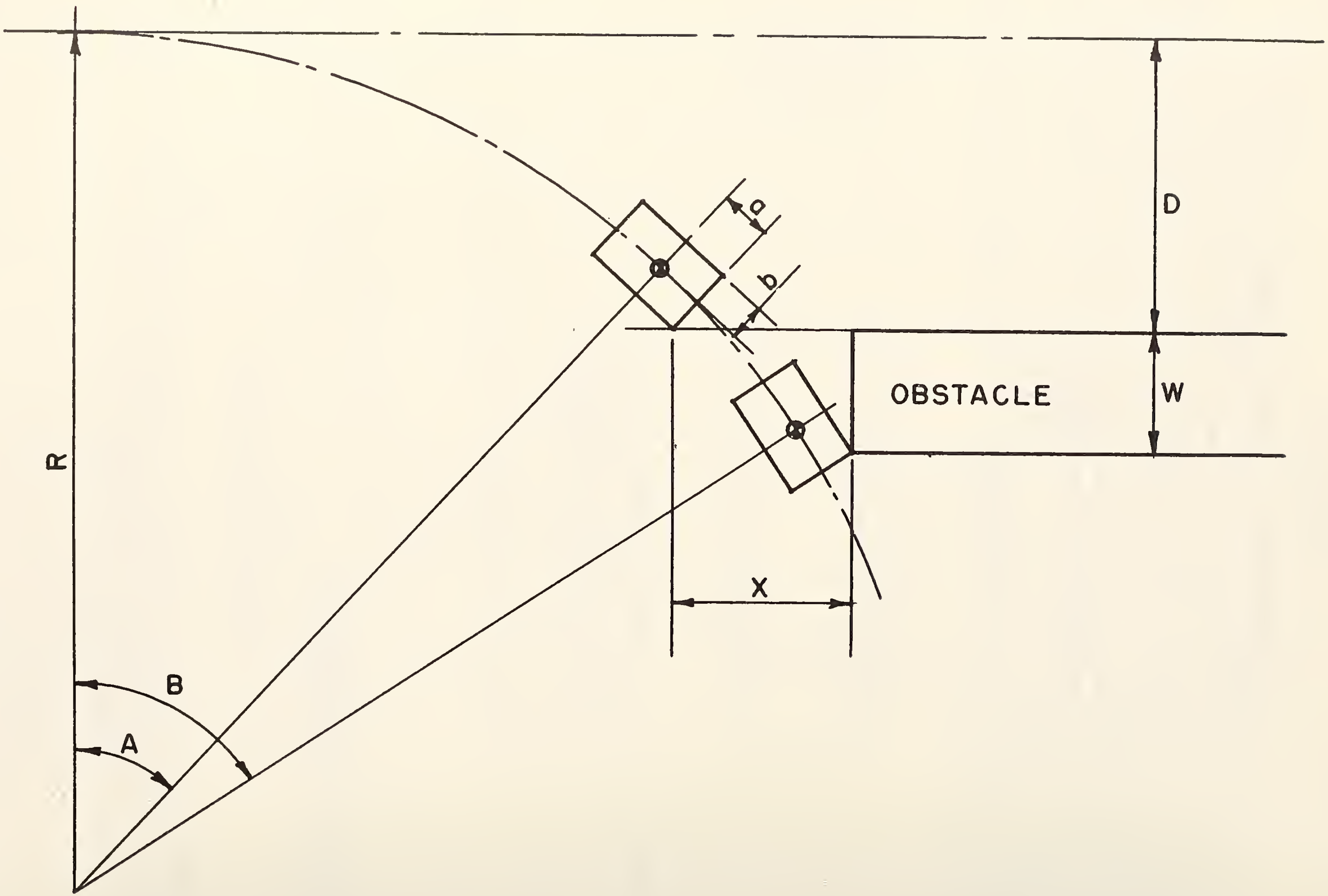


FIGURE G.1. EXPOSURE LENGTH PARAMETERS

APPENDIX H

POST PROPERTIES FOR VARIOUS SOIL TYPES

To determine post performance variations as a function of soil conditions, a series of pendulum tests were conducted. The original test matrix was to consist of 80 tests as follows:

Posts: W6 X 8.5 steel 6'-0" long with 44" embedment
6 X 8" Douglas Fir 5'-3" long with 35" embedment

Axes: Major and minor

Broad Soil Classifications: Sandy loam
Saturated clay
Stiff clay
Base material
Fixed support

Repeatability: 4 tests of each configuration

Since previous tests had been run with a pendulum weight of 4,000 lb and an impact speed of 30 fps, these conditions were first used. However, unlike the previous tests, no pad was used in the impact area. On completion of the data reduction for the first 16 tests with a base material support, it was found that the rise portion of the force-time curve, which was of interest in determining the constants for BARRIER VII inputs, occurred much too fast (as low as 1 or 2 milliseconds). Thus, the pendulum impact speed was reduced from 30 to 20 fps, and a 2-inch plastic pad of Dow Ethafoam 600 was attached in the impact area of the post. This reduced the post inertia-peak effect and produced a rise time of about 15 to 20 milliseconds, which is considered to be more realistic of actual field conditions where railing deformation and take-up of slack occurs in transmitting the impact loads to the posts. The final matrix of conducted tests, including the repeat tests for the base material, is shown in Table H.1.

Instrumentation for the pendulum tests consisted of a voice track, impact switch, speed trap, and two accelerometer channels recorded on magnetic tape at 60 ips. The tapes were played back on visicorder traces at 32 ips for preliminary checks of the tests. The tapes were then used for A/D reductions at the Institute sled lab facility. Data was passed through a Class 180 filter before digitizing. A sample rate of 16,000 hz for 4 channels was used, and 4 records of 2048 words per record (0.5 second) were recorded on 9-track tape during the accelerometer calibration portion of the run. Sixteen records (2.0 seconds) were then taken for the speed trap, impact switch, and accelerometer test data. Data on the 9-track tape was then transmitted to a 7-track tape at the Institute's Hewlett-Packard computer facility, where a small program was used to generate the output sheets and plots shown in Figures H.1 and H.2.

As a back-up program for the data reduction, high-speed photography was attempted. A Locam camera with a film speed of 500 frames per second was first tried without success. In the calibration test of Table H.1, where the pendulum impact speed was reduced to 20 fps, a Hycam camera was used at 1000 frames per second. Though every frame was recorded in the data reduction, the results were still not satisfactory. The difficulty can be seen in sheets 2 and 3 of Figure H.2, where the displacement is almost linear and the velocity changes are so small that they cannot be distinguished in the cine analysis. Thus, the analysis attempt was terminated and the Locam camera was used for documentary purposes only. In cases of accelerometer or instrument malfunction, the tests were simply repeated, as denoted by the letter A following the test numbers in Table H.1.

TABLE H.1. MATRIX OF CONDUCTED PENDULUM TESTS

Test No.	Date	Specimen	Axis	Support Soil	Failure Type
F-1	11/10/76	Wood	Weak	Base material	Post broke
F-2	11/10/76	Wood	Strong	Base material	Post broke
F-3	11/10/76	Steel	Strong	Base material	Post yielded
F-4	11/11/76	Steel	Weak	Base material	Post yielded
F-5	11/11/76	Wood	Weak	Base material	Post broke
F-6	11/11/76	Wood	Strong	Base material	Post broke
F-7	11/23/76	Steel	Weak	Base material	Post yielded
F-8	11/23/76	Steel	Strong	Base material	Post yielded
F-9	11/30/76	Wood	Weak	Base material	Post broke
F-10	11/30/76	Wood	Strong	Base material	Soil yielded
F-10A	12/1/76	Wood	Strong	Base material	Soil yielded
F-11	12/1/76	Steel	Weak	Base material	Post yielded. Tape accidentally erased
F-12	12/2/76	Steel	Strong	Base material	Post yielded
F-13	12/2/76	Wood	Weak	Base material	Premature fracture of post
F-14	12/2/76	Wood	Strong	Base material	Soil yielded
F-15	12/3/76	Steel	Strong	Base material	Post yielded
F-16	12/3/76	Steel	Weak	Base material	Post yielded
Cal.	12/7/76	Wood	Strong	Fixture	Post broke—used to check revised test procedure
F-17	2/4/77	Wood	Weak	Fixture	Post broke
F-18	2/4/77	Wood	Strong	Fixture	Post broke
F-19	2/8/77	Steel	Strong	Fixture	Post yielded
F-20	2/8/77	Steel	Weak	Fixture	Post yielded
F-21	2/14/77	Wood	Weak	Fixture	Post broke
F-22	2/14/77	Wood	Strong	Fixture	Post broke
F-23	2/14/77	Steel	Strong	Fixture	Post yielded
F-24	2/14/77	Steel	Weak	Fixture	Post yielded
F-25	2/14/77	Wood	Weak	Fixture	Post broke
F-26	2/16/77	Wood	Strong	Fixture	Post broke
F-27	2/16/77	Steel	Strong	Fixture	Post yielded
F-28	2/17/77	Steel	Weak	Fixture	Post yielded
F-29	2/17/77	Wood	Weak	Fixture	Post broke
F-30	2/17/77	Wood	Strong	Fixture	Post broke
F-31	2/17/77	Steel	Weak	Fixture	Post yielded
F-32	2/17/77	Steel	Strong	Fixture	Post yielded
F-33	2/23/77	Wood	Strong	Sandy loam	Soil yielded and lost instrumentation
F-34	2/24/77	Wood	Weak	Sandy loam	Soil yielded
F-35	2/24/77	Steel	Strong	Sandy loam	Soil yielded
F-36	2/25/77	Steel	Weak	Sandy loam	Soil yielded
F-37	2/25/77	Wood	Strong	Sandy loam	Soil yielded
F-38	2/25/77	Wood	Weak	Sandy loam	Soil yielded
F-39	2/25/77	Steel	Strong	Sandy loam	Soil yielded
F-40	3/1/77	Steel	Weak	Sandy loam	Soil yielded
F-41	3/1/77	Wood	Weak	Sandy loam	Soil yielded
F-42	3/1/77	Wood	Strong	Sandy loam	Soil yielded
F-43	3/1/77	Steel	Strong	Sandy loam	Soil yielded
F-44	3/1/77	Steel	Weak	Sandy loam	Soil yielded—lost instrumentation
F-45	3/4/77	Wood	Strong	Sandy loam	Soil yielded
F-46	3/4/77	Wood	Weak	Sandy loam	Soil yielded
F-47	3/4/77	Steel	Strong	Sandy loam	Soil yielded
F-48	3/4/77	Steel	Weak	Sandy loam	Soil yielded

Test No.	Date	Specimen	Axis	Support Soil	Failure Type
F-33A	3/8/77	Wood	Strong	Sandy loam	Soil yielded
F-44A	3/8/77	Steel	Weak	Sandy loam	Soil yielded
F-49	3/30/77	Wood	Weak	Stiff clay	Soil yielded
F-50	3/30/77	Wood	Strong	Stiff clay	Soil yielded
F-51	3/30/77	Steel	Weak	Stiff clay	Post and soil yielded
F-52	3/31/77	Steel	Strong	Stiff clay	Soil yielded
F-53	3/31/77	Wood	Weak	Stiff clay	Soil yielded
F-54	3/31/77	Wood	Strong	Stiff clay	Soil yielded
F-55	3/31/77	Steel	Strong	Stiff clay	Soil yielded
F-56	4/4/77	Steel	Weak	Stiff clay	Post and soil yielded
F-57	4/4/77	Wood	Weak	Stiff clay	Soil yielded
F-58	4/5/77	Wood	Strong	Stiff clay	Soil yielded
F-59	4/5/77	Steel	Strong	Stiff clay	Soil yielded
F-60	4/6/77	Steel	Weak	Stiff clay	Post yielded
F-61	4/6/77	Wood	Strong	Stiff clay	Soil yielded
F-62	4/6/77	Wood	Weak	Stiff clay	Soil yielded
F-63	4/6/77	Steel	Weak	Stiff clay	Post yielded
F-64	4/7/77	Steel	Strong	Stiff clay	Soil yielded
F-65	4/7/77	Steel	Weak	Saturated clay	Soil yielded
F-66	4/7/77	Steel	Strong	Saturated clay	Soil yielded
F-67	4/8/77	Wood	Strong	Saturated clay	Soil yielded
F-68	4/8/77	Wood	Weak	Saturated clay	Soil yielded
F-69	4/8/77	Steel	Weak	Saturated clay	Soil yielded
F-70	4/8/77	Steel	Strong	Saturated clay	Soil yielded—lost instrumentation
F-70A	4/11/77	Steel	Strong	Saturated clay	Soil yielded
F-71	4/11/77	Wood	Strong	Saturated clay	Soil yielded
F-72	4/11/77	Wood	Weak	Saturated clay	Soil yielded
F-73	4/11/77	Steel	Weak	Saturated clay	Soil yielded
F-74	4/11/77	Steel	Strong	Saturated clay	Soil yielded
F-75	4/12/77	Wood	Strong	Saturated clay	Soil yielded
F-76	4/12/77	Wood	Weak	Saturated clay	Soil yielded
F-77	4/12/77	Steel	Weak	Saturated clay	Soil yielded
F-78	4/12/77	Steel	Strong	Saturated clay	Soil yielded
F-79	4/12/77	Wood	Strong	Saturated clay	Soil yielded
F-80	4/13/77	Wood	Weak	Saturated clay	Soil yielded
F-81	4/27/77	Steel	Strong	Base material	Soil yielded
F-82	4/27/77	Steel	Weak	Base material	Post yielded
F-83	4/27/77	Wood	Weak	Base material	Post fractured
F-84	4/28/77	Wood	Strong	Base material	Soil yielded
F-85	4/28/77	Steel	Weak	Base material	Post yielded
F-86	4/29/77	Steel	Strong	Base material	Soil yielded
F-87	4/29/77	Wood	Weak	Base material	Post fractured
F-88	5/2/77	Wood	Strong	Base material	Soil yielded—lost instrumentation
F-88A	5/2/77	Wood	Strong	Base material	Soil yielded
F-89	5/2/77	Steel	Strong	Base material	Soil yielded
F-90	5/3/77	Steel	Weak	Base material	Post yielded
F-91	5/3/77	Wood	Weak	Base material	Soil yielded
F-92	5/3/77	Wood	Strong	Base material	Soil yielded
F-93	5/3/77	Steel	Strong	Base material	Soil yielded
F-94	5/4/77	Steel	Weak	Base material	Post yielded
F-95	5/4/77	Wood	Strong	Base material	Soil yielded
F-96	5/4/77	Wood	Weak	Base material	Post fractured

```
**** INPUT FOR CALIBRATION ****
NREC  = NUMBER OF RECORDS IN TAPE FILE            =            4
NRE   = NUMBER OF RECORDS TO SKIP                 =            2
NCH   = NUMBER OF A/D CHANNELS                    =            4
IRECN = LENGTH OF EACH TAPE RECORD (WORDS)        =         2048
ICH   = A/D CHANNEL WHICH CONTAINS THE CAL.       =            4
DUR   = DURATION OF TAPE FILE (SEC)               =       .51200
FREQ  = FREQUENCY OF CAL. SINE-WAVE (CPS)         =    100.00000

*** OUTPUT FROM SUBROUTINE CAL ***


TAPE FILE HEADING    =  F-19   CAL   2/8/77
NUMBER OF RECORDS    =           4
WORDS PER RECORD     =        2048
NUMBER OF CHANNELS   =           4
SAMPLE RATE (SPS)    =       16000
TIME DURATION (SEC)  =        .512
TEST ID              =           0

READING RECORD NO.   =           1
READING RECORD NO.   =           2
READING RECORD NO.   =           3
READING RECORD NO.   =           4

CALIBRATION BASE-LINE  =  -.22082E+01
AVG OF SINE-WAVE       =   .16622E+01
SINE-WAVE AMPLITUDE    =   .26111E+01

**** INPUT FOR RUN DATA ****
NREC  = NUMBER OF RECORDS IN TAPE FILE            =           16
NRE   = NUMBER OF RECORDS TO SKIP                 =           12
NCH   = NUMBER OF A/D CHANNELS                    =            4
IRECN = LENGTH OF TAPE RECORDS (WORDS)            =         2048
I1    = DATA POINT WHERE P.C. 1 IS TRIGGERED=                   28
I1    = DATA POINT WHERE P.C. 2 IS TRIGGERED=                  226
I3    = DATA POINT WHERE EVENT STARTS             =          236
DUR   = DURATION OF TAPE FILE (SEC)               =      2.04800
DIS   = DISTANCE BETWEEN PHOTO-CELLS (FT)         =      1.00000
WT    = PENDULUM WEIGHT (LBS)                     =4000.00000
CA    = ACCELEROMETER CAL EQUIVANCE               =   -2.82800

*** OUTPUT FROM PENDULUM TEST ***


TIME BETWEEN EACH SAMPLE              (SEC) =      .00025
TRAVEL TIME BETWEEN PHOTO-CELLS       (SEC) =      .04975
PENDULUM SPEED FROM PHOTO-CELLS       (FPS) =    20.10050


TAPE FILE HEADING    =  F-19   TEST   2/8/77
NUMBER OF RECORDS    =          16
WORDS PER RECORD     =        2048
NUMBER OF CHANNELS   =           4
SAMPLE RATE (SPS)    =       16000
```

FIGURE H. 1 TYPICAL A/D OUTPUT (SHEET 1 OF 4)

```
TIME DURATION (SEC) =      2.048
TEST ID             =          0

READING RECORD NO.  =          1
READING RECORD NO.  =          2
READING RECORD NO.  =          3
READING RECORD NO.  =          4
READING RECORD NO.  =          5
READING RECORD NO.  =          6
READING RECORD NO.  =          7
READING RECORD NO.  =          8
READING RECORD NO.  =          9
READING RECORD NO.  =         10
READING RECORD NO.  =         11
READING RECORD NO.  =         12
READING RECORD NO.  =         13
READING RECORD NO.  =         14
READING RECORD NO.  =         15
READING RECORD NO.  =         16
```

FIGURE H. 1 TYPICAL A/D OUTPUT (SHEET 2 OF 4)

SUMMARY OF EXPERIMENTAL DATA FOR PENDULUM TEST- F-19

TIME (M-SEC)	ACCEL (G'S)	VEL (FPS)	DISP (IN)	FORCE (LBS)	IMPULSE (LB-SEC)
.00	-.0	20.10	.00	58.8	.0
1.00	-.1	20.10	.24	206.9	.1
2.00	-.1	20.09	.48	503.0	.5
3.00	-.2	20.09	.72	651.1	1.1
4.00	-.2	20.08	.96	735.7	1.8
5.00	-.2	20.07	1.21	883.8	2.6
6.00	-.3	20.06	1.45	1031.9	3.5
7.00	-.3	20.05	1.69	1391.5	4.7
8.00	-.5	20.03	1.93	1856.9	6.4
9.00	-.7	20.00	2.17	2851.1	8.7
10.00	-1.4	19.94	2.41	5495.4	12.9
11.00	-2.4	19.85	2.65	9514.7	20.4
12.00	-2.9	19.75	2.88	11566.6	30.9
13.00	-3.7	19.61	3.12	14866.6	44.2
14.00	-4.5	19.47	3.35	17891.7	60.5
15.00	-4.5	19.33	3.59	18060.9	78.5
16.00	-4.1	19.21	3.82	16474.3	95.8
17.00	-3.6	19.10	4.05	14358.9	111.2
18.00	-3.2	18.99	4.28	12814.7	124.8
19.00	-3.3	18.87	4.50	13195.5	137.8
20.00	-4.1	18.74	4.73	16453.2	152.6
21.00	-4.3	18.60	4.95	17257.1	169.5
22.00	-4.0	18.48	5.18	16157.0	186.2
23.00	-4.0	18.35	5.40	15860.9	202.2
24.00	-3.8	18.23	5.62	15162.8	217.7
25.00	-3.6	18.12	5.83	14337.8	232.4
26.00	-3.3	18.02	6.05	13110.8	246.2
27.00	-2.7	17.94	6.27	10953.1	258.2
28.00	-2.3	17.87	6.48	9303.1	268.3
29.00	-2.1	17.81	6.70	8457.0	277.2
30.00	-2.0	17.74	6.91	7991.6	285.4
31.00	-2.0	17.68	7.12	7906.9	293.4
32.00	-1.8	17.62	7.33	7356.9	301.0
33.00	-1.7	17.57	7.54	6891.6	308.1
34.00	-1.6	17.52	7.76	6574.2	314.9
35.00	-1.5	17.47	7.97	6087.7	321.2
36.00	-1.4	17.43	8.17	5749.2	327.1
37.00	-1.4	17.38	8.38	5453.1	332.7
38.00	-1.2	17.35	8.59	4776.1	337.8
39.00	-1.0	17.32	8.80	4099.2	342.3
40.00	-.9	17.29	9.01	3464.6	346.1
41.00	-.8	17.27	9.22	3210.7	349.4
42.00	-.8	17.24	9.42	3041.5	352.5
43.00	-.7	17.22	9.63	2787.7	355.4
44.00	-.6	17.20	9.84	2576.1	358.1
45.00	-.6	17.18	10.04	2597.3	360.7
46.00	-.8	17.15	10.25	3041.5	363.5
47.00	-.8	17.13	10.45	3253.1	366.7
48.00	-.8	17.10	10.66	3105.0	369.8
49.00	-.7	17.08	10.86	2956.9	372.9
50.00	-.7	17.06	11.07	2914.6	375.8
51.00	-.7	17.04	11.27	2703.0	378.6
52.00	-.5	17.02	11.48	2110.7	381.0
53.00	-.5	17.00	11.68	2110.7	383.1

FIGURE H. 1 TYPICAL A/D OUTPUT (SHEET 3 OF 4)

54.00	-.5	16.99	11.89	2005.0	385.2
55.00	-.6	16.97	12.09	2322.3	387.4
56.00	-.5	16.95	12.29	2110.7	389.6
57.00	-.5	16.94	12.50	1941.5	391.6
58.00	-.4	16.93	12.70	1433.8	393.3
59.00	-.3	16.92	12.90	1095.3	394.6
60.00	-.3	16.91	13.11	1328.0	395.8
61.00	-.4	16.90	13.31	1433.8	397.1
62.00	-.3	16.88	13.51	1391.5	398.6
63.00	-.4	16.87	13.71	1455.0	400.0
64.00	-.4	16.86	13.92	1518.4	401.5
65.00	-.4	16.85	14.12	1433.8	402.9
66.00	-.4	16.84	14.32	1560.7	404.4
67.00	-.4	16.83	14.52	1560.7	406.0
68.00	-.3	16.82	14.72	1137.6	407.4
69.00	-.3	16.81	14.93	1095.3	408.5
70.00	-.2	16.80	15.13	841.5	409.4
71.00	-.2	16.79	15.33	883.8	410.3
72.00	-.3	16.78	15.53	1222.3	411.4
73.00	-.3	16.77	15.73	1222.3	412.6
74.00	-.2	16.77	15.93	883.8	413.6
75.00	-.2	16.76	16.13	883.8	414.5
76.00	-.3	16.75	16.34	1222.3	415.6
77.00	-.2	16.74	16.54	989.6	416.7
78.00	-.1	16.74	16.74	376.1	417.4
79.00	-.1	16.74	16.94	249.2	417.7
80.00	-.2	16.73	17.14	841.5	418.2
81.00	-.2	16.72	17.34	968.4	419.1
82.00	-.2	16.72	17.54	799.2	420.0
83.00	-.1	16.72	17.74	376.1	420.6
84.00	-.1	16.71	17.94	397.3	421.0
85.00	-.2	16.71	18.14	672.3	421.5
86.00	-.1	16.70	18.34	460.7	422.1
87.00	-.1	16.70	18.54	206.9	422.4
88.00	-.1	16.70	18.74	206.9	422.6
89.00	-.1	16.70	18.94	376.1	422.9
90.00	-.1	16.70	19.14	312.6	423.3
91.00	.0	16.70	19.34	.0	423.4
92.00	-.0	16.69	19.54	122.2	423.5

FIGURE H. 1 TYPICAL A/D OUTPUT (SHEET 4 OF 4)

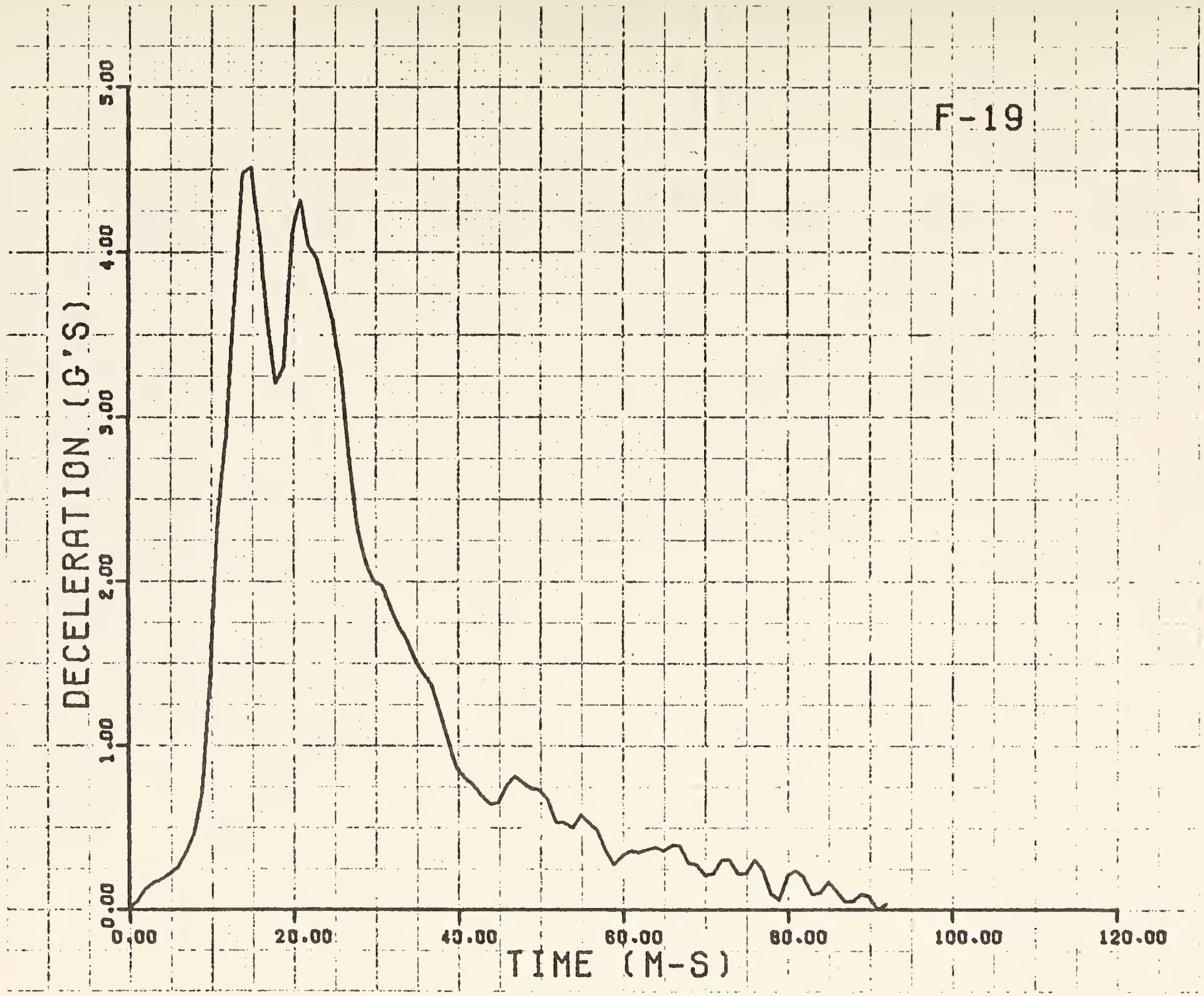


FIGURE H. 2 TYPICAL A/D PLOT (SHEET 1 OF 5)

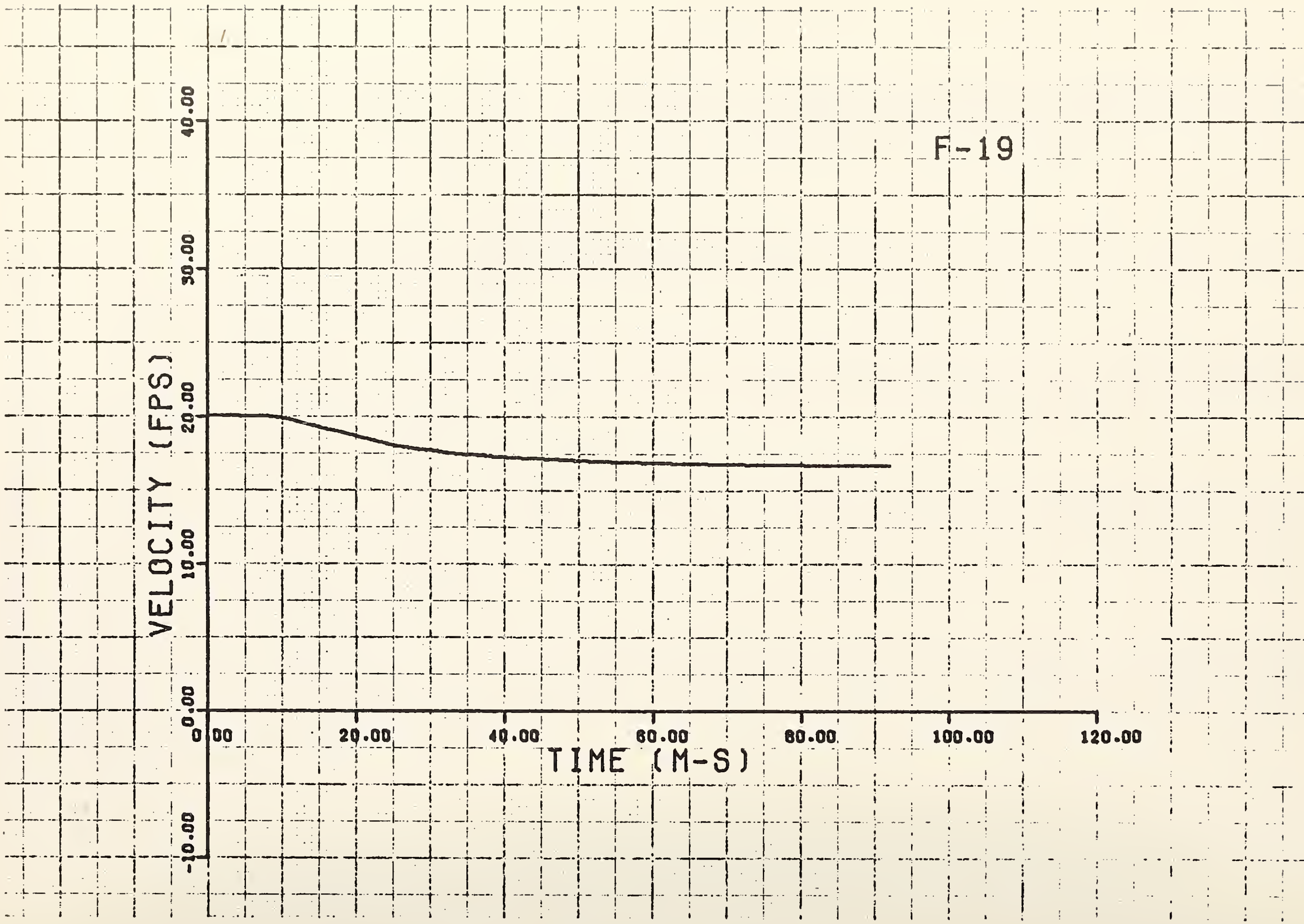


FIGURE H. 2 TYPICAL A/D PLOT (SHEET 2 OF 5)

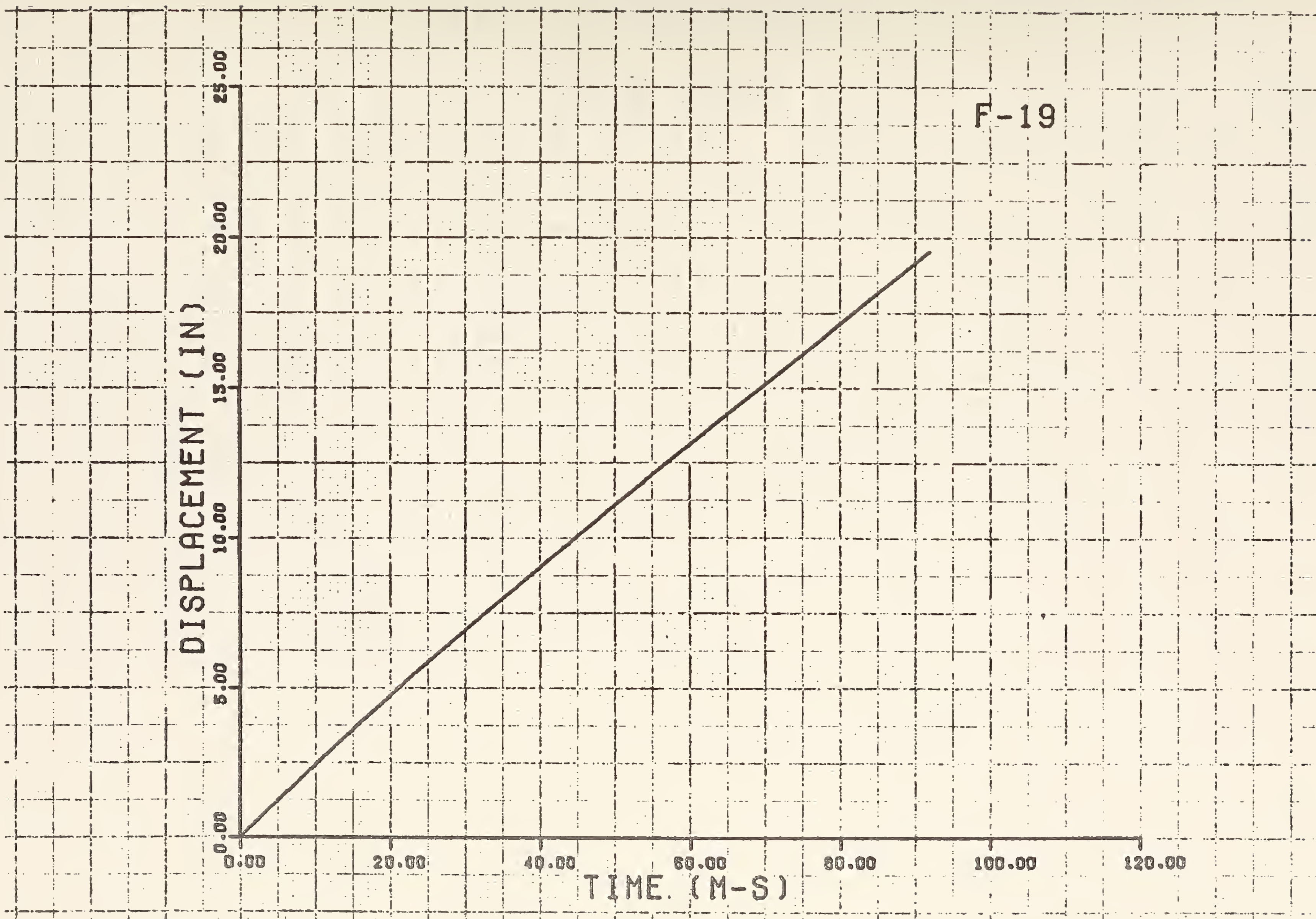


FIGURE H. 2 TYPICAL A/D PLOT (SHEET 3 OF 5)

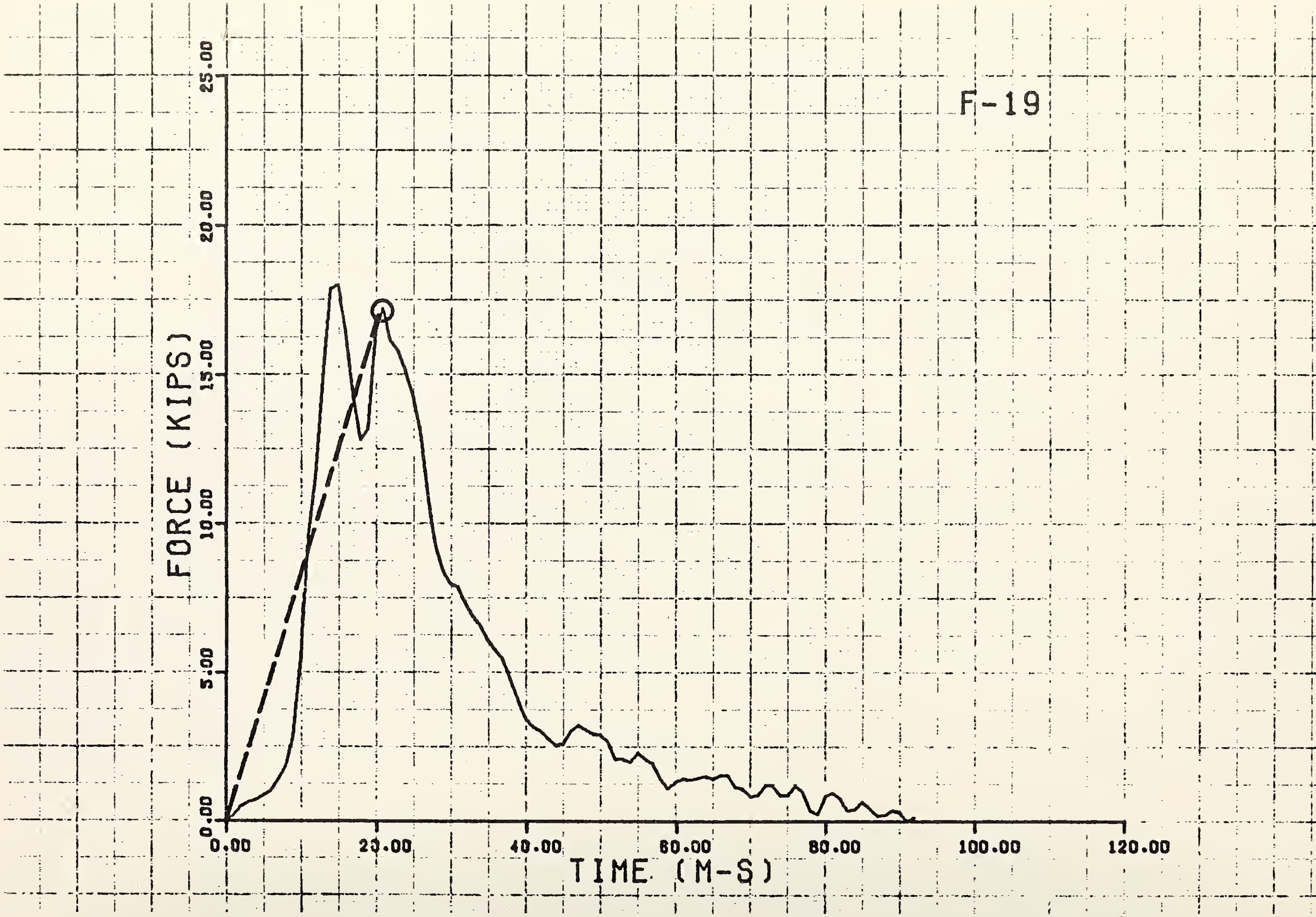


FIGURE H. 2 TYPICAL A/D PLOT (SHEET 4 OF 5)

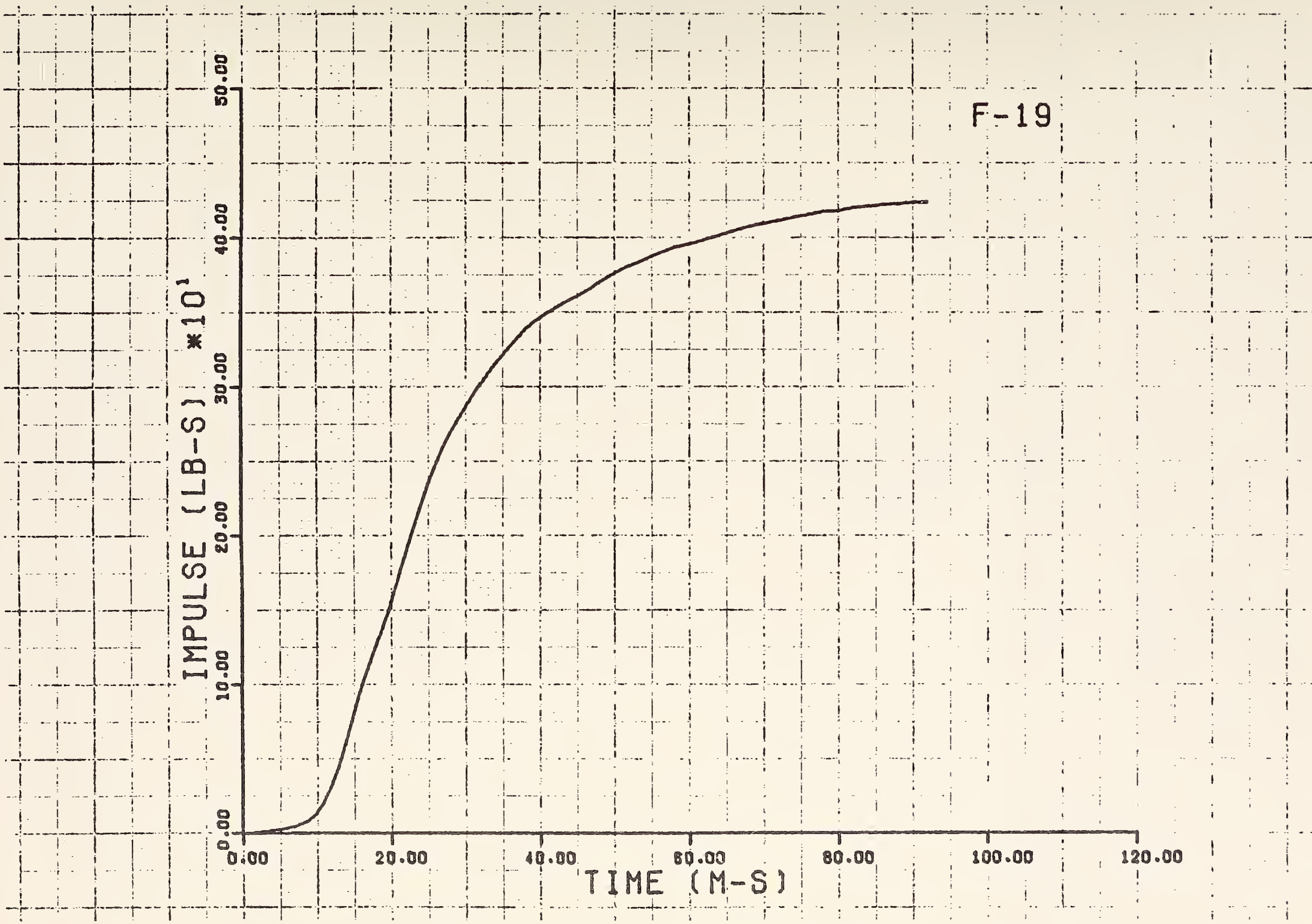


FIGURE H. 2 TYPICAL A/D PLOT (SHEET 5 OF 5)

The method for determining the BARRIER VII inputs from the pendulum data is illustrated by the dashed line in sheet 4 of Figure H.2. Note that the inertia peak was ignored since post weights are placed at the railing node in BARRIER VII. Corresponding to the peak force in the small circle of the figure, the corresponding time, displacement, and force were read from the associated computer output sheet (see the arrow in sheet 3 of Figure H.1). These values were then used to prepare the pendulum test results shown in Table H.2 for the wood posts and Table H.3 for the steel posts. Note that average values of the maximum forces and distances were used to determine stiffnesses, and these values were finally used to prepare the BARRIER VII inputs shown in Table H.4.

The results shown in this appendix are determinations of post properties for the BARRIER VII program. Since inputs for this program must be in English units, no metric equivalents are shown. If conversion to metric units should be desired, the following factors can be used:

Multiply	By	To Obtain
in.	2.540 E–02	m
lbf	4.448 E+00	N
kip (1000 lbf)	4.448 E+03	N
fps	3.048 E–01	m/s
kip/in.	1.751 E–01	N/m
in.-kip	1.130 E–04	Nm

TABLE H.2. PENDULUM TEST RESULTS FOR 6" X 8" DOUGLAS FIR POSTS

Test No.	Maximum Force (kips)	Time (m-sec)	Distance (in.)	Remarks
Base Material Support (v_i = 30 fps)				
Weak Axis Tests				
F-1	6.3	2	0.71	Post fracture
F-5	8.6	4	1.43	Post fracture
F-9	7.2	5	1.78	Post fracture
F-13	–	–	–	Premature post fracture
Averages	7.4		1.31	k = 5.65 kips/in.
Strong Axis Tests				
F-2	13.8	7	2.47	Post fracture
F-6	–	–	–	Bad test
F-10	11.4	6	2.10	Soil yield
F-10A	9.2	7	2.40	Soil yield
F-14	10.8	5	1.74	Soil yield
Averages	11.3		2.18	k = 5.18 kips/in.
Base Material Support (v_i = 20 fps)				
Weak Axis Tests				
F-83	11.2	22	5.19	Post fracture
F-87	6.5	19	4.52	Post fracture
F-91	8.0	22	5.32	Soil yield
F-96	11.1	16	3.81	Post fracture
Averages	9.2		4.71	k = 1.95 kips/in.
Strong Axis Tests				
F-84	11.7	25	5.88	Soil yield
F-88A	6.4	24	5.74	Soil yield
F-92	7.3	19	4.63	Soil yield
F-95	7.2	20	4.78	Soil yield
Averages	8.2		5.26	k = 1.56 kips/in.
Fixed Supports				
Weak Axis Tests				
F-17	14.5	16	3.80	Post fracture
F-21	14.4	15	3.59	Post fracture
F-25	8.2	12	2.87	Post fracture
F-29	10.2	12	2.99	Post fracture
Averages	11.8		3.31	k = 3.56 kips/in.
Strong Axis Tests				
F-18	16.1	15	3.59	Post fracture
F-22	14.9	15	3.57	Post fracture
F-26	17.2	14	3.35	Post fracture
F-30	16.7	15	3.72	Post fracture
Averages	16.2		3.56	k = 4.55 kips/in.
Stiff Clay Support				
Weak Axis Tests				
F-49	2.9	11	2.62	Soil yield
F-53	4.1	12	2.86	Soil yield
F-57	5.5	23	5.45	Soil yield
F-62	7.0	24	5.72	Soil yield
Averages	4.9		4.16	k = 1.18 kips/in.
Strong Axis Tests				
F-50	4.3	12	2.86	Soil yield
F-54	4.1	14	3.33	Soil yield
F-58	4.6	15	3.60	Soil yield
F-61	7.7	20	4.81	Soil yield
Averages	5.2		3.65	k = 1.42 kips/in.
Saturated Clay Support				
Weak Axis Tests				
F-68	4.0	12	2.87	Soil yield
F-72	3.3	10	2.39	Soil yield
F-76	3.8	11	2.63	Soil yield
F-80	3.8	11	2.65	Soil yield
Averages	3.7		2.64	k = 1.40 kips/in.
Strong Axis Tests				
F-67	3.7	13	3.09	Soil yield
F-71	3.3	13	3.11	Soil yield
F-75	2.9	11	2.63	Soil yield
F-79	4.1	11	2.62	Soil yield
Averages	3.5		2.86	k = 1.22 kips/in.
Sandy Loam Support				
Weak Axis Tests				
F-34	5.5	16	3.87	Soil yield
F-38	6.0	15	3.58	Soil yield
F-41	5.4	14	3.32	Soil yield
F-46	5.8	16	3.74	Soil yield
Averages	5.7		3.63	k = 1.57 kips/in.
Strong Axis Tests				
F-33	4.4	7	4.11	Soil yield
F-33A	7.5	17	4.01	Soil yield
F-37	5.3	16	3.81	Soil yield
F-42	4.2	15	3.53	Soil yield
F-45	4.2	19	4.49	Soil yield
Averages	5.1		3.99	k = 1.28 kips/in.

TABLE H.3. PENDULUM TEST RESULTS FOR W6 × 8.5 STEEL POSTS

Test No.	Maximum Force (kips)	Time (m-sec)	Distance (in.)	Remarks
Base Material Support (v_i = 30 fps)				
Weak Axis Tests				
F-4	3.3	7	2.46	Post yield
F-7	4.6	6	2.14	Post yield
F-11				Lost instrumentation
F-16	4.2	7	2.44	Post yield
Averages	4.0		2.35	k = 1.70 kips/in.
Strong Axis Tests				
F-3	13.8	5	1.78	Post yield
F-8	11.7	10	3.60	Post yield
F-12	11.7	13	4.49	Post yield
F-15	12.3	9	3.09	Post yield
Averages	12.4		3.24	k = 3.83 kips/in.
Base Material Support (v_i = 20 fps)				
Weak Axis Tests				
F-82	4.8	15	3.59	Post yield
F-85	4.1	15	3.64	Post yield
F-90	5.1	18	4.36	Post yield
F-94	4.3	18	4.36	Post yield
Averages	4.6		3.99	k = 1.15 kips/in.
Strong Axis Tests				
F-81	12.7	17	4.06	Soil yield
F-86	12.7	21	5.00	Soil yield
F-89	10.2	15	3.65	Soil yield
F-93	8.3	22	5.22	Soil yield
Averages	11.0		4.48	k = 2.46 kips/in.
Fixed Supports				
Weak Axis Tests				
F-20	5.1	20	4.72	Post yield
F-24	5.3	21	5.00	Post yield
F-28	5.3	21	5.02	Post yield
F-31	4.7	21	5.18	Post yield
Averages	5.1		4.98	k = 1.02 kips/in.
Strong Axis Tests				
F-19	17.3	21	4.95	Post yield
F-23	16.6	15	3.58	Post yield
F-27	16.5	20	4.69	Post yield
F-32	17.0	15	3.78	Post yield
Averages	16.8		4.25	k = 3.95 kips/in.

Test No.	Maximum Force (kips)	Time (m-sec)	Distance (in.)	Remarks
Stiff Clay Support				
Weak Axis Tests				
F-51	2.5	18	4.28	Post and soil yield
F-56	4.0	24	5.62	Post and soil yield
F-60	3.6	25	6.07	Post and soil yield
F-63	3.5	26	6.24	Post and soil yield
Averages	3.4		5.55	k = 0.61 kips/in.
Strong Axis Tests				
F-52	3.1	26	6.14	Soil yield
F-55	4.8	23	5.43	Soil yield
F-59	8.7	17	4.07	Soil yield
F-64	7.5	21	5.02	Soil yield
Averages	6.0		5.16	k = 1.16 kips/in.
Saturated Clay Support				
Weak Axis Tests				
F-65	2.3	15	3.61	Soil yield
F-69	2.8	15	3.59	Soil yield
F-73	2.8	17	4.07	Soil yield
F-77	2.8	14	3.35	Soil yield
Averages	2.7		3.66	k = 0.74 kips/in.
Strong Axis Tests				
F-66	2.4	11	2.65	Soil yield
F-70A	3.0	13	3.13	Soil yield
F-74	4.4	13	3.11	Soil yield
F-78	3.9	13	3.11	Soil yield
Averages	3.4		3.00	k = 1.13 kips/in.
Sandy Loam Support				
Weak Axis Tests				
F-36	3.6	20	4.85	Soil yield
F-40	3.4	15	3.53	Soil yield
F-44				Lost instrumentation
F-44A	3.5	21	4.94	Soil yield
F-48	3.6	20	4.70	Soil yield
Averages	3.5		4.50	k = 0.78 kips/in.
Strong Axis Tests				
F-35	5.5	14	3.38	Soil yield
F-39	6.4	14	3.35	Soil yield
F-43	6.4	14	3.31	Soil yield
F-47	8.2	15	3.55	Soil yield
Averages	6.6		3.40	k = 1.94 kips/in.

TABLE H.4. BARRIER VII POST PROPERTIES FOR VARIOUS SOIL TYPES

Soil Type	Fixed Support		Base Material		Stiff Clay		Saturated Clay		Sandy Loam		Properties Used in This Program	
Post Type*	Steel	Wood	Steel	Wood	Steel	Wood	Steel	Wood	Steel	Wood	Steel	Wood
Input Parameter:												
k_A (k/in.)†	1.02	3.56	1.15	1.95	0.61	1.18	0.74	1.40	0.78	1.57	2.03	2.20
k_B (k/in.)†	3.95	4.55	2.46	1.56	1.16	1.42	1.13	1.22	1.94	1.28	1.40	1.66
M_{PA} (in.-k)‡	352.8	340.2	231.0	172.2	126.0	109.2	71.4	73.5	138.6	107.1	241.5	218.4
M_{PB} (in.-k)‡	107.1	247.8	96.6	193.2	71.4	102.9	56.7	77.7	73.5	119.7	83.7	273.0
F_{PA} (k)	5.1	11.8	4.6	9.2	3.4	4.9	2.7	3.7	3.5	5.7	4.0	13.0
F_{PB} (k)	16.8	16.2	11.0	8.2	6.0	5.2	3.4	3.5	6.6	5.1	11.5	10.4
δ_A (in.)	4.98	3.31	3.99	4.71	5.55	4.16	3.66	2.64	4.50	3.63	7.90	7.40
δ_B (in.)	4.25	3.56	4.48	5.26	5.16	3.65	3.00	2.86	3.40	3.99	8.20	7.40

*W6 X 8.5 steel posts 6'-0" long with 44-in. embedment.
6" X 8" Douglas Fir posts 5'-3" long with 35-in. embedment.
†A = major axis; B = minor axis.
‡Moments based on height to center of railing = 21 in.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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