THE DEVELOPMENT OF A COST-EFFECTIVENESS MODEL FOR GUARDRAIL SELECTION

INTERIM PROGRESS REPORT

Contract No. DOT-FH-11-8827
SwRI Project 03-4309

Prepared for The
Department of Transportation
Federal Highway Administration

by
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PREFACE

This interim report describes (a) the progress of the first ten months of work and (b) the proposed approach for subsequent work of an 18-month study entitled "The Development of a Cost-Effectiveness Model for Guardrail Selection." The work was performed by Southwest Research Institute for the Federal Highway Administration under Contract No. DOT-FH-11-8827. The SwRI project number is 03-4309.

Only summaries and typical results are presented here. The various data files, computer program listings, and computer output sheets are available to FHWA upon request.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF WORKSHEETS

INTRODUCTION

Because of the increasing problems of staggering increases in highway construction and the limited funding available, it has become of critical importance that a decision policy from a cost-effectiveness standpoint be formulated for selecting the various alternatives between guardrail types. This is particularly true for the rural, low-volume highway. With such roads, strict adherence to the current warranting and installation procedures could lead to the installation of guardrails of maximum effectiveness at some sites and no installations at other sites because of a lack of available funds. Thus, the need exists for the development of effective criteria for the selection of guardrail types based on a cost-effectiveness analysis. The value of such a cost-effectiveness decision-making policy would 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 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 cost-effectiveness model and selection criteria will be presented in a manual or handbook for use by highway and traffic engineers at the state and local levels. Specifically, the study involves the following tasks:

- Task 1. Collect and synthesize (a) available guardrail dynamic crash data and (b) cost data for the various guardrail types and impact conditions.

- Task 2. Develop cost-effectiveness model that includes estimates of guardrail performance for various construction combinations and vehicle impact characteristics.

- Task 3. Collect accident reconstruction data.

- Task 4. Verify model validity by application of the reconstruction data.

- Task 5. Prepare final report including (a) technical documentation of the cost-effectiveness model and (b) a user manual for state and local highway engineers.

This interim report describes the research efforts completed under Tasks 1, 2, and 3 and outlines the proposed approach for Task 4. Discussions of the task efforts follow.

COMPLETED RESEARCH EFFORTS

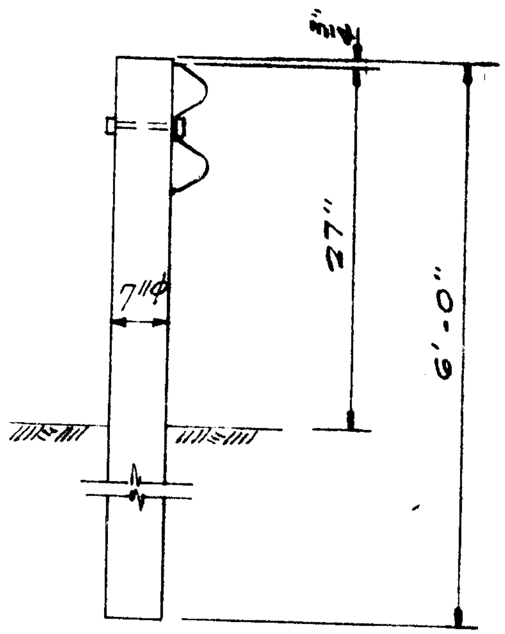
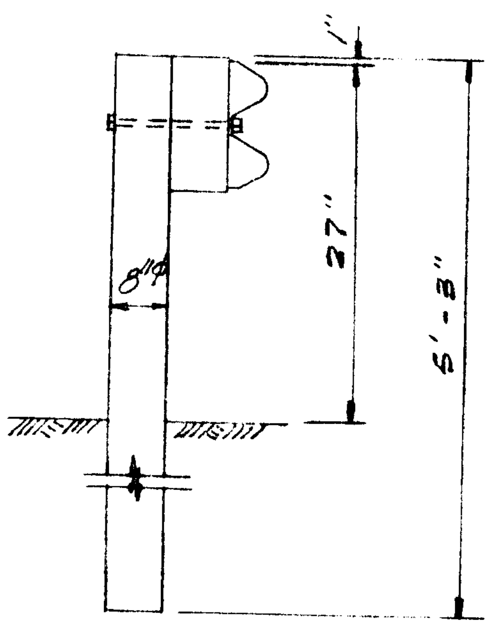
Task 1A Collection and Synthesis of Guardrail Dynamic Crash Data

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, is included as Attachment B in Monthly Progress Report 3.

The eleven guardrail types selected for this program are shown in Table 1. To prepare a full-scale data base, the test results of the NCHRP 115 update were compared with these types. Inclusion criteria included (1) identical post material and spacing, (2) identical railing shapes and

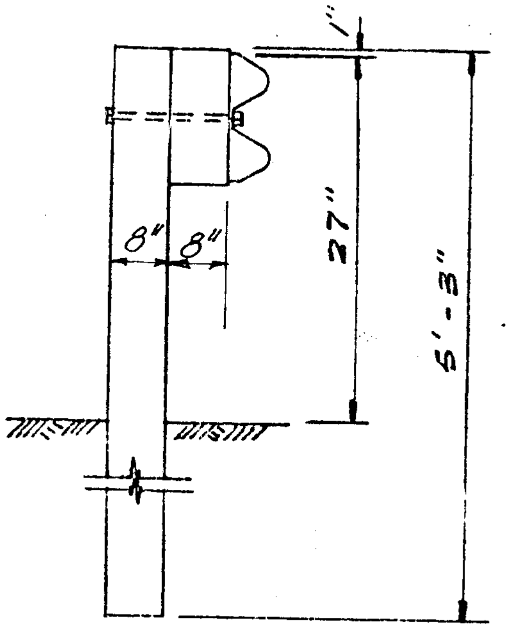
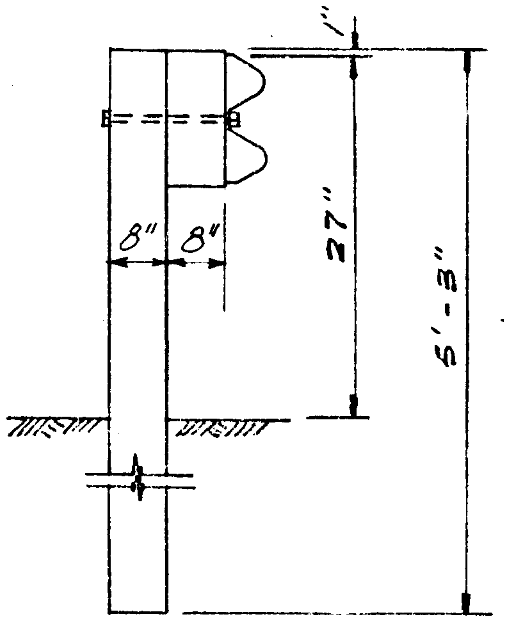
TABLE 1

GUARDRAIL TYPES

 	DESIGN A Beam: 12 ga. W Post: 7" dia. wood Post Spacing: 12'-6"
 	DESIGN B Beam: 12 ga. W Blockout: 8" x 8" wood Post: 8" dia. wood Post Spacing: 6'-3"

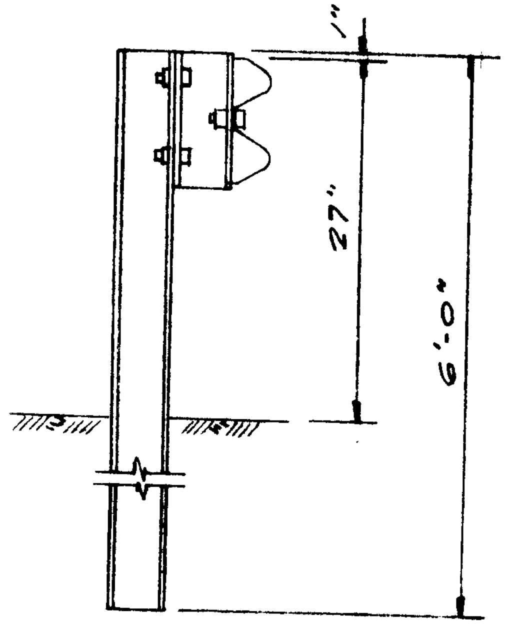
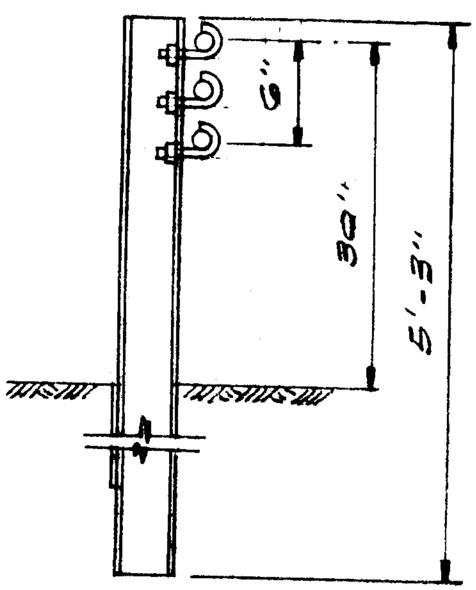
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1 (Cont'd)

	DESICN C Beam: 12 ga. W Blockout: 8" x 8" wood Post: 8" x 8" wood Post Spacing: 12'-6"
	DESIGN D Beam: 12 ga. W Blockout: 6" x 8" wood Post: 6" x 8" wood Post Spacing: 6'-3"

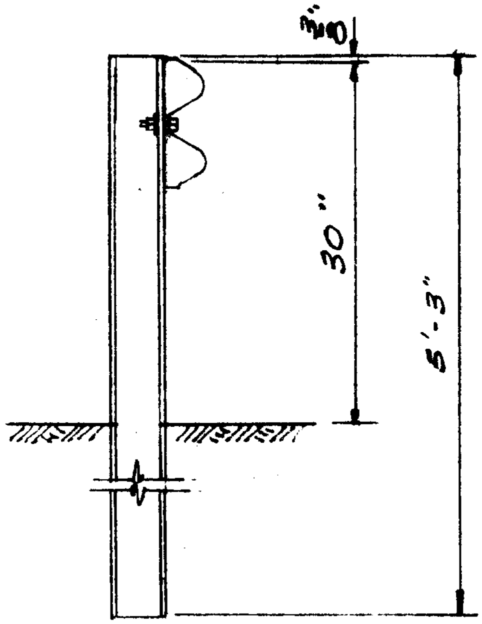
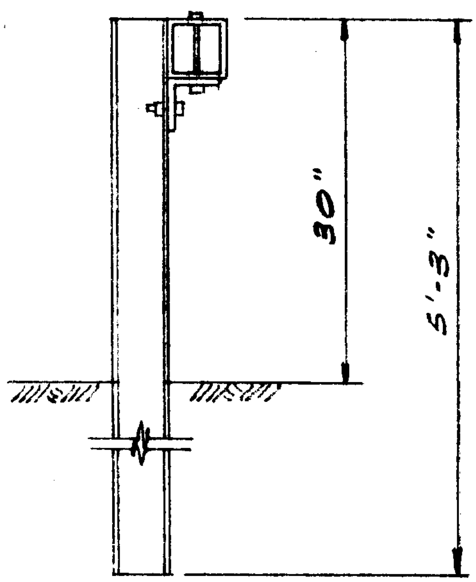
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1 (Cont'd)

	DESIGN E Beam: 12 ga. W Blockout: Charley Post: Charley Post Spacing: 6'-3"
	DESIGN G1 Beam: 3-$\frac{3}{4}$" cables Post: S3 x 5.7 Post Spacing: 16'-0"

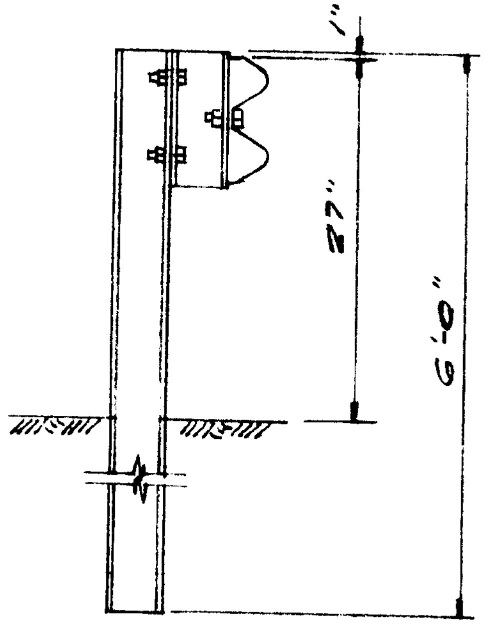
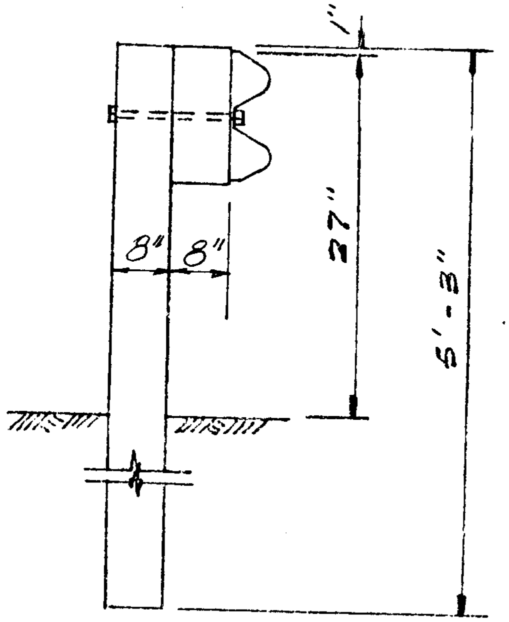
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1 (Cont'd)

	DESIGN G2 Beam: 12 ga. W Post: S3 x 5.7 Post Spacing: 12'-6"
	DESIGN G3 Beam: TS6x6x0.1875 Post: S3 x 5.7 Post Spacing: 6'-0"

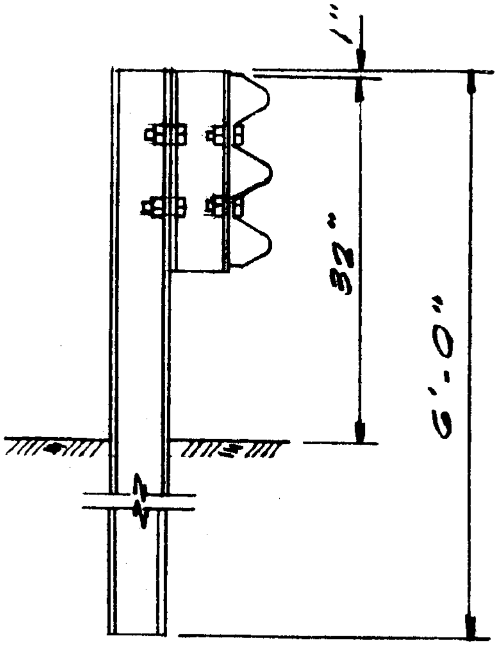
Metric conversion: Multiply ft by 0.305 to obtain m
Multiply in. by 0.0254 to obtain m

TABLE 1 (Cont'd)

	DESIGN G4S Beam: 12 ga. W Blockout: W6x8.5 Post: W6x8.5 Post Spacing: 6'-3"
	DESIGN G4W Beam: 12 ga. W Blockout: 8" x 8" wood Post: 8" x 8" wood Post Spacing: 6'-3"

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

TABLE 1 (Cont'd)

	DESIGN THRIE Beam: 12 ga. Thrie Blockout: W6x8.5 Post: W6x8.5 Post Spacing: 6'-3"

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

materials, and (3) railing heights within $\pm$ 3 inches (7.62 cm). 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. 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 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 results of all of the various BARRIER VII correlation runs are shown in Tables 3 through 11. Some difficulties were encountered with the runs. 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 7, further reduction to 0.0 (no damping) was not significant. Therefore, a multiplier of 1.0 was selected for predominant use. However, as shown

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: 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
ODH-2	2	A	12 ga. W-beam	4"x6" SYP	None	12-6	27	1963 Ford Sedan 4404	62.0	25.3	1.2 (200ms)	2.6 (200ms)	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 (200ms)	3.5 (200ms)	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 (200ms)	3.4 (200ms)	6.5	5.2	75	6	35	Exit angle 18°
ODH-5	2	A	12 ga. W-beam	6"x6" SYP notched	None	12-6	27	1959 Pontiac Sedan 4407	70.8	26.7	2.2 (200ms)	3.9 (200ms)	7.2	2.9	112	7	31	Exit angle 7°
105	3	C	12 ga. W-beam	8"x8" DF	8"x8"x 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"x8" DF	6"x8"x 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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	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	S3x5.7	None	12-6	30	1961 Plymouth 3500	54	25	2.7	-	6.8	4.0	60	6	20	Exit angle 14°
40	6	G2	12 ga. W-beam	S3x5.7	None	12-6	30	1961 Plymouth 3500	35	35	2.8	-	9.0	4.0	40	5	25	Vehicle snagged on rail

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

Metric conversion: Multiply lbs 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 (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
41	6	G2	12 ga. W-beam	S3x5.7	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	S3x5.7	None	12-6	30	1961 Plymouth 3300	58	25	2.7	-	6.0	4.0	60	6	20	Exit angle 14°
25	6	G3	TS6x6x0.1875	S3x5.7	None	6-0	27	1961 Plymouth 3500	50	25	5.5	-	3.0	1.0	24	4	20	Exit angle 11°
34	6	G3	TS6x6x0.1875	S3x5.7	None	6-0	27	1961 Plymouth 3500	49	35	7.2	-	5.1	-	30	9	25	Exit angle 12°
114	8	G3	TS6x6x0.1875	S3x5.7	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	TS6x6x0.1875	S3x5.7	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	W6x8.5	W8x10	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	W6x8.5	W6x8.5	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	W6x8.5	2-W6x8.5 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	W6x8.5	2-W6x8.5 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	W6x8.5	W6x8.5	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	W6x8.5	W6x8.5	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	W6x8.5	W8x10	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"x8" SYP	8"x8"x 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"x8" SYP	8"x8"x 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"x8" SYP	8"x8"x 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 C6x8.2 rub rail	8"x8" DF	8"x8"x 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"x8" DF	8"x8"x 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"x8" DF	8"x8"x 1'-2" DF	6-3	24	1962 Chrysler Sedan 4570	59	25	-	-	-	1.50	37	5	35	Exit angle 19°
272	4	G4W	12 ga. W-beam	8"x8" DF	8"x8"x 1'-2" DF	6-3	27	1970 Mercury Sedan 4960	66	26	5.55	5.45	-	2.22	37	4	30	Exit angle 5°

*Revised data for Test 6-39.

TABLE 2 (Cont'd)

Test No.	Ref.	Design Type	Beam	Post	Blockout	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
AS-2	32	Thrie	12-ga. Thrie	W6x8.5	W6x8.5	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	W6x8.5	W6x8.5	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	W6x8.5	M14x17.2	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

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			Use		Use

*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

TABLE 4

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 ↑ (Run 2)

No good. End anchor post failed. (Run 3)

*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

TABLE 5

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
					↑ Use					↑ Use

*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

TABLE 6

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 7-21	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.	10000.	10000.	10000.	10000.	76.8	76.8		76.8		76.8		76.8
F_{PA} (k)		10000.	10000.	10000.	10000.	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.	10000.	10000.	10000.	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	↑ Use		↑ Use		Light car test ↑ 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 7

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.	10000.	76.8	76.8	76.8		76.8	76.8
F_{PA} (k)		1.50	3.20		10000.	10000.	10000.	10000.	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.	10000.	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 8

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.	10000.	76.8		10000.	10000.	76.8	76.8	76.8	76.8		76.8
F_{PA} (k)		10000.	10000.	10000.	3.20		10000.	10000.	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.	10000.	14.32		10000.	10000.	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
								Post properties reduced to those of 24" plate	New post properties based on pendulum tests of actual posts					
					↑ 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 9

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.	252.	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 10

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 11

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 ↑ (Run 2, Test 32-AS-2)

Use ↑ (Run 2, Test 32-AS-4)

in Table 8, 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 5, 6, 7, and 10 were of no value and are crossed out. In Tables 5 and 10, the input data were checked when numerical instability diagnostics were encountered. In Table 5, 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 10, 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. Unfortunately, such was not the case with the Table 10 runs, and the error was not found until the numerical instability occurred.

The deleted results in Tables 6 and 7 were caused by a re-analysis 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 6 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 7. 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 W6x8.5 post. As shown in Table 5, a beam model for the railing might be more satisfactory for Type E, but, as shown in Table 9, 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 5 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 4 and 4-276 in Table 9). 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 (see Appendix A) so that some rational basis could be established for determining the required post properties. Except for bending about the major axes of the W6x8.5 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, W6x8.5 and Charley posts in very stiff or frozen soils will produce greater accident severities than those predicted by this model. Loose or soft soils will produce lesser severities. However, the relative severities of the various guardrail types at a particular site will 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 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 6 and 7-2 of Table 8 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 6 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.

Table 12 is a summary of the tests which 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 for the complex vehicle/guardrail full-scale

TABLE 12

SUMMARY OF TEST CORRELATIONS

Test/Simulation	Vehicle Accelerations (g's) Longitudinal	Vehicle Accelerations (g's) Lateral	Vehicle Accelerations (g's) Resultant	Maximum Dynamic Deflection (ft)*	Exit Conditions Reported Angle	Exit Conditions Velocity Vector	Exit Conditions Vehicle Heading Angle	Barrier Damage Beam (ft)*	Barrier Damage No. of Posts Damaged	Barrier Damage 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

*Multiply ft by 0.305 to obtain m

TABLE 12 (Cont'd)

Test/Simulation	Vehicle Accelerations (g's) Longitudinal	Lateral	Resultant	Maximum Dynamic Deflection (ft)*	Exit Conditions Reported Angle	Velocity Vector	Vehicle Heading Angle	Barrier Damage Beam (ft)*	No. of Posts Damaged	Railing Model
				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

*Multiply ft by 0.305 to obtain m

tests that were used. Consequently, the correlation portion of the computer runs was considered complete.

Task 1B Collection and Synthesis of Cost Data

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 component costs. Such fatal and injury costs include the property damage, which will be independently determined in this study by estimating vehicle and barrier damage costs. Thus, definitive fatality and injury costs are required that exclude property damage.

A direct cost approach has been 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 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 econimic 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 13 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 14 shows the 1971 cost components and severities for injuries.[12] Again excluding productivity and property damage, the estimated 1975 cost for an injury is

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

Vehicle Prices. Table 15 contains the 1975 sticker prices for the various domestic automobile models. Refinements could be made in establishing typical prices by including in the 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. Thus, a simple average of the 1975 sticker prices was used for vehicle prices. Using the subcompact and compact categories in Table 15 results in an average of

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

TABLE 13

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

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

TABLE 14

INJURY SEVERITY CLASSES IN THE 1972 SOCIETAL COST STUDY

	PERMANENT TOTAL DISABILITY	PERMANENT PARTIAL DISABILITY & PERMANENT DISFIGUREMENT	NO PERMANENT DISABILITY
PERCENT DISTRIBUTION OF INJURIES	.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 15

1975 AUTOMOBILE PRICES

COMPARING PRICES—'75 vs. '74

Comparison of selected 1975 and 1974 domestic models by market class. Prices are Manufacturer's Suggested Retail Prices. The 1975 prices are those in effect on March 25, 1975. The 1974 prices are those in effect at the end of the model year. No adjustment has been made for year-to-year equipment changes.

SMALL CARS

Subcompacts

	March 25, 1975	Final 1974
Pinto 2-dr.	$2,769	$2,527
Vega 2-dr.	2,786	2,505
Gremlin 2-dr.	2,798	2,481
Astre S 2-dr.	2,841	....
Bobcat 2-dr.	3,189	....
Vega 2-dr. Wagon	3,016	2,748
Astre S 2-dr. Wagon	3,071	....
Pinto 2-dr. Wagon	3,153	2,771
Bobcat 2-dr. Wagon	3,481	....

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

	March 25, 1975	Final 1974
Maverick	$3,025	$2,790
Hornet	3,074	2,774
Nova S	3,099	....
Comet	3,113	2,849
Ventura S	3,162	....
Omega F-85	3,203	....
Nova	3,205	2,811
Apollo/Skylark S	3,234	....
Valiant Duster	3,243	2,829
Ventura	3,293	2,892
Dart Sport	3,297	2,878
Omega	3,422	3,043
Apollo/Skylark	3,463	3,037
Camaro	3,540	3,162
Firebird	3,713	3,335

LUXURY SMALL (Lowest-priced 2-dr.)

	March 25, 1975	Final 1974
Pacer 6	$3,299	....
Mustang II 4	3,529	$3,134
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)

	March 25, 1975	Final 1974
Matador	$3,545	$3,195
Chevelle	3,657	3,345
Fury	3,672	3,271
Coronet	3,719	3,327
LeMans	3,720	3,341
Cutlass	3,821	3,793
Torino	3,954	3,236
Century	3,972	3,790
Montego	4,092	3,327
Monte Carlo	4,249	3,885
Elite	4,767	4,437
Charger SE	4,903	....
Cordoba	5,072	....
Cougar	5,218	4,706
Grand Prix	5,296	4,936

INTERMEDIATE WAGONS (V-8, 2-Seat)

	March 25, 1975	Final 1974
Matador	$3,943	$3,477
Fury	4,309	3,655
Chevelle	4,318	3,701
Torino	4,336	3,818
Coronet	4,358	3,699
LeMans	4,555	4,053
Century	4,636	4,205
Cutlass	4,665	4,289
Montego	4,674	4,083

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

LOW STANDARD

	March 25, 1975	Final 1974
Chevrolet Impala	$4,548	$4,135
Ford LTD	4,712	4,370
Plym. Gran Fury Cus.	4,761	4,400

HIGH STANDARD

	March 25, 1975	Final 1974
Pontiac Catalina	$4,612	$4,190
Buick LeSabre	4,771	4,355
Oldsmobile Delta 88	4,774	4,373
Dodge Royal Monaco	4,848	4,446
Chrysler Newport	4,854	4,677
Mercury Marquis	5,115	5,080
Riviera (2-dr.)	6,420	5,678
Toronado (2-dr.)	6,523	5,933
Thunderbird (2-dr.)	7,701	7,330

LUXURY STANDARD

	March 25, 1975	Final 1974
Cadillac deVille	$8,801	$ 8,100
Imperial LeBaron	8,844	7,804
Lincoln Continental	9,656	8,238
Eldorado (2-dr.)	9,935	9,110
Mark IV (2-dr.)	11,082	10,194

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

	March 25, 1975	Final 1974
Chevrolet Impala	$5,001	$4,561
Pontiac Safari	5,149	4,692
Ford LTD	5,158	4,752
Plym. Gran Fury Cus.	5,176	4,767
Dodge Royal Monaco	5,292	4,839
Mercury Marquis	5,411	4,960
Olds. Cus. Cruiser	5,413	4,981
Buick Estate Wagon	5,447	5,019
Chrys. Twn. & Ctry	6,099	5,767

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

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 16.

As shown in Table 17, the guardrail repair costs also vary considerably, ranging from 30 to 130 percent of the corresponding installation costs. Because of this variation, it was decided that an average percentage of the installation cost should be used for repair cost. Reasonable values would appear to be about 50% for the cable system, in which only posts will be damaged, and about 75% for all other types. An interesting

TABLE 16

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 4.35		5.23		4.15		5.39 6.38 6.00		5.83 6.43
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 6.37	9.35	4.52		6.63		6.63
6	7.90	4.70 4.28	9.25	5.64 6.22		5.19 4.82		6.05 6.38		6.13
7		3.88		5.34		4.20	9.93	5.57		5.80
8	5.45	5.00 7.50		6.75 8.00	6.04	5.40 6.50		5.05 8.00		8.40
9			12.00	6.27	6.87	5.27 5.97		7.73		

*Contractor has option of W6x8.5 or wood posts.

TABLE 16 (Cont'd)

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

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

TABLE 17

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.

<u>Conclusion</u>: Use 50% of original installation cost for cable system (G1) and 75% for all other types.

point in this portion of the work was that several states bill the responsible party for guardrail repair. Thus, the flexibility to enter such costs as societal rather than government/state costs will be used in the final model.

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

Vehicle Delay Cost. 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, worth of time, etc. An average value of $10 per hour will be used for illustrative purposes.

Task 2 Development of Cost-Effectiveness Model

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 vehicle and the heavy 4500-lb 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 18 is a summary of the usable results.

Since trucks and buses are not included in this study, the traffic mix will be assumed to consist of 25% for 2250-lb class vehicles and 75% for 4500-lb class vehicles, as shown in Table 18. Encroachment frequencies will be multiplied by these percentages to determine the corresponding estimated number of encroachments by vehicle class.

Impact Condition Extrapolations. The impact conditions selected for this study are shown in Table 19. Assuming the post shape did not affect the soil response,[17] it was concluded that the guardrail response of Types B and G4W in Table 1 would be identical. Thus, with 10 distinct guardrail types and the 2 vehicle classes, 3 speeds, and 4 impact angles shown in Table 19, 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 1 and 2. With these plots,

TABLE 18

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.

TABLE 19

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

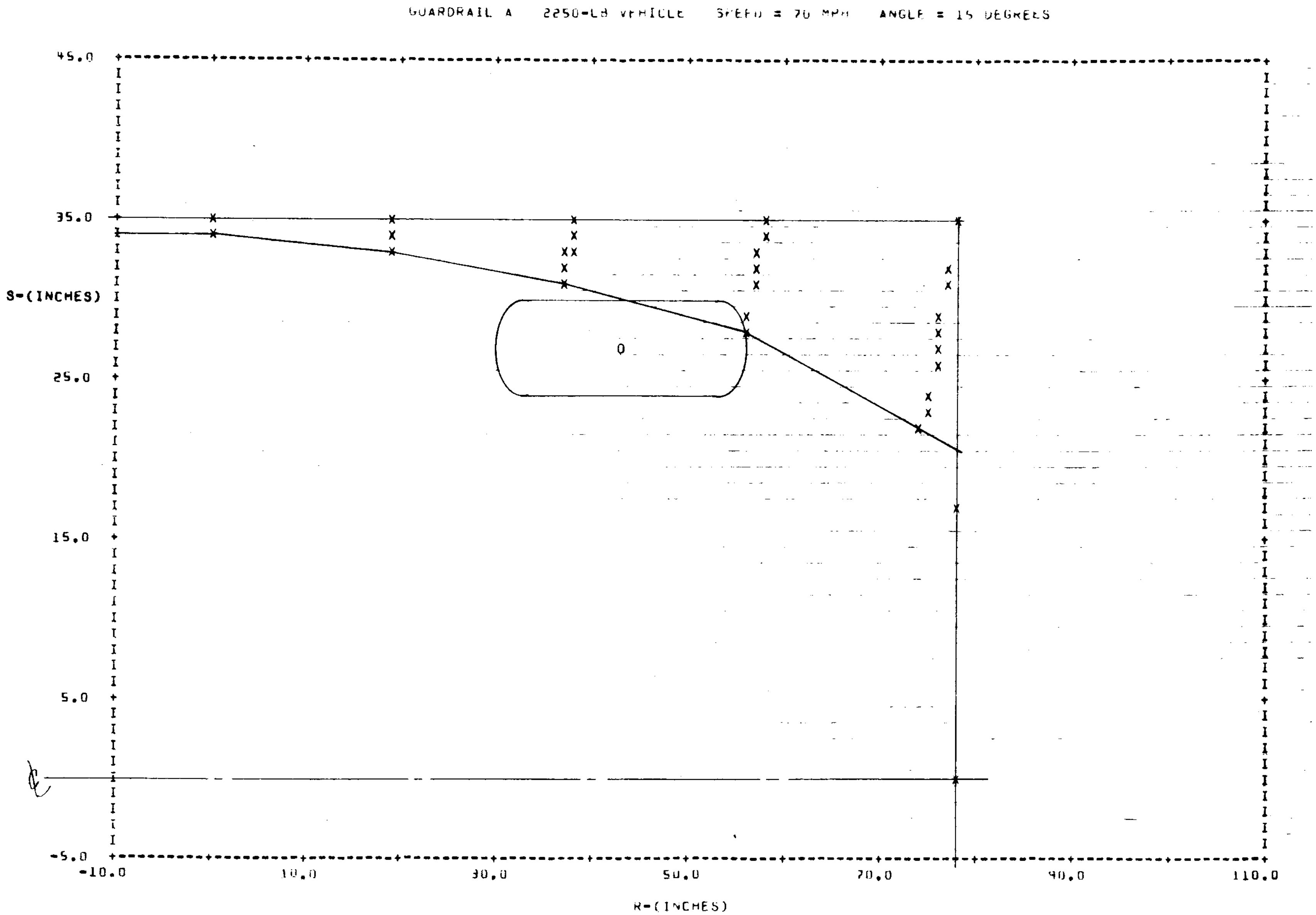


FIGURE 1. VEHICLE DEFORMATION (FRONT HALF)

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

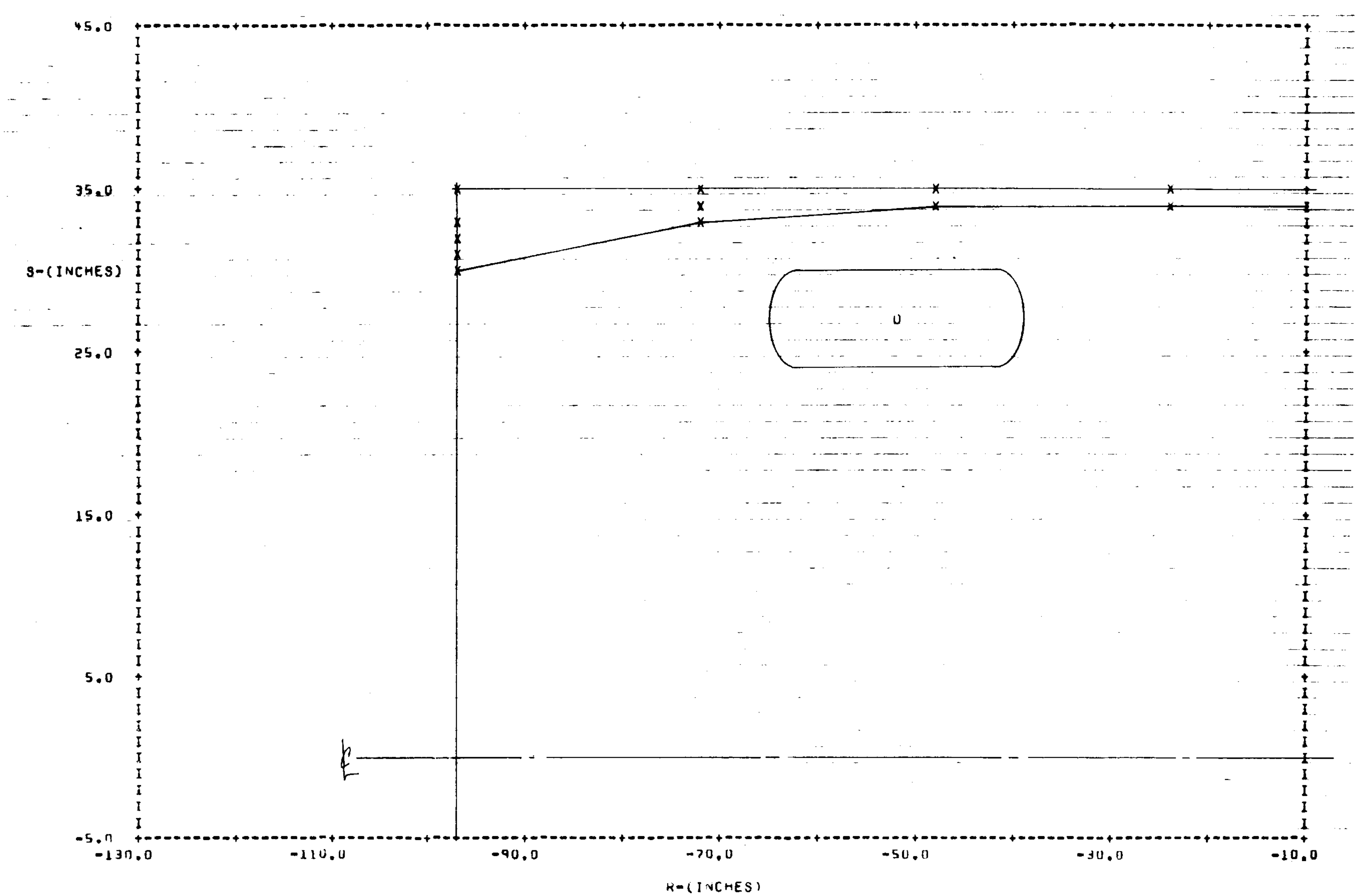


FIGURE 2. VEHICLE DEFORMATION (REAR HALF)

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.

An example of the pertinent extrapolation data is shown in Table 20. In a few 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 have been obtainable, this refinement will not be included in the final model. The linear footage of damaged rail will be used for guardrail damage.

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 21. 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. Table 22 shows the comparison of the HVOSM and BARRIER VII runs. Though the barrier force-deflection characteristics as determined from the BARRIER VII outputs were used for the HVOSM inputs, the differences between the two predictions are pronounced. Part of this might have been caused by activating the steer degree of freedom in the HVOSM runs instead of holding the front wheel steer angles constant at zero degrees.

TABLE 20

TYPICAL EXTRAPOLATION DATA, GUARDRAIL TYPE B/G4W, 2250-LB VEHICLE WEIGHT

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			
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

Metric conversion: Multiply ft by 0.305 to obtain m
Multiply mph by 1.609 to obtain km/hr

TABLE 21

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

TABLE 22

COMPARISON OF COMPUTER SIMULATIONS
(4500-lb vehicle, 70 mph, 30-degree impact)

Item	Guardrail Type: A	B/G4W	C	D	E	G1	G2	G3	G4S
Max. 50-ms longitudinal acceleration									
BARRIER VII	4.40	5.63	4.97	4.61	5.07	1.70	2.88	5.15	4.92
HVOSM	7.95	3.10	6.11	7.88	8.34	3.47	2.46	4.90	8.20
Max. 50-ms lateral acceleration									
BARRIER VII	5.57	5.69	6.37	4.97	5.97	2.22	3.60	4.64	4.90
HVOSM	9.58	2.94	7.81	9.66	10.15	7.94	2.33	7.36	10.74
Max. dynamic deflection (ft)									
BARRIER VII	7.47	7.21	6.99	8.21	6.64	24.50	12.14	16.11	8.38
HVOSM	3.46	2.17	4.00	3.92	3.75	8.54	3.25	5.17	3.83
Max. roll angle (degrees)*									
BARRIER VII	-	-	-	-	-	-	-	-	-
HVOSM	6.71	6.82	6.07	6.46	6.04	-12.81	6.49	-12.71	6.09

*(Plus/minus) angle = roll (toward/away from) guardrail.

However, even with the more severe HVOSM predictions, it can be seen that vehicle roll is not a likely problem for the selected guardrails.

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 Glennon estimates were selected for this study. Table 23 shows the encroachment rates that will be used.

The distribution of lateral displacements will be estimated from the average curve in Figure 3. The distribution of impacts for the category values of vehicle speeds and impact angles was first 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 4. The assumption that these two distributions were completely independent resulted in the combined distribution of speeds and angles shown in Table 24. Some of the resulting high-speed, high-angle impacts were simply not considered

TABLE 23

ENCROACHMENT RATE TABLE

Type of Highway	Description of Collision Direction	Encroachment Rate (events/mile/year)
Narrow Two-lane Rural Highway	1. Both directions	0.00060 ADT
	2. One direction only - right side	0.00030 ADT
	3. One direction only - left side	0.00030 ADT
Wide Two-lane or Undivided Four-lane Rural Highway	1. Both directions	0.00037 ADT
	2. One direction only - right side	0.00019 ADT
	3. One direction only - left side	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.

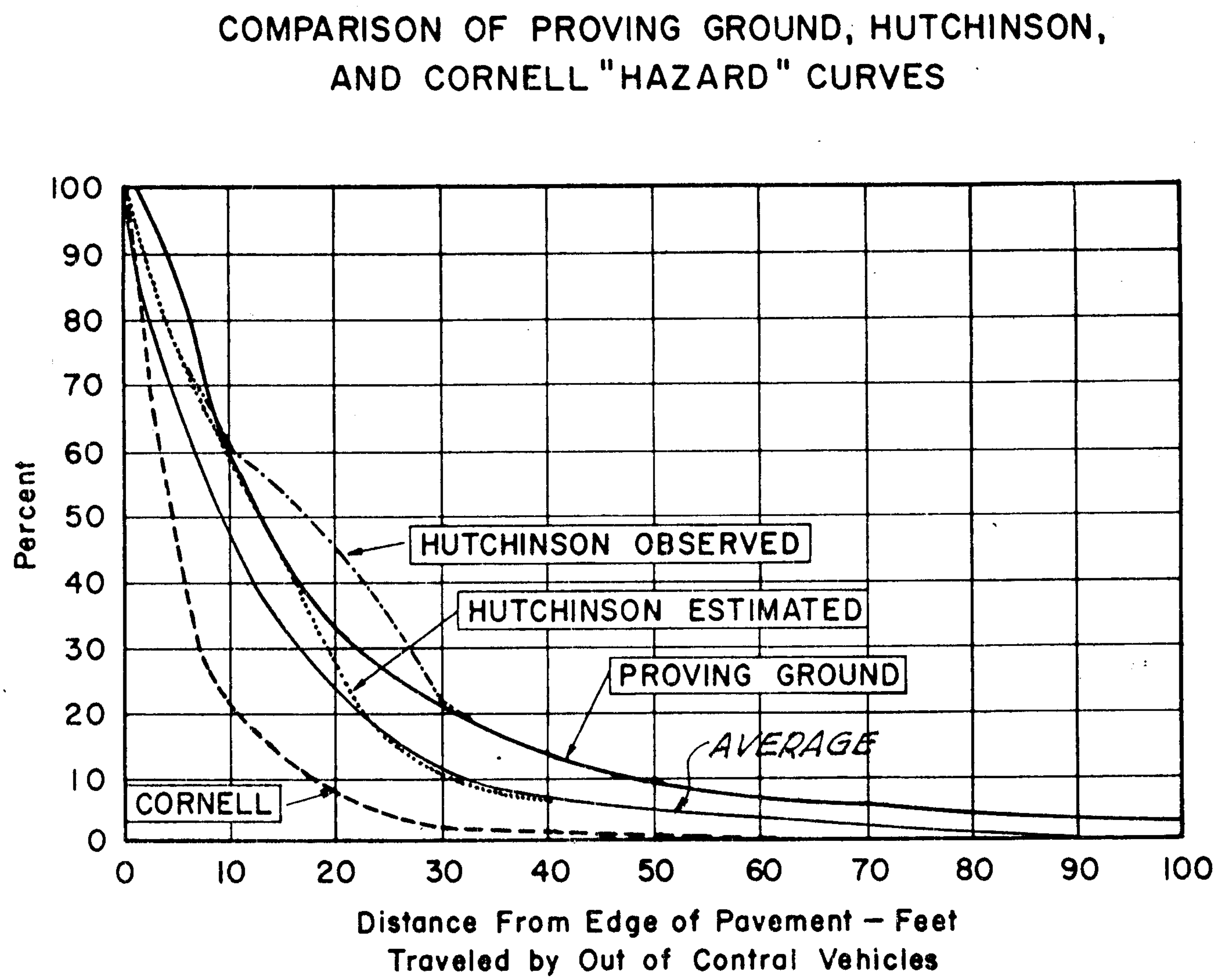
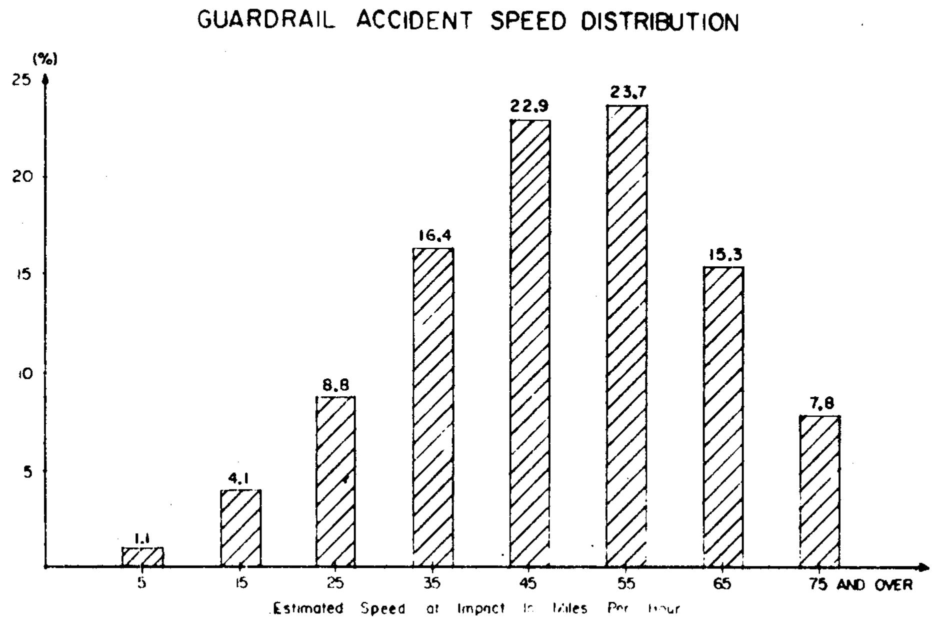


FIGURE 3. DISTRIBUTION OF LATERAL DISPLACEMENTS (Ref. 22)



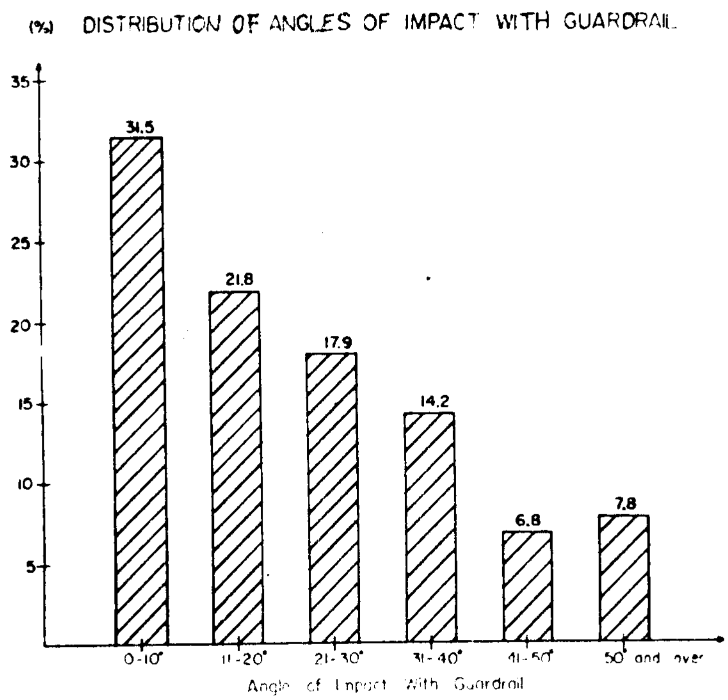


FIGURE 4. DISTRIBUTION OF VEHICLE SPEEDS AND IMPACT ANGLES (Ref. 23)

TABLE 24

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)

possible. The values shown in parentheses, calculated by using the point mass approach discussed in Reference 24, represent distributions for a guardrail about 3 feet from the edge of the pavement. These values appear much more realistic. Thus, it was decided to formulate combined probabilities by using the following:

(1) The average curve for distribution of lateral displacements from Figure 3;

(2) The distribution of impact speeds from Figure 4;

(3) The point mass approach with a coefficient of friction of unity for determination of the 95 percentile impact angle (see Reference 24);

(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. A sample program output sheet with the combined probabilities is shown in Figure 5. Category values include offset distances of 10, 20, 30, 40, 50, 60 feet and highway curvatures of 0, ± 2, ± 4, ± 6, ± 8, ± 10 degrees, where the (+/-) angles indicate curves to the driver's (left/right). For each of these 66 combinations, sheets similar to Figure 5 are ready and can be used in the final manual. To determine the probable number of impacts by vehicle class, it will simply be necessary to multiply the probabilities shown by the traffic mix percentages discussed earlier and the expected encroachments from Table 23.

PROBABILITIES

```
*******************************
*                             *
* OFFSET DISTANCE =  20.  FEET *
*                             *
* DEGREE OF CURVE =   4.      *
*                             *
*******************************
```

SPEED (MPH)	IMPACT ANGLE (DEGREES)	PROBABILITY
30.	7.	.00036
30.	15.	.00853
30.	25.	.03428
30.	30.	.02766

95 PERCENTILE IMPACT ANGLE = 39.62 DEGREES

50.	7.	.00413
50.	15.	.06907
50.	25.	.03498
50.	30.	.00040

95 PERCENTILE IMPACT ANGLE = 25.39 DEGREES

70.	7.	.00744
70.	15.	.04434
70.	25.	.00181
70.	30.	.00000

95 PERCENTILE IMPACT ANGLE = 19.39 DEGREES

FIGURE 5. TYPICAL COMPUTER PROBABILITY TABLE

Traffic Delay Time. The formulation of traffic delay time estimates for accident blockage and guardrail repair congestion is discussed in Appendix E. Traffic queuing and assumed average vehicle speeds for one-half mile site lengths of 20 mph during the accident blockage and 35 mph during repair are included. An average speed of 30 mph is assumed for the "gawkers" traveling in the opposite direction during the accident blockage. Two, three, and four-lane rural roads and four, six, and eight-lane freeways are included with AADT's up to the capacity of the highway. Figure 6 is an example of the computer output sheets that have been prepared and can be included in the final manual. In addition, curves similar to those shown in Figures 7 and 8 could be included for those users who prefer the curves to the tabular data.

The use of several hundred computer output sheets to show combined probabilities and traffic delay will produce a rather voluminous volume. However, when properly arranged and tabbed and possibly distributed as a second volume for the user's manual, its use will be easy and quick. Data from the typical probability sheet shown in Figure 5 cannot be readily presented in the form of curves. Also, the format of the sheet is such that the probabilities are arranged in the exact order that they will be used in determining impact severities. This will be discussed later in the Proposed Approach section.

Task 3 Collection of Reconstructed Accident Data

The instructions and accident forms that were sent out to

```
**********************************************************************
*                                                                    *
* TWO-LANE RURAL ROAD                                  AADT =  8000. *
*                                                                    *
**********************************************************************
```

OPERATING SPEED AT THIS AADT = 43.8 MPH

TIME DELAY CAUSED BY ACCIDENT BLOCKAGE

TIME TO REMOVE BLOCKAGE (HRS)	VEHICLE HOURS OF DELAY
.50	4.5
1.00	16.6
1.50	36.4
2.00	63.8
2.50	98.7

TIME DELAY CAUSED BY REPAIR CONGESTION

NO QUEUING AT THIS AADT. DEMAND/CAPACITY = .36

TIME TO REPAIR GUARDRAIL (HRS)	VEHICLE HOURS OF DELAY
5.00	10.1
10.00	20.1
15.00	30.2
20.00	40.2
25.00	50.3
30.00	60.3

FIGURE 6. TYPICAL COMPUTER TRAFFIC DELAY TABLE

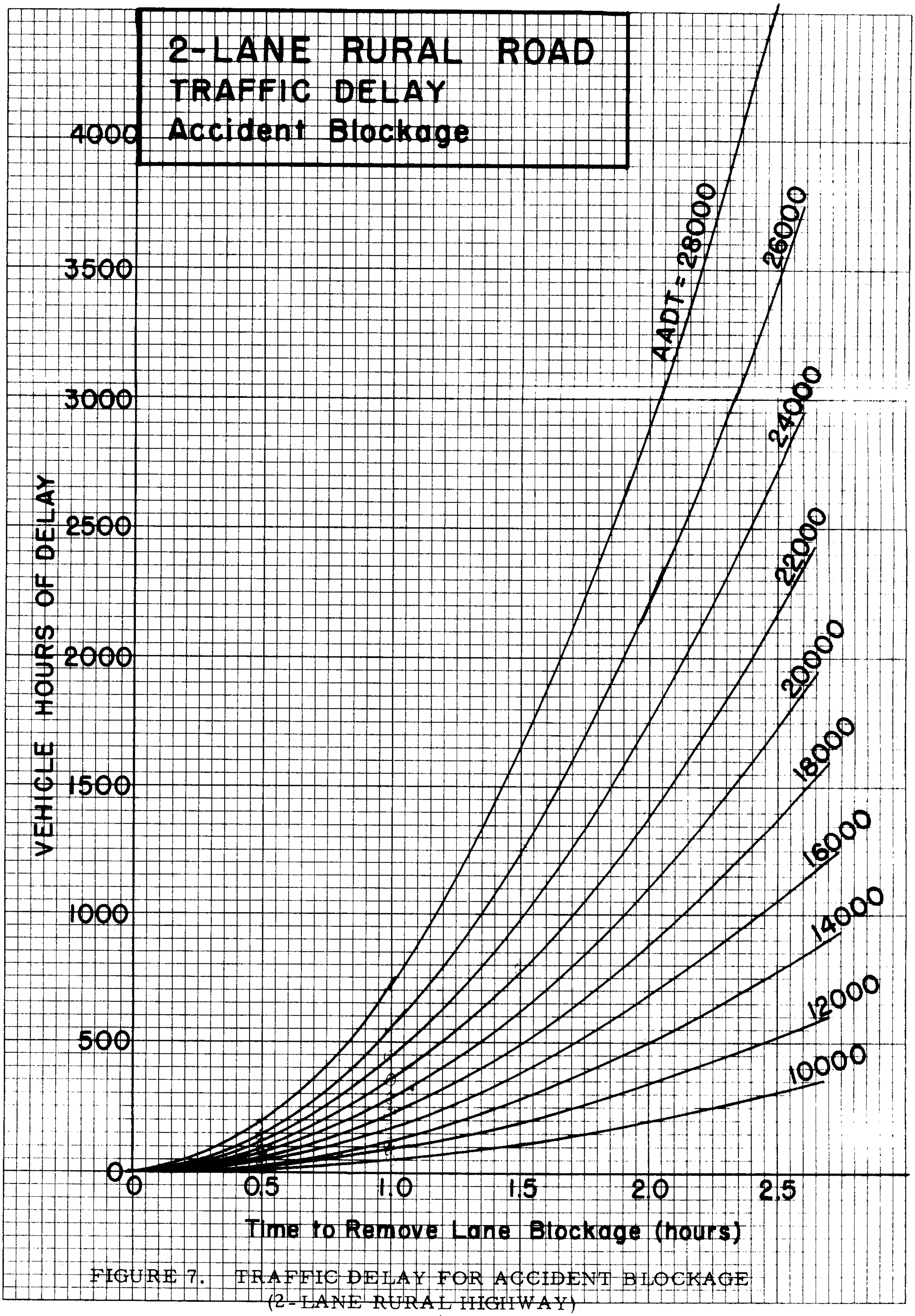


FIGURE 7. TRAFFIC DELAY FOR ACCIDENT BLOCKAGE (2-LANE RURAL HIGHWAY)

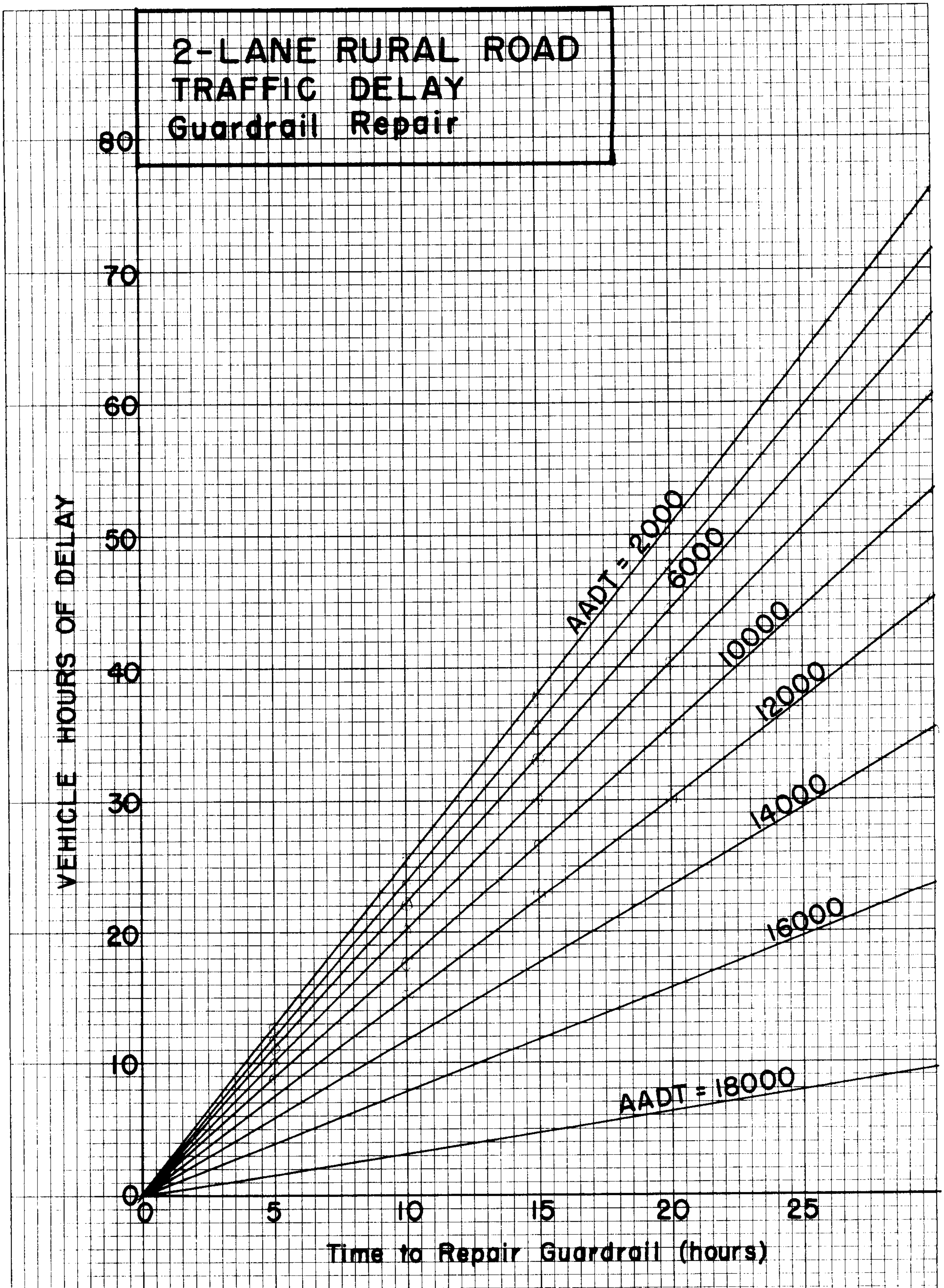


FIGURE 8. TRAFFIC DELAY FOR GUARDRAIL REPAIR (2-LANE RURAL HIGHWAY)

the six accident investigation teams are shown in Appendix F. To date, 11 accident reports have been received. Unfortunately, no more than about three or four of them will be of usable value for two reasons. First, most of the reports have 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 has been so poor that computer simulations of the accidents are not possible from the reported data. Remedial measures have included telecons requesting corrected data and memoranda increasing the number of investigation criteria that must be met before reporting the accident.

The list of accident investigation criteria has restricted the accident teams and reduced the number of reported accidents. It appears that a large number of the guardrail hits are freakish in nature. For example, the SwRI team has visited between 50 and 60 accident sites with none meeting the criteria. On a recent day, four sites were inspected. One involved a vehicle that crossed a drainage ditch and hit the back of a guardrail. Another impact was so slight that the contact point with the guardrail could not be found. A third was a median barrier impact, and the fourth was an impact with the turned-down Texas twist end terminal. Other teams have reported similar difficulties. However, six months remain in this task, and several usable reports should be forthcoming.

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 will likely be received, along with the inevitable scatter that will be exhibited, it has been considered necessary to judiciously assume the interfaces and check the assumption with the data that is received. The allowable limits shown in Figure 9 are based on a severity index as defined by

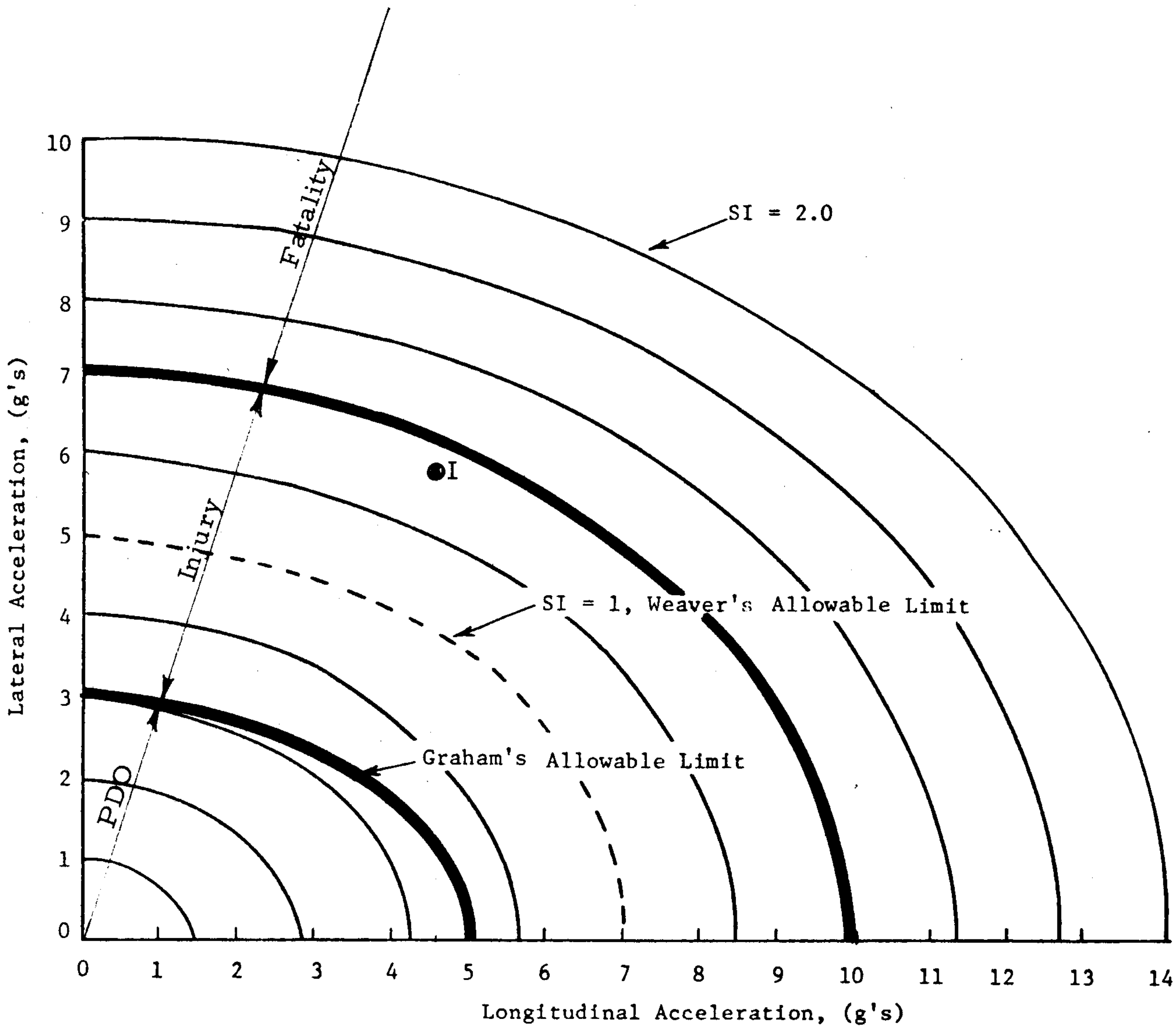
$$SI = \sqrt{\frac{G^2_{long.}}{G^2_{XL}} + \frac{G^2_{lat.}}{G^2_{YL}}}$$

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 is assumed as a reasonable interface location between injury and fatality accidents.

PROPOSED APPROACH

Task 4 Verification of Model Validity

The proposed approach for verification of the model validity is much the same as that used in the correlation portion of the study. To illustrate the technique, one report, received from the Pennsylvania team, has been simulated with a BARRIER VII run. A comparison of the simulated



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

and reported results is shown in Table 25. It is felt that the principal cause of the discrepancies shown was the type of vehicle involved (a 1972 Fiat 850 Spyder). These small foreign cars are quite soft from the standpoint of damage from frontal impact. The extensive vehicle damage and only slight guardrail damage would indicate that the vehicle deformation properties used in BARRIER VII were probably too stiff for this case. Of course, the reported impact speed is difficult to estimate and might have been too high.

The reported 25.5-ft length of damaged rail in Table 25 is not realistic from the repair standpoint and would probably involve at least three 12'-6" sections for a total of 37.5 ft. The length of guardrail contact in the simulation was 37.45 ft.

To illustrate the validation approach for the severity level indicator, the acceleration level from Table 25 is plotted in Figure 9. While the point is close to the assumed injury/fatality interface, it is in the injury band. By means of this figure, the acceleration levels and other extrapolation data in Table 20 can be used to prepare accident severity levels as shown in Table 26 for the 2250-lb vehicle. Table 27 is similarly prepared from the extrapolation data for the 4500-lb vehicle. Note that the maximum dynamic deflections are included in the tables to indicate if the guardrail type should be used at the site under investigation.

Task 5 Preparation of User Manual

To provide the desired flexibility in the final manual, all cost parameters have been isolated from the probability and severity

TABLE 25

COMPARISON OF SIMULATED AND REPORTED ACCIDENT

Item	BARRIER VII	Accident Report
Barrier Deflection	4.63 ft (maximum dynamic)	2.75 in. (permanent)
No. of Posts Damaged	7	3 slightly damaged
Length of Railing Damaged (ft)	37.5	25.5
Vehicle Damage	40% (estimated from computer print) 80% (estimated from report photographs)	$\frac{\$1500}{3200*} = 47\%$
Maximum 50-ms Accelerations (g's)		
Longitudinal	4.57	2 injuries
Lateral	5.74	(one total ejection)

*$3200 price proposed for 2250-lb vehicles.

TABLE 26

ACCIDENT SEVERITY LEVELS

GUARDRAIL TYPE G4W   VEHICLE CLASS (LB) 2, 250

Speed (mph)	Impact Angle (deg)	Maximum Dynamic Deflection (ft)	Occupant Severity		Guardrail Damage (ft)	Vehicle Damage
			Injury	Fatality		
30	7	0.44	0	0	12.5	0.15
30	15	0.75	0	0	12.5	0.20
30	25	0.82	1.0	0	12.5	0.20
30	30	1.39	1.0	0	12.5	0.30
50	7	0.62	0	0	12.5	0.35
50	15	1.17	1.0	0	25.0	0.40
50	25	3.47	0	1.0	25.0	0.35
50	30	3.33	0	1.0	25.0	0.35
70	7	0.60	1.0	0	25.0	0.35
70	15	1.27	0	1.0	25.0	0.60
70	25	2.79	0	1.0	25.0	0.35
70	30	4.37	0	1.0	37.5	0.35

TABLE 27

ACCIDENT SEVERITY LEVELS

GUARDRAIL TYPE G4W VEHICLE CLASS (LB) 4,500

Speed (mph)	Impact Angle (deg)	Maximum Dynamic Deflection (ft)	Occupant Severity		Guardrail Damage (ft)	Vehicle Damage
			Injury	Fatality		
30	7	0.56	0	0	12.5	0.15
30	15	0.85	0	0	12.5	0.20
30	25	1.37	1.0	0	25.0	0.25
30	30	2.01	1.0	0	25.0	0.35
50	7	0.80	0	0	25.0	0.35
50	15	2.23	1.0	0	37.5	0.50
50	25	3.77	1.0	0	37.5	0.40
50	30	4.13	1.0	0	37.5	0.45
70	7	0.74	1.0	0	25.0	0.70
70	15	2.34	1.0	0	37.5	0.45
70	25	5.79	1.0	0	50.0	0.50
70	30	7.21	1.0	0	50.0	0.45

estimates of the study. One approach that could be used is in the form of worksheets. In the illustrations that follow, it will be shown from the tables and figures contained in this report how the required societal and government/state costs can be determined. It will be assumed that a G4W guardrail will be evaluated for a two-lane rural road with an AADT of 8000 in a state of FHWA Region 5. The guardrail offset distance is 20 ft on a 4-degree curve to the left. The length-of-need of the guardrail is 1000 ft. It will require one hour to remove the damaged vehicle from the road and ten hours to repair the guardrail. A useful life of 15 years at a current rate of interest of 8% is assumed.

The proposed steps in the cost-effectiveness analysis are as follows:

Worksheet 1. VEHICLE ENCROACHMENTS. Required outside information for this worksheet includes the type of highway and estimates of the length-of-need of the guardrail, the traffic mix, and the AADT. The Encroachment Rate Table (Table 23) is then used for item 2. Other items are computed as indicated.

Worksheet 2. EXPECTED NUMBER OF IMPACTS. Required outside information for this worksheet includes the offset distances from the center of the outside lanes to the face of the guardrail and the degree of curve (see Figures 10 and 11). The number of encroachments (item 3) are transferred from Worksheet 1. The probabilities (item 4) are read from the Probability Tables (see Figure 5). Other items are computed as indicated.

Worksheet 1 **WI**

VEHICLE ENCROACHMENTS

1. Type of Highway 2-lane rural

2. Encroachment Rate 0.00030
(from Encroachment Rate Table)

3. Length-of-Need for Guardrail (ft) 1000

4. AADT 8000

5. Traffic Mix

   5.1 2250-lb vehicles 0.25

   5.2 4500-lb vehicles 0.75

6. Yearly No. of Encroachments

   6.1 2250-lb vehicles 0.1136
   (2 x 3 x 4 x 5.1 ÷ 5280)

   6.2 4500-lb vehicles 0.3409
   (2 x 3 x 4 x 5.2 ÷ 5280)

Worksheet 2 **W2**

EXPECTED NUMBER OF IMPACTS

1. Offset Distances (ft)

   1.1 Right side 20

   1.2 Left side 30

2. Degree of Curve +4

3. No. of Encroachments

   3.1 2250-lb vehicles (from W1, 6.1) 0.1136

   3.2 4500-lb vehicles (from W1, 6.2) 0.3409

Speed (mph)	Impact Angle (deg)	4. Probabilities (From Probability Tables) 4.1 Right Side	4.2 Left Side*	5. No. of Impacts 5.1 2250-lb Vehicles 3.1 x (4.1 + 4.2)	5.2 4500-lb Vehicles 3.2 x (4.1 + 4.2)
30	7	0.00036	0.00008	0.00005	0.00015
30	15	0.00853	0.00134	0.00112	0.00336
30	25	0.03428	0.00823	0.00483	0.01449
30	30	0.02766	0.03381	0.00698	0.02096
50	7	0.00413	0.00077	0.00056	0.00167
50	15	0.06907	0.01873	0.00997	0.02993
50	25	0.03498	0.03921	0.00843	0.02529
50	30	0.00040	0.00791	0.00094	0.00283
70	7	0.00744	0.00141	0.00101	0.00302
70	15	0.04434	0.02205	0.00754	0.02263
70	25	0.00181	0.00935	0.00127	0.00380
70	30	0.00000	0.00007	0.00001	0.00002

*Enter zeros for divided highways.

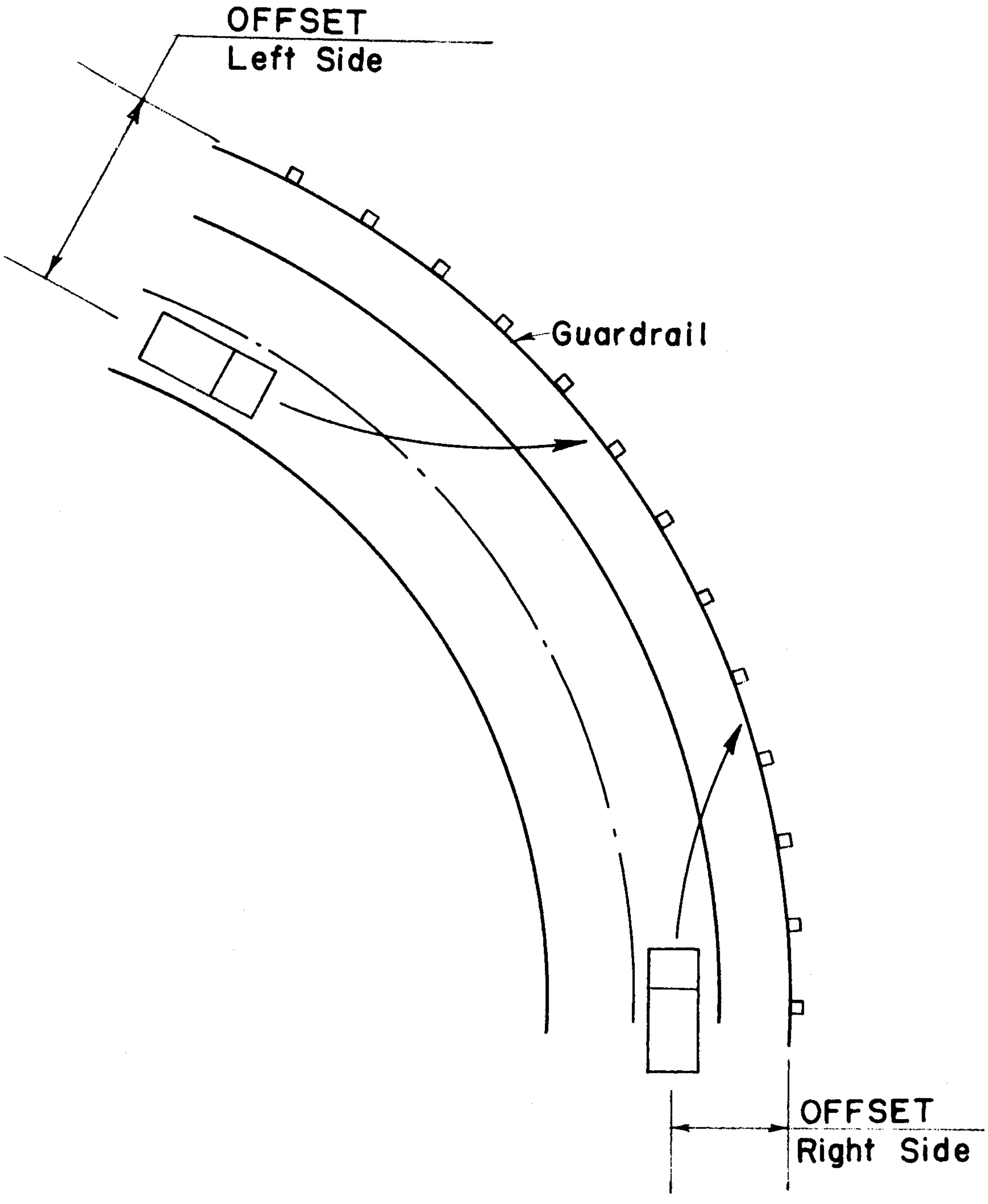


FIGURE 10. OFFSET DISTANCES
(+ DEGREE OF CURVE)

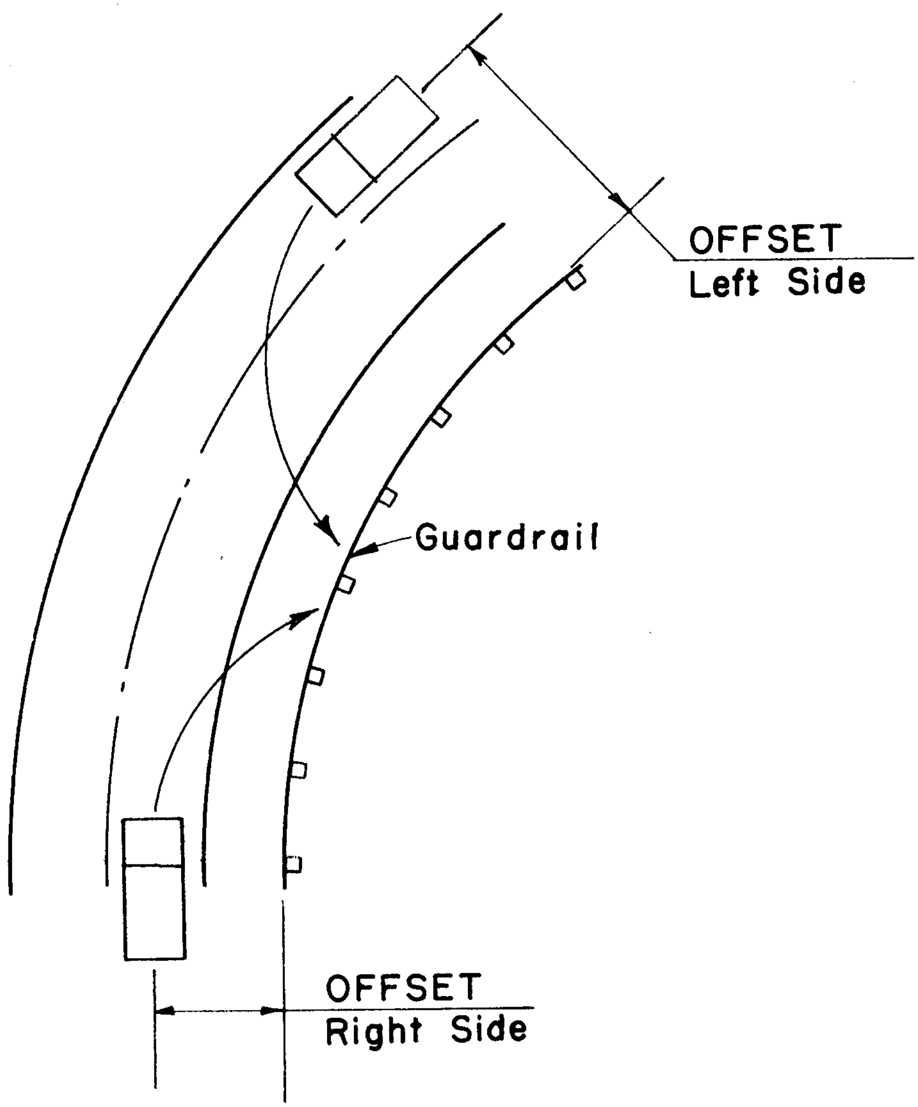


FIGURE 11. OFFSET DISTANCES
(- DEGREE OF CURVE)

Worksheets 3 and 4. YEARLY ACCIDENT SEVERITIES. Required outside information for this worksheet includes the guardrail type. The number of impacts (item 2) is transferred from Worksheet 2. Severities (item 3) are then obtained by multiplying item 2 by the corresponding severity levels (Table 26 for Worksheet 3 and Table 27 for Worksheet 4).

Worksheet 5. TRAFFIC DELAY COST. Required information for this worksheet includes estimates for the times to remove the damaged vehicle from the roadway and to repair the guardrail. Traffic delays (item 5) are obtained from the Traffic Delay Tables (see Figure 6). The probability of blockage is assumed from Lampella's historical data (see Table E.1). The number of impacts (item 6) are transferred from Worksheet 2. Other items are computed as indicated.

Worksheet 6. YEARLY ACCIDENT COSTS. Accident severities and traffic delay (item 1) are transferred from Worksheets 3, 4, and 5. Unit costs (item 2) are taken from the supplied typical cost information, or the agency can use its own values.

Worksheet 7. GUARDRAIL INSTALLATION AND MAINTENANCE COSTS. Unit installation costs may be obtained from the supplied typical cost information, or the agency may use its own values. Typical maintenance costs will not be given and may either be estimated or omitted. Note that barrier damage repair can be entered in Worksheet 6 or Worksheet 7, depending on how the costs are handled.

Worksheet 8. TOTAL COSTS. Total societal and government/state costs are computed on the basis of present worth. Economic

Worksheet 3 **W3**

YEARLY ACCIDENT SEVERITIES (2250-LB VEHICLES)

1. Guardrail Type G4W

Speed (mph)	Impact Angle (deg)	2. No. of Impacts (W2, 5. 1)	3. Severity per Year (2 x corresponding value from Accident Severity Level Tables)			
			No. of Injuries	No. of Fatalities	Guardrail Damage (ft)	Vehicle Damage
30	7	0.00005	0	0	0.002	0.000
30	15	0.00112	0	0	0.042	0.000
30	25	0.00483	0.005	0	0.181	0.001
30	30	0.00698	0.007	0	0.262	0.002
50	7	0.00056	0	0	0.021	0.000
50	15	0.00997	0.010	0	0.499	0.004
50	25	0.00843	0	0.008	0.422	0.003
50	30	0.00094	0	0.001	0.047	0.000
70	7	0.00101	0.001	0	0.051	0.000
70	15	0.00754	0	0.008	0.377	0.005
70	25	0.00127	0	0.001	0.064	0.001
70	30	0.00001	0	0.000	0.001	0.000
Totals			3.1 0.023	3.2 0.018	3.3 1.969	3.4 0.016

Worksheet 4 **W4**

YEARLY ACCIDENT SEVERITIES (4500-LB VEHICLES)

1. Guardrail Type G4W

Speed (mph)	Impact Angle (deg)	2. No. of Impacts (W2, 5.2)	3. Severity per Year (2 x corresponding value from Accident Severity Level Tables) No. of Injuries	No. of Fatalities	Guardrail Damage (ft)	Vehicle Damage
30	7	0.00015	0	0	0.006	0.000
30	15	0.00336	0	0	0.126	0.001
30	25	0.01449	0.014	0	0.725	0.004
30	30	0.02096	0.021	0	1.048	0.007
50	7	0.00167	0	0	0.084	0.001
50	15	0.02993	0.030	0	1.871	0.015
50	25	0.02529	0.025	0	1.581	0.010
50	30	0.00283	0.003	0	0.177	0.001
70	7	0.00302	0.003	0	0.151	0.002
70	15	0.02263	0.023	0	1.414	0.010
70	25	0.00380	0.004	0	0.285	0.002
70	30	0.00002	0.000	0	0.002	0.000
Totals			3.1 0.123	3.2 0	3.3 7.470	3.4 0.053

Worksheet 5

W5

TRAFFIC DELAY COST

1. Highway Type 2-Lane Rural
2. AADT 8000
3. Estimated time to remove damaged vehicle (hrs) 1.0
4. Estimated time to repair damaged guardrail (hrs) 10.0
5. Traffic delay per accident (vehicle hours from Traffic Delay Tables)
   - 5.1 Delay caused by traffic blockage 16.6
   - 5.2 Delay caused by repair congestion 20.1
   - 5.3 Total delay (5.1 + 5.2) 36.7

Speed (mph)	Impact Angle (deg)	6. No. of Impacts: 6.1 2250-lb Vehicles (W2, 5.1)	6.2 4500-lb Vehicles (W2, 5.2)	6.3 Total (6.1 + 6.2)	7. Probability of Blockage	Traffic Delay (vehicle hours) (5.3 x 6.3 x 7)
30	7	0.00005	0.00015	0.00020	0.32	0.002
30	15	0.00112	0.00336	0.00448	0.22	0.036
30	25	0.00483	0.01449	0.01932	0.18	0.128
30	30	0.00698	0.02096	0.02794	0.14	0.144
50	7	0.00056	0.00167	0.00223	0.32	0.026
50	15	0.00997	0.02993	0.03990	0.22	0.322
50	25	0.00843	0.02529	0.03372	0.18	0.223
50	30	0.00094	0.00283	0.00387	0.14	0.020
70	7	0.00101	0.00302	0.00403	0.32	0.047
70	15	0.00754	0.02263	0.03017	0.22	0.244
70	25	0.00127	0.00380	0.00507	0.18	0.033
70	30	0.00001	0.00002	0.00003	0.14	0.000
	Total					8. 1.225

9. Unit Cost per Vehicle Hour $ 10.00
10. Yearly Traffic Delay Cost C_{YD} (8 x 9) $ 12.30

Worksheet 6 **W6**

YEARLY ACCIDENT COSTS

FHWA Region 5

Item	1. Expected Amount	2. Unit Cost (from Unit Cost Tables)	3. Total Cost (1 x 2) ($)
No. of injuries	W3, 3.1 0.023 W4, 3.1 0.123 Total 0.146	$ 4,500	3.1 $ 657.00
No. of fatalities	W3, 3.2 0.018 W4, 3.2 0 Total 0.018	$ 33,100	3.2 $ 595.80
Barrier damage repair* (ft)	W3, 3.3 1.969 W4, 3.3 7.470 Total 9.439	$ 0.75(6.69) = 5.02	3.3 $ 47.40
2250-lb vehicle damage	W3, 3.4 0.016	$ 3,200	3.4 $ 51.20
4500-lb vehicle damage	W4, 3.4 0.053	$ 5,300	3.5 $ 280.90
Travel delay (vehicle hours)	W5, 8 1.225	$ 10.	3.6 $ 12.30
		Yearly Societal Cost C_{YS} = Total	4. $ 1644.60

*Include this item if responsible party is billed for the damage. If the state assumes the repair costs, include the item in Worksheet 7.

Worksheet 7 **W7**

GUARDRAIL INSTALLATION AND MAINTENANCE COSTS

1. Guardrail Type G4W FHWA Region 5

2. Length-of-Need for Guardrail (Ft) 1000

3. Unit Installation Cost (from Unit Cost Table) $ 6.69

4. Installation Cost C_I (2 x 3) $ 6690.00

5. Maintenance Cost

   5.1 Estimated Maintenance Cost per Ft per Year $ 1.50

   5.2 Yearly Maintenance Cost C_{YM} (2 x 5.1) $ 1500.00

6. Barrier Damage Repair*

   6.1 Expected Amount W3, 3.3 See Worksheet 6
   W4, 3.3 ______
   Total ______

   6.2 Unit Cost (from Unit Cost Tables) $ ______

   6.3 Yearly Repair Cost C_{YR} (6.1 x 6.2) $ ______

*Include this item if state assumes the repair costs. If responsible party is billed for repair costs, enter the item in Worksheet 6.

Worksheet 8 **W8**

TOTAL COSTS

1. Guardrail Type G4W

2. Estimated Useful Life of Guardrail (Years) 15

3. Assumed Interest Rate (%) 8

4. Economic Present Worth Factors

   4.1 Present Value K_P of $1 at Compound Interest 0.3152
   (Interest Table I. 1)

   4.2 Present Value K_A of Annuity of $1 8.559
   (Interest Table I. 2)

5. Estimated Salvage Value of Guardrail (Future Dollars) C_{FS} =
$ 3.00 (1000) = $3000

6. Total Government/State Present Worth Cost
   $C_G = C_I + C_{YM} (K_A) + C_{YR} (K_A) - C_{FS} (K_P)$

   6.1 Installation (W7, 4) $ 6,690.00

   6.2 Maintenance $C_{YM} \times K_A$
   (W7, 5.2) 1500.00 x 4.2 8.559 = $ 12,838.50

   6.3 Repair (if assumed by State) $C_{YR} \times K_A$
   (W7, 6.3) ______ x 4.2 ______ = $ ______

   6.4 Less Salvage Value $C_{FS} \times K_P$
   5 3000.00 x 4.1 0.3152 = - $ 945.60

   Total C_G = $ 18,582.90

7. Total Societal Present Worth Cost
   $C_S = C_{YS} (K_A) + C_{YD} (K_A)$

   7.1 Accident Damage $C_{YS} \times K_A$
   (W6, 4) 1644.60 x 4.2 8.559 = $ 14,076.10

   7.2 Traffic Delay $C_{YD} \times K_A$
   (W5, 10) 12.30 x 4.2 8.559 = $ 105.30

   Total C_S = $ 14,181.40

present worth factors (item 4) are shown in Tables I. 1 and I. 2. The useful life of a guardrail can be estimated at 15 to 20 years. An estimate of the salvage value in future dollars (item 5) can be included if desired.

As discussed above, the present worth societal and government/state costs will be computed for each of the guardrails of interest. It is anticipated that the results can then be compared as shown in Figure 12. This figure shows a plot for the total of ten guardrail systems that are included in this study. By drawing the dashed line from the left to the bottom of the envelope as shown, all systems to the upper right of the line can be eliminated immediately. Remaining are systems 2, 6, and 8. System 8 is the most effective of these from the standpoint of societal costs but has the highest government cost. By comparing the ratios $\Delta y_1/\Delta x_1$ and $\Delta y_2/\Delta x_2$, the agency can determine what is lost in effectiveness with the cheaper systems. For example, since $\Delta y_2/\Delta x_2 < \Delta y_1/\Delta x_1$, more can be gained in moving from system 8 to 6 than from 6 to 2. The final selection will probably depend to a large extent on the available funding.

The manner in which Figure 12 is prepared offers still more flexibility in the proposed study. In its simplest form, the figure could represent costs at a single guardrail site. In expanded forms, the figure could be prepared for all of the guardrail sites along a stretch of highway or for all of the needs of, say, a particular highway district. For this latter case, a state agency might use the plots as aids in deciding how state funds will be allocated to the various districts.

INTEREST TABLE I. 1

PRESENT VALUE K_P OF \$1 AT COMPOUND INTEREST

$$K_P = (1+r)^{-T}$$

USEFUL LIFE T (YEARS)	INTEREST RATE I (PERCENT)										
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1.0	1.0000	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2.0	1.0000	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264
3.0	1.0000	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513
4.0	1.0000	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830
5.0	1.0000	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209
6.0	1.0000	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645
7.0	1.0000	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132
8.0	1.0000	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665
9.0	1.0000	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241
10.0	1.0000	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855
11.0	1.0000	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505
12.0	1.0000	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186
13.0	1.0000	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897
14.0	1.0000	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633
15.0	1.0000	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394
16.0	1.0000	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176
17.0	1.0000	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978
18.0	1.0000	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799
19.0	1.0000	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635
20.0	1.0000	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486
21.0	1.0000	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351
22.0	1.0000	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228
23.0	1.0000	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117
24.0	1.0000	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015
25.0	1.0000	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923
26.0	1.0000	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839
27.0	1.0000	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763
28.0	1.0000	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693
29.0	1.0000	0.7493	0.5631	0.4243	0.3207	0.2529	0.1846	0.1406	0.1073	0.0822	0.0630
30.0	1.0000	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573

INTEREST TABLE I.2

PRESENT VALUE K_A OF ANNUITY OF $1

$$K_A = \frac{1-(1+r)^{-T}}{r}$$

USEFUL LIFE T (YEARS)	INTEREST RATE I (PERCENT)										
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1.0	1.000	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2.0	2.000	1.970	1.941	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736
3.0	3.000	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487
4.0	4.000	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170
5.0	5.000	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791
6.0	6.000	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355
7.0	7.000	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868
8.0	8.000	7.651	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335
9.0	9.000	8.565	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759
10.0	10.000	9.471	8.982	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145
11.0	11.000	10.367	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495
12.0	12.000	11.254	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814
13.0	13.000	12.133	11.348	10.635	9.986	9.393	8.853	8.358	7.904	7.487	7.103
14.0	14.000	13.003	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367
15.0	15.000	13.864	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606
16.0	16.000	14.717	13.577	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824
17.0	17.000	15.561	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022
18.0	18.000	16.397	14.992	13.753	12.659	11.689	10.828	10.059	9.372	8.756	8.201
19.0	19.000	17.225	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365
20.0	20.000	18.044	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514
21.0	21.000	18.856	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649
22.0	22.000	19.659	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772
23.0	23.000	20.454	18.292	16.443	14.857	13.488	12.303	11.272	10.371	9.580	8.883
24.0	24.000	21.242	18.914	16.935	15.247	13.799	12.550	11.469	10.529	9.707	8.985
25.0	25.000	22.022	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077
26.0	26.000	22.794	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161
27.0	27.000	23.558	20.706	18.327	16.330	14.643	13.210	11.987	10.935	10.027	9.237
28.0	28.000	24.315	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307
29.0	29.000	25.064	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370
30.0	30.000	25.806	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427

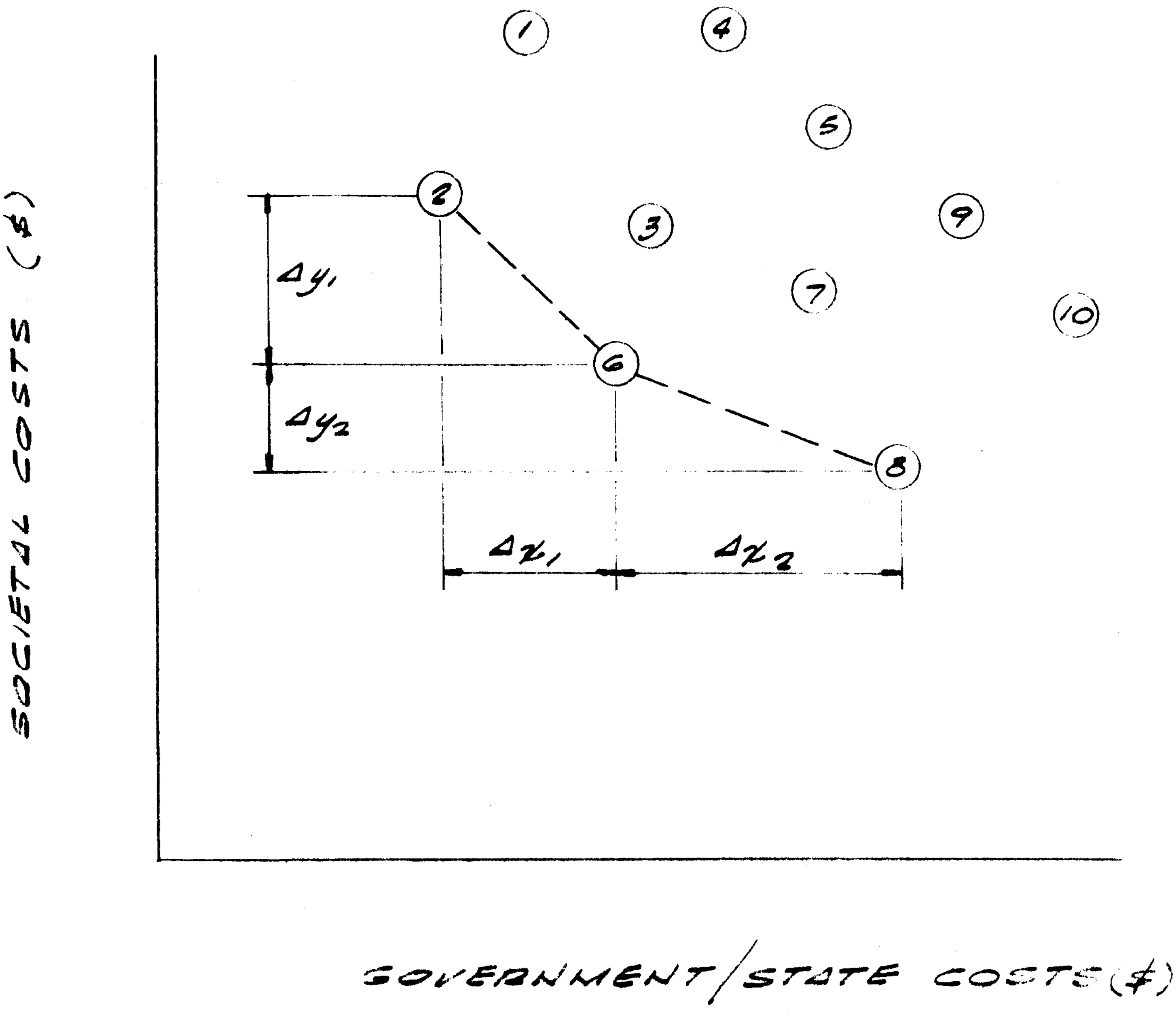


FIGURE 12. GUARDRAIL EVALUATION

While the procedures are simple and straightforward with the eight worksheets discussed above, the work in preparing them is rather lengthy. As an alternative procedure, the accident severities and various small programs used for developing the worksheets were combined into a single computer program SSCOST. Figure 13 is a sample of the cost summary output sheet. Included in the program is an order-of-magnitude estimate of the societal cost for no guardrail. This estimate is based on the assumption of a fatality and total vehicle destruction (80%) when the vehicle travels the specified offset distance to the obstacle. The fatality and total vehicle destruction are also assumed if a candidate guardrail deflects more than the specified distance from the face of the guardrail to the obstacle.

Figures 14, 15, and 16 illustrate guardrail evaluations for various injury and fatality costs. The injury and fatality costs in Figure 14 are the direct cost estimates previously discussed. The costs in Figures 15 and 16 are values used in References 33 and 34, respectively. All of the figures are for a straight rural road of two 10-foot lanes, an 8-foot shoulder, a 6-foot guardrail-to-obstacle distance, and an AADT of 5,000. Note from the figures that while the values change, with different I and F costs, the relative positions of the guardrail types are unchanged. The high societal costs of the G1 system are caused by deflections in excess of the 6-foot distance specified from the guardrail to the obstacle.

Inserting their own estimates of costs, state agencies could use the SSCOST program to generate figures similar to Figure 14 for various

```
2-LANE ROAD, AADT = 5,000, GUARDRAIL TYPE THRIE, HIGH FATALITY COST

        SHEET 6. COST SUMMARY


YEARLY ACCIDENT COSTS

    FHWA REGION =  6               GUARDRAIL TYPE = THRIE

    NO. OF INJURIES =  .12910 AT 5880. DOLLARS EACH =                    259.09
    NO. OF FATALITIES =  .00506 AT241600. DOLLARS EACH =                1223.55
    BARRIER DAMAGE = 3.26424 FEET AT  7.50 DOLLARS PER FT =               24.48
    2250-LB VEHICLE DAMAGE =  .00721 PERCENT AT 3200. DOLLARS EACH =      23.06
    4500-LB VEHICLE DAMAGE =  .02414 PERCENT AT 5300. DOLLARS EACH =     127.95
    TRAVEL DELAY = 1.08643 VEHICLE-HOURS AT 10.00 DOLLARS EACH =          10.86

    TOTAL YEARLY SOCIETAL COST =                                        2169.00


    GUARDRAIL INSTALLATION =  1000. FEET AT 10.00 DOLLARS PER FT =     10000.00

    YEARLY MAINTENANCE =  1000. FEET AT 0.00 DOLLARS PER FT =              0.00


    ECONOMIC FACTORS FOR 15.-YEAR SERVICE LIFE AT  8. PERCENT INTEREST
         PRESENT VALUE OF FUTURE DOLLAR  =  .3152
         PRESENT VALUE OF YEARLY ANNUITY = 8.5595
```

TOTAL GOVERNMENT/STATE PRESENT WORTH COST		TOTAL SOCIETAL PRESENT WORTH COST	
INSTALLATION	10000.00	ACCIDENT DAMAGE	18472.50
MAINTENANCE	0.00	TRAFFIC DELAY	92.99
LESS SALVAGE VALUE	315.24		
TOTAL	9684.76	TOTAL	18565.49

JOB FINISHED

FIGURE 13. SAMPLE OUTPUT SHEET OF SSCOST PROGRAM

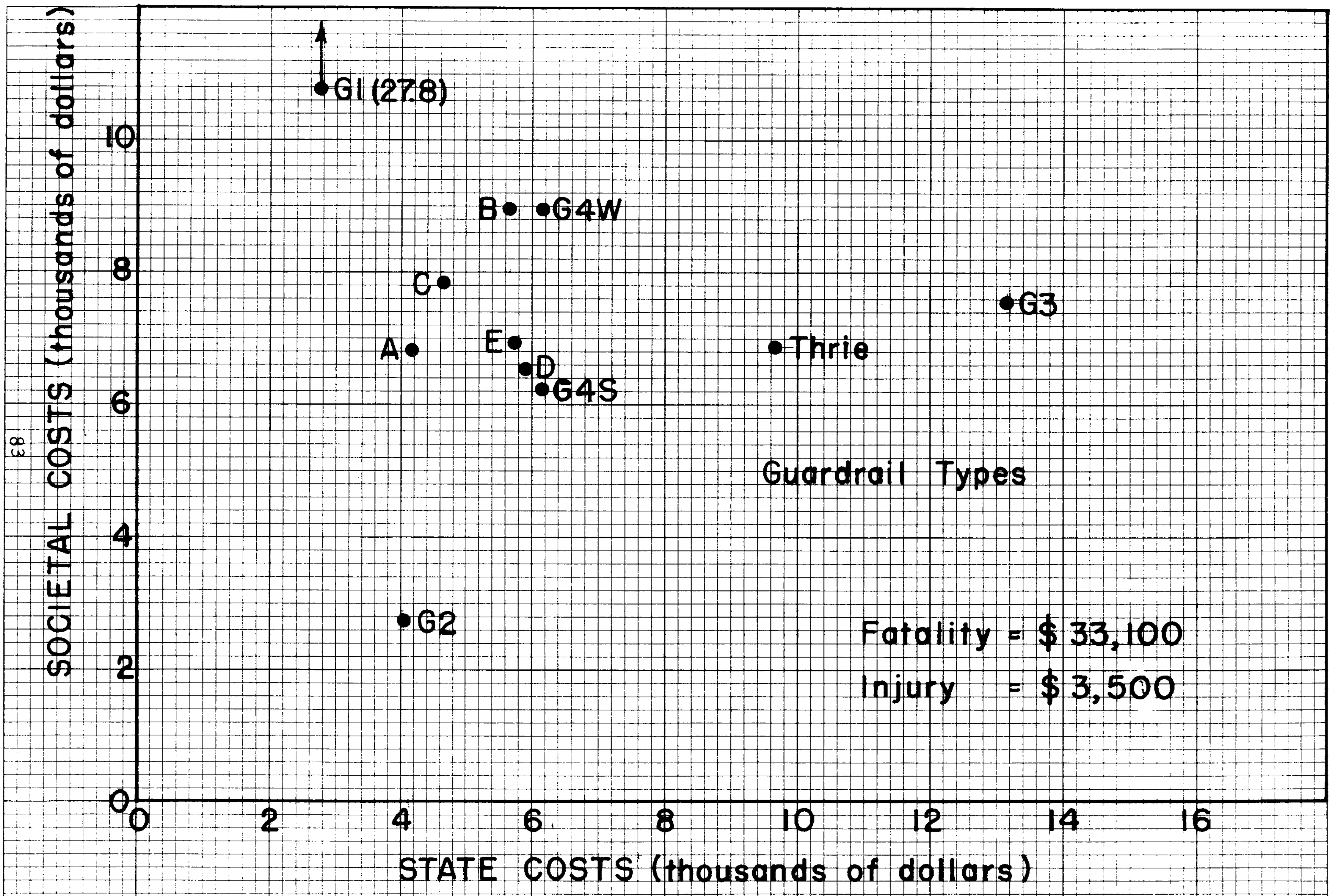


FIGURE 14. GUARDRAIL COMPARISONS WITH F = $33, 100 AND I = $3, 500

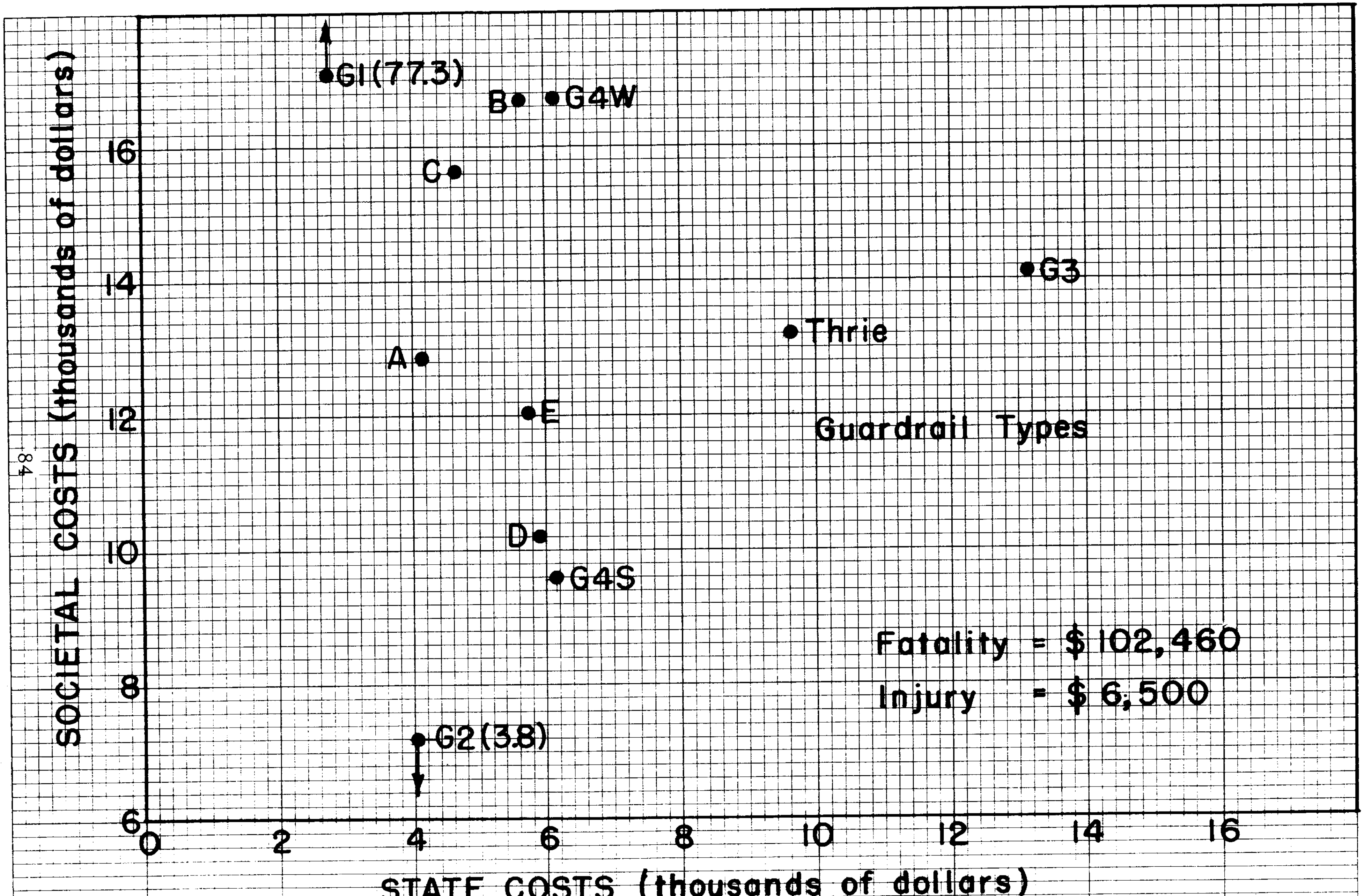


FIGURE 15. GUARDRAIL COMPARISONS WITH F = $102,460 AND I = $6,500

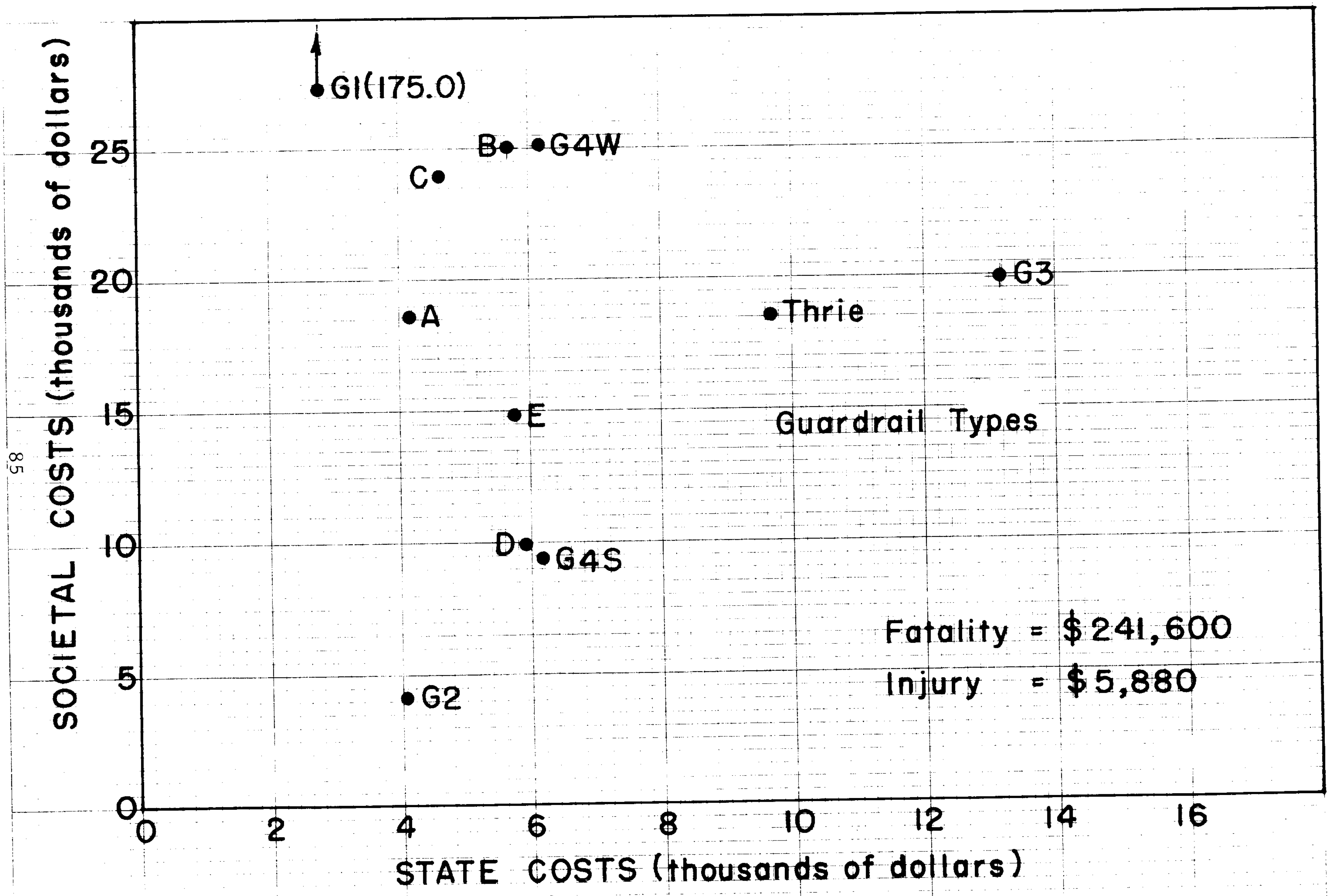


FIGURE 16. GUARDRAIL COMPARISONS WITH F = $241,600 AND I = $5,880

roadside and traffic conditions. The program input is simple, and run times are minimal (e.g., 9.706 cp seconds were used on a CDC 6500 computer to run 33 cases). By supplying the local highway offices with such figures, cost-effective guardrail choices could be made quickly. For local analysis without benefit of a computer, it is desirable that the worksheet approach be shortened or replaced with charts and/or nomographs that are easier to use. The problem is compounded by the number of significant variables whose local or regional values should be input by the agency. However, an effort will be made to develop a procedure that is satisfactory to FHWA.

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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.

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,

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

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

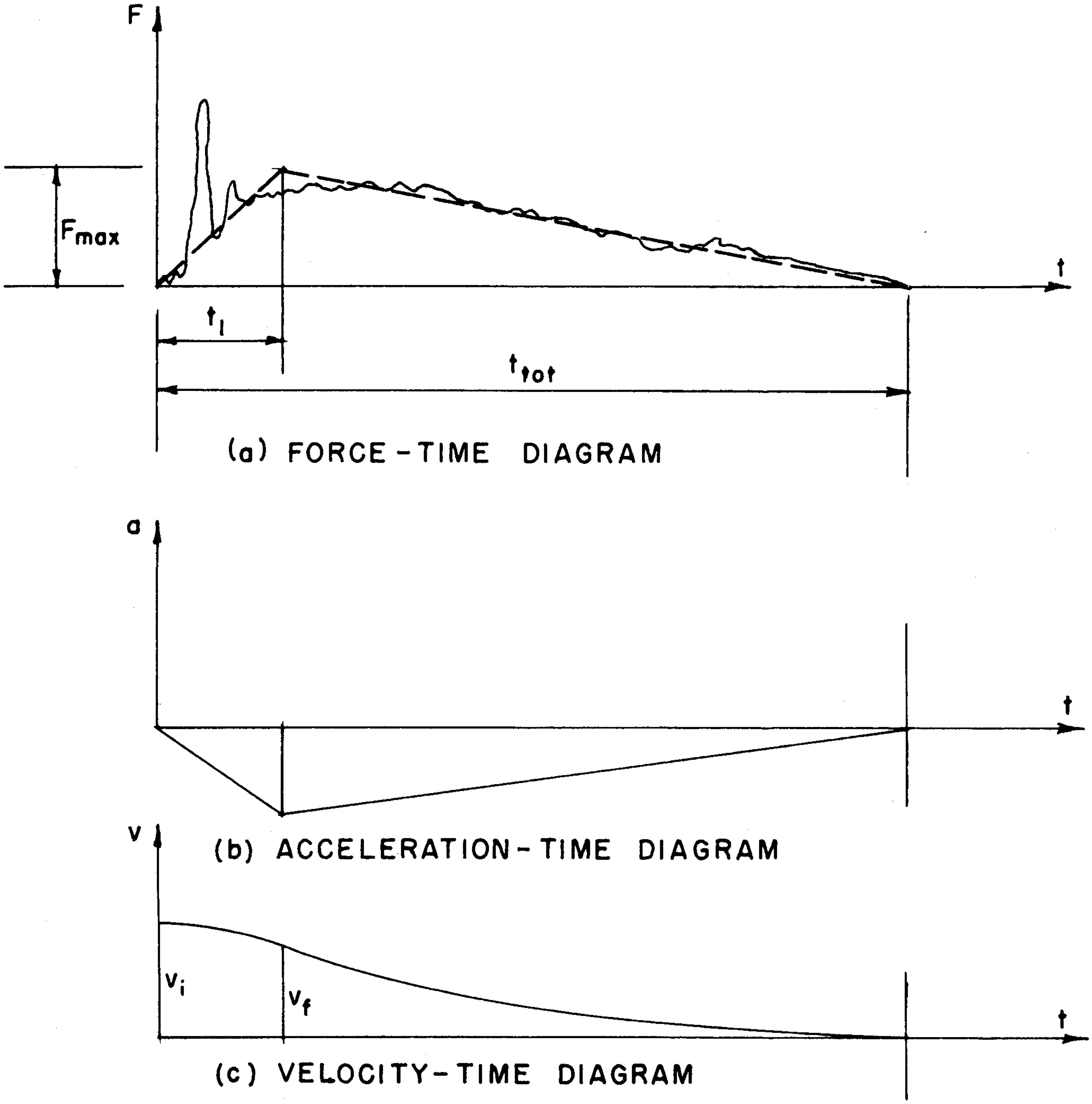


FIGURE A.1 DETERMINATION OF POST PROPERTIES

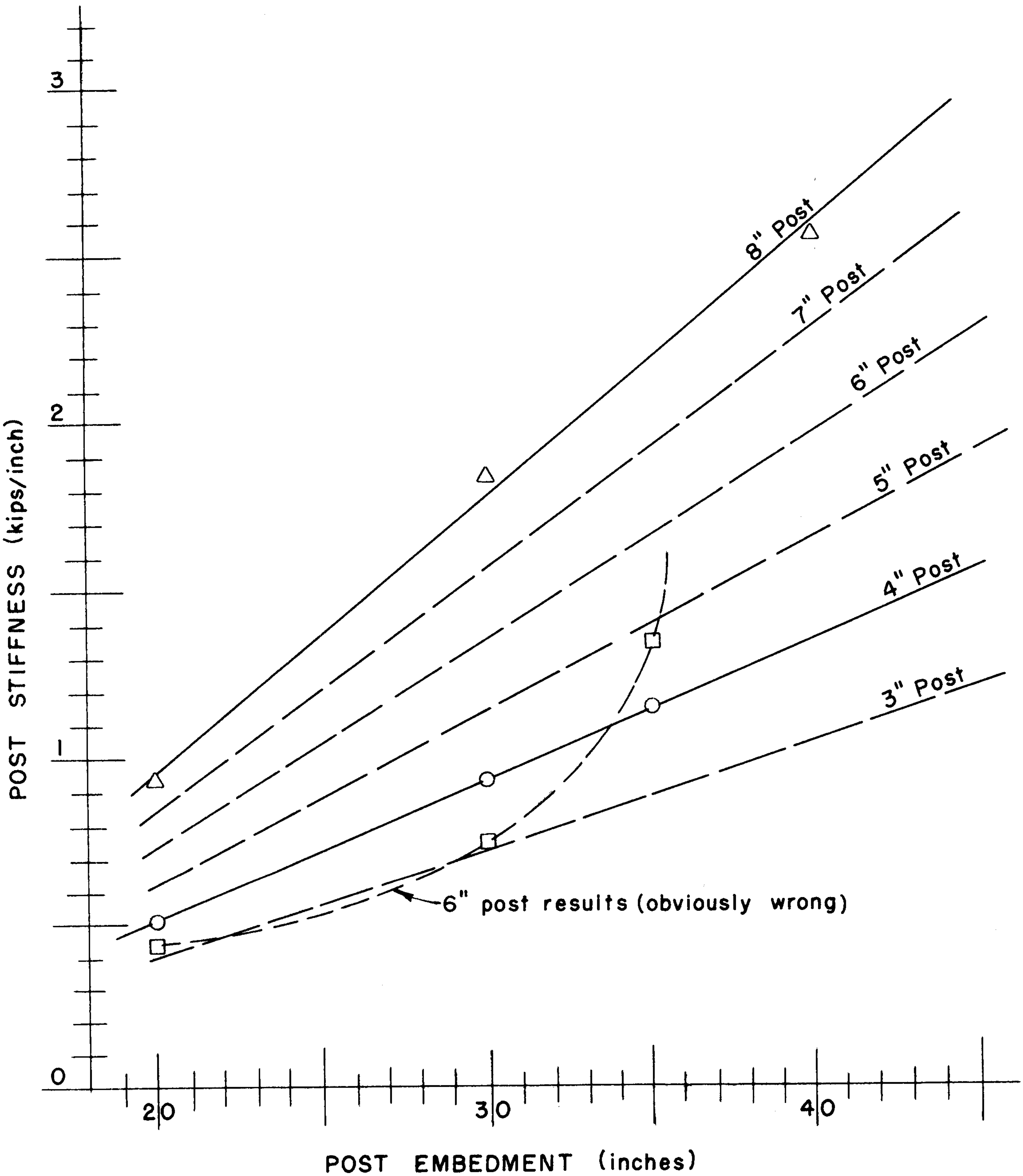


FIGURE A.2 POST STIFFNESSES

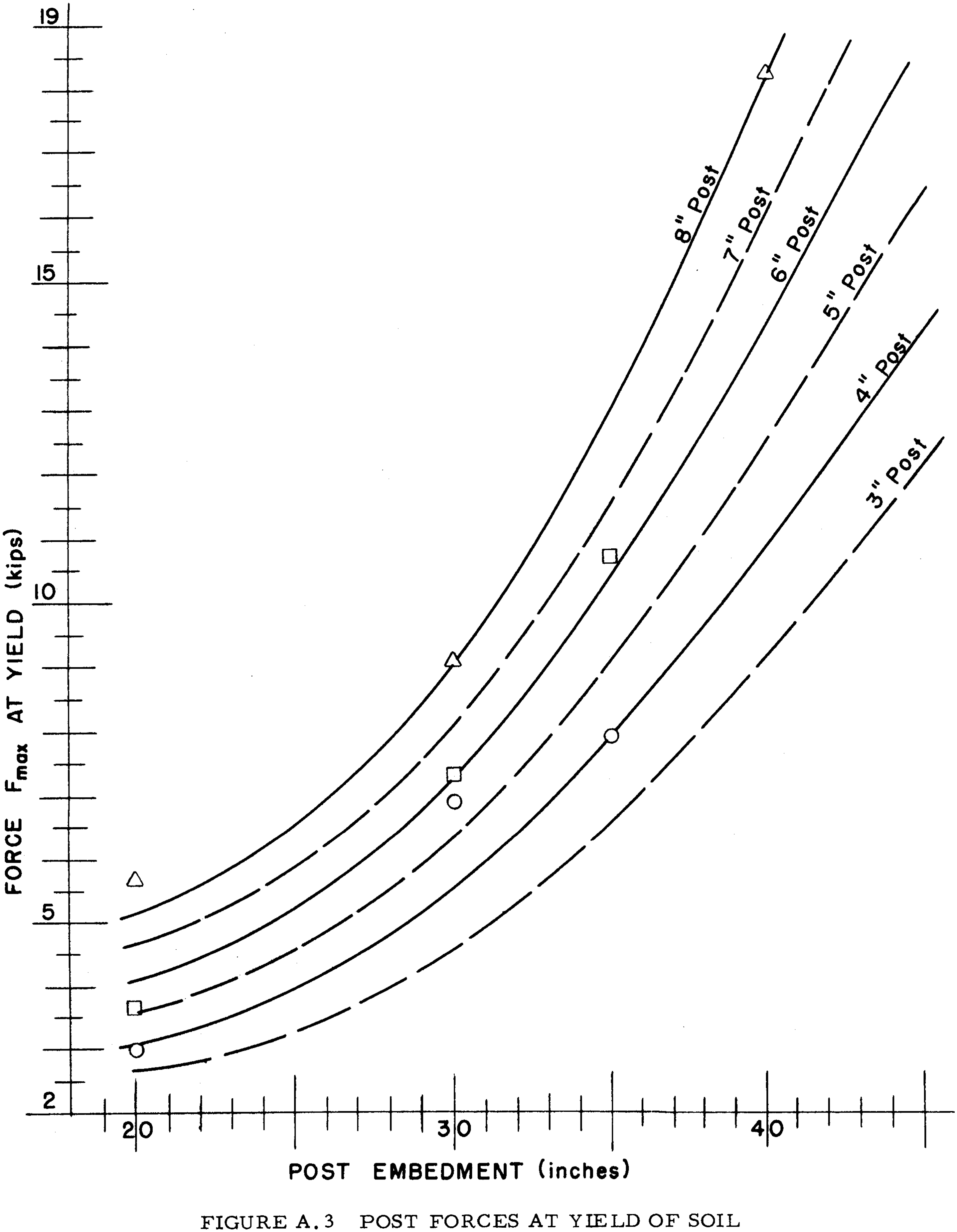


FIGURE A.3 POST FORCES AT YIELD OF SOIL

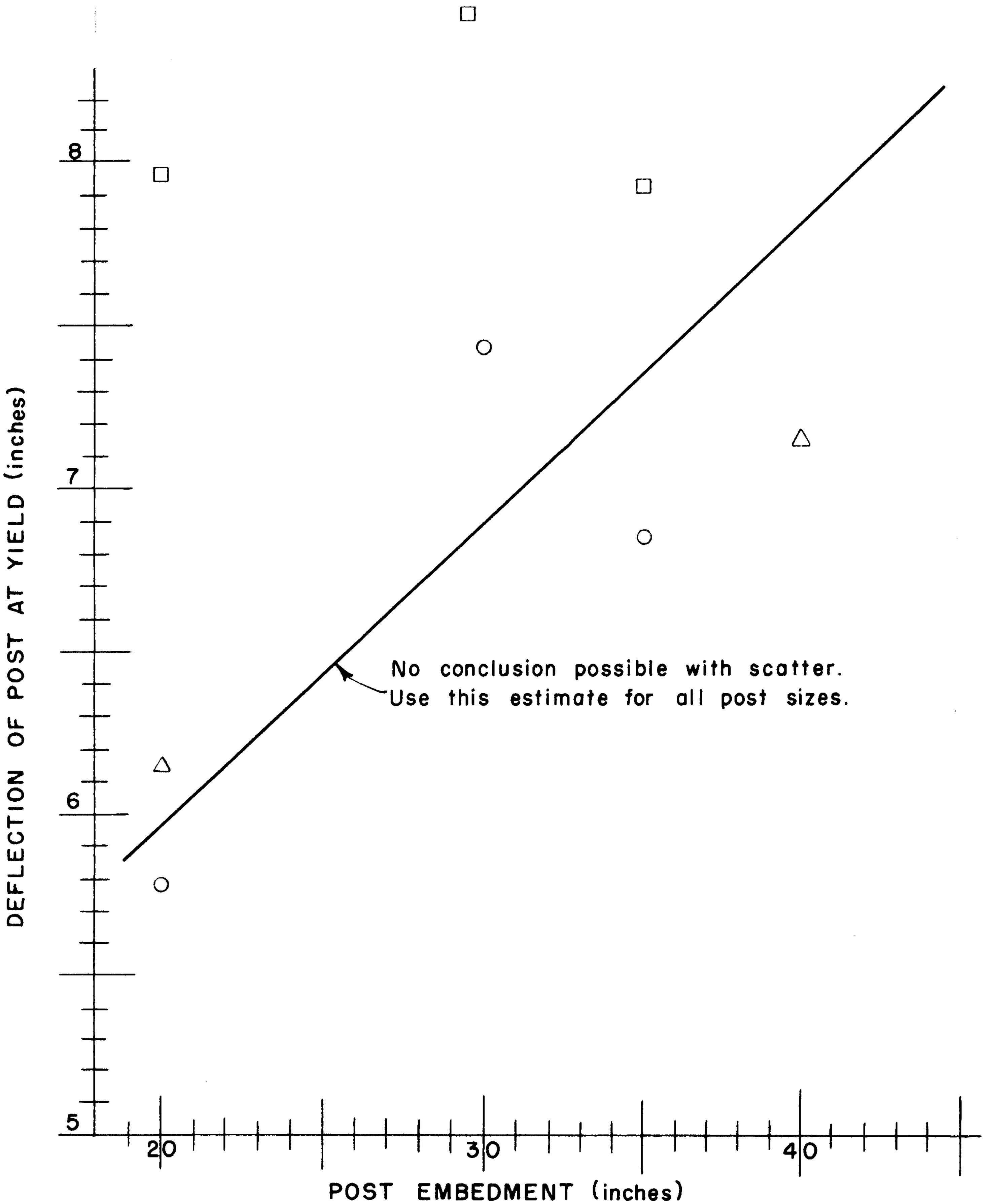


FIGURE A.4 DEFLECTIONS OF POSTS AT YIELD OF SOIL

$$\Delta = v_f (t) + 2/3 (v_i - v_f) (t_1)$$
$$= 1/3 (2 v_i + v_f) (t_1) \text{ in feet} \quad (A.2)$$
$$= 4 (2 v_i + v_f) (t_1) \text{ in inches}$$

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

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

was used. With a 4000-lb pendulum, this gave

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

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
W6x8.5	5.71	1.55	308.3	83.7
S3x5.7	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:

<u>Cable System</u> (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

<u>12 gauge W-beam</u>

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

<u>Box Beam System</u> (TS 6x6x0.1875)

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 19, the equation is

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

Reference 20 contains the equations

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

and

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

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

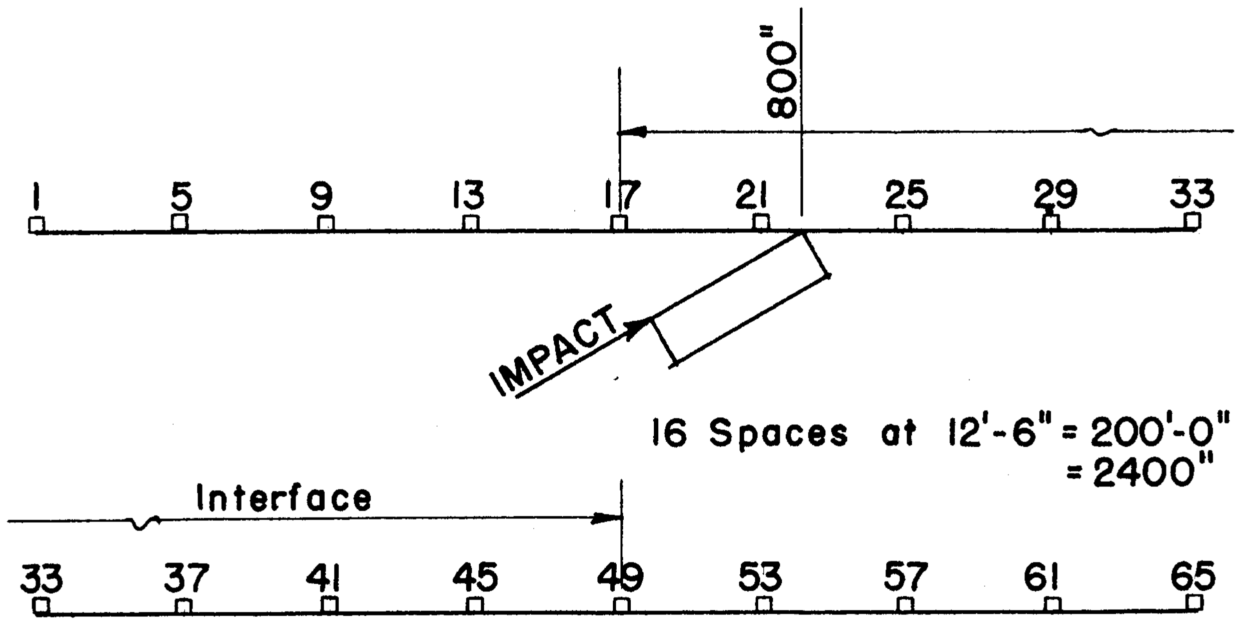
From this comparison, as well as comparisons with the minimal information that could be obtained from the automobile manufacturers, it was decided to use equation (A.6) for the light 2250-lb vehicle class and equation (A.5) for the heavy 4500-lb vehicle class. The application of these equations for the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

APPENDIX B

TYPICAL GUARDRAIL AND VEHICLE CONFIGURATIONS

For the BARRIER VII extrapolation runs, the various guardrail configurations were selected to conform closely to those configurations used 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. 1. 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.



Control Nodes

No.	X
1	0
65	2400

65 Nodes

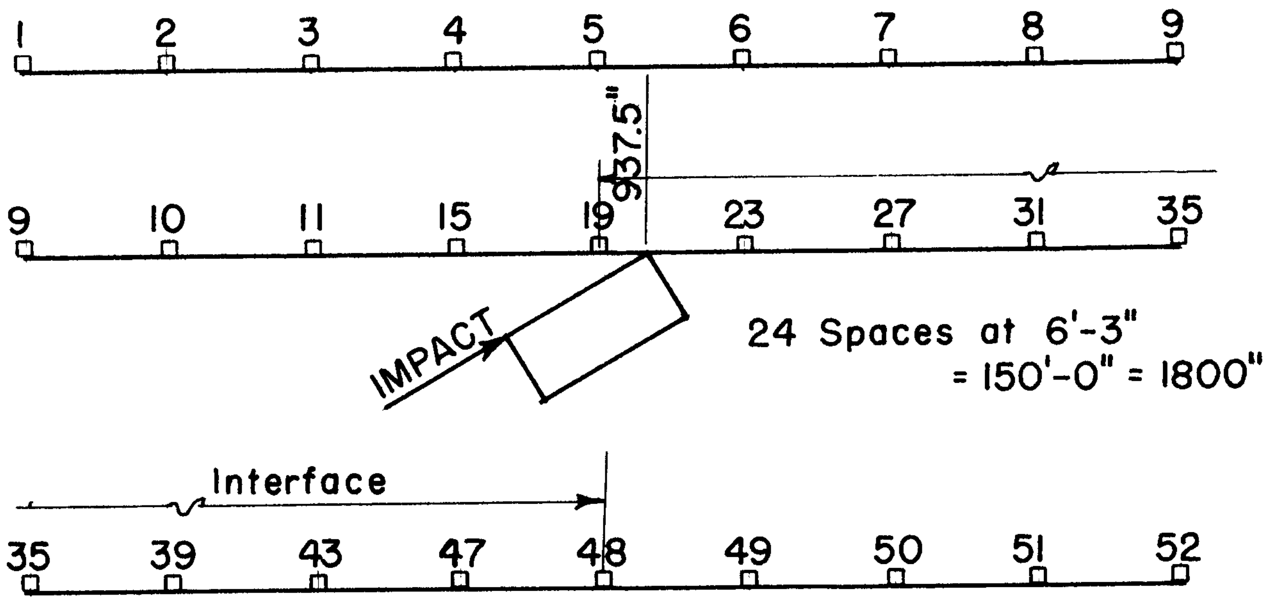
64 Beams
17 Posts

81 Members

Post properties:

	Guardrail Type A	Guardrail Type C
Size	7" round	8"x8"
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

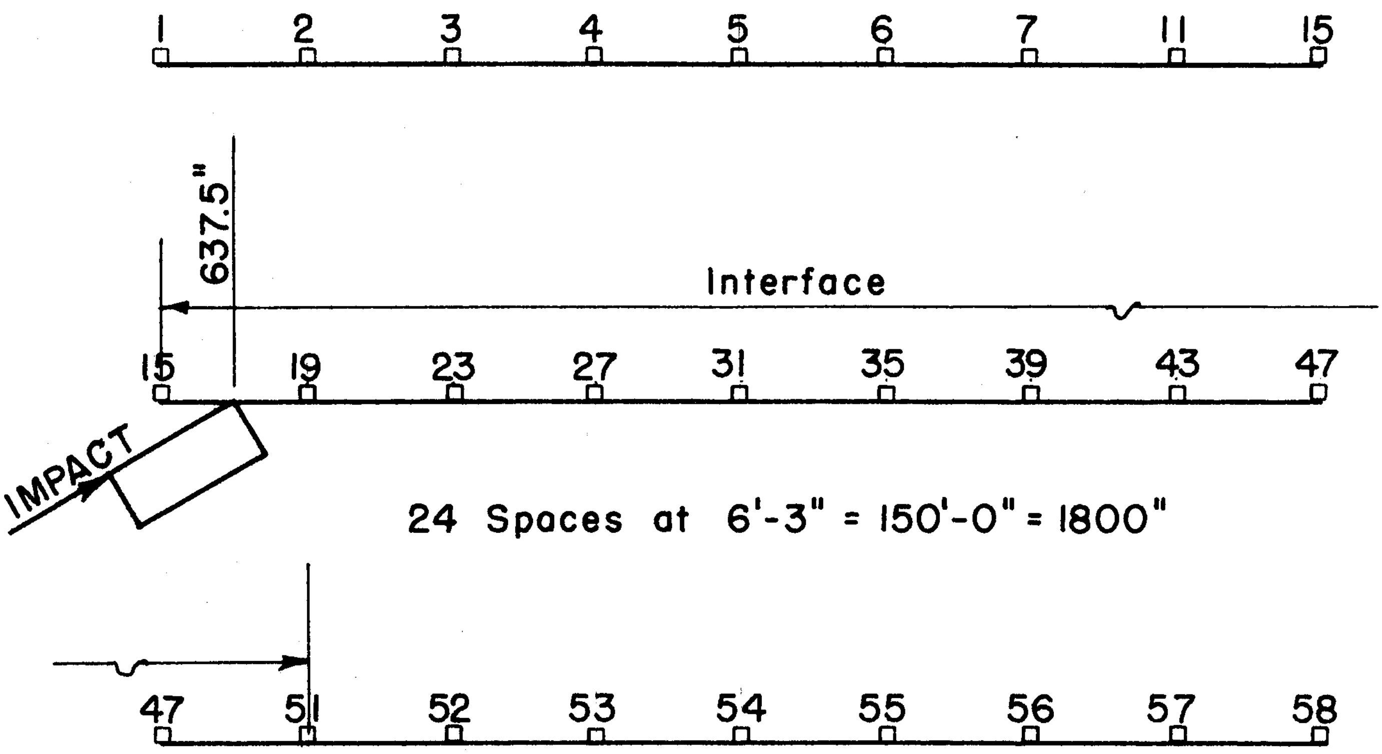
51 Cables
25 Posts

76 Members

Post properties:

	Guardrail Type B	Type D	Type G4W
Size	8"x8"	6"x8"	8"x8"
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

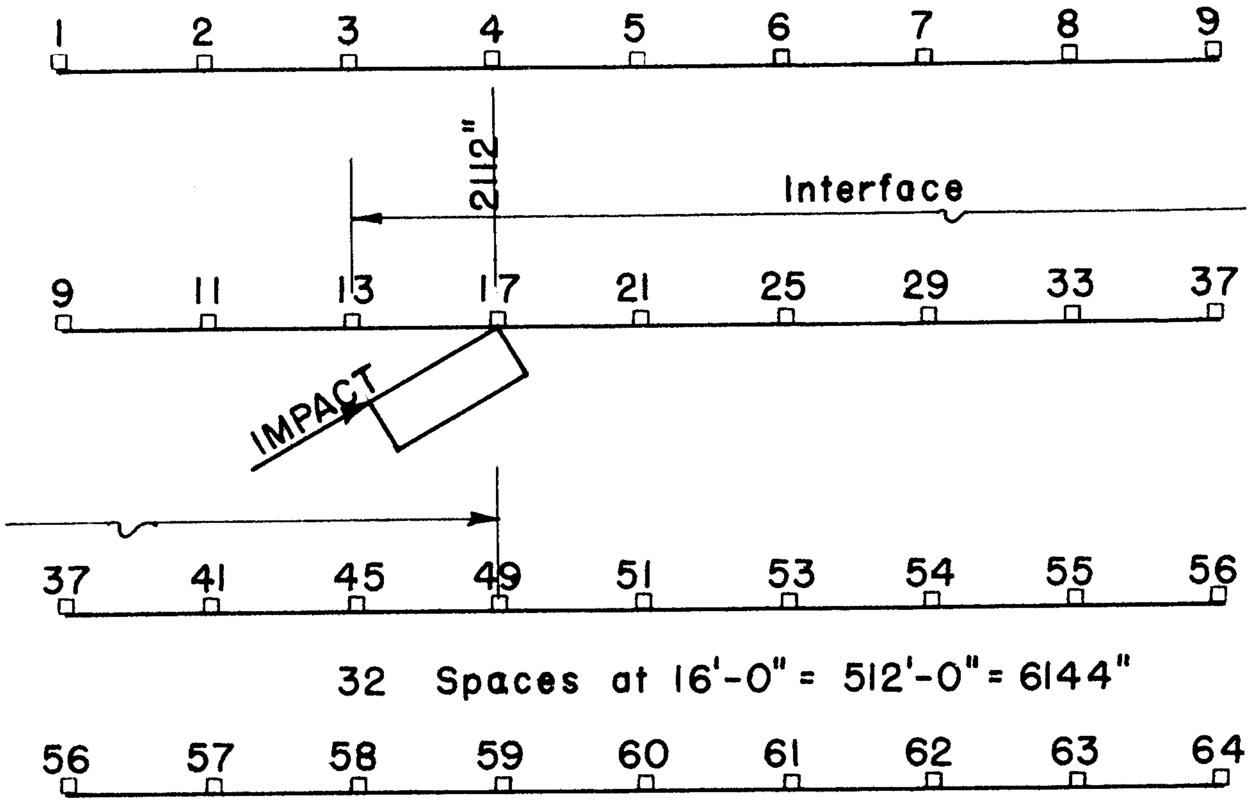
57 Cables
25 Posts

82 Members

Post properties:

	Type E	Guardrail Type G4S	Thrie
Size	Charley	W6x8.5	W6x8.5
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

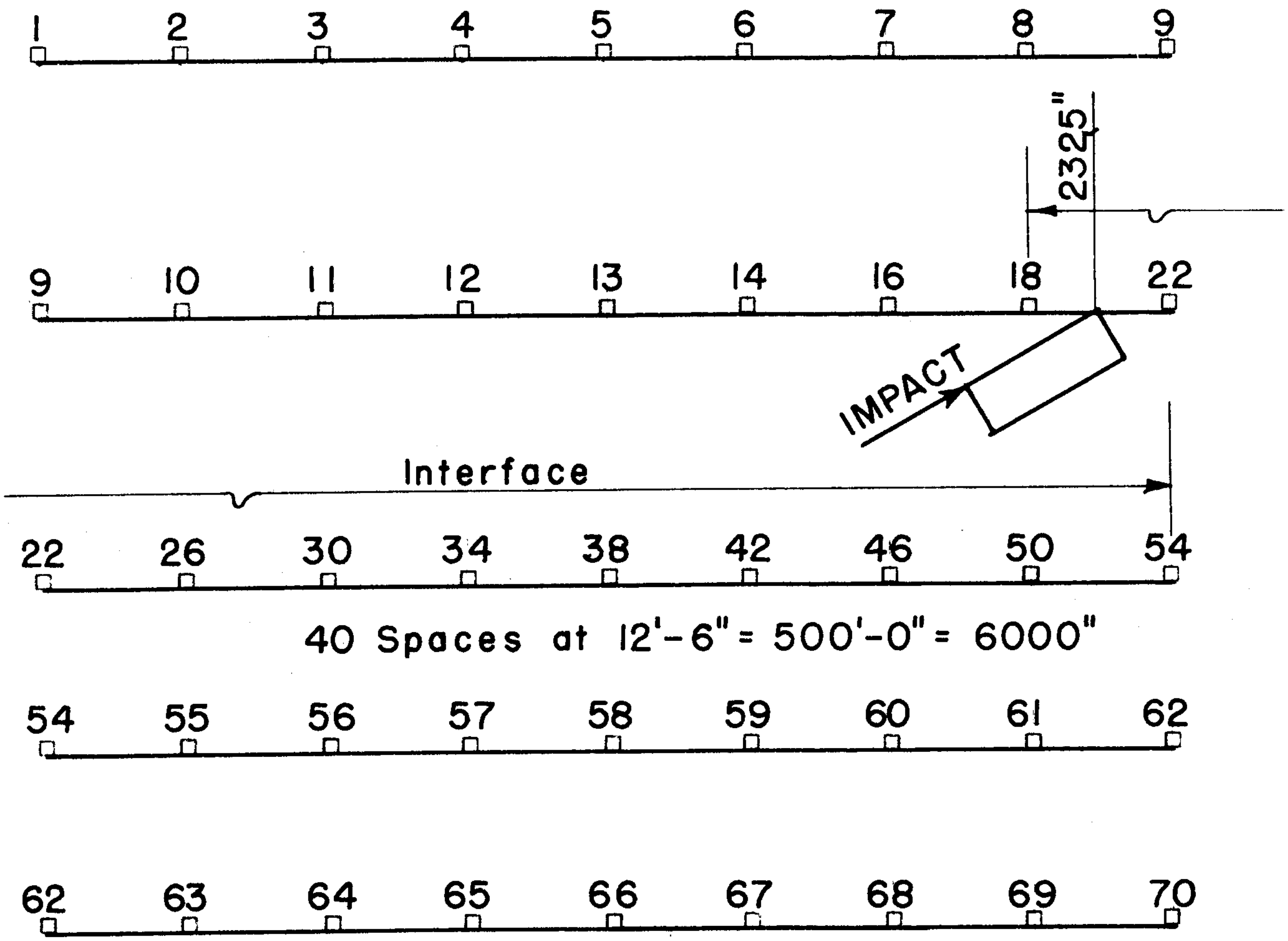
64 Nodes

63 Cables
33 Posts

96 Members

Post properties: (see Table B.1)

FIGURE B.4 GUARDRAIL TYPE G1 CONFIGURATION



Control Nodes

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

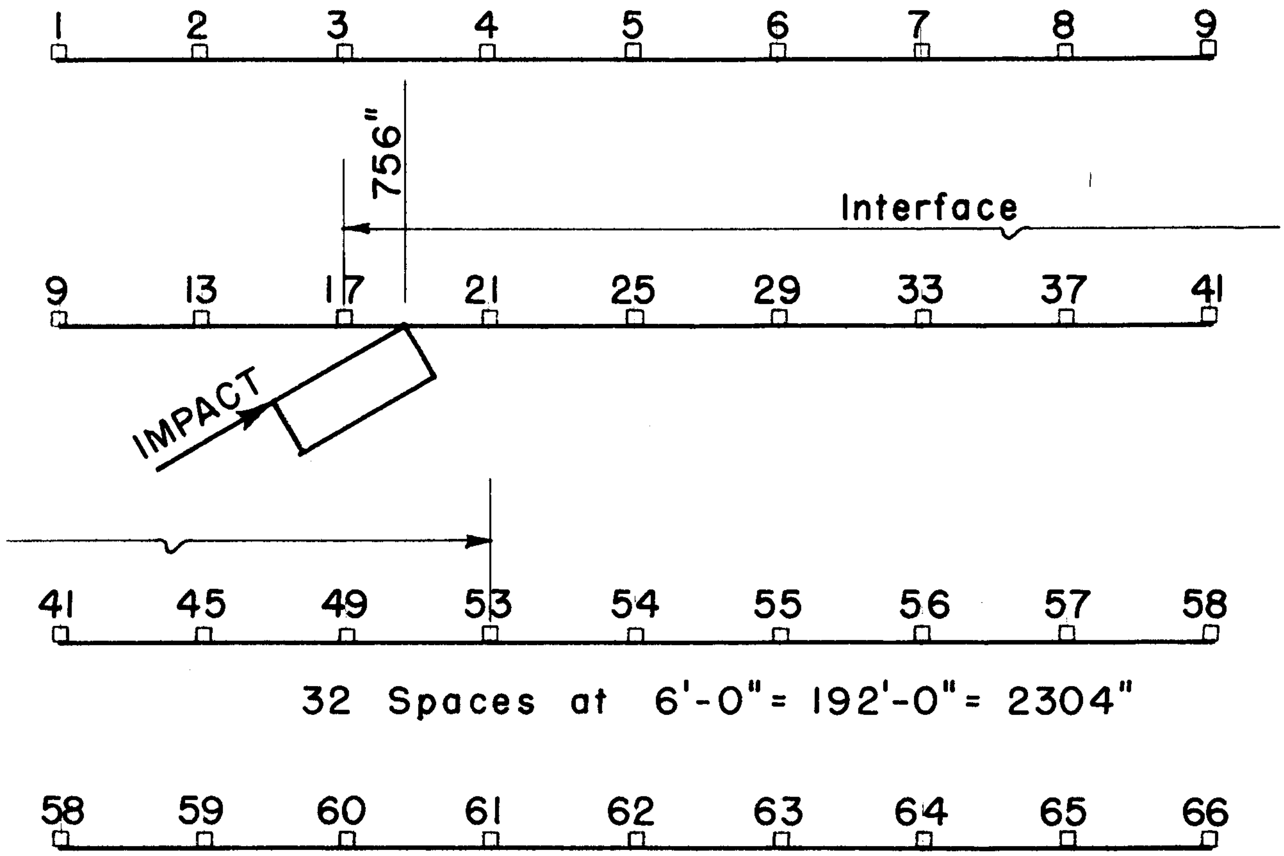
70 Nodes

69 Beams
41 Posts

110 Members

Post properties: (see Table B. 1)

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.1)

FIGURE B.6 GUARDRAIL TYPE G3 CONFIGURATION

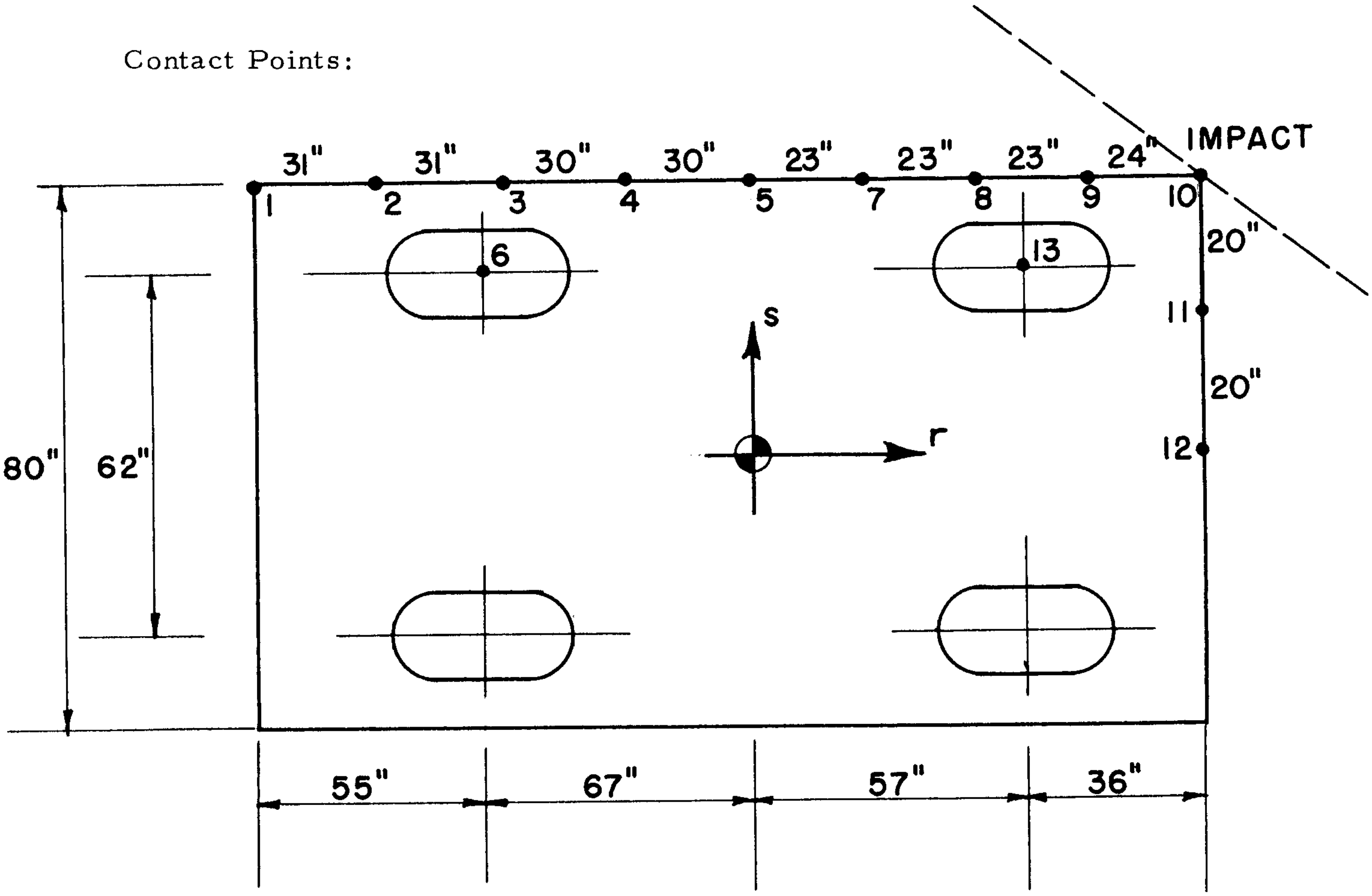
TABLE B.1

POST PROPERTIES (GUARDRAIL TYPES G1, G2, AND G3)

Post Properties:	Guardrail Type G1	Guardrail Type G2	Guardrail Type G3
Size	S3x5.7	S3x5.7	S3x5.7
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.

Contact Points:



Weight = 4500 lb

$I = [1.26(4500) - 1750](12) = 47,000$ lb-in.-sec^2

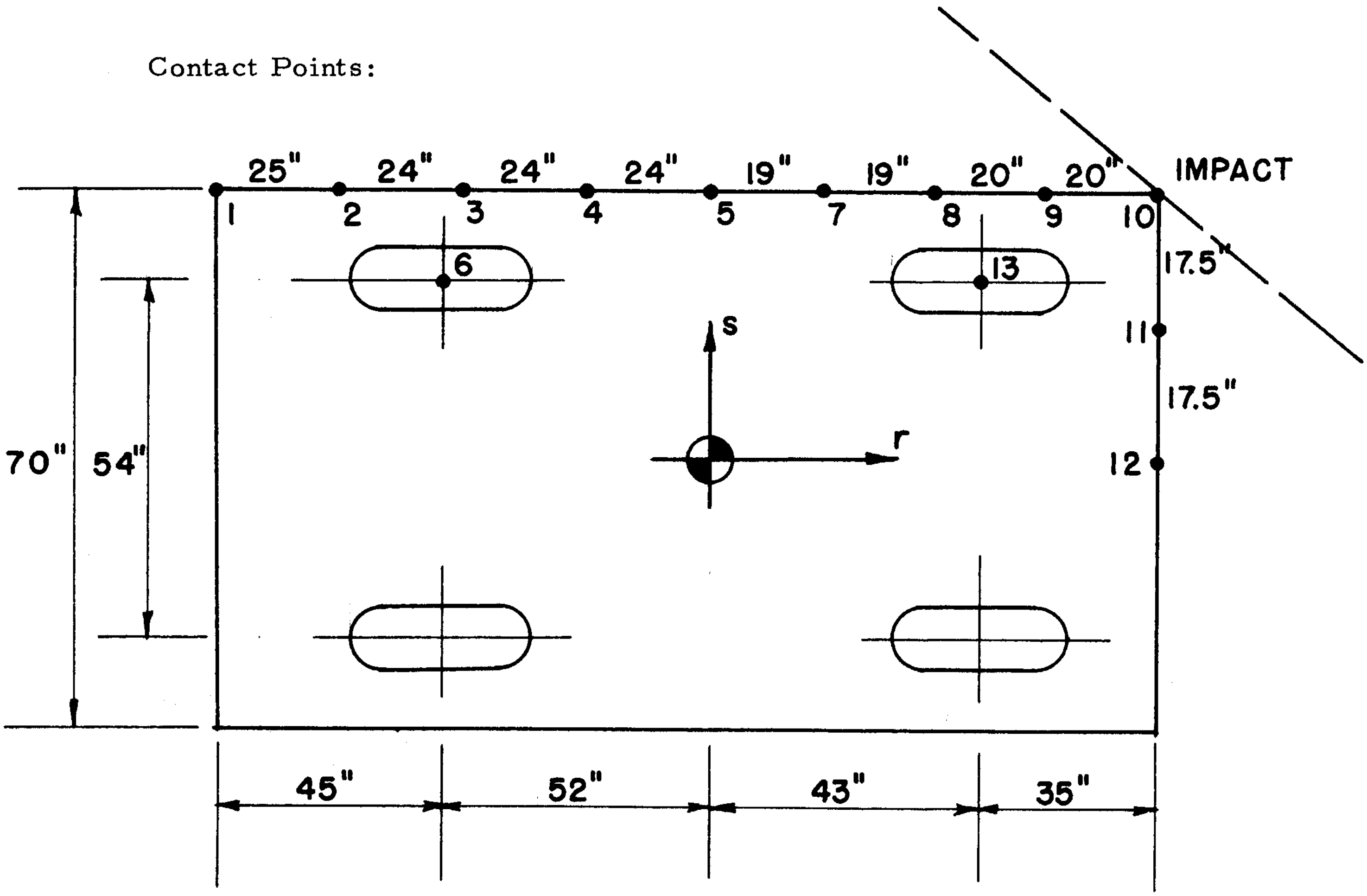
Drag forces:

$$\text{Front wheels} = \frac{4500\ (67)\ (0.50)}{124\ (2)} = 608 \text{ lb}$$

$$\text{Rear wheels} = \frac{4500\ (57)\ (0.50)}{124\ (2)} = 517 \text{ lb}$$

FIGURE B.7 TYPICAL 4500-LB VEHICLE PROPERTIES

Contact Points:



Weight = 2250 lb

$$I = \frac{0.225\ (2250)^{1.572}\ (12)}{32.2} = 15,600 \text{ lb-in.-sec}^2$$

Drag forces:

$$\text{Front wheels} = \frac{2250\ (52)\ (0.50)}{95\ (2)} = 308 \text{ lb}$$

$$\text{Rear wheels} = \frac{2250\ (43)\ (0.50)}{95\ (2)} = 255 \text{ lb}$$

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 as shown in Figure 5, the average curve for distribution of lateral displacements from Figure 3 and the distribution of impact speeds from Figure 4 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 $F_c = ma = \frac{W}{g}\left(\frac{v^2}{r}\right)$, 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

$$r_{min} = \frac{v^2}{g\,\mu} \qquad (D.1)$$

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,

$$r = \sqrt{(r_{min} - \frac{w}{2})^2 + a^2}$$

$$\sin D = \frac{a}{r} \qquad (D.2)$$

$$\cos B = \frac{r_{min} - L_T}{r}$$

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

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

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

$$R \cos A + r \cos B = R - L_T + r_{min} \qquad (D.3)$$

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

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

$$\cos B = \frac{(R - L_T + r_{min})^2 - R^2 + r^2}{2 (R - L_T + r_{min}) r} \qquad (D.4)$$

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

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

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

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

yield

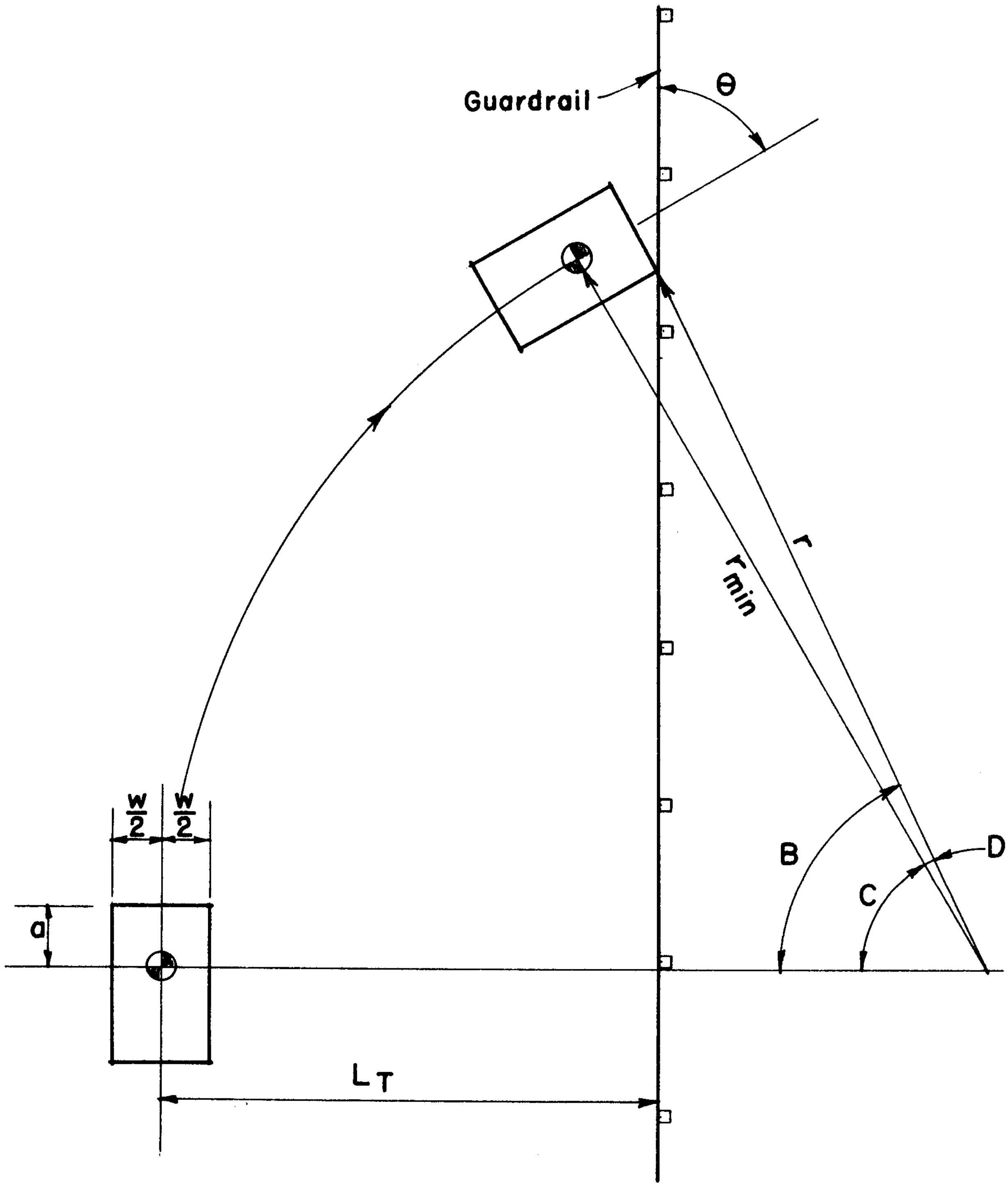


FIGURE D. 1 POINT MASS CONDITIONS FOR STRAIGHT ROAD

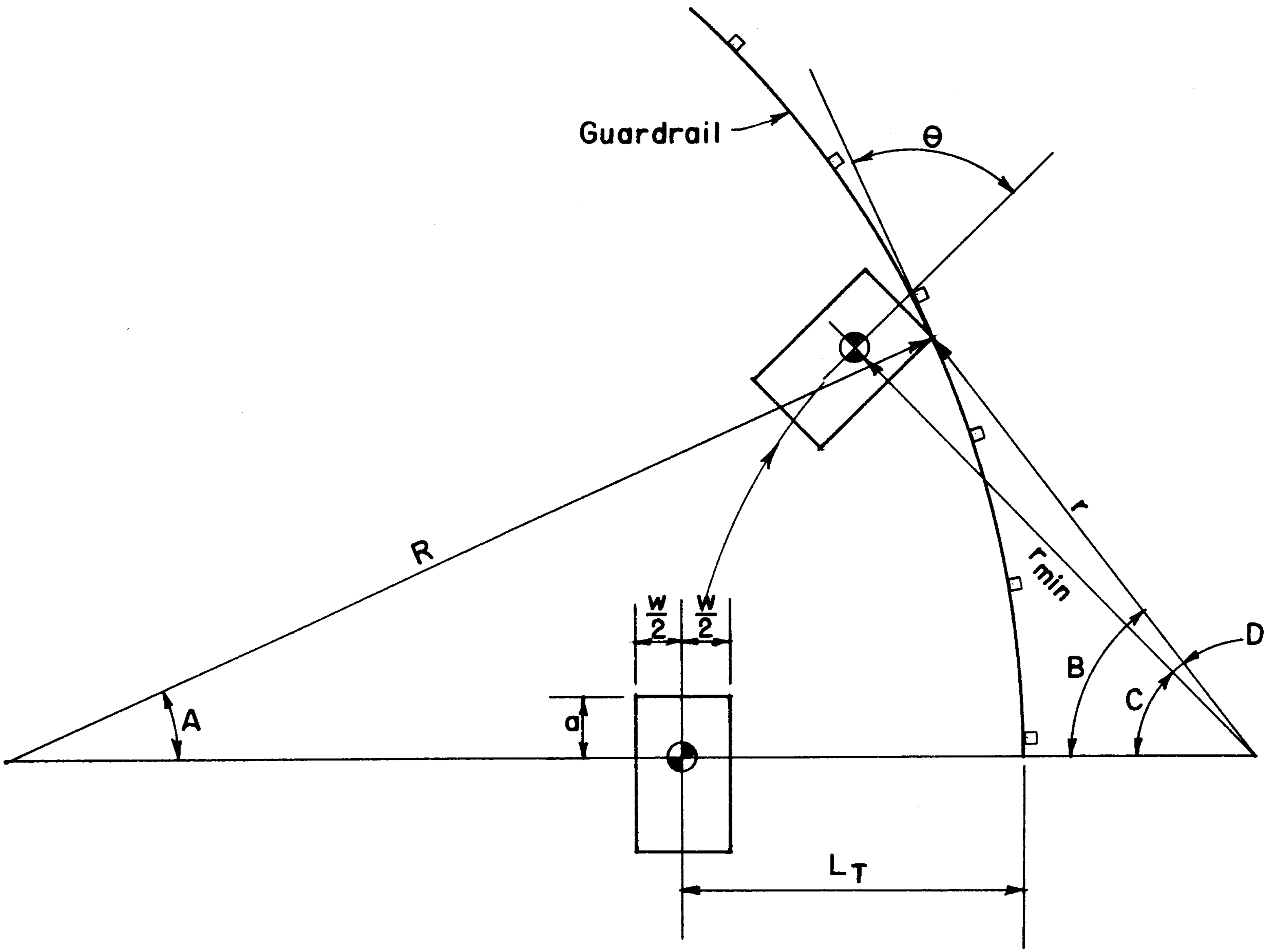


FIGURE D.2 POINT MASS CONDITIONS FOR POSITIVE DEGREE OF CURVE

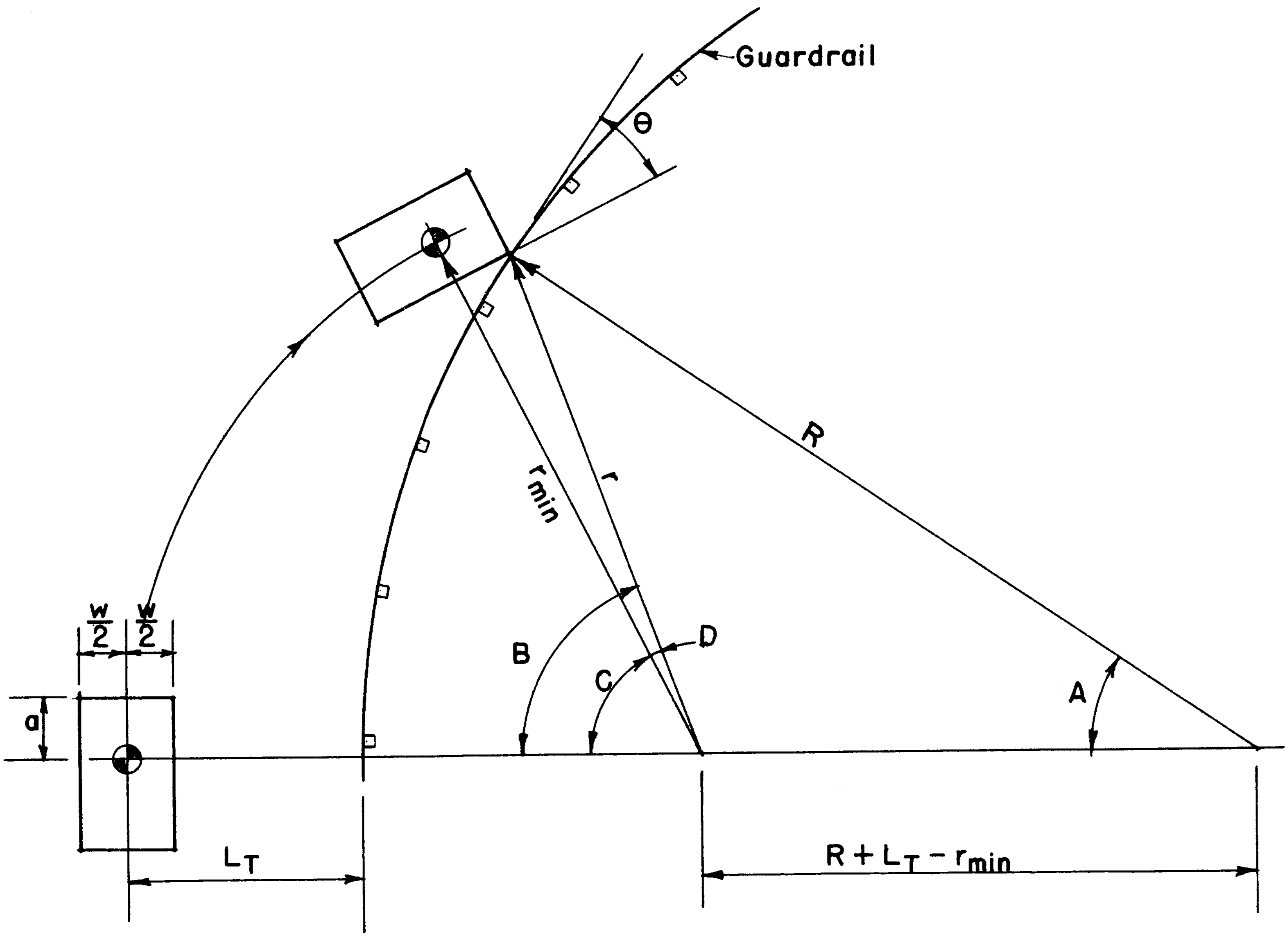


FIGURE D.3 POINT MASS CONDITIONS FOR NEGATIVE DEGREE OF CURVE

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

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

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,

$$\theta_P = \sigma X_P + \beta \qquad (D.7)$$

where θ_P = impact angle for probability P
σ = standard deviation
X_P = area under normal curve from $-\infty$ to probability 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

$$\sigma = \frac{\beta}{4.00} \qquad (D.8)$$

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

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

This formulation was programmed to yield the probability tables, a typical sample of which is shown in Figure 5. The various distributions (i.e., vehicle speed, offset distance, and impact angle) were 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 follow:

(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]

$$C = 2000\ NWT \qquad \text{(E. 1)}$$

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])

The resulting one-way capacities were as follow:

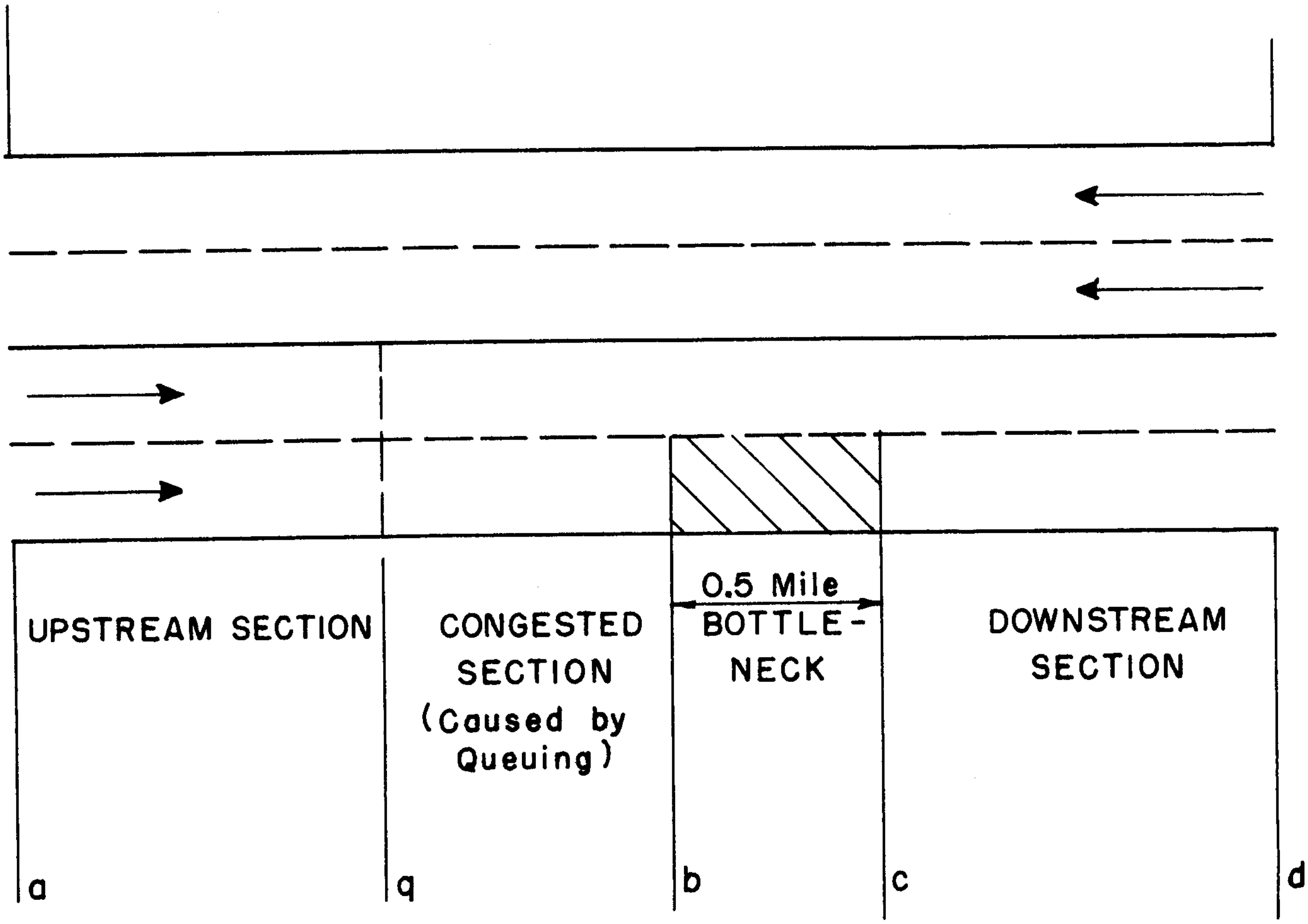


FIGURE E.1 DIAGRAM OF HIGHWAY UNDER QUEUING CONDITIONS

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 midnight to 6 AM, 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

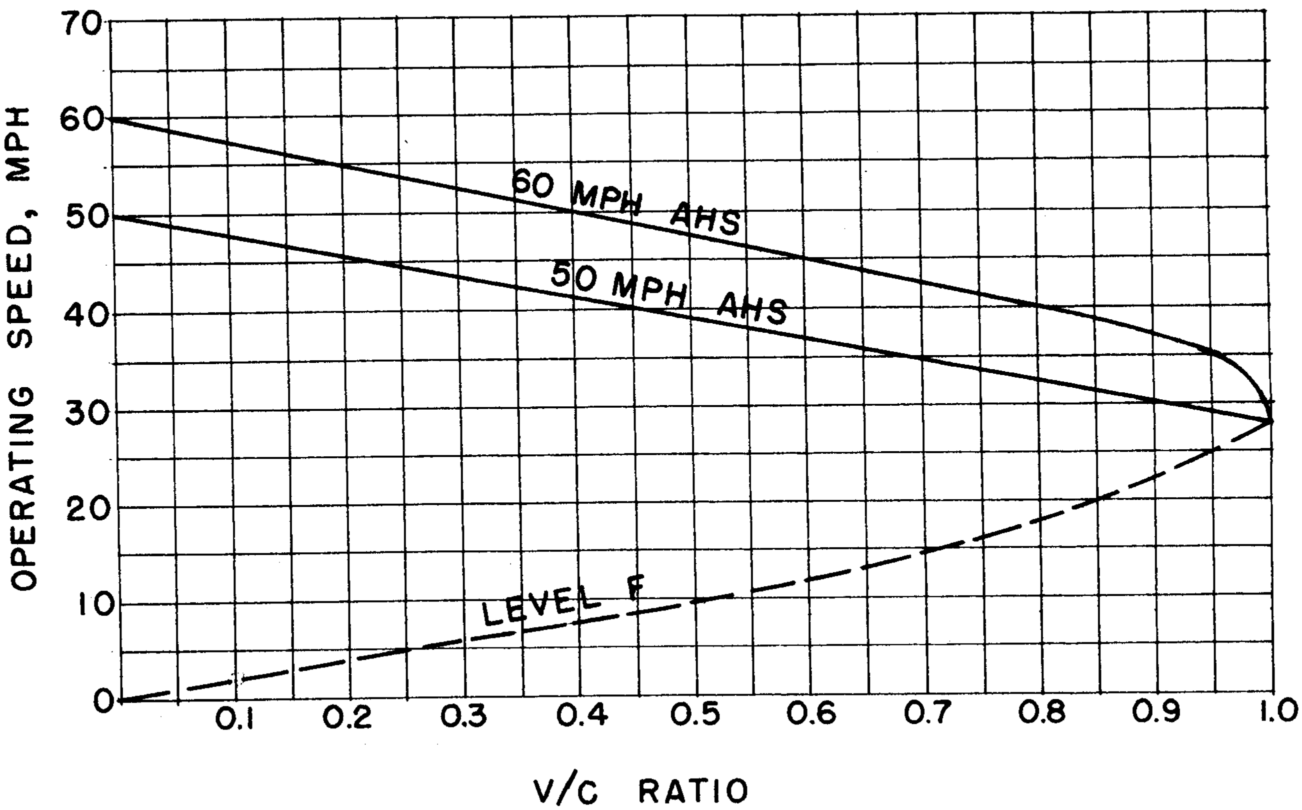
$$D/C = AHT/C \tag{E.3}$$

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.



Ref: HCM

FIGURE E.2 FREEWAY RUNNING SPEEDS OF PASSENGER CARS

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

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

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

$$D/C_{bc} = AHT/C_r \qquad (E.6)$$

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

$$V/C_{qb} = C_r/C_{qb}$$
$$\text{and} \quad V_{bc} = V/C_r = 1.00 \qquad (E.7)$$

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

The next four steps apply only for the queuing condition.

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

$$R_q = AHT - C_{bc} \qquad (E.8)$$

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

$$d\,V_{aq} = AHT/S_{aq}$$
$$d\,V_{qb} = C_{bc}/S_{qb} \qquad (E.9)$$
$$d\,V_{bc} = AHT/S_{bc}$$

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

$$dd = d\,V_{qb} - d\,V_{aq} \qquad (E.10)$$

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

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

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

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

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

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

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

TABLE 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 G4S	W-beam W-beam (B.O.)	27 27	7" dia (W) W6x8.5(S)	12'-6" 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 G4W D	W-beam (B.O.) W-beam (B.O.) W-beam (B.O.)	27 27 27	8x8 (W) 8x8 (W) 6x8 (W)	12'-6" 6'-3" 6'-3"
4. University of Miami Miami, Florida	G2 G4S	W-beam W-beam (B.O.)	30 27	S3x5.7(S) W6x8.5(S)	12'-6" 6'-3"
5. Pennsylvania Team University Park, Pennsylvania	G3 E	Box beam W-beam (B.O.)	30 27	S3x5.7(S) Charley	6'-0" 6'-3"
6. Calspan Corporation Buffalo, New York	G1 G3	3-3/4" cables Box beam	30 30	S3x5.7(S) S3x5.7(S)	16'-0" 6'-0"

[a](B.O.) - beam blocked-out from post.

[b]Post material code - (C) - concrete, (S) - steel, (W) - wood.

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 1. General details of the various types are shown in Table 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 10 types shown in Table 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.

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 1 and 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.

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.

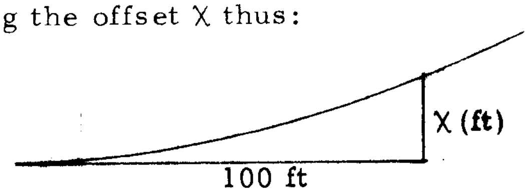
- Average lane width: Record in feet-inches the average width of the traffic lanes.

- 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 X thus:

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



- 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 (TS6x6), 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.
		_______	_______

- 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 - VEHICLE 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.

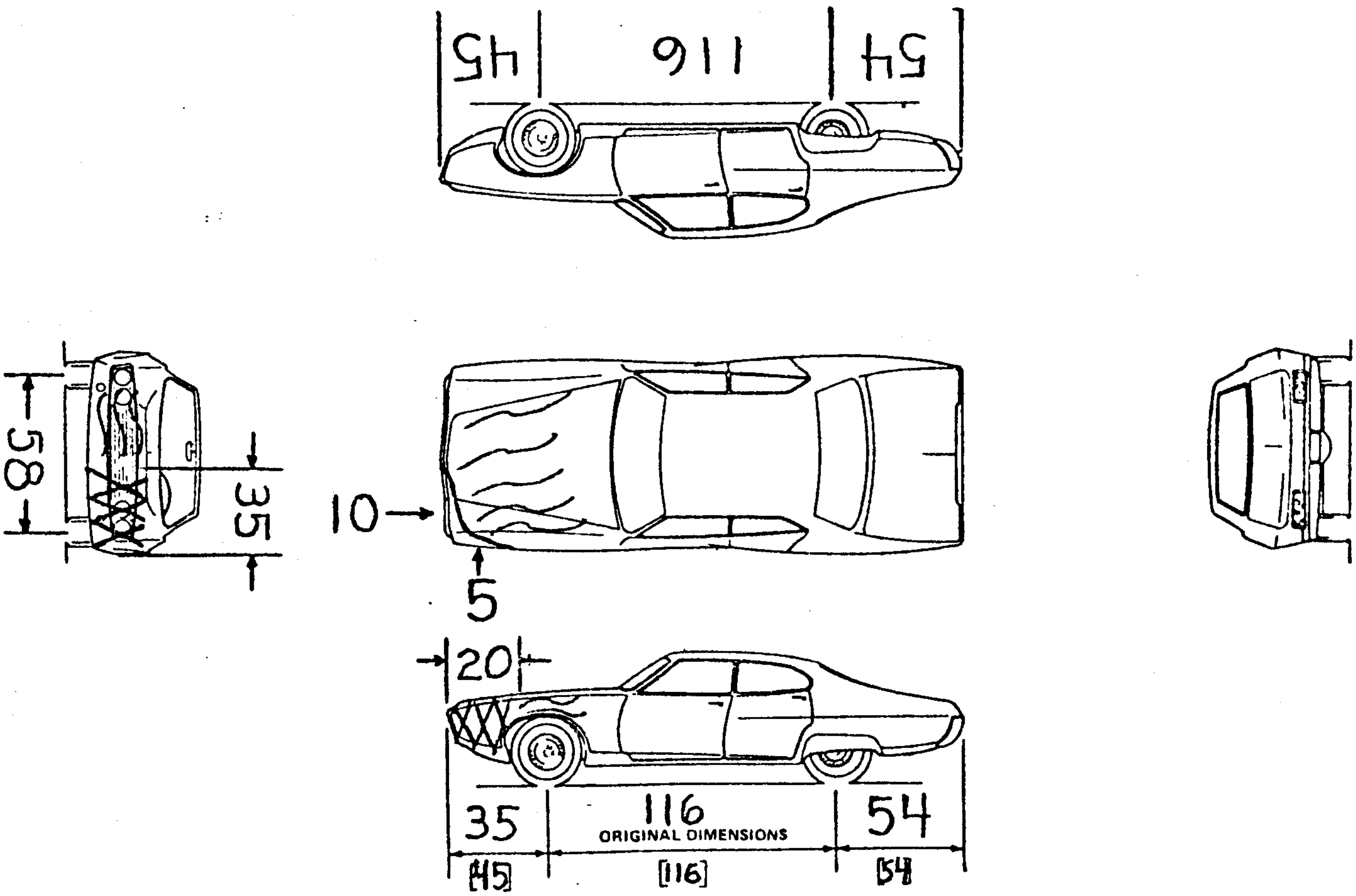
  Code (0) - Unknown if used
  (1) - Not used
  (3) - Lap only used
  (4) - Shoulder only used
  (5) - Child seat used
  (6) - Other
  (7) - No occupant for seated position
  (8) - Lap and shoulder used
  (9) - Not applicable; no belts for this position

- 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
317 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 Royca
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 Volkswagen
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

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* Corporation codes 1-4 (h) 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-)
13408 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) Calliente (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)

<u>GENERAL MOTORS OF CANADA LTD</u>

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

<u>KAISER MOTORS (JEEP)</u>

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

<u>CHECKER</u>

15102 Checker, Marathon

<u>INTERNATIONAL HARVESTER</u>

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

<u>STUDEBAKER</u>

15405 Avanti II
15408 Lark

<u>HARLEY-DAVIDSON</u>

1555- Motorcycle

<u>GENERAL VEHICLES CORPORATION</u>

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, 180C
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, 3800
45503 Jaguar 420, XJ-6, XJ-12, V-12
45510 Jaguar F 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
86309 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
4895- 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
68108 Audi 100LS, 100GL, Fox, Super 90
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68309 NSU 1000, 1200
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Italy

72210 De Tomaso Mangusta, Pantera, Deauville
75108 Alfa Romeo 1750 Berlina, Guila
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75119 Alfa Romeo 1750 & 1600 GTV, Spyder
76109 Fiat 500, 650, 850, 124,128,131 sedans
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78110 Maserati
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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)

95103 Saab 95, 96, 99
95115 Saab Sonnett
95208 Volvo 122, 142, 144, 145, 164, 522
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)
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Truck

11 Small Van (Econoline)
12 Pickup
13 Unknown Light Truck (<1½ 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
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63 Amphibious Vehicle
64 Farm Vehicles
65 Construction Vehicles
66 Trailer-Private (camper)
67 Trailer-Commercial (cargo)
68 Train (Cars)
69 Locomotive, Switcher

Objects

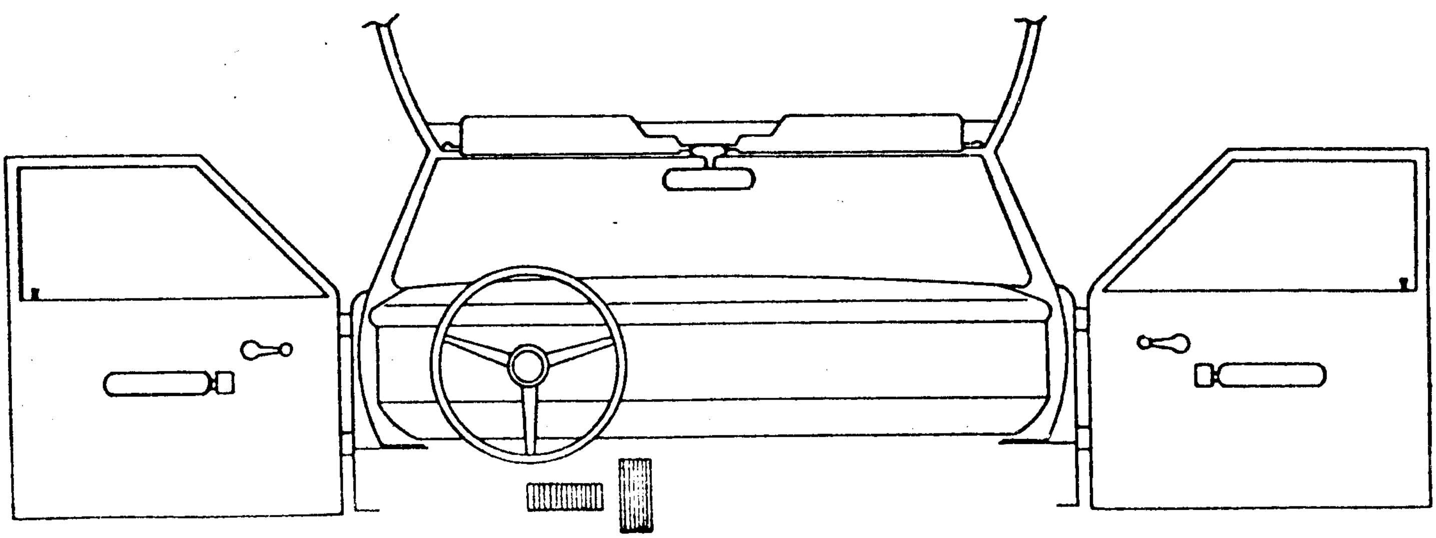
70 Pedestrian
71 Bicyclist, Other Pedalcycle
72 Pedestrian Conveyance (e.g. Person Riding Animal, Cart, etc.)
73 Large Animal
74 Fallen Objects such as Objects Dislodged from Other Vehicles, Fallen Trees, Rocks, etc.
75 Traffic Cones, Barrels, Construction Barriers
76 Construction or Emergency Equipment
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

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

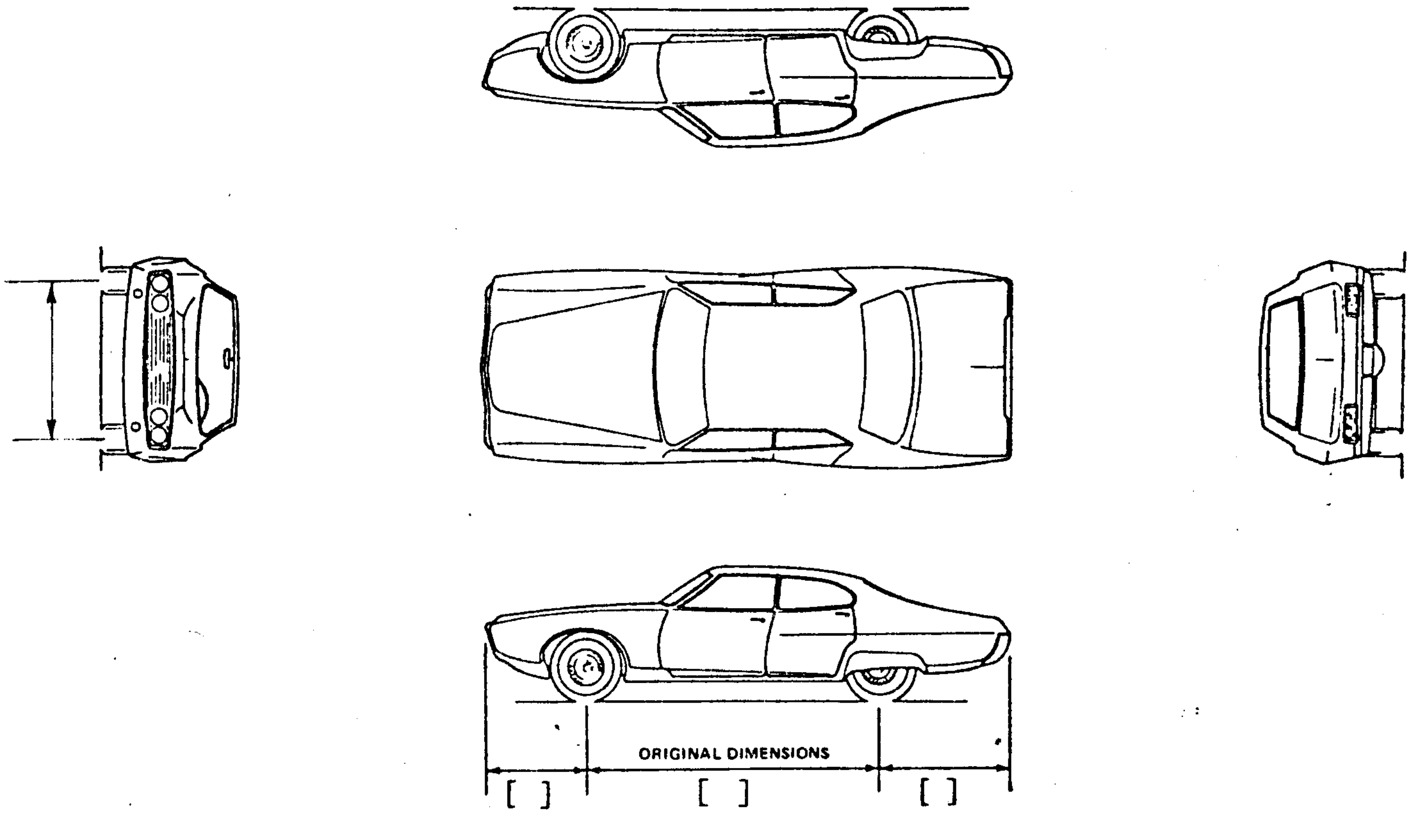
- Vehicle No. ____________
- Vehicle Identification No. ______
- Vehicle Make ____________
- Vehicle Model ____________
- Vehicle Model Year __________
- Vehicle 5 Digit Code __________
- Cargo Carried ____________
- Location of Cargo ____________
- Occupant Ejection ____________
- Occupant Compartment 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	____ ____	____ ____-____ ____ ____ ____-____	____ ____