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16. Abstract

The purpose of the research was to develop traffic-safe end treatments for parallel-drainage structures that would not appreciably restrict water flow. Guidelines or warrants for use of the end treatments were also developed. Parallel-drainage culverts are used to convey water under driveways, side roads, or median crossovers.

Preliminary designs were first evaluated using a computer simulation program and a full-scale test program. From these studies, tentative design parameters were selected, including the ditch and driveway slopes and the grate spacing.

The end treatment developed in the preliminary studies was then subjected to full-scale prototype testing. These tests involved evaluation of the end treatment on a 6.7 to 1 driveway slope with a subcompact automobile. The end treatment was subjected to tests at 40 mph (64.4 km/h) and 50 mph (96.5 km/h). A benefit/cost analysis was conducted to determine warrants for the use of the treatments.

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Unclassified	Unclassified		

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SAFETY TREATMENT OF ROADSIDE PARALLEL-DRAINAGE STRUCTURES

by

Hayes E. Ross, Jr.
T. J. Hirsch
Dean Sicking

Research Report 280-2F
on
Research Study No. 2-8-79-280
Safe End Treatment for Roadside Culverts

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The U. S. Department of Transportation
Federal Highway Administration

June 1981
(Revised May 1982)

Texas Transportation Institute
Texas A&M University
College Station, Texas

METRIC CONVERSION FACTORS

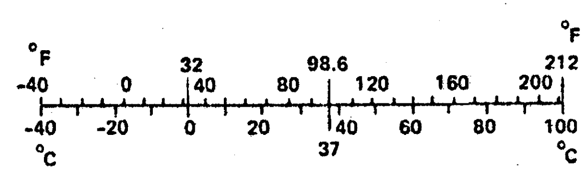
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



DISCLAIMER

KEY WORDS

Culvert(s), Drainage, Safety, Roadside, Test(s), Treatment, Driveway

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute, the Texas State Department of Highways and Public Transportation, and the Federal Highway Administration. Harold Cooner, John Nixon, and Samuel Fox of the SDHPT and C. P. Damon of the FHWA worked closely with the researchers, and their comments and suggestions were appreciated.

ABSTRACT

The purpose of the research was to develop traffic-safe end treatments for parallel-drainage structures that would not appreciably restrict water flow. Guidelines or warrants for use of the end treatments were also developed. Parallel-drainage culverts are used to convey water under driveways, side roads, or median crossovers.

Preliminary designs were first evaluated using a computer simulation program and a full-scale test program. From these studies, tentative design parameters were selected, including the ditch and driveway slopes and the grate spacing.

The end treatment developed in the preliminary studies was then subjected to full-scale prototype testing. These tests involved evaluation of the end treatment on a 6.7 to 1 driveway slope with a subcompact automobile. The end treatment was subjected to tests at 40 mph (64.4 km/h) and 50 mph (96.5 km/h). A benefit/cost analysis was conducted to determine warrants for the use of the treatments.

To achieve a traffic-safe driveway/culvert design the following conditions should be met:

1. The roadway sideslope (or ditch slope) should be 6 to 1 or flatter.
2. The driveway slope should be 6 to 1 or flatter.
3. The transition area between the roadway sideslope and the driveway slope should be rounded or smoothed as opposed to an abrupt transition.
4. Safety treatment of the culvert opening should include an end section cut to match the driveway slope with cross members (grates) spaced approximately every 2 ft (0.61 m) perpendicular to the

direction of water flow. The cross members should be designed to support a concentrated wheel load of approximately 10,000 lb (44,480 N) ap- plied at midspan.

Guidelines for use of safety treatments were developed through a benefit/cost analysis. Assumptions made in the analysis were: (1) the roadway side slope was 6 to 1, (2) the roadway had a 12 ft (3.66 m) shoulder, and (3) the centerline of the driveway culvert was 25 ft (7.62 m) from the edge of the travelway.

Three driveway/culvert options were evaluated:

I. Untreated condition (1-1/2 to 1 driveway slope and no culvert end treatment).

II. Driveway slope of 6 to 1 with culvert end cut to match slope with no safety grates.

III. Same as II but with safety grates on culvert.

Based on the benefit/cost analysis, guidelines were developed that identify conditions (traffic volume and culvert size) that warrant safety treatment of parallel drainge culverts on rural high-speed highways. These warrants are presented in Figure 19 of the report.

IMPLEMENTATION STATEMENT

Results of this study have been implemented by the Texas State Department of Highways and Public Transportation. The Highway Design Division has issued policy statements on driveways and parallel drainage structures for new construction projects. Revisions have been made in the SDHPT design manual. The Safety and Maintenance Operations Division has issued guidelines for access driveways and driveway culverts. The study has also been well received and implemented by a large number of other states.

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I. INTRODUCTION

Drainage ditches parallel almost all modern highways. Driveways, side roads, and median crossings commonly incorporate pipe culverts to accommodate the surface runoff carried by these ditches. Recent field reviews of drainage culverts revealed that improvements and some modification of design details could improve both drainage and safety (1). Many of the safety grates used in the past to cover the open ends of culverts have small openings and the grates are easily clogged with debris. This causes water to back up and flow over the roadway, the ditch crossing, or adjacent property. In some cases safety grates do not possess enough strength to be effective or they are used on small pipe culverts which need no safety treatment.

The objective of this study was to develop guidelines for safety treatment of driveway, side road, and median crossover culverts that (1) can be safely traversed by an errant vehicle and (2) will exhibit desirable hydraulic behavior.

An errant vehicle must be able to safely negotiate the culvert and adjoining slopes of the ditch and ditch crossing. This study investigated these two basic areas by use of a computer simulation program and full-scale crash tests to determine both the slope combinations and the grating with the fewest cross members that can be safely negotiated by an errant vehicle. No hydraulic analysis was attempted. For this study it was assumed that the grate with the fewest members was the best grate from a hydraulic standpoint.

II. EVALUATION CRITERIA

A review of the literature showed that there are no nationally recognized safety performance standards for roadside drainage structures. Deceleration and stability of a vehicle during impact are the two primary measures of performance for safety appurtenances such as guardrails, crash cushions, etc. Desirably, the appurtenance will satisfy both criteria. Previous research (2,6), showed that a very flat ditch slope, a very flat driveway slope, and a very long culvert would be necessary to satisfy these criteria for the present problem. In view of the economic and hydraulic implications of such a design it was concluded that tradeoffs would be necessary to achieve an acceptable balance between the controlling elements. Performance was therefore judged acceptable if the vehicle smoothly traversed the slopes and did not roll over or pitch over at speeds up through 50 mph (80.5 km/h).

III. VEHICLE SIMULATION AND SLOPE EVALUATION

Design of a traffic-safe parallel drainage structure not only involves the culvert itself but adjoining slopes as well. In fact, the slopes can in many cases be a greater hazard than the culvert structure. Studies of median cross-over geometry pointed to the need for relatively flat slopes to minimize errant vehicle rollover (2,6). The computer program, Highway-Vehicle-Object-Simulation-Model (HVOSM) (3), was used to examine the behavior of a vehicle traversing various driveway conditions. Parameters investigated included departure angle, departure speed, and the path of vehicle encroachment; the side slopes of both the ditch and the driveway; the type of transition zone between the two slopes; depth of the ditch; and vehicle size. These parameters are illustrated in the definition sketch of Figure 1.

Following is the range of each parameter evaluated:

DEPARTURE ANGLE: 15° and head-on

DEPARTURE SPEED: 30 mph (48.3 km/h), 40 mph (64.4 km/h), 50 mph (80.5 km/h), and 60 mph (96.6 km/h)

PATH: 15° angled path across transition (path 1), 15° angled path across ditch bottom (path 2), and head-on path into driveway slope (path 3)

ROADSIDE SLOPE: 4:1 and 6:1

DRIVEWAY SLOPE: 4:1, 5:1, and 6:1

TRANSITION TYPE: Abrupt and Rounded

DITCH DEPTH: 2 ft (0.61 m) and 3 ft (0.92 m)

VEHICLE SIZE: 2250 lb (1022 kg) and 4500 lb (2044 kg)

A total of 68 computer runs were made to evaluate the various parameters. Further details and results of these runs are given in Appendix A.

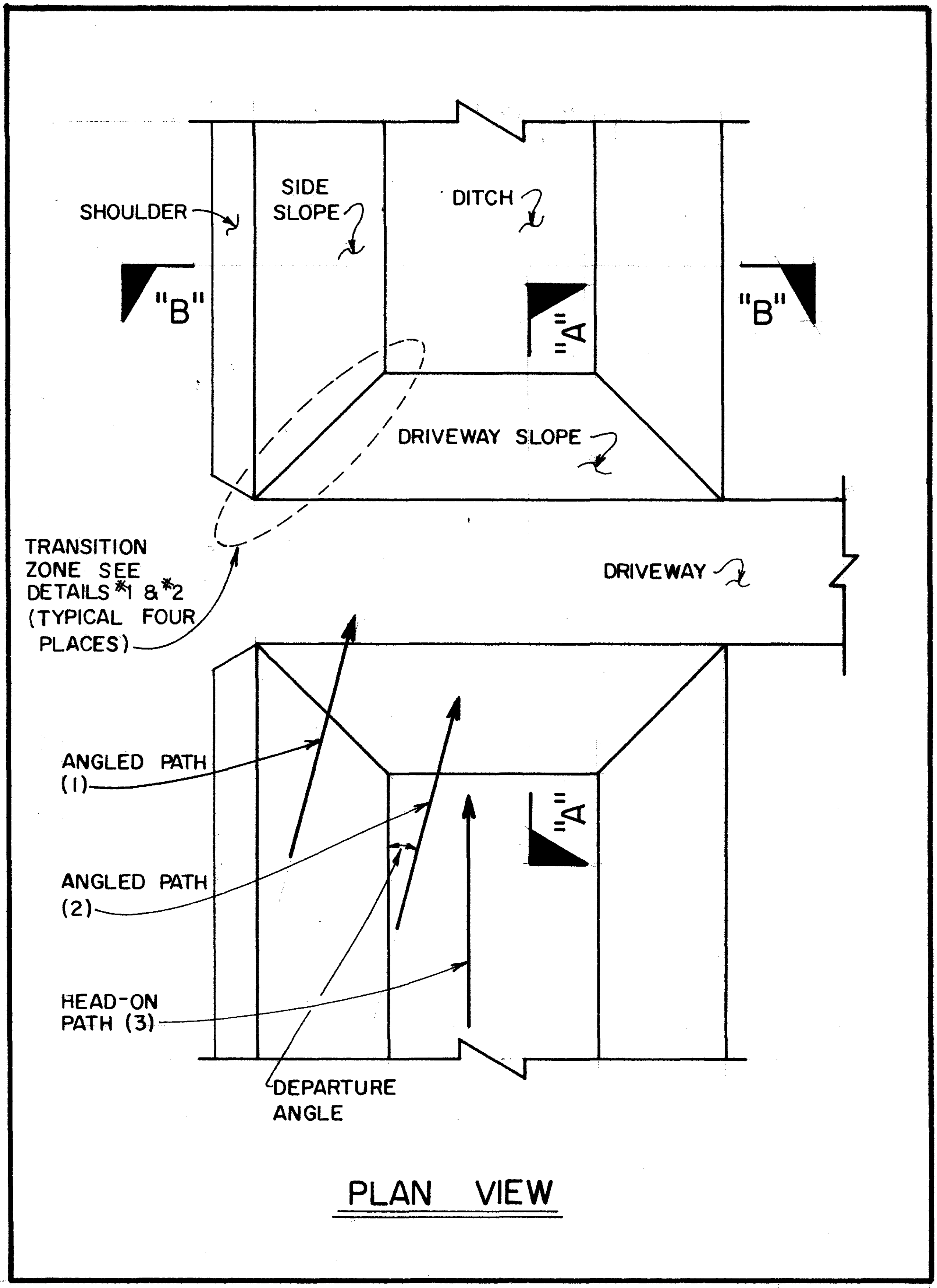


Figure 1. Definition Sketch.

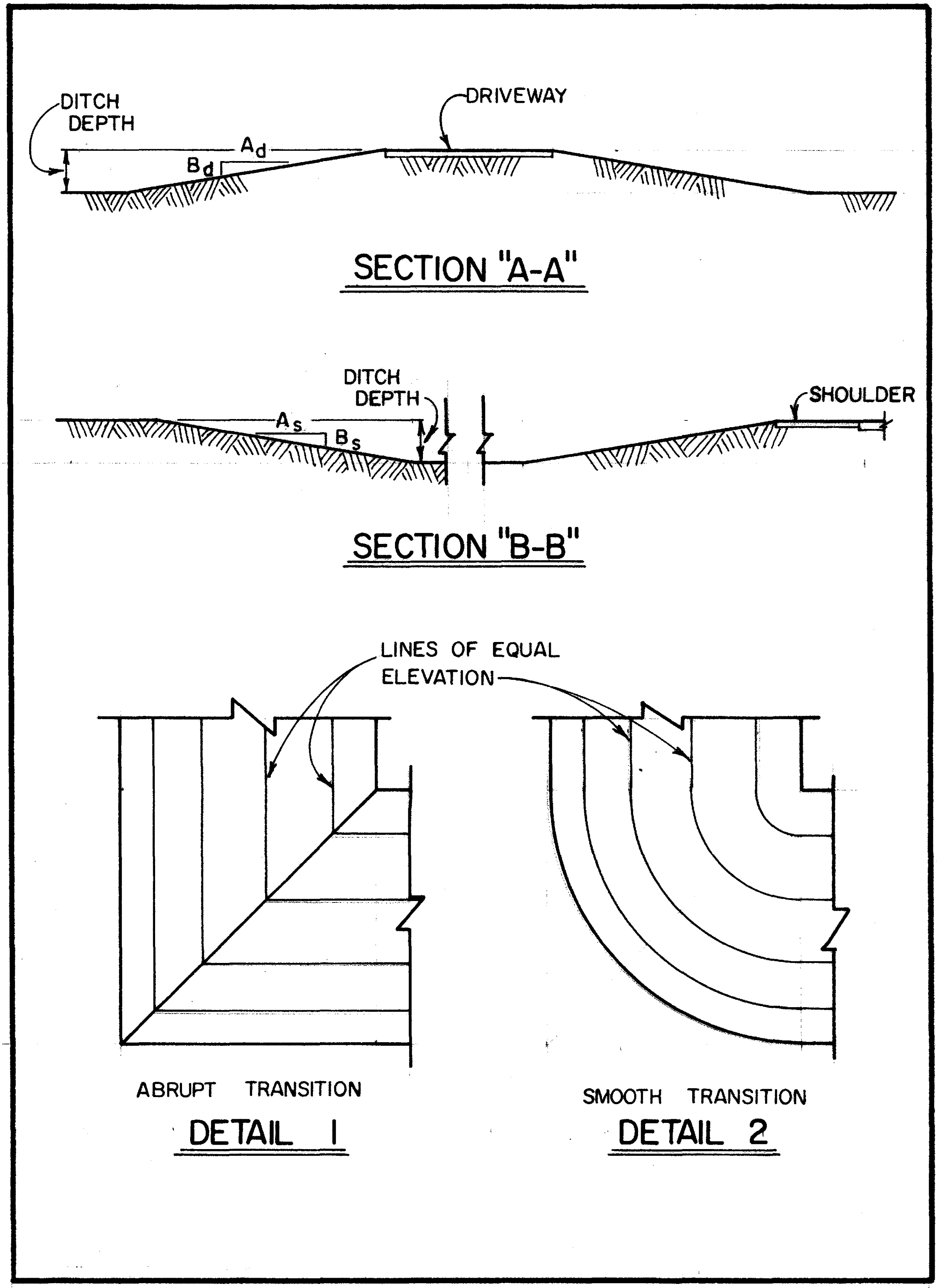


Figure 1. Definition Sketch. (continued)

Tentative conclusions reached as a result of the 68 computer runs were as follows:

1. Curved transitions between the ditch and driveway slopes significantly reduce the potential for rollover when the errant vehicle crosses the transition area.
2. Rollover will occur at speeds between 40 mph (64.4 km/h) and 50 mph (80.5 km/h) for 4:1 ditch and driveway slopes and ditch depths of 2 ft (0.61 m) and 3 ft (0.92 m), rgardless of the type of transition used.
3. Rollover will occur at speeds between 40 mph (64.4 km/h) and 50 mph (80.5 km/h) for 6:1 ditch and driveway slopes and a ditch depth of 2 ft (0.61 m), regardless of the type of transition used.
4. Rollover will occur at speeds between 50 mph (80.5 km/h) and 60 mph (96.5 km/h) for 6:1 ditch and driveway slopes and a ditch depth of 3 ft (0.92 m), regardless of the type of transition used.
5. The 4500 lb (2043 kg) automobile did not appear to be more stable than the 2250 lb (1022 kg) automobile.

IV. FULL-SCALE TESTS

A series of full-scale tests were conducted to verify the HVOSM results and to evaluate impact performance of the safety treatments. The test vehicles were 1974 and 1975 Chevrolet Vegas weighing approximately 2250 lb (1022 kg). Further details of the test vehicles are given in Appendix B-2. In each test the vehicle was towed to the test site along a guidance cable, released, and then allowed to traverse the test area in a free-wheel (no steer input), no-braking mode. A summary of the 12 full-scale tests is given in Table 1. Further details are presented in the following sections.

IV-1. Slope Tests

As has been previously discussed, the impact behavior of a vehicle leaving the roadway in the area of a driveway is highly dependent on the slopes of the ditch and driveway. The initial phase of the test program was therefore designed to evaluate the relative hazard of the driveway slope. An earth berm was constructed to simulate the driveway. A sketch of the berm as constructed for tests 1-1 through 1-4 is shown in Figure 2, and photos of the berm are shown in Figure 3. Note that the slope on the approach side of the berm was 3.8 to 1, slightly steeper than the intended slope of 4 to 1.

Tests 1-1 through 1-4 were conducted to determine an approximate maximum speed at which a driveway with a slope of approximately 4 to 1 could be traversed without attendant vehicle rollover. In each test the vehicle's speed was increased over that of the previous test. This process was continued until rollover occurred in test 1-4. Sequential photos of test 1-4 are shown in Figure 4. From these four tests it was determined that an automobile, approaching a driveway with a 4 to 1 slope from a head-on path (path 3 of Figure 1), would roll over (actually pitch over) at a speed somewhere between 40 mph (64.4 km/h) and 50 mph (80.5 km/h).

TABLE 1. SUMMARY OF FULL-SCALE TEST CONDITIONS

TEST NO.	VEHICLE SPEED (mph)	VEHICLE PATH (See Fig. 1)	DRIVEWAY SLOPE	DITCH SLOPE	CULVERT CONFIGURATION
1-1	30	3	3.8:1	N/A	No Culvert
1-2	35	3	3.8:1	N/A	No Culvert
1-3	40	3	3.8:1	N/A	No Culvert
1-4	50	3	3.8:1	N/A	No Culvert
5-1	50	3	6.7:1	N/A	No Culvert
7-1	50	3	6.7:1	N/A	(See Fig. 5)
7-2	50	3	6.7:1	N/A	(See Fig. 5)
7-4	20	3	6.7:1	N/A	(See Fig. 5)
7-5	50	3	6.7:1	N/A	(See Fig. 5)
7-6	50	3	6.7:1	N/A	(See Fig. 5)
9-1	40	2	6.5:1	6.8:1	(See Fig. 12)
9-2	50	2	6.5:1	6.8:1	(See Fig. 12)

Metric Conversions: 1 mph = 1.609 km/h

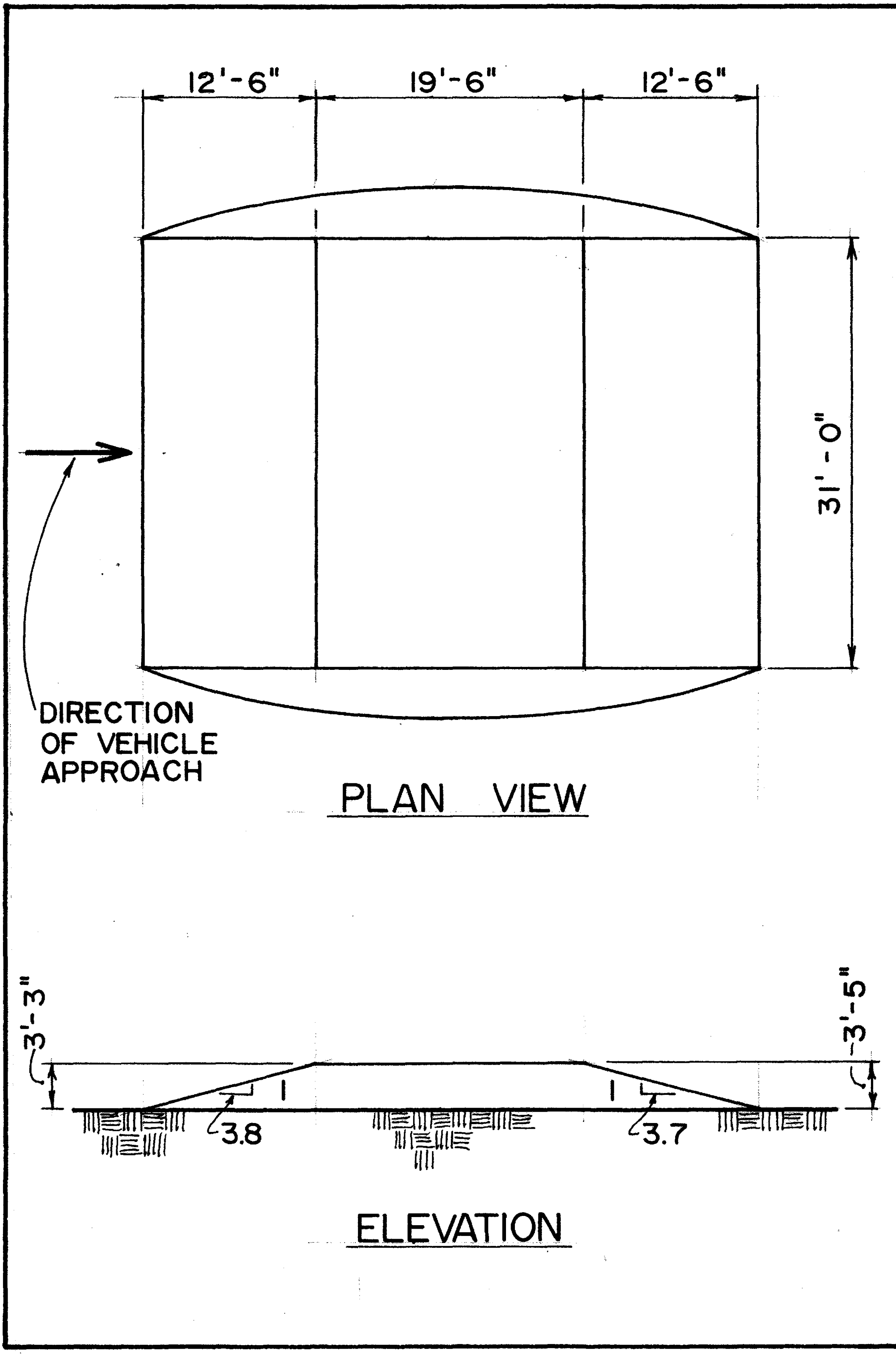
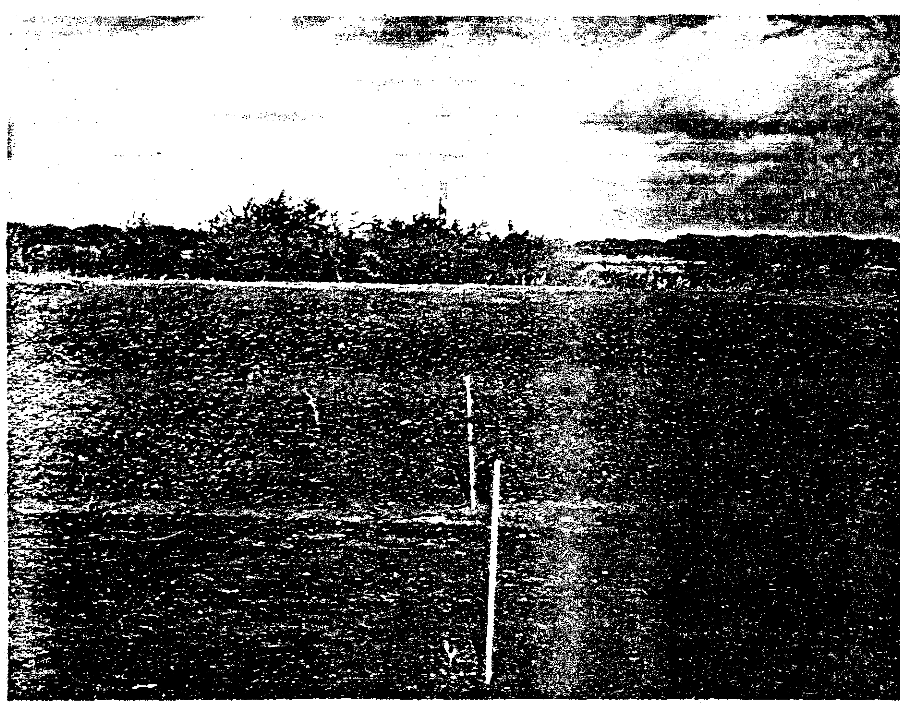


Figure 2. Berm Dimensions for Tests 1-1 through 1-4.

Side View



View Looking in Direction of Vehicle Travel

Figure 3. Photos of Earth Berm, Tests 1-1 through 1-4.

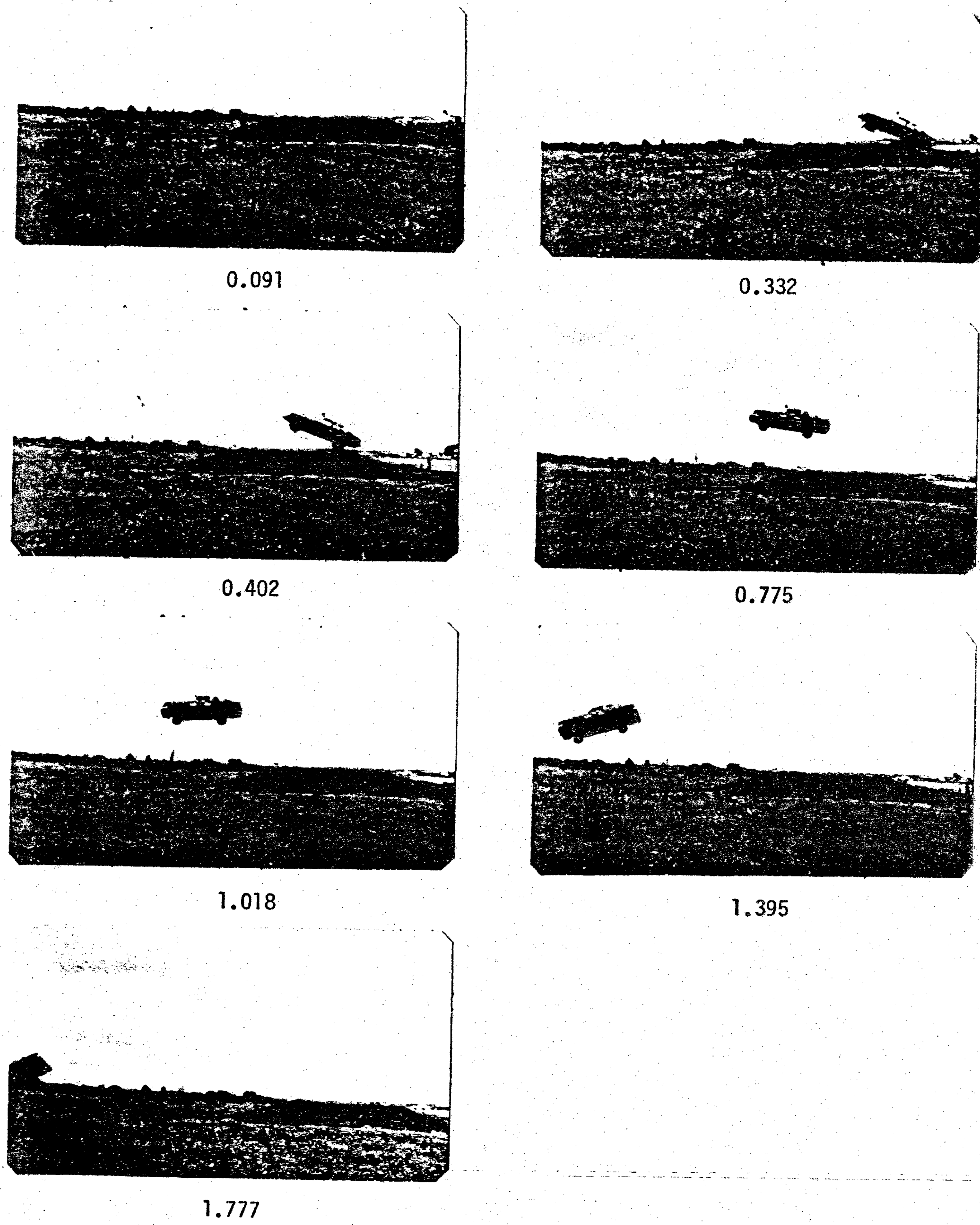


Figure 4. Sequential Photos, Test 1-4.

After test 1-4 the berm slopes were flattened to the dimensions shown on the first page of Figure 5. In this case the slope on the approach side was 6.7 to 1, slightly flatter than the intended 6 to 1 slope. It was obvious from test 1-3 that an automobile could traverse the 6 to 1 slope at speeds in excess of 40 mph (64.4 km/h) without rolling over. Hence, test 5-1 was conducted at 50 mph (80.5 km/h) with the automobile approaching from a head-on path. Although the vehicle was airborne for approximately 75 ft (22.9 m) it remained upright with no appreciable pitching. Sequential photos of the test are shown in Figure 6.

As a result of the slope tests, it was concluded that the driveway slope must be 6 to 1 or flatter if rollover was to be avoided for speeds up through 50 mph (80.5 km/h). Further details of the slope tests are given in Appendix B-3.

IV-2. Tests of Culvert Safety Treatments

The next series of tests (7-1 through 7-6) were conducted to determine if safety treatment of the culvert end was needed in addition to the sloped end treatment. The 6.7 to 1 driveway slope was used in each test. It was assumed that a head-on path into the driveway culvert would be as critical, or more critical, than any other path regarding the culvert itself. Based on this assumption, a 24 in. (61.0 cm) diameter corrugated steel pipe culvert with a sloped end was installed in the earth berm as shown on the first page of Figure 5. This culvert size was selected since the diameter of most driveway culverts in Texas are equal to or less than 24 in. (61.0 cm). Vehicle impact point for this series of tests was selected such that the right side wheels of the test vehicle traversed the center of the culvert end.

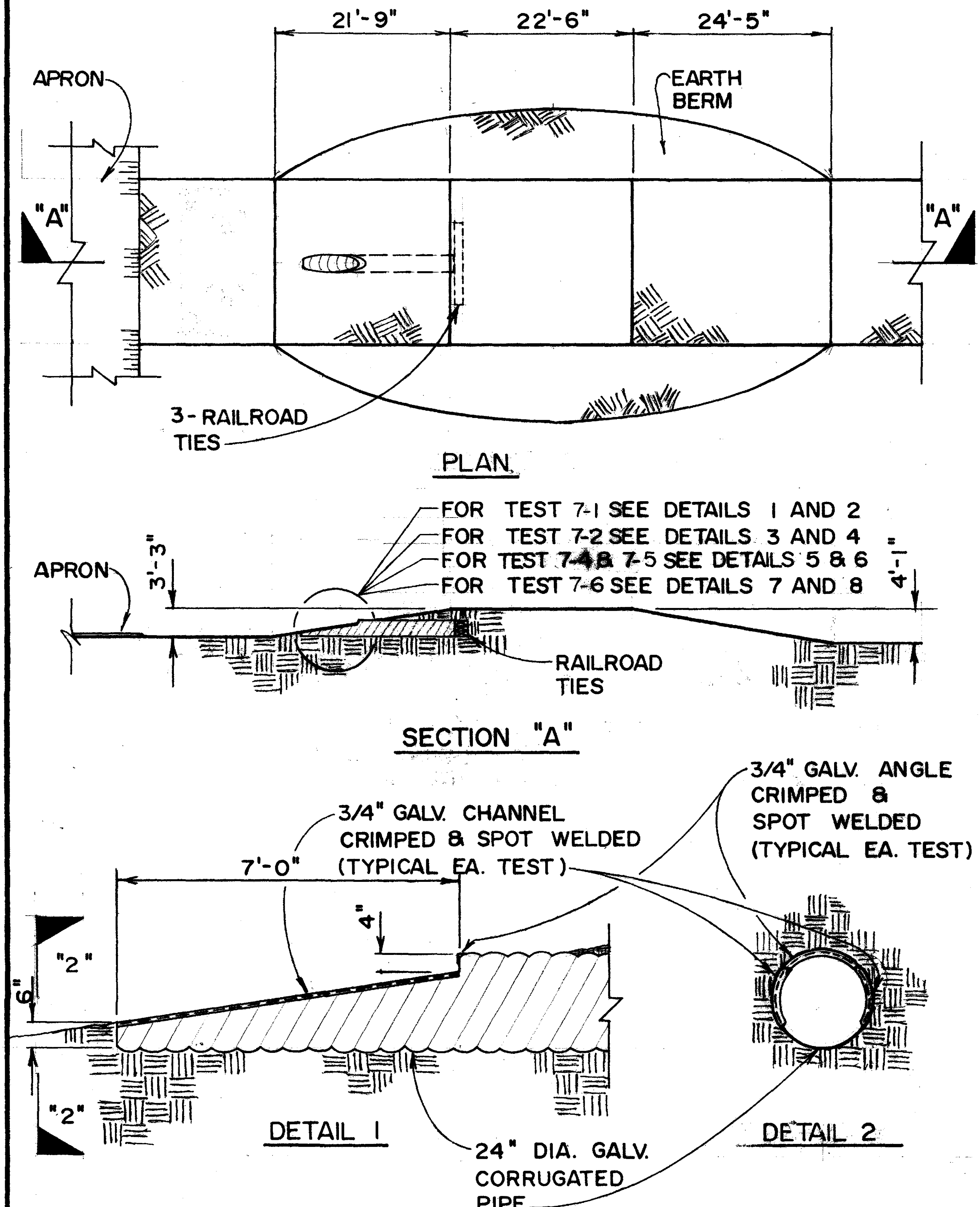


Figure 5. Berm and Culvert Details, Tests 5-1 through 7-6.

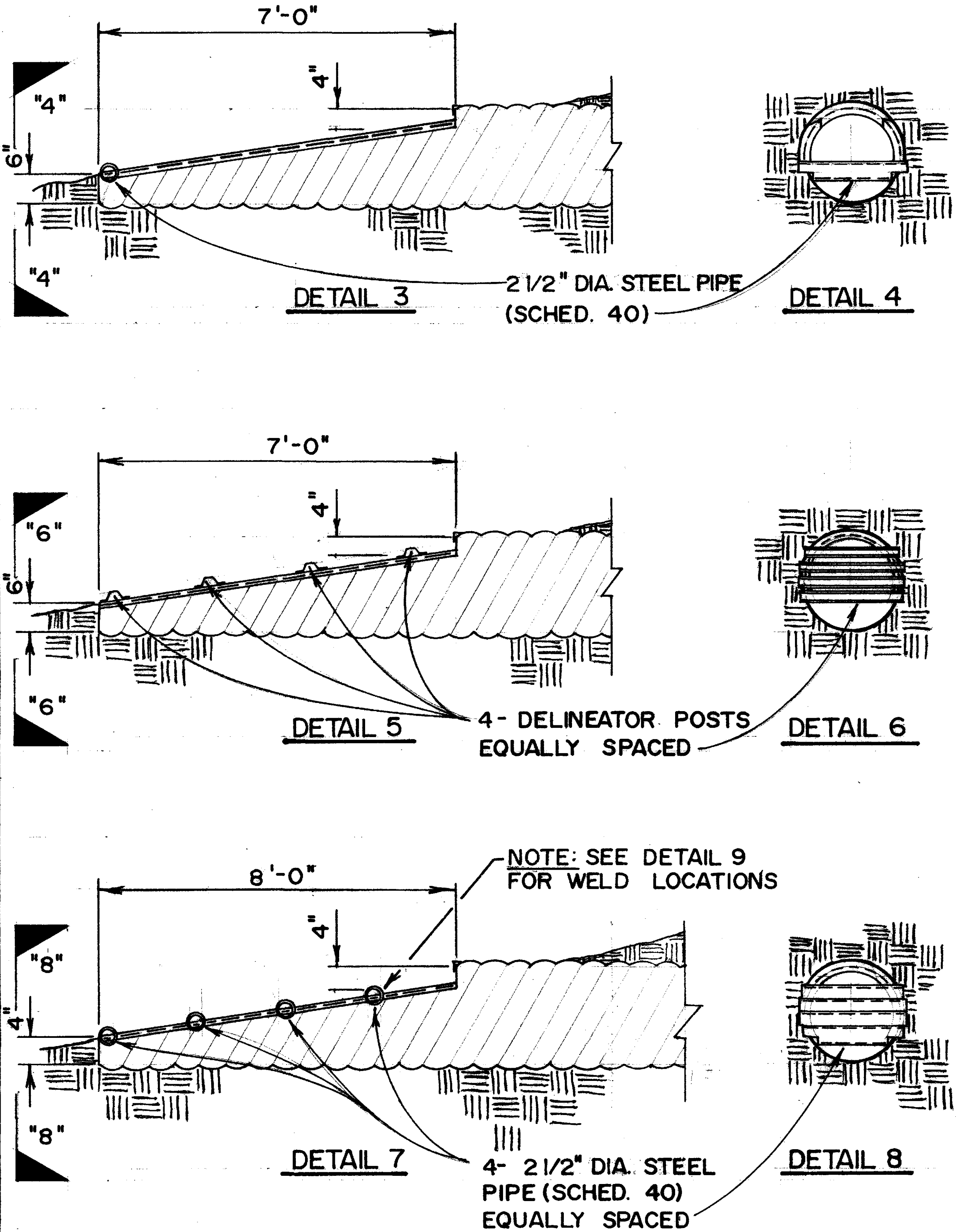
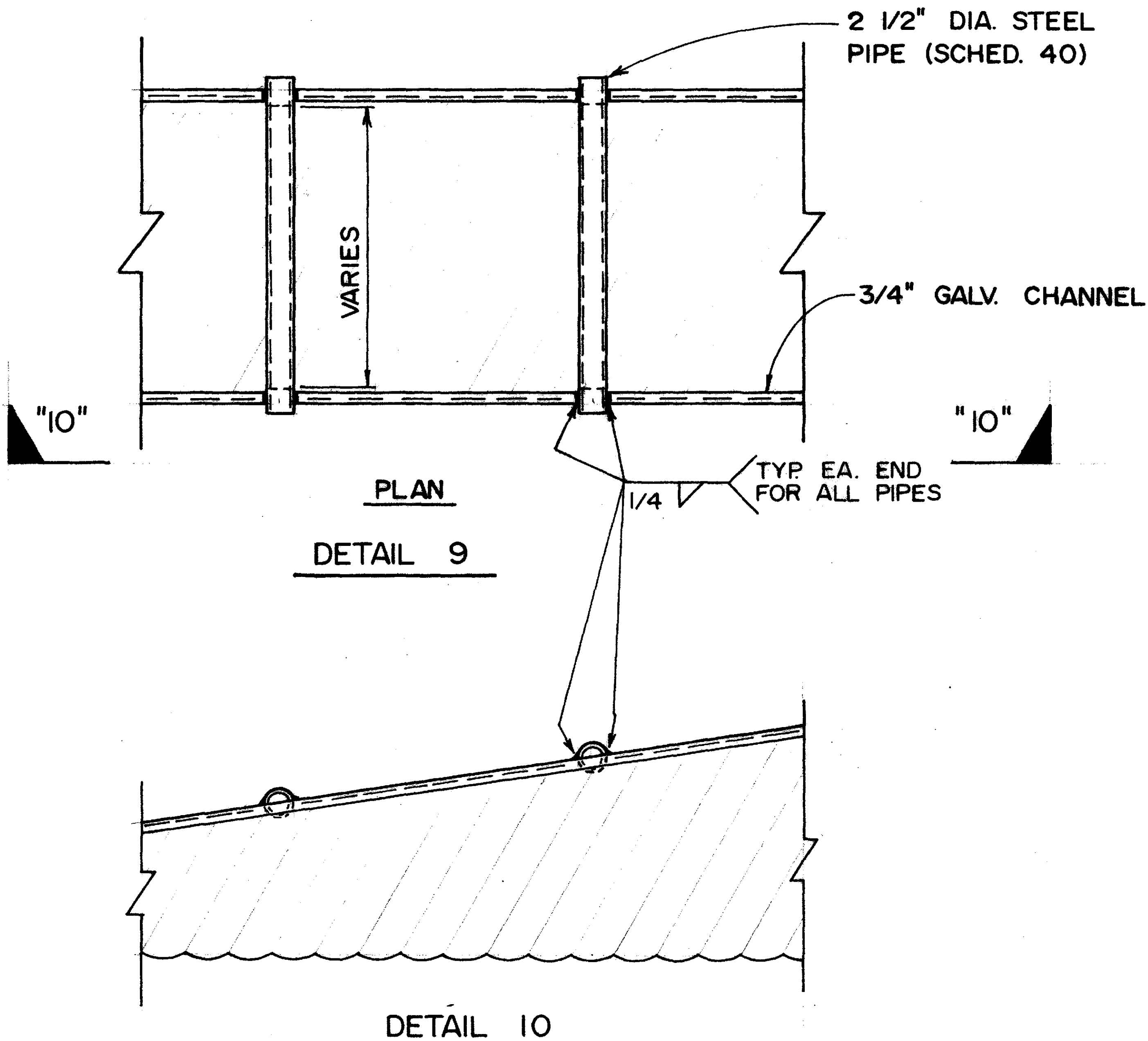


Figure 5. Berm and Culvert Details, Tests 5-1 through 7-6. (continued)



Metric Conversions

1 in = 2.54 cm
1 ft = 0.30 m

Figure 5. Berm and Culvert Details, Tests 5-1 through 7-6. (continued)

Details of the culvert configuration for each of the culvert tests are given in Figure 5. The first test, 7-1, was conducted at 50 mph with an open culvert, i.e., no grate members. Photos of the installation are given in Figure 7 and sequential photos of the test are given in Figure 8. Large pitch and roll rates occurred after impact with the culvert, and the vehicle rolled over. In the next test, 7-2, a single grate member was placed across the culvert as shown in details 3 and 4 of Figure 5 and the photos of Figure 9. Very little improvement in vehicle behavior occurred and rollover again occurred.

Analysis of test 7-2 showed that grates spaced approximately on 2 ft (0.61 m) centers was needed to avoid excessive wheel hop and wheel snagging. The next treatment therefore incorporated this feature as shown in details 5 and 6 of Figure 5. Photos of the grate and vehicle before test 7-4 are shown in Figure 10. Grate members consisted of 2 lb/ft (2.98 kg/m) steel flanged channel sections. The channel section was chosen since it is widely used as a delineator post by TSDHPT and would therefore be readily available. The first test on this treatment, test 7-4, was conducted at 20 mph (32.2 km/h) and the results were acceptable. Test 7-5 was conducted at 50 mph (80.5 km/h) and rollover occurred due to structural failure of the grates. Photos of the culvert before and after test 7-4 are shown in Figure 10.

In test 7-6, a 2-1/2 (6.35 cm) I.D. standard steel pipe (schedule 40) was used as a grate member. Details 7 through 10 of Figure 5 show how the pipe was attached to the culvert. Photos of the test vehicle and culvert before the test are shown in Figure 11 and sequential photos of the test are shown in Figure 12. Although the vehicle was airborne approximately 65 ft (19.8 m) it remained upright and the test was deemed acceptable. The culvert was only slightly damaged.

Further details of the culvert tests are given in Appendix B-4.

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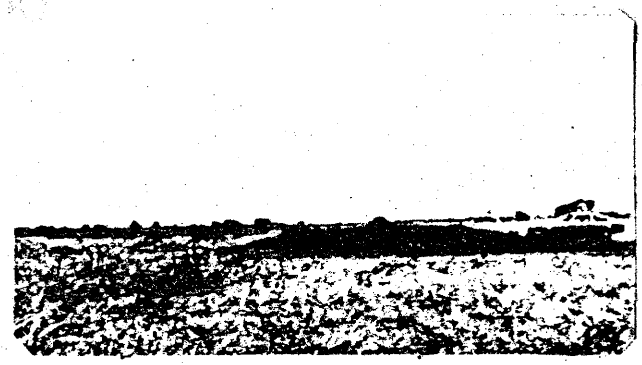

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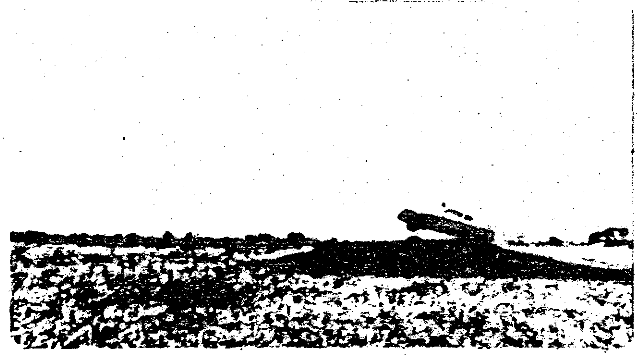

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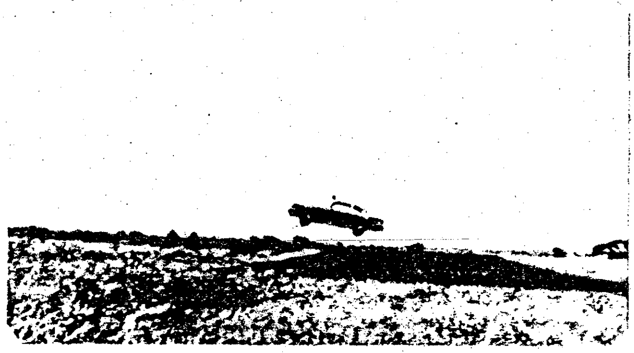

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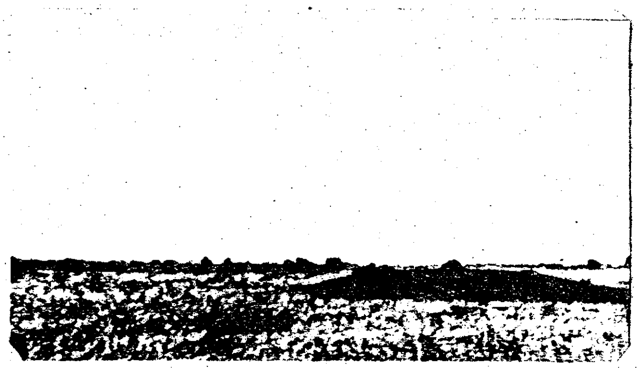

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Figure 6. Sequential Photos, Test 5-1.

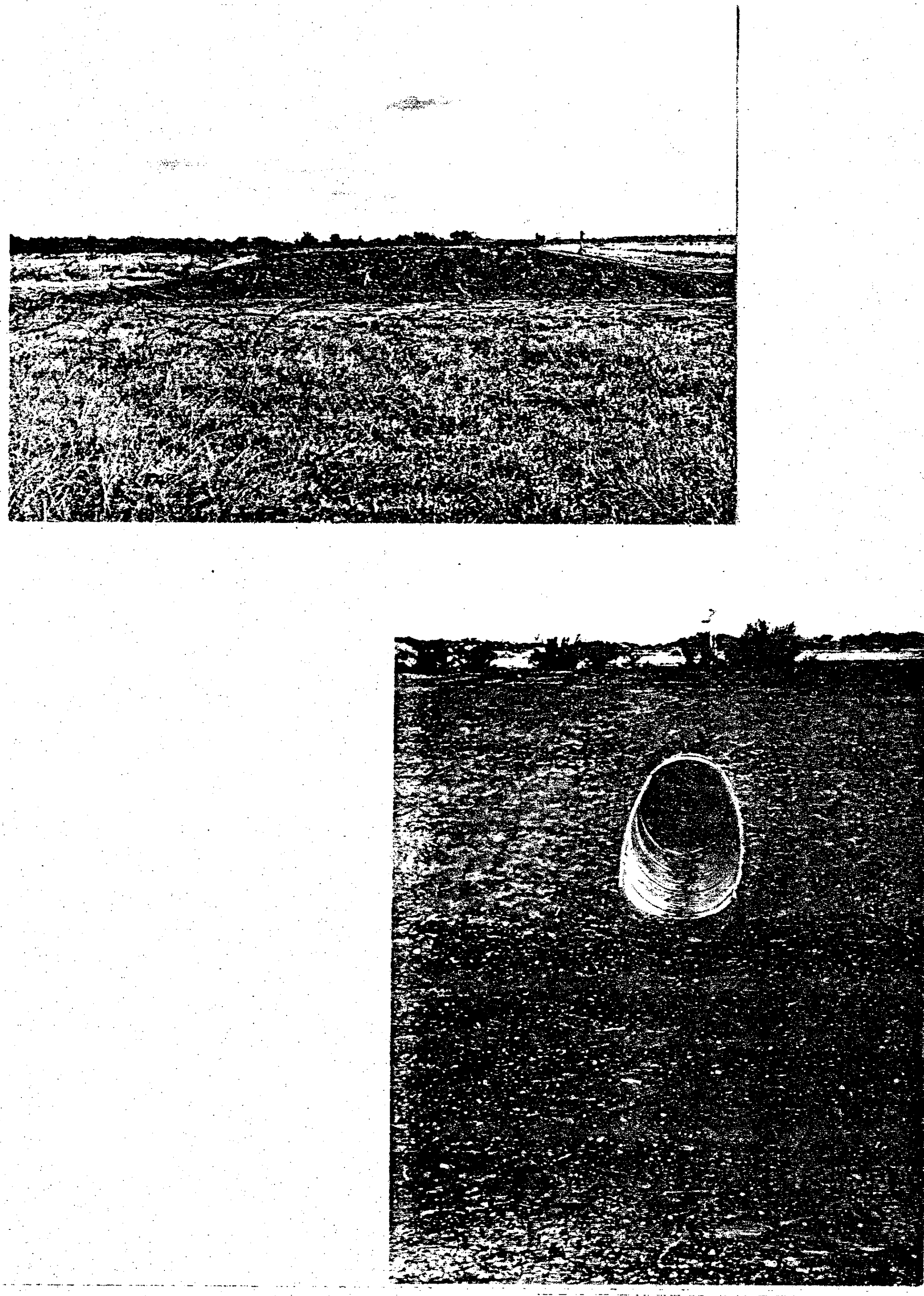


Figure 7. Test Installation Before Test 7-1.

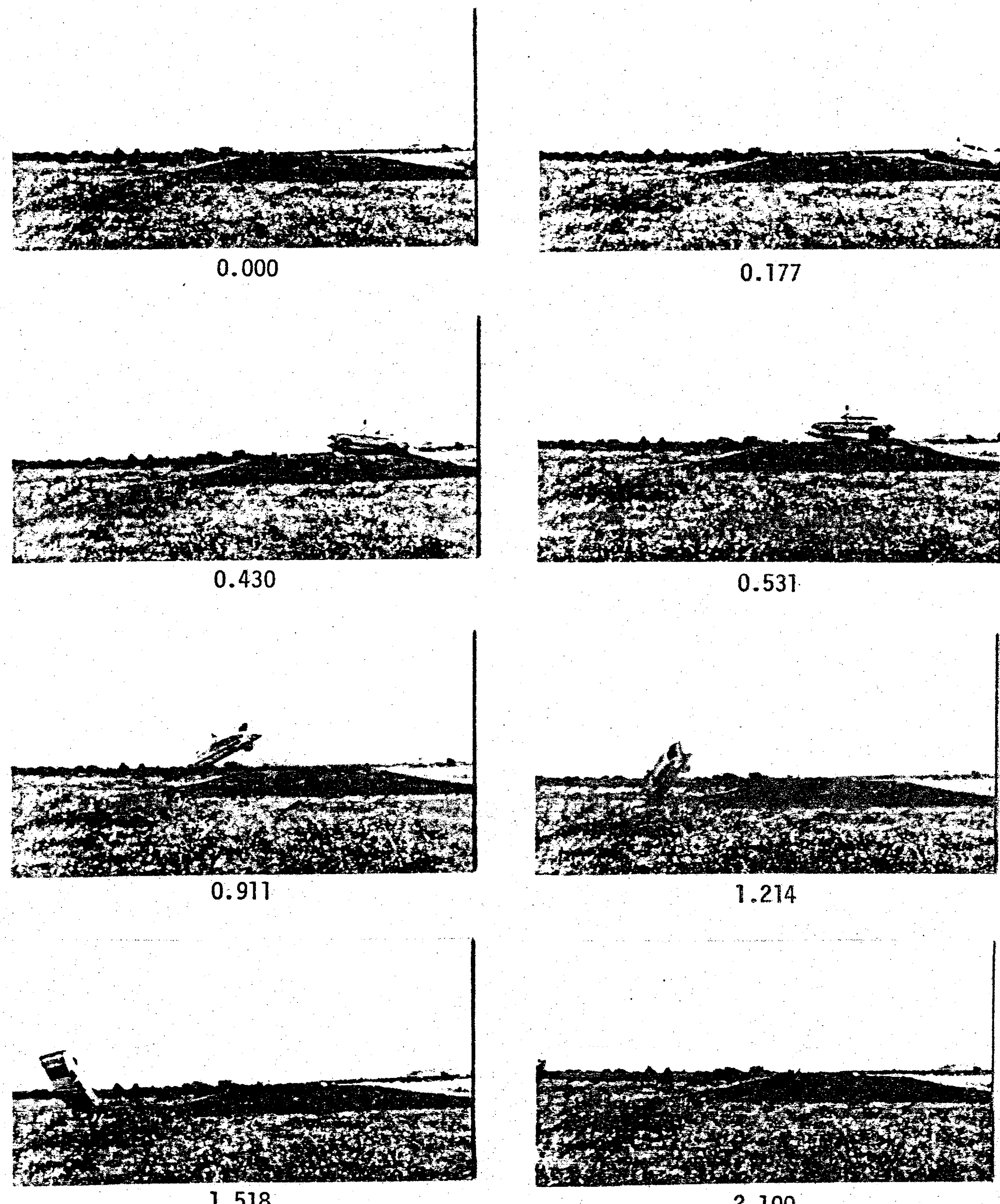


Figure 8. Sequential Photos, Test 7-1.

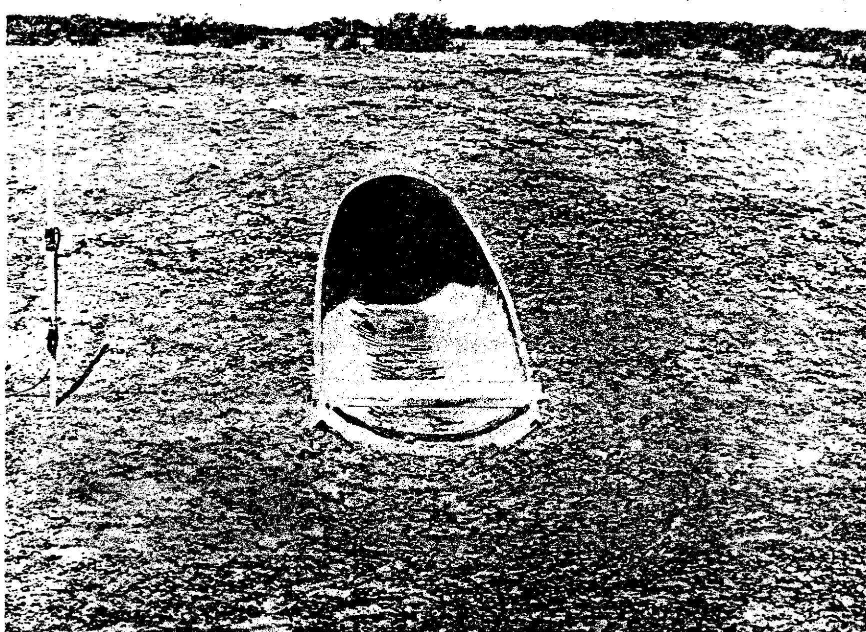


Figure 9. Culvert Installation Before Test 7-2.

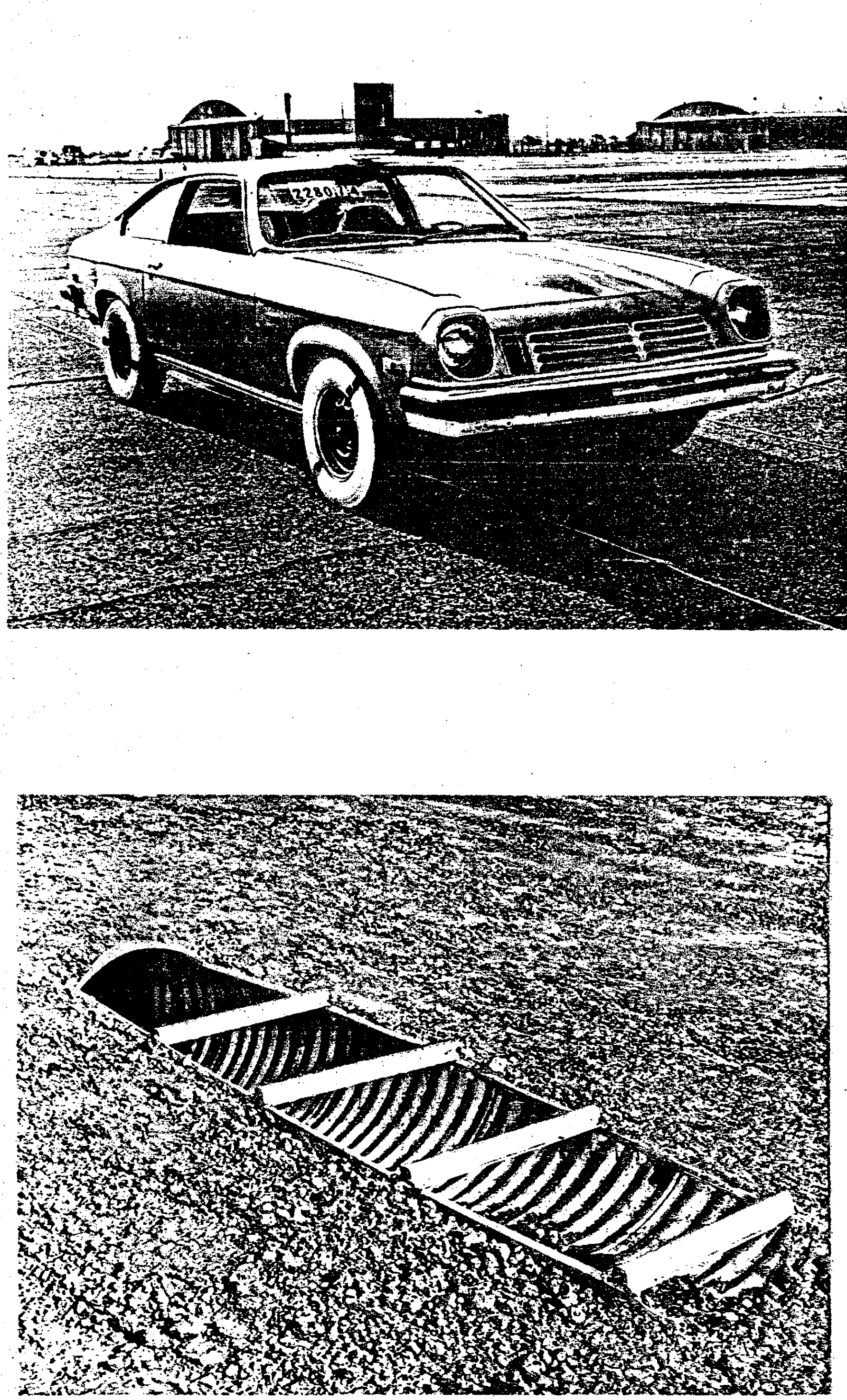
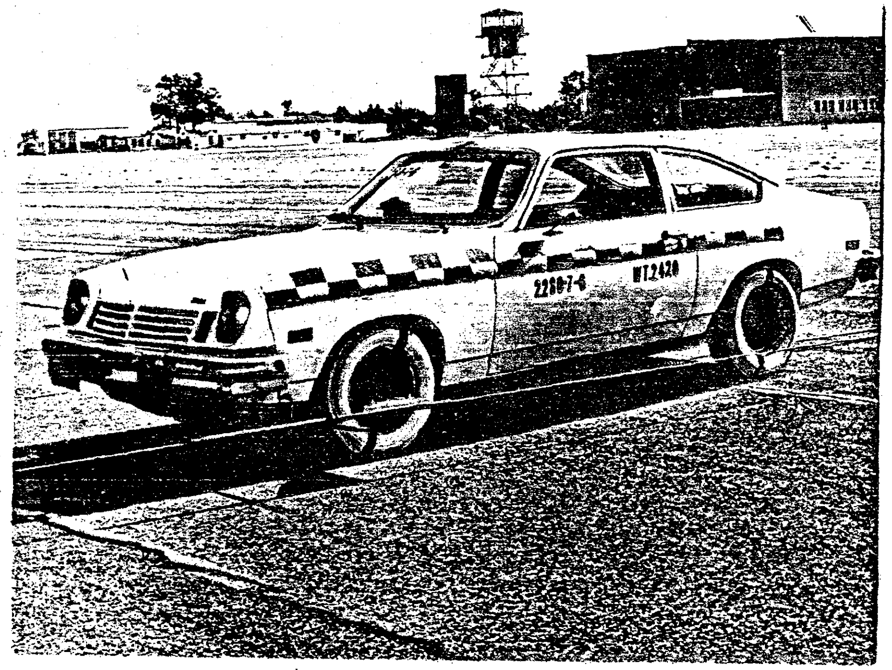


Figure 10. Test Vehicle and Installation Before Test 7-4.



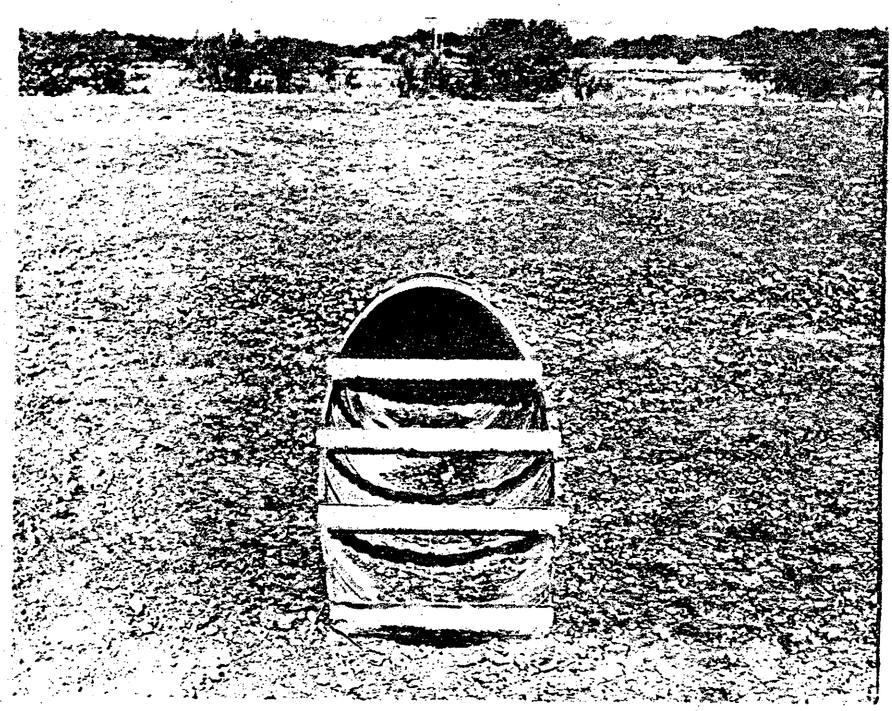
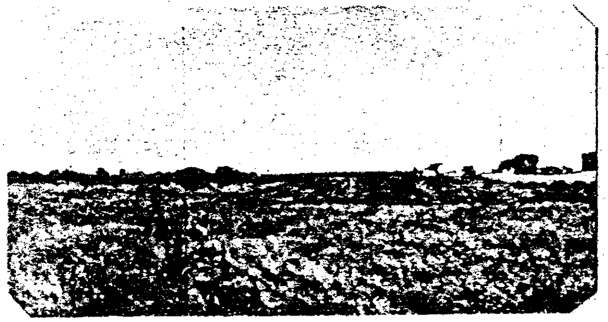


Figure 11. Test Vehicle and Installation Before Test 7-6.



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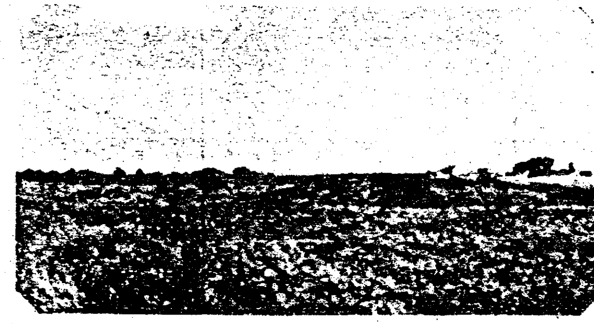

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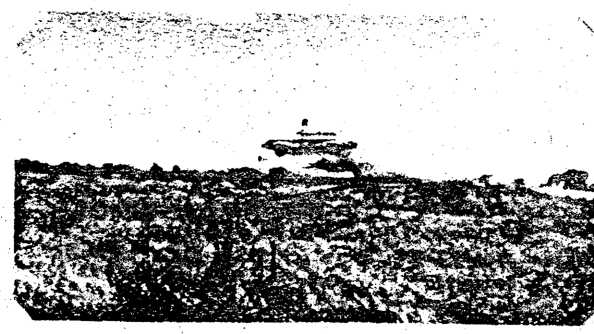

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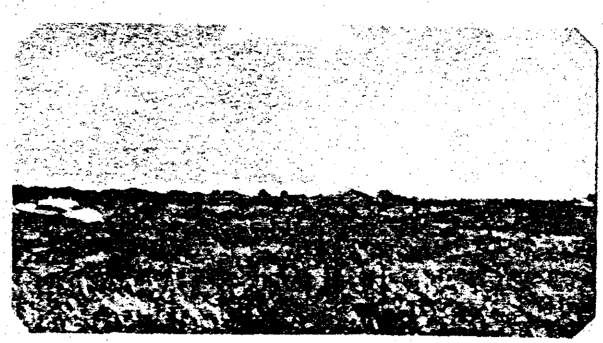


1.902

Figure 12. Sequential Photos, Test 7-6.

Analysis of the crash tests and the computer simulations showed that the dynamic wheel load on a grate member is about 10,000 lb (44,480 N) when impacted by a 4500 lb (2043 kg) automobile at 50 mph (80.5 km/h), assuming the culvert is on a 6 to 1 slope. It is therefore suggested that a 10,000 lb (44,480 N) concentrated load applied at midspan be used in designing a cross member, its attachment to the culvert and/or riprap, and any reinforcing that may be necessary to the culvert and/or riprap.

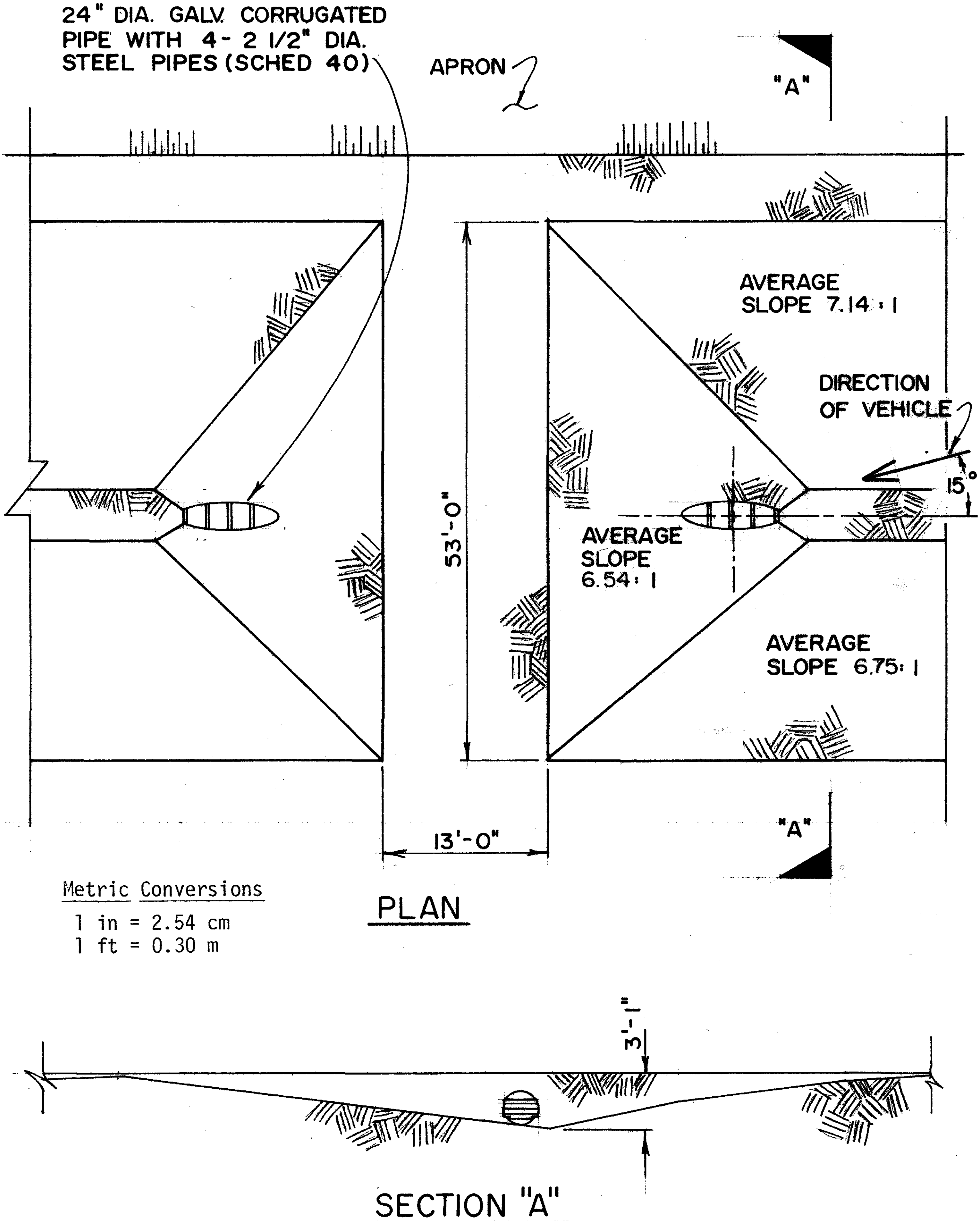
It is noted that the 2-1/2 in. (96.4 cm) schedule 40 steel pipe used in the test program, while structurally adequate for a 2250 lb (1022 kg) automobile and a 24 in. (61.0 cm) diameter culvert, would probably not have supported a 4500 lb (2043 kg) automobile. Calculations show that a 3 in. (7.6 cm) I.D., schedule 40 pipe would have been needed for the larger auto.

IV-3. Full-Scale Prototype Tests

The final two tests, 9-1 and 9-2, were selected to verify the tentative conclusions reached as a result of the simulation work and the full-scale slope and culvert testing. A full-scale prototype of a ditch-driveway configuration was therefore constructed as shown in Figure 13 and the photos of Figure 14. Test 9-1 was conducted at 40 mph (64.4 km/h) and the approach path into the driveway was as shown in Figure 13. The path was such that the left side wheels crossed the culvert. No adverse vehicle behavior occurred during the test, and the results were considered acceptable.

Test 9-2 was identical to test 9-1 except the speed was increased to 50 mph (80.5 km/h). Sequential photos of the test are shown in Figure 15. The vehicle remained upright and sustained only minor damage. Photos of the vehicle and the culvert after the test are shown in Figure 16.

Further details of the prototype tests are given in Appendix B-5. A summary of the results of the 12 crash tests is given in Table 2.



Metric Conversions

1 in = 2.54 cm
1 ft = 0.30 m

Figure 13. Test Site Conditions, Tests 9-1 and 9-2.

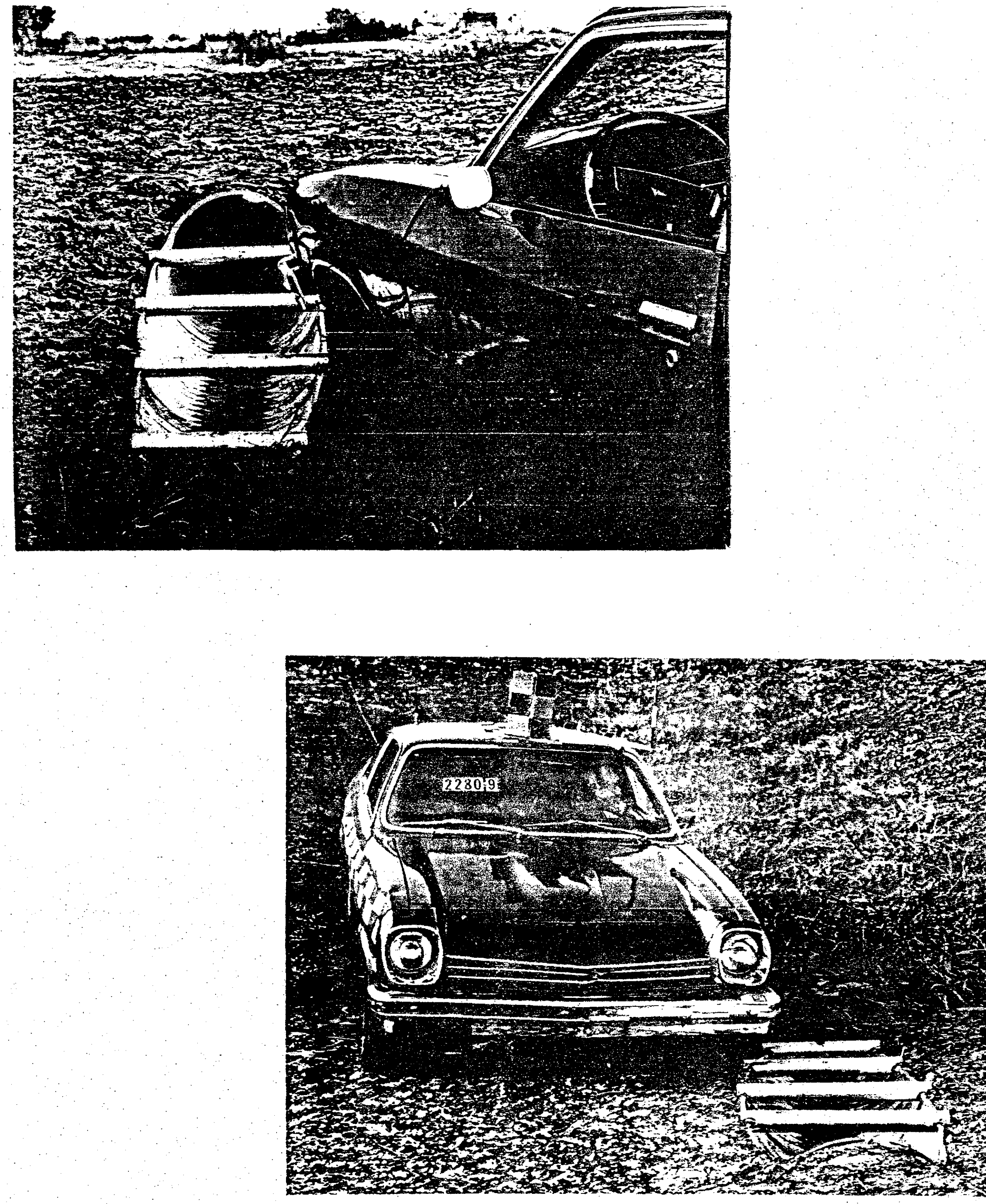


Figure 14. Test Site, Tests 9-1 and 9-2.

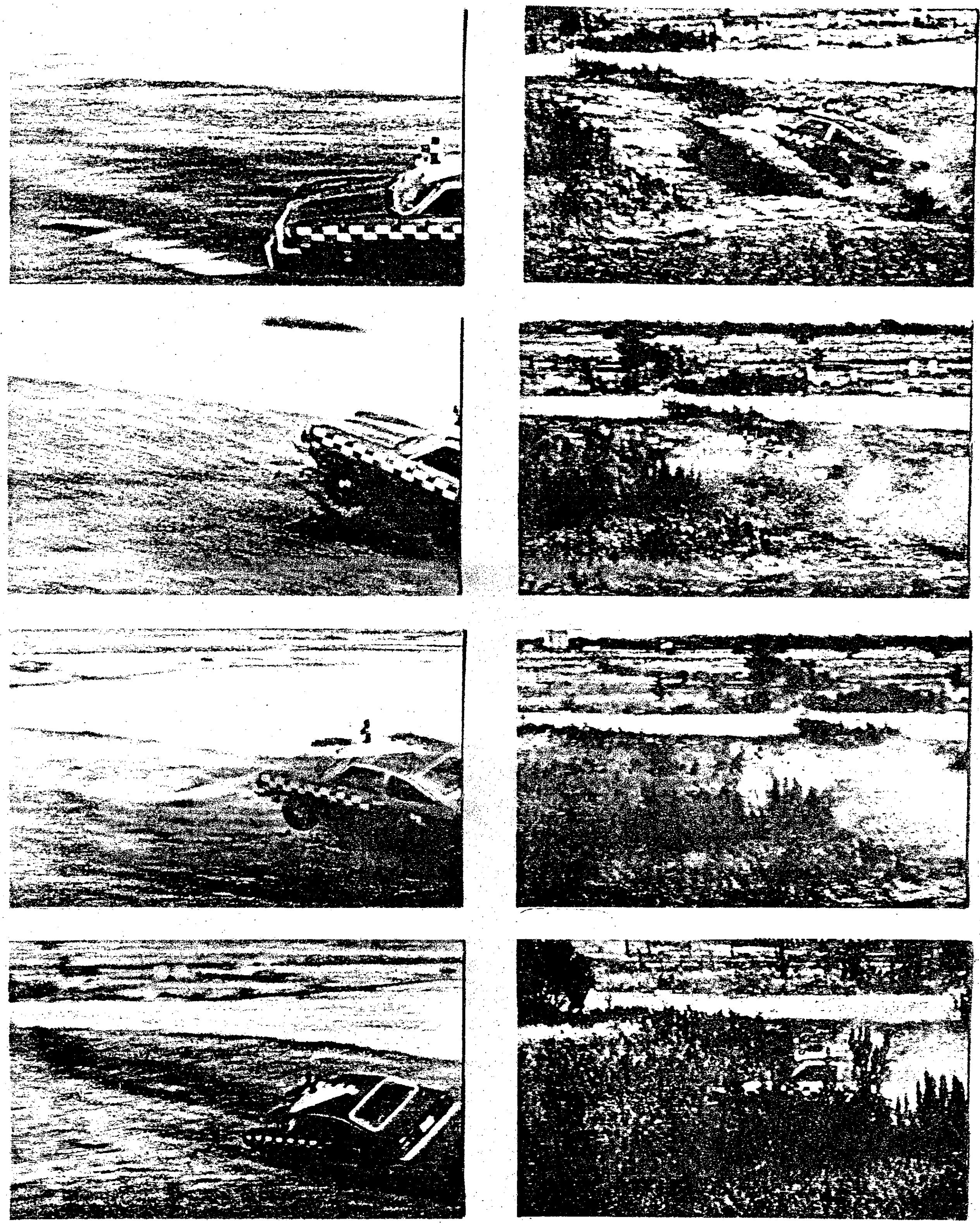


Figure 15. Sequential Photos, Test 9-2.

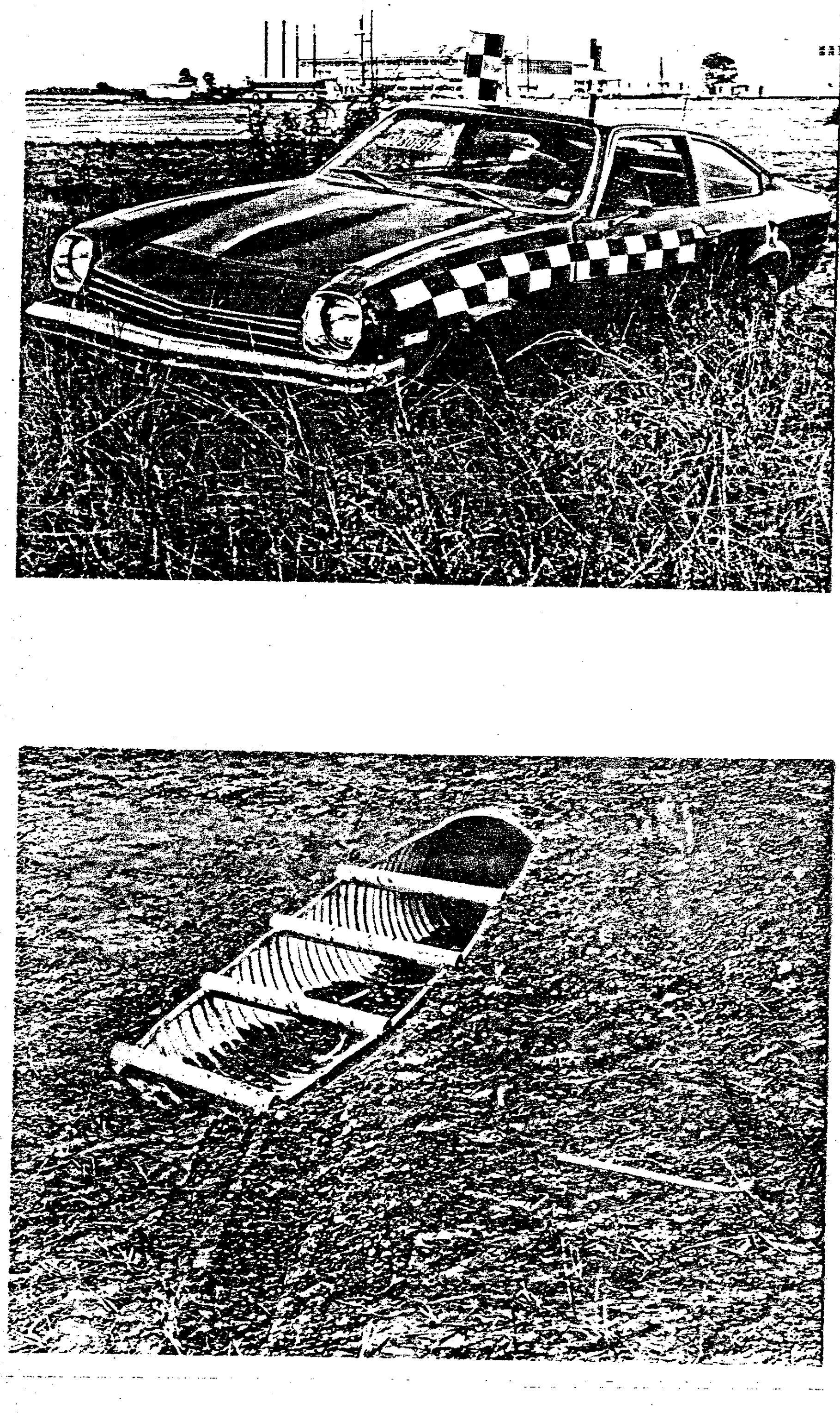


Figure 16. Vehicle After Test 9-2.

TABLE 2. SUMMARY OF FULL-SCALE TEST RESULTS

TEST NO.	VEHICLE SPEED (mph)	VEHICLE PATH (See Fig. 1)	DRIVEWAY SLOPE	DITCH SLOPE	CULVERT CONFIGURATION	RESULTS
1-1	30	3	3.8:1	N/A	No Culvert	Satisfactory - no rollover
1-2	35	3	3.8:1	N/A	No Culvert	Satisfactory - no rollover
1-3	40	3	3.8:1	N/A	No Culvert	Satisfactory - no rollover
1-4	50	3	3.8:1	N/A	No Culvert	Unsatisfactory - vehicle pitched over
5-1	50	3	6.7:1	N/A	No Culvert	Satisfactory - no rollover
7-1	50	3	6.7:1	N/A	(See Fig. 5)	Unsatisfactory - vehicle rolled over
7-2	50	3	6.7:1	N/A	(See Fig. 5)	Unsatisfactory - vehicle rolled over
7-4	20	3	6.7:1	N/A	(See Fig. 5)	Satisfactory - no rollover
7-5	50	3	6.7:1	N/A	(See Fig. 5)	Unsatisfactory - vehicle rolled over
7-6	50	3	6.7:1	N/A	(See Fig. 5)	Satisfactory - no rollover
9-1	40	2	6.5:1	6.8:1	(See Fig. 12)	Satisfactory - no rollover
9-2	50	2	6.5:1	6.8:1	(See Fig. 12)	Satisfactory - no rollover

Metric Conversions: 1 mph = 1.609 km/h

V. WARRANTS FOR SAFETY TREATMENT OF PARALLEL DRAINAGE STRUCTURES

A benefit/cost (B/C) analysis was made to develop warrants for safety treatment of parallel drainage structures and adjoining roadside slopes. According to SDHPT policy, one of three options will normally be selected to install a driveway or median crossover.

I. Driveway or median crossover slope will be approximately 1-1/2 to 1 and the culvert end will have no safety treatment. This is considered the baseline or untreated condition.

II. Driveway or median crossover slope will be approximately 6 to 1 and the culvert end will be cut to match the 6 to 1 slope. There will be no safety grates on the culvert.

III. Option 3 is the same as 2 except the culvert end will have a safety grate treatment per the recommendations presented elsewhere in this report.

As per SDHPT recommendations, the analysis was conducted assuming (1) the roadway side slope was 6 to 1, (2) the roadway had a 12 ft (3.66 m) shoulder, and (3) the centerline of the driveway culvert was 25 ft (7.62 m) from the edge of the travelway. Four culvert sizes (diameters) were evaluated for each option; 18 in. (45.7 cm), 24 in. (61.0 cm), 36 in. (91.4 cm), and 48 in. (122 cm).

With the above three options and the assumed roadside geometry, an analysis was conducted to determine which option had the largest B/C ratio for a given set of conditions. A description of the B/C analysis procedure used is given in Chapter VII of reference 7 and in reference 8 and will not be repeated here. Input required to perform the analysis includes cost of treatment, accident or societal cost, traffic volume, hazard size and location, discount rate, and the severity index of the hazard being evaluated.

Four severity indices were required for each of the four culvert sizes. Reference should be made to Table VII-C-1 of reference 7 for an interpretation of severity index values. Listed in Table 3 are the severity indices used in the analysis. They were determined through the combined judgment of SDHPT and TTI engineers, taking into consideration the crash test reported elsewhere in this report. It was assumed that a 1-1/2 to 1 driveway slope was equal in severity to an untreated culvert end regardless of the culvert size. Also note it was assumed that the severity index of a safety grated culvert on a 6 to 1 slope was equal to the severity index of the 6 to 1 slope.

An incremental B/C analysis was performed to evaluate the three options. Listed in Table 4 are estimated costs to upgrade option I to option II and option II to option III, as provided by SDHPT. Accident or societal costs were obtained from reference 9. Incremental benefits were defined as the difference in societal costs of any two options and incremental costs were the difference in SDHPT direct costs of the two options.

Plotted in Figures 17 and 18 are the B/C versus traffic volume for upgrading option I to II and option II to III, respectively. The "kink" in the curves at an ADT of approximately 3000 is caused by the vehicle encroachment data used in the analysis procedure (see Figure VII-C-1 of reference 7). From Figure 17 it can be seen that option II when compared with option I has a B/C greater than one for all but the very low traffic volumes. For 36 in. (91.4 cm) diameter and smaller culverts the breakpoint occurs at an ADT of approximately 100. For the 48 in. (121.9 cm) diameter

TABLE 3. ASSUMED SEVERITY INDICES

CULVERT DIAMETER (in.)	DRIVEWAY SLOPE	SEVERITY INDEX DRIVEWAY SLOPE	UNTREATED CULVERT END	SLOPED CULVERT END WITH NO GRATES	SLOPED CULVERT END WITH GRATES
18	1-1/2 to 1	7.2	7.2	N/A	N/A
18	6 to 1	5.2	N/A	5.8	5.2
24	1-1/2 to 1	7.2	7.2	N/A	N/A
24	6 to 1	5.2	N/A	6.0	5.2
36	1-1/2 to 1	7.2	7.2	N/A	N/A
36	6 to 1	5.2	N/A	6.6	5.2
48	1-1/2 to 1	7.2	7.2	N/A	N/A
48	6 to 1	5.2	N/A	7.2	5.2

N/A - Not Applicable

TABLE 4. INCREMENTAL COST OF TREATMENTS

CULVERT DIAMETER (in.)	COST TO UPGRADE FROM OPTION I TO II ($)	COST TO UPGRADE FROM OPTION II TO III	
		CONSTRUCTION ($)	MAINTENANCE ($/YEAR)
18	375	225	150
24	378	300	150
36	475	600	150
48	835	900	150

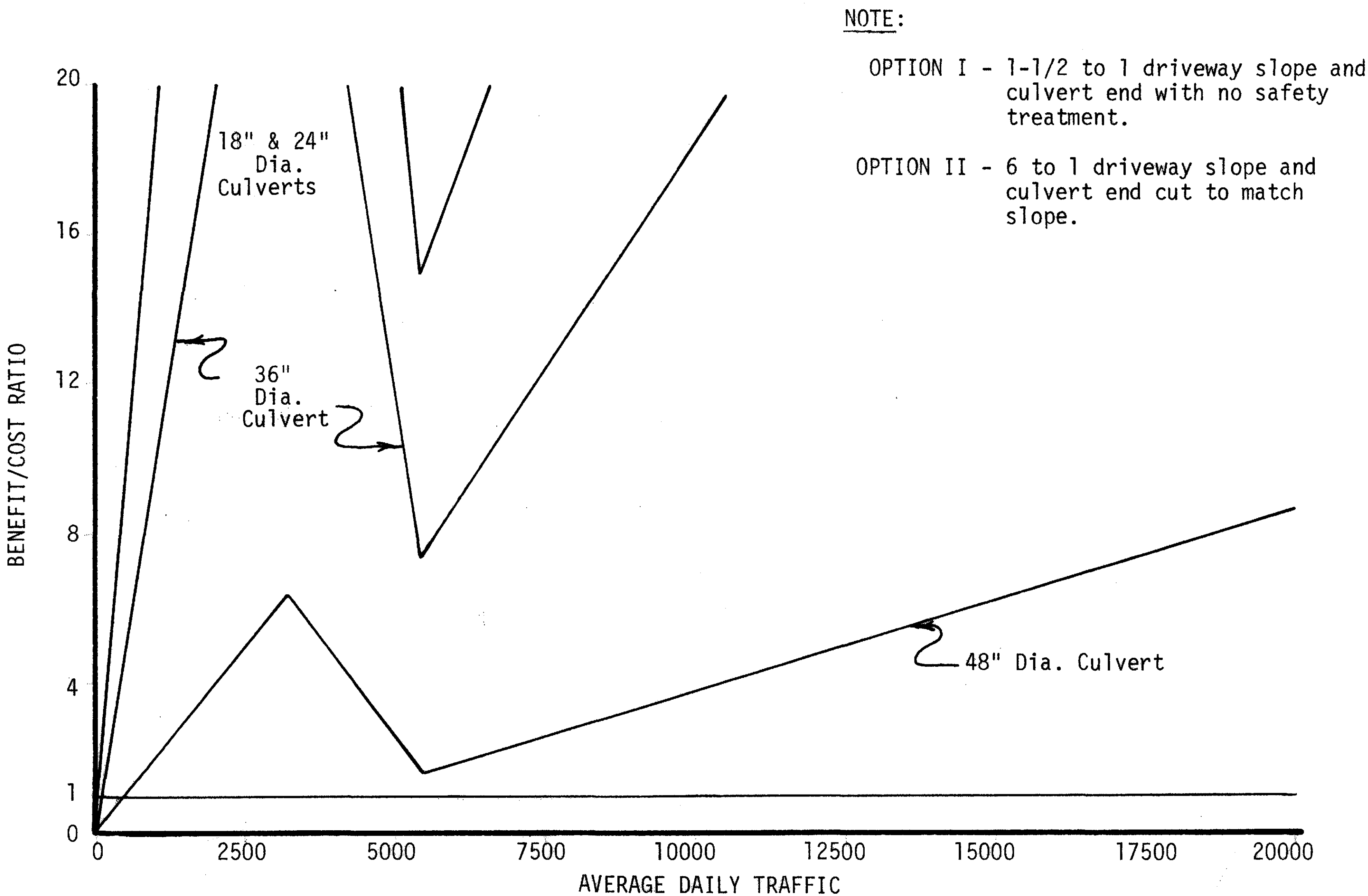


FIGURE 17. BENEFIT/COST RATIO TO UPGRADE FROM OPTION I TO OPTION II.

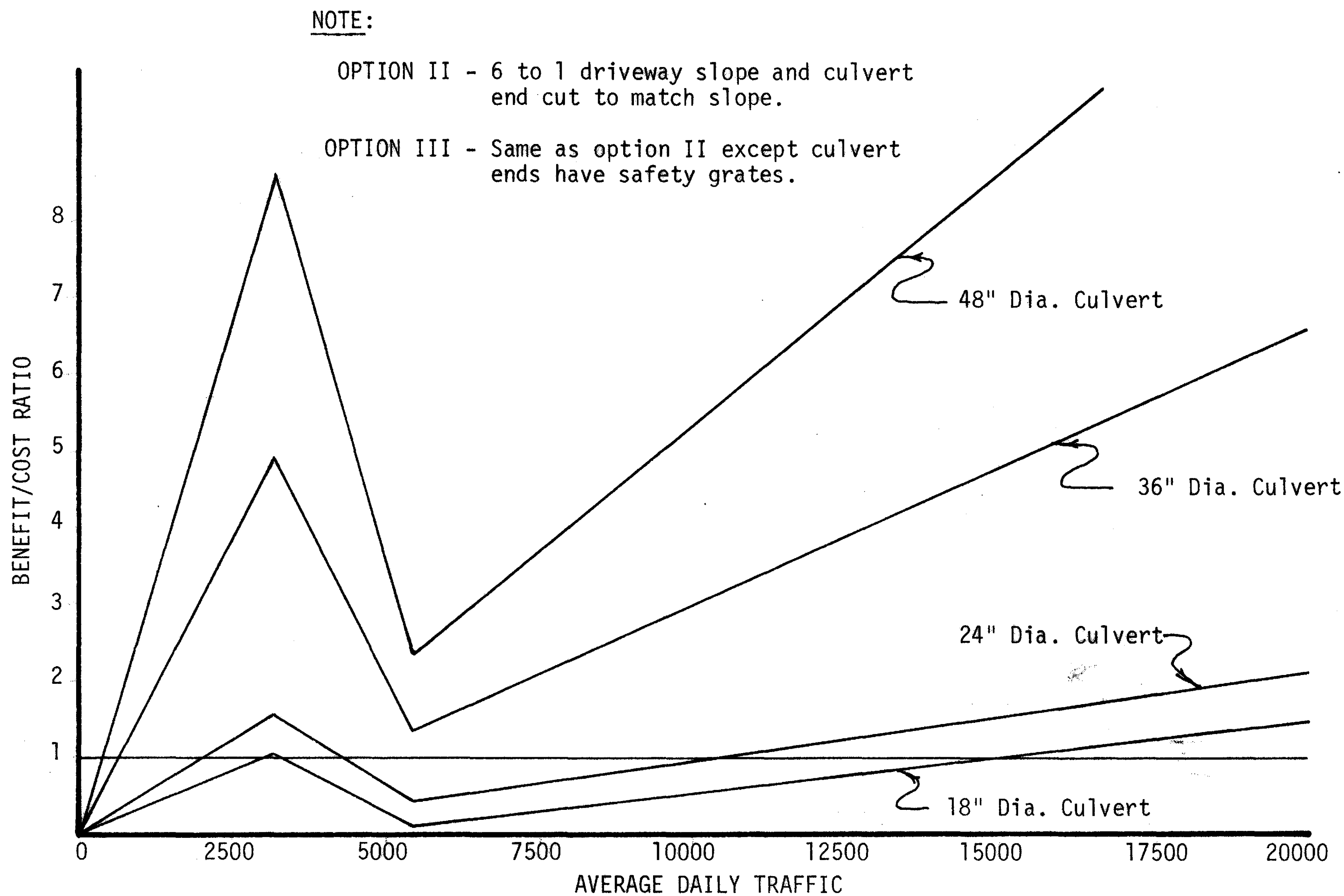


FIGURE 18. BENEFIT/COST RATIO TO UPGRADE FROM OPTION II TO OPTION III.

culvert the breakpoint occurs at an ADT near 500. Note that relatively large benefits can be gained in option II for the smaller culverts whereas relatively small increases in benefits are gained in option II for the larger culvert. This is due to two factors. First, the severity index of the larger culvert in option II was estimated to be the same as that in option I. Second, for large culverts the culvert hazard itself is a significant part of the overall driveway/culvert hazard envelope.

Figure 18 shows the incremental B/C ratio for upgrading from option II to III. These results indicate the addition of safety grates for 24 in. (61.0 cm) diameter or smaller culverts is probably not cost beneficial for ADT's of approximately 13,000 or less. However, safety grates appear warranted on culverts with diameters 36 in. (91.9 cm) or greater for an ADT above approximately 500.

Table 5 summarizes the findings of the B/C analysis.

Shown in Figure 19 is a set of warrants derived from Figures 17 and 18 for safety treatment of parallel drainage structures. Basically, these warrants indicate options that provide the greatest benefits consistent with the given constraints and inherent assumptions. Some tradeoffs were made in deriving these warrants in the interest of conciseness and simplicity.

Since the warrants of Figure 19 were based in part on judgment they should not be treated as absolutes. Discretion must be used in their application, especially when existing conditions and/or costs differ from those employed in the analysis.

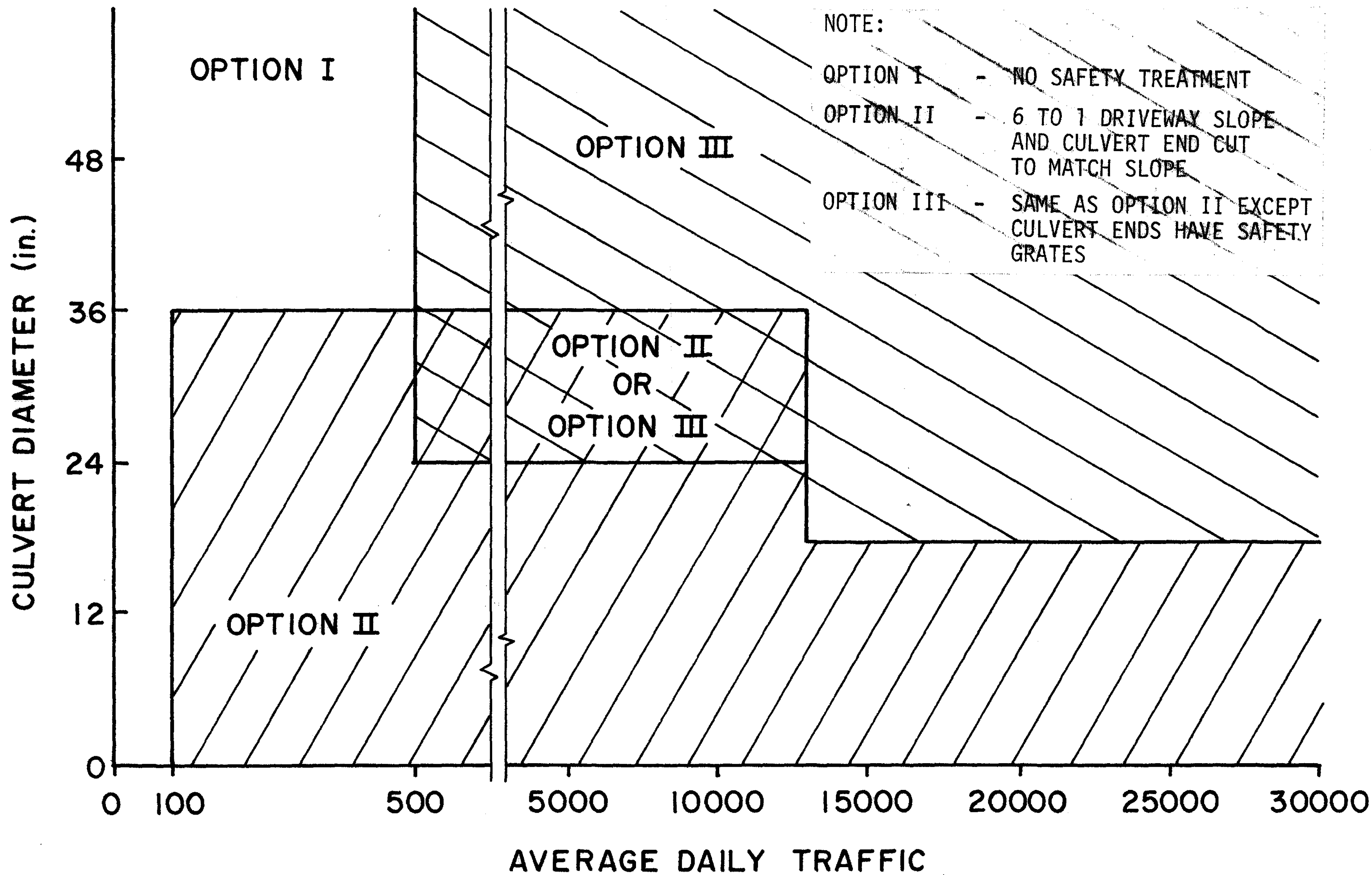


FIGURE 19. WARRANTS FOR SAFETY TREATMENT OF PARALLEL DRAINAGE CULVERTS

VI. CONCLUSIONS

There are no nationally recognized safety performance standards for roadside drainage structures. The following performance standard was therefore adopted for this study: "An errant automobile should be able to smoothly traverse a ditch-driveway-culvert configuration without rollover for speeds up through 50 mph (80.5 km/h)." To meet this standard it has been shown that the following conditions should be met:

1. The roadway sideslope (or ditch slope) should be 6 to 1 or flatter.
2. The driveway slope should be 6 to 1 or flatter.
3. The transition area between the roadway sideslope and the driveway slope should be rounded or smoothed as opposed to an abrupt transition.
4. Safety treatment of the culvert opening should include an end section cut to match the driveway slope with cross members (grates) spaced approximately every 2 ft (0.61 m) perpendicular to the direction of flow. The cross members should be designed to support a concentrated wheel load of approximtely 10,000 lb (44,480 N) applied at midspan.

Guidelines for use of safety treatments were developed through a benefit/cost analysis. Assumptions made in the analysis were: (1) the roadway side slope was 6 to 1, (2) the roadway had a 12 ft (3.66 m) shoulder, and (3) the centerline of the driveway culvert was 25 ft (7.62 m) from the edge of the travelway.

Three driveway/culvert options were evaluated:

I. Untreated condition (1-1/2 to 1 driveway slope and no culvert end treatment).

II. Driveway slope of 6 to 1 with culvert end cut to match slope with no safety grates.

III. Same as II but with safety grates on culvert.

Based on the benefit/cost analysis, guidelines were developed that identify conditions (traffic volume and culvert size) that warrant safety treatment of parallel drainage culverts on rural high-speed highways. These warrants are presented in Figure 19 of the report.

APPENDIX A. HVOSM PARAMETER STUDY

A. HVOSM PARAMETRIC STUDY

A series of computer simulations were conducted to gain insight regarding the hazard of ditch-driveway problems. Three encroachment parameters, four ditch-driveway parameters, and one automobile parameter were investigated with the Highway-Vehicle-Object-Simulation-Model (HVOSM) (3). The parameters and the ranges of each are given in Chapter III. A total of 68 sets or combinations of the eight parameters were evaluated, and the results are given in Tables A-1 and A-2.

Data for the two automobiles simulated are given in Tables A-3 and A-4. The subcompact car data were obtained from reference 5, and the full-size car data were obtained from reference 6.

TABLE A-1. HVOSM RESULTS, 3 FT DITCH.

	VEHICLE DATA				ROADSIDE DATA			SIMULATION RESULTS								
											VEHICLE ACCELERATIONS (G's)					
											PEAK			50 ms AVG.		
RUN NO.	WEIGHT (lb)	DEPARTURE SPEED (mph)	DEPARTURE ANGLE (deg)	PATH[a]	TYPE OF TRANSITION	DRIVEWAY SLOPE[a] ($a_d : b_d$)	SIDE SLOPE[a] ($a_s : b_s$)	MAX. ROLL ANGLE (deg)	MAX. PITCH ANGLE (deg)	DIST. VEHICLE AIRBORNE (ft)	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL
1	2250	40	15	1	Abrupt	4:1	4:1	17	22	62	7.3	2.9	16.5	4.9	2.0	6.8
2	2250	40	15	1	Curved	4:1	4:1	13	14	62	2.7	2.8	24.9	1.4	1.3	17
3	2250	40	15	2	N/A	4:1	4:1	2	14	72	0.5	2.3	32.0	0.3	1.4	20.5
4	2250	40	0	3	N/A	4:1	4:1	0	17	75	6.5	0	31.9	3.9	0	9.2
5	2250	40	15	1	Curved	4:1	5:1	27	24	66	1.7	4.6	20.7	0.7	2.8	13.4
6	2250	40	15	1	Abrupt	6:1	5:1	70	8	56	1.0	1.8	13.8	0.7	1.0	8.7
7	2250	40	15	1	Abrupt	6:1	6:1	17	12	64	2.9	3.2	14.8	1.7	1.9	9.7
8	2250	40	15	2	N/A	6:1	6:1	19	14	54	2.6	2.5	10.6	1.8	1.5	6.7
9	2250	50	15	1	Abrupt	4:1	4:1	360	14	94	3.6	1.7	28.2	3.0	1.2	20.1
10	2250	50	15	1	Curved	4:1	4:1	190	24	86	5.1	3.0	27.5	4.6	1.3	18.8
11	2250	50	15	2	N/A	4:1	4:1	30	28	110	9.6	8.1	24.4	6.3	4.9	9.9
12	2250	50	0	3	N/A	4:1	4:1	0	21	77	6.2	0	30.5	6.2	0	12.5
13	4500	50	15	1	Abrupt	4:1	4:1	52	22	70	2.2	11.9	7.8	1.7	8.8	4.3
14	4500	50	15	2	N/A	4:1	4:1	33	23	98	2.6	2.6	22.1	1.9	1.6	15.5
15	4500	50	0	3	N/A	4:1	4:1	0	22	98	6.7	0.1	27.0	3.7	0.1	21.4
16	2250	50	15	1	Curved	4:1	5:1	360	17	98	2.6	46.9	9.7	2.1	16.7	7.7
17	2250	50	15	2	N/A	4:1	5:1	360	32	110	9.6	76.6	11.6	2.9	20.4	5.9
18	2250	50	15	1	Abrupt	6:1	5:1	39	6	83	2.2	6.8	14.0	1.3	5.4	7.1
19	2250	50	15	2	N/A	6:1	5:1	27	14	85	4.4	6.9	18.2	2.9	4.0	6.9

[a]See Figure 1.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.609 km/h
1 ft = 0.305 m

TABLE A-1. HVOSM RESULTS, 3 FT DITCH. (continued)

	VEHICLE DATA				ROADSIDE DATA			SIMULATION RESULTS								
											VEHICLE ACCELERATIONS (G's)					
											PEAK			50 ms AVG.		
RUN NO.	WEIGHT (lb)	DEPARTURE SPEED (mph)	DEPARTURE ANGLE (deg)	PATH[a]	TYPE OF TRANSITION	DRIVEWAY SLOPE[a] ($a_d : b_d$)	SIDE SLOPE[a] ($a_s : b_s$)	MAX. ROLL ANGLE (deg)	MAX. PITCH ANGLE (deg)	DIST. VEHICLE AIRBORNE (ft)	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL
20	2250	50	15	1	Abrupt	6:1	6:1	194	14	95	5.4	11.2	4.5	3.9	6.4	1.5
21	2250	50	15	1	Curved	6:1	6:1	11	8	87	1.5	2.8	19.6	1.0	1.5	13.1
22	2250	50	15	2	N/A	6:1	6:1	37	14	85	4.3	7.1	21.2	2.7	3.3	9.5
23	2250	50	0	3	N/A	6:1	6:1	0	16	90	6.0	0	25.3	3.9	0	11.9
24	4500	50	15	1	Abrupt	6:1	6:1	54	13	76	2.5	12.1	7.1	2.0	9.39	5.4
25	4500	50	15	2	N/A	6:1	6:1	59	14	83	2.9	15.6	22.6	2.6	12.0	7.6
26	2250	60	15	2	N/A	4:1	4:1	206	22	123	6.4	16.2	10.3	6.4	11.6	3.6
27	2250	60	0	1	N/A	4:1	4:1	0	180	152	40.2	0	12.1	29.2	0	11.0
28	4500	60	15	1	Abrupt	4:1	4:1	187	8	103	2.3	24.5	11.9	2.3	16.9	9.0
29	4500	60	15	2	N/A	4:1	4:1	13	38	128	7.1	1.0	48.0	3.9	0.7	20.6
30	4500	60	0	3	N/A	4:1	4:1	0	21	143	4.0	0	54.0	2.0	0	28.9
31	2250	60	15	1	Abrupt	6:1	5:1	183	11	118	3.6	9.5	18.2	3.3	5.0	13.1
32	2250	60	15	2	N/A	6:1	5:1	209	17	123	7.2	12.6	2.9	5.4	8.7	0.7
33	2250	60	15	1	Abrupt	6:1	6:1	195	28	133	6.5	1.7	10.8	5.7	0.7	7.5
34	2250	60	15	1	Curved	6:1	6:1	47	11	121	5.0	11.0	17.7	3.4	6.9	6.4
35	2250	60	15	2	N/A	6:1	6:1	197	15	154	10.1	54.4	8.9	5.0	16.8	2.9
36	2250	60	0	3	N/A	6:1	6:1	0	26	130	14.0	0	24.6	7.6	0	10.6
37	4500	60	15	1	Abrupt	6:1	6:1	192	12	105	2.1	5.2	24.6	1.9	2.6	12.2
38	4500	60	15	2	N/A	6:1	6:1	188	14	115	3.5	31.7	16.0	2.8	19.2	7.7
39	4500	60	0	3	N/A	6:1	6:1	0	-22	124	10.2	0	28.9	7.1	0	12.3

[a]See Figure 1.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.609 km/h
1 ft = 0.305 m

TABLE A-2. HVOSM RESULTS, 2 FT DITCH.

	VEHICLE DATA				ROADSIDE DATA			SIMULATION RESULTS								
											VEHICLE ACCELERATIONS (G's)					
											PEAK			50 ms AVG.		
RUN NO.	WEIGHT (lb)	DEPARTURE SPEED (mph)	DEPARTURE ANGLE (deg)	PATH[a]	TYPE OF TRANSITION	DRIVEWAY SLOPE[a] ($a_d : b_d$)	SIDE SLOPE[a] ($a_s : b_s$)	MAX. ROLL ANGLE (deg)	MAX. PITCH ANGLE (deg)	DIST. VEHICLE AIRBORNE (ft)	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL
1	2250	30	15	1	Abrupt	6:1	6:1	14	16	33	2.6	2.0	4.4	1.6	1.2	2.4
2	2250	40	15	2	N/A	4:1	4:1	38	19	74	1.6	13.0	20.7	0.8	7.7	11.3
3	2250	40	0	3	N/A	4:1	4:1	0	18	77	4.6	0	26.9	4.6	0	13.4
4	2250	40	15	1	Curved	4:1	5:1	63	11	52	1.7	9.1	10.6	1.7	7.4	4.6
5	2250	40	15	2	N/A	4:1	5:1	32	12	75	0.7	8.7	18.0	0.5	5.8	8.1
6	2250	40	15	1	Curved	6:1	5:1	182	11	46	3.5	9.4	4.3	2.3	4.5	2.4
7	2250	40	15	1	Abrupt	6:1	6:1	181	12	47	3.7	8.4	1.9	3.3	6.2	1.6
8	2250	40	15	1	Curved	6:1	6:1	53	8	53	2.5	7.2	6.6	1.8	3.6	2.5
9	2250	40	15	2	N/A	6:1	6:1	29	14	58	2.7	3.9	11.0	1.8	1.8	6.5
10	4500	40	15	1	Abrupt	6:1	6:1	32	8	43	1.7	2.8	9.3	1.3	1.6	4.9
11	4500	40	15	2	N/A	6:1	6:1	37	7	56	2.0	4.2	9.6	1.6	2.8	3.2
12	2250	50	15	1	Curved	4:1	4:1	42	31	66	7.3	6.3	5.0	4.5	3.4	2.8
13	2250	50	15	2	N/A	4:1	4:1	185	15	109	5.4	3.4	32.9	4.4	2.1	19.3
14	2250	50	0	3	N/A	4:1	4:1	0	180	111	27.4	0	13.1	23.3	0	10.5
15	2250	50	15	1	Curved	4:1	5:1	118	150	70	8.8	8.0	4.1	8.0	7.2	2.8
16	2250	50	15	2	N/A	4:1	5:1	588	70	113	4.5	64.3	11.9	2.4	19.7	6.5
17	2250	50	15	1	Curved	6:1	5:1	230	49	61	6.0	7.2	2.7	5.0	5.3	1.7
18	2250	50	15	2	N/A	6:1	5:1	182	21	88	5.9	6.4	18.5	3.4	3.0	6.3
19	2250	50	15	1	Abrupt	6:1	6:1	223	52	81	9.6	2.1	5.9	6.6	2.0	3.6

[a]See Figure 1.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.609 km/h
1 ft = 0.305 m

TABLE A-2. HVOSM RESULTS, 2 FT DITCH. (continued)

	VEHICLE DATA				ROADSIDE DATA			SIMULATION RESULTS								
											VEHICLE ACCELERATIONS (G's)					
											PEAK			50 ms AVG.		
RUN NO.	WEIGHT (lb)	DEPARTURE SPEED (mph)	DEPARTURE ANGLE (deg)	PATH[a]	TYPE OF TRANSITION	DRIVEWAY SLOPE[a] ($a_d : b_d$)	SIDE SLOPE[a] ($a_s : b_s$)	MAX. ROLL ANGLE (deg)	MAX. PITCH ANGLE (deg)	DIST. VEHICLE AIRBORNE (ft)	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL
20	2250	50	15	1	Curved	6:1	6:1	40	25	71	5.5	5.4	5.0	3.6	2.6	2.7
21	2250	50	15	2	N/A	6:1	6:1	78	15	87	6.0	13.2	4.7	3.7	6.2	2.3
22	4500	50	15	1	Abrupt	6:1	6:1	42	12	56	2.6	4.5	5.6	2.0	3.4	3.1
23	4500	50	15	2	N/A	6:1	6:1	185	9	77	3.0	22.1	13.3	2.8	9.5	3.8
24	2250	60	15	1	Curved	4:1	4:1	240	60	93	11.7	4.3	6.6	8.8	3.1	4.9
25	2250	60	15	2	N/A	6:1	5:1	62	13	125	6.6	16.4	13.3	4.6	9.1	5.7
26	2250	60	15	1	Curved	6:1	6:1	29	35	75	6.3	5.4	13.8	3.5	3.4	4.3
27	2250	60	0	3	N/A	6:1	6:1	0	30	125	15.7	0	17.6	9.0	0	8.6
28	4500	60	15	1	Abrupt	6:1	6:1	68	21	73	3.3	5.6	2.8	3.3	5.6	2.7
29	4500	60	0	3	N/A	6:1	6:1	0	35	103	14.9	0	14.3	10.4	0	9.0

[a]See Figure 1.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.609 km/h
1 ft = 0.305 m

TABLE A-3. HVOSM INPUT, SMALL CAR.

```
                                        PROJECT  #2280--DRIVEWAY PARAMETRIC STUDY
                      DSN=V1540041        1972 VEGA-IS DEGREE APPROACH AT 40 MPH/NO TRANSITION

      INERTIAL DATA                    DIMENSIONS                                           SUSPENSION DATA

 MS   =  5.8310 LB.-SEC.**2/IN     A   = 43.8700 INCHES        KF     =  96.000 LB./IN.       LAMBDAF =   0.500
 MUF  =  0.4240        ..          B   = 53.1300   ..          KR     = 121.000 LB./IN.       LAMBDAR =   0.500
 MUR  =  0.5750        ..          TF  = 55.1000   ..          CF'    =  37.000 LBS.          OMEGAF  =   0.0     INCHES
                                   TR  = 54.1000   ..          CR'    =  58.000 LBS.          OMEGAR  =   0.0     INCHES
 IX   =  2000.0 LB.-SEC.**2-IN     ZF  =  8.5800   ..        EPSILONF=    0.001 IN./SEC.      TS      =  38.000 INCHES
 IY   = 12000.0        ..          ZR  =  7.2100   ..        EPSILONR=    0.001 IN./SEC.      RR      = 11690.0 LB-IN/RAD
 IZ   = 15600.0        ..          RHO =  1.3100   ..          CF     =   2.000 LB-SEC/IN     RF      =     0.0 LB-IN/RAD
 IXZ  =-100.000        ..          RW  = 11.8300   ..          CR     =   2.000 LB-SEC/IN     KRS     =  -0.010 ROLL STEER COEFF.
 IR   =  250.00        ..
 G    = 386.400 IN/SEC.**2                                    AKFC   = 300.000 LB/IN          AKRC    = 300.000 LB/IN
                                                              AKFCP  =   2.000 LB/IN3         AKRCP   =   2.000 LB/IN3
                                                              OMEGFC =  -2.200 IN             OMEGRC  =  -2.200 IN
                                                              AKFE   = 300.000 LB/IN          AKRE    = 300.000 LB/IN
                                                              AKFEP  =   2.000 LB/IN3         AKREP   =   2.000 LB/IN3
                                                              OMEGFE =   3.840 IN             OMEGRE  =   4.850 IN

                                      INITIAL CONDITIONS                                             ACCELEROMETER POSITIONS

 PHIO   =   0.0   DEGREES   XCO'  =4360.000INCHES  PO       =  0.0   DEG/SEC  UO          = 705.600 IN/SEC     X1  =  0.0  INCHES
 THETAO=    0.0     ..      YCO'  = 880.000  ..    QO       =  0.0     ..     VO          =   0.0     ..       Y1  =  0.0    ..
 PSIO   =  15.000   ..      ZCO'  = -19.700  ..    RO       =  0.0     ..     WO          =   0.0     ..       Z1  =  0.0    ..
 PHIRO  =   0.0     ..      DELTA1=   0.0    ..    D(PHIR)/DT= 0.0     ..     D(DEL1)/DT= =   0.0     ..       X2  =  0.0    ..
 PSIF1O=    0.0     ..      DELTA2=   0.0    ..    D(PSIF)/DT= 0.0   RAD/SC   D(DEL2)/DT= =   0.0     ..       Y2  =  0.0    ..
                            DELTA3=   0.0    ..                               D(DEL3)/DT= =   0.0     ..       Z2  =  0.0    ..

                                                  DRIVER CONTROL TABLES

     T      PSIF     TQF     TQR      T      PSIF     TQF     TQR      T      PSIF     TQF     TQR      T      PSIF     TQF     TQR
    SEC     DEG     LB/FT   LB/FT    SEC     DEG     LB/FT   LB/FT    SEC     DEG     LB/FT   LB/FT    SEC     DEG     LB/FT   LB/FT

    0.0     0.0      0.0     0.0

       TIRE DATA              TERRAIN TABLE ARGUMENTS                 PROGRAM CONTROL DATA

 KT          1240.000 LB/IN                                  START TIME              =   0.0    SEC
 SIGMAT  =      6.000                                        END TIME                =   5.000
 LAMBDAT =     10.000                                        INCR FOR INTEGRATION    =   0.0050  ..
 AO      =   3625.000      SOIL DAMPING= 0.001 SPI           PRINT INTERVAL          =   0.010   ..
 A1      =      7.711      SOIL FRICT. = 0.250               THETA MAX (TO SWITCH)=     70.000 DEG
 A2      =   2344.000      SSTIFF    =    4000. LB/IN        UVWMIN(STOP)            =   0.0
 A3      =      1.550      NO.X TEMPS. =  6                  PQRMIN(STOP)            =   0.0
 A4      =   5500.000      NO.Y TEMPS. =  7                  INDCRB                  =  -1   (=0.NO CURB.=1 CURB.=-1 STEER DEG.OF FREEDOM)
 AMU     =      0.500      NO. VAR AMU =  0                  MODE OF INTEGRATION     =   1   (=0 VAR.ADAMS-MOULT..=1 RUNGE-KUTTA.=2FIX.AM)
 OMEGT   =      0.750      TABLES                            DTCMP1                  =   1.  (=1.0 SUPPLY INITIAL POSITION)
                                                                                             (=0.0 CAR RESTS ON TERRAIN)

 COEFF. OF TIRE FRICTION
          VS.
 (SPEED AND  LOAD) DATA
 ALPHA= 0.0          1/(LB-MPH)
```

TABLE A-3. HVOSM INPUT, SMALL CAR. (continued)

```
XKVTH= 0.0          1/ MPH
XKL=   0.0          1/LB

    VEHICLE MONITOR POINTS

                 X         Y         Z
               (IN.)     (IN.)     (IN.)

POINT 1    79.100    32.700     4.800
POINT 2    79.100   -32.700     4.800
POINT 3   -96.300    32.700     6.500
POINT 4   -96.300   -32.700     6.500
```

TABLE A-3. HVOSM INPUT, SMALL CAR. (continued)

DSN=V1540041

PROJECT #2280--DRIVEWAY PARAMETRIC STUDY
1972 VEGA-15 DEGREE APPROACH AT 40 MPH/NO TRANSITION

FRONT WHEEL CAMBER
VS
SUSPENSION DEFLECTION

DELTAF INCHES	PHIC DEGREES
-4.000	-4.750
-3.000	-3.080
-2.000	-1.750
-1.000	-0.730
0.0	0.0
1.000	0.480
2.000	0.650
3.000	0.780
4.000	0.830

CURB IMPACT DATA

YC1'	=	0.0	INCHES
YC2'	=	0.0	"
ZC2'	=	0.0	"
DELTC	=	0.0	SEC(INTEG.INCR.)
PHIC1	=	0.0	DEGREES
PHIC2	=	0.0	"
MUC	=	0.0	
IPSI	=	300.000	LB-SEC**2-IN
CPSI'	=	1000.000	LB-IN
OMEGA PSI	=	0.614	RAD
KPSI	=	********	LB-IN/RAD
EPSILON PSI	=	0.010	RAD/SEC
TRAIL,FRONT(PI)	=	1.500	INCHES

BARRIER DIMENSIONS

(YB')0	=	0.0	INCHES
DELYB'	=	0.0	"
ZBT'	=	0.0	"
ZBB'	=	0.0	"

VEHICLE DIMENSIONS

XVF	=	0.0	INCHES
XVR	=	0.0	"
YV	=	0.0	"
ZVT	=	0.0	"
ZVB	=	0.0	"

INDB = 0 (=1 RIGID BARRIER, FINITE VERT. DIM.)
=2 " " INFINITE " ")
=3 DEFORM.BARRIER,FINITE " ")
=4 " " INFINITE " ")

SPRUNG MASS-BARRIER IMPACT DATA

KV	=	0.0	LB/IN**3
SET	=	0.0	DEFL.RATIO
CONS	=	0.0	ENERGY RATIO
MUB	=	0.0	
EPSILON V	=	0.0	IN/SEC
EPSILON B	=	0.0	LB
DELTB	=	0.0	SEC (INTEG.INCR)

BARRIER LOAD DEFLECT.

SIGMAR 0	=	0.0
SIGMAR 1	=	0.0
SIGMAR 2	=	0.0
SIGMAR 3	=	0.0
SIGMAR 4	=	0.0
SIGMAR 5	=	0.0
SIGMAR 6	=	0.0
SIGMAR 7	=	0.0
SIGMAR 8	=	0.0
SIGMAR 9	=	0.0
SIGMAR 10	=	0.0

STRUCTURAL HARDPOINTS RELATIVE TO C. G.

	X	Y (INCHES)	Z	STIFFNESS LB/IN
POINT 1	0.0	0.0	0.0	0.0
POINT 2	0.0	0.0	0.0	0.0
POINT 3	0.0	0.0	0.0	0.0

TABLE A-4. HVOSM INPUT, LARGE CAR.

PROJECT #2280--DRIVEWAY PARAMETRIC STUDY

DSN=F1550961 FULL-SIZED VEHICLE--15 DEGREE APPROACH AT 50 MPH--NO TR

INERTIAL DATA

MS = 8.8510 LB.-SEC.**2/IN
MUF = 0.5694 ''
MUR = 0.9317 ''
IX = 4560.0 LB.-SEC.**2-IN
IY = 30000.0 ''
IZ = 33000.0 ''
IXZ =-150.000 ''
IR = 625.00 ''
G = 386.400 IN/SEC.**2

DIMENSIONS

A = 54.0000 INCHES
B = 66.0000 ''
TF = 62.0000 ''
TR = 60.7000 ''
ZF = 10.2240 ''
ZR = 11.7750 ''
RHO = -1.6300 ''
RW = 13.4600 ''

KF = 105.000 LB./IN.
KR = 120.000 LB./IN.
CF' = 40.000 LBS.
CR' = 55.000 LBS.
EPSILONF= 0.300 IN./SEC.
EPSILONR= 0.300 IN./SEC.
CF = 1.500 LB-SEC/IN
CR = 2.000 LB-SEC/IN

AKFC = 300.000 LB/IN
AKFCP = 2.000 LB/IN3
OMEGFC= -3.000 IN
AKFE = 300.000 LB/IN
AKFEP = 2.000 LB/IN3
OMEGFE= 4.000 IN

SUSPENSION DATA

LAMBDAF = 0.500
LAMBDAR = 0.500
OMEGAF = 0.0 INCHES
OMEGAR = 0.0 INCHES
TS = 47.000 INCHES
RR = 40000.0 LB-IN/RAD
RF =107000.0 LB-IN/RAD
KRS = 0.030 ROLL STEER COEFF.

AKRC = 300.000 LB/IN
AKRCP = 2.000 LB/IN3
OMEGRC = -3.500 IN
AKRE = 300.000 LB/IN
AKREP = 2.000 LB/IN3
OMEGRE = 4.500 IN

INITIAL CONDITIONS

PHI0 = 0.0 DEGREES
THETA0= 0.0 ''
PSI0 = 15.000 ''
PHIR0 = 0.0 ''
PSIF10= 0.0 ''

XC0' =4360.000INCHES
YC0' = 880.000 ''
ZC0' = -22.400 ''
DELTA1= 0.0 ''
DELTA2= 0.0 ''
DELTA3= 0.0 ''

P0 = 0.0 DEG/SEC
Q0 = 0.0 ''
R0 = 0.0 ''
D(PHIR)/DT= 0.0 ''
D(PSIF)/DT= 0.0 RAD/SC

U0 = 882.000 IN/SEC
V0 = 0.0 ''
W0 = 0.0 ''
D(DEL1)/DT= 0.0 ''
D(DEL2)/DT= 0.0 ''
D(DEL3)/DT= 0.0 ''

ACCELEROMETER POSITIONS

X1 = 0.0 INCHES
Y1 = 0.0 ''
Z1 = 0.0 ''
X2 = 0.0 ''
Y2 = 0.0 ''
Z2 = 0.0 ''

DRIVER CONTROL TABLES

T SEC	PSIF DEG	TQF LB/FT	TQR LB/FT	T SEC	PSIF DEG	TQF LB/FT	TQR LB/FT	T SEC	PSIF DEG	TQF LB/FT	TQR LB/FT	T SEC	PSIF DEG	TQF LB/FT	TQR LB/FT
0.0	0.0	0.0	0.0												

TIRE DATA

KT 1300.000 LB/IN
SIGMAT = 6.000
LAMBDAT = 10.000
A0 =4000.000
A1 = 8.400
A2 =3000.000
A3 = 1.710
A4 =4200.000
AMU = 0.550
OMEGT = 0.750

TERRAIN TABLE ARGUMENTS

SOIL DAMPING= 0.001 SPI
SOIL FRICT. = 0.250
SSTIFF = 4000. LB/IN
NO.X TEMPS. = 6
NO.Y TEMPS. = 7
NO. VAR AMU = 0
TABLES

PROGRAM CONTROL DATA

START TIME = 0.0 SEC
END TIME = 4.000
INCR FOR INTEGRATION = 0.0050 ''
PRINT INTERVAL = 0.010 ''
THETA MAX (TO SWITCH)= 70.000 DEG
UVWMIN(STOP) = 0.0
PQRMIN(STOP) = 0.0
INDCRB = -1 (=0.NO CURB.=1 CURB.=-1 STEER DEG.OF FREEDOM)
MODE OF INTEGRATION = 1 (=0 VAR.ADAMS-MOULT..=1 RUNGE-KUTTA.=2FIX.AM)
DTCMP1 = 1. (=1.0 SUPPLY INITIAL POSITION)
(=0.0 CAR RESTS ON TERRAIN)

COEFF. OF TIRE FRICTION
VS.
(SPEED AND LOAD) DATA
ALPHA= 0.0 1/(LB-MPH)

TABLE A-4. HVOSM INPUT, LARGE CAR. (continued)

```
XKVTH= 0.0          1/ MPH
XKL=   0.0          1/LB

      VEHICLE MONITOR POINTS

              X         Y         Z
            (IN.)     (IN.)     (IN.)

POINT 1   87.000    39.500    10.000
POINT 2   87.000   -39.500    10.000
POINT 3-121.000    39.500     9.500
POINT 4-121.000   -39.500     9.500
```

TABLE A-4. HVOSM INPUT, LARGE CAR. (continued)

```
                                             PROJECT #2280--DRIVEWAY PARAMETRIC STUDY
                            DSN=F1550961   FULL-SIZED VEHICLE--15 DEGREE APPROACH AT 50 MPH--NO TR

     FRONT WHEEL CAMBER
             VS
    SUSPENSION DEFLECTION

      DELTAF    PHIC
      INCHES    DEGREES

      -5.000    -5.700
      -4.000    -3.900
      -3.000    -2.450
      -2.000    -1.300
      -1.000    -0.400
       0.0       0.300
       1.000     0.600
       2.000     0.650
       3.000     0.300
       4.000    -0.400
       5.000    -1.300

     CURB IMPACT DATA                                                      SPRUNG MASS-BARRIER IMPACT DATA
                                               BARRIER DIMENSIONS                                                               BARRIER LOAD DEFLECT.
 YC1'           =    0.0    INCHES          (YB')0 =    0.0    INCHES       KV          =    0.0    LB/IN**3          SIGMAR 0 =    0.0
 YC2'           =    0.0      ''            DELYB' =    0.0      ''         SET         =    0.0    DEFL.RATIO        SIGMAR 1 =    0.0
 ZC2'           =    0.0      ''            ZBT'   =    0.0      ''         CONS        =    0.0    ENERGY RATIO      SIGMAR 2 =    0.0
 DELTC          =    0.0     SEC(INTEG.INCR.)  ZBB'   =    0.0      ''         MUB         =    0.0                      SIGMAR 3 =    0.0
 PHIC1          =    0.0    DEGREES           VEHICLE DIMENSIONS            EPSILON V=       0.0    IN/SEC            SIGMAR 4 =    0.0
 PHIC2          =    0.0      ''            XVF    =    0.0    INCHES       EPSILON B=       0.0    LB                SIGMAR 5 =    0.0
 MUC            =    0.0                    XVR    =    0.0      ''         DELTB       =    0.0     SEC              SIGMAR 6 =    0.0
                                            YV     =    0.0      ''                                 (INTEG.INCR)      SIGMAR 7 =    0.0
 IPSI           = 300.000 LB-SEC**2-IN      ZVT    =    0.0      ''                                                   SIGMAR 8 =    0.0
 CPSI'          =1000.000 LB-IN             ZVB    =    0.0      ''                                                   SIGMAR 9 =    0.0
 OMEGA PSI      =   0.523 RAD               INDB =  0 (=1 RIGID BARRIER, FINITE VERT. DIM.)                           SIGMAR10 =    0.0
 KPSI           =******** LB-IN/RAD                   =2   ''       ''     INFINITE   ''    ''  )
 EPSILON PSI    =   0.010 RAD/SEC                     =3 DEFORM.BARRIER,FINITE   ''    ''  )
 TRAIL.FRONT(PT)=   1.500 INCHES                      =4   ''       ''     INFINITE   ''    ''  )
                                                                     STRUCTURAL HARDPOINTS RELATIVE TO C. G.
                                                                                    X          Y          Z     STIFFNESS
                                                                                           (INCHES)                LB/IN
                                                                     POINT    1    0.0        0.0        0.0         0.0
                                                                     POINT    2    0.0        0.0        0.0         0.0
                                                                     POINT    3    0.0        0.0        0.0         0.0
```

APPENDIX B. FULL-SCALE TESTS

B-1. Introduction

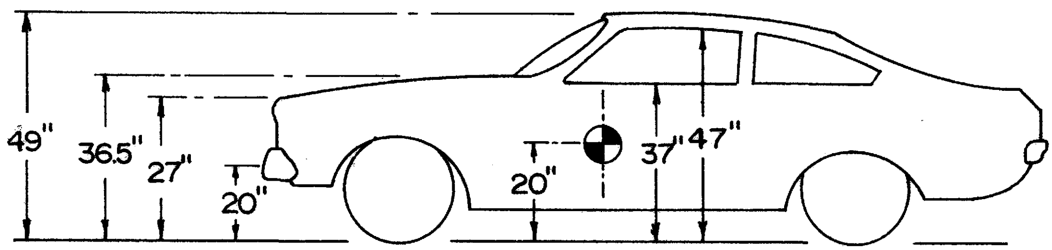
This section provides details of 12 crash tests conducted during this study. For convenience, the tests are divided into three groups, namely, slope tests, culvert tests, and prototype tests. The slope tests were conducted to determine an acceptable slope for a driveway or ditch crossing. The culvert tests were conducted to determine what, if any, safety treatment was needed for the end of the culvert. The prototype tests were conducted on a typical ditch-driveway installation to determine if the final design was acceptable.

Data collection and data reduction procedures for all tests were in accordance with recognized guidelines (4). Test results consist of data derived from the accelerometer readings, photos of the impact phase, and photos of damage to the test vehicles and installations. Four plots are presented for each test. These plots are the longitudinal, transverse, and vertical accelerations versus time, and the roll angle versus time. The accelerometers were placed at the approximate center of gravity of the test vehicles.

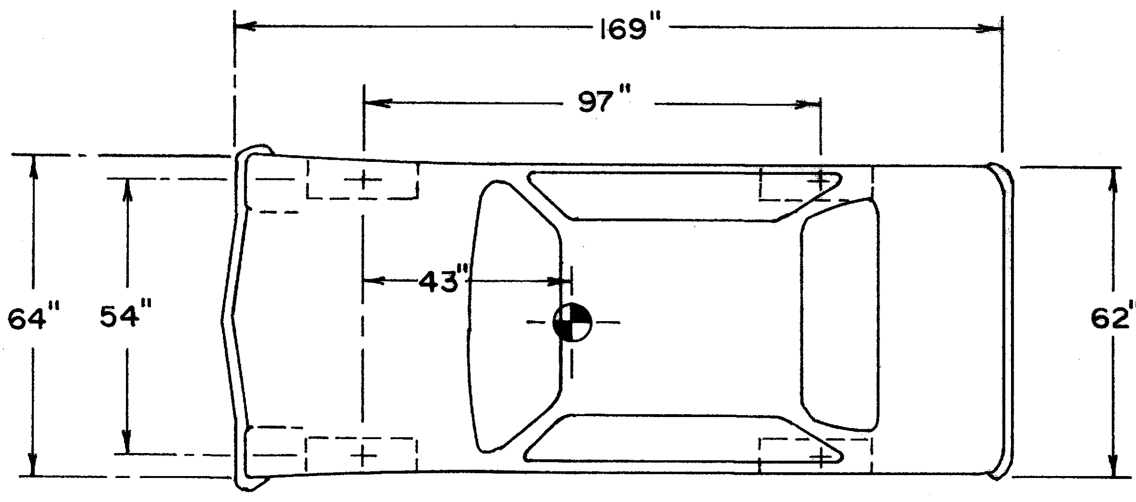
B-2. Test Vehicles

Test vehicles consisted of 1974-75 Chevrolet Vegas weighing approximately 2250 lb (1022 kg). Figure B-1 shows dimensions of a typical 1974-75 Vega. Design differences between the Vegas tested were very minor.

Before-test and after-test photos of the vehicle are presented in subsequent sections of the Appendix. In some cases the same vehicle was used in two or more tests. This was done only if the previous test caused minor damage to the vehicle.



ELEVATION



PLAN

Figure B-1. Dimensions of Test Vehicle.

B-3. Slope Tests

Following is a description of the tests conducted to evaluate the hazard of driveway slope. A summary of the results of these tests is shown in Table B-1. As shown in this table the steepest slope that can be safely traversed by an errant vehicle at 50 mph (80.5 km/h) is 6 to 1. A discussion of these results and the conclusions drawn therefrom can be found in Section IV-1.

The first four tests were conducted on the earth berm shown in Figures 2 and 3. The final test in this series was conducted on the earth berm illustrated in Figure 5. The impact point for all tests was the center of the berm, and the vehicle path was perpendicular to the face of the berm.

B-3-1. Test No. 1-1

Figure B-2 shows the test vehicle prior to impact with the 4 to 1 slope. The test speed was 30 mph (48.3 km/h). Figures B-3 and B-4 contain sequential photos taken during impact. As shown, the vehicle was launched a short distance and came down on the back of the earth berm. Vehicle damage was minor.

Figures B-5, B-6, and B-7 contain longitudinal, transverse, and vertical acceleration versus time plots. Figure B-8 shows the roll angle versus time.

TABLE B-1. SUMMARY OF SLOPE TEST RESULTS

TEST NO.	TEST SPEED (mph)	SLOPE	DISTANCE VEHICLE AIRBORNE (ft)	VEHICLE DAMAGE CLASSIFICATION TAD	SAE	PEAK 50 MS AVG. ACCELERATION (g's)	DID VEHICLE PITCH OVER?
1-1	30	4:1	18.5	No noticeable damage		6.4	No
1-2	35	4:1	43	RFQ-2	12FREW2	9.9	No
1-3	40	4:1	53	RFQ-3	12FREW3	11.3	No
1-4	50	4:1	106	R&T-6	12FRAW8	17.2	Yes
5-1	50	6:1	75.5	FO-1	12FDLW1	13.4	No

Metric Conversions:

1 mph = 1.609 km/h
1 ft = 0.305 m

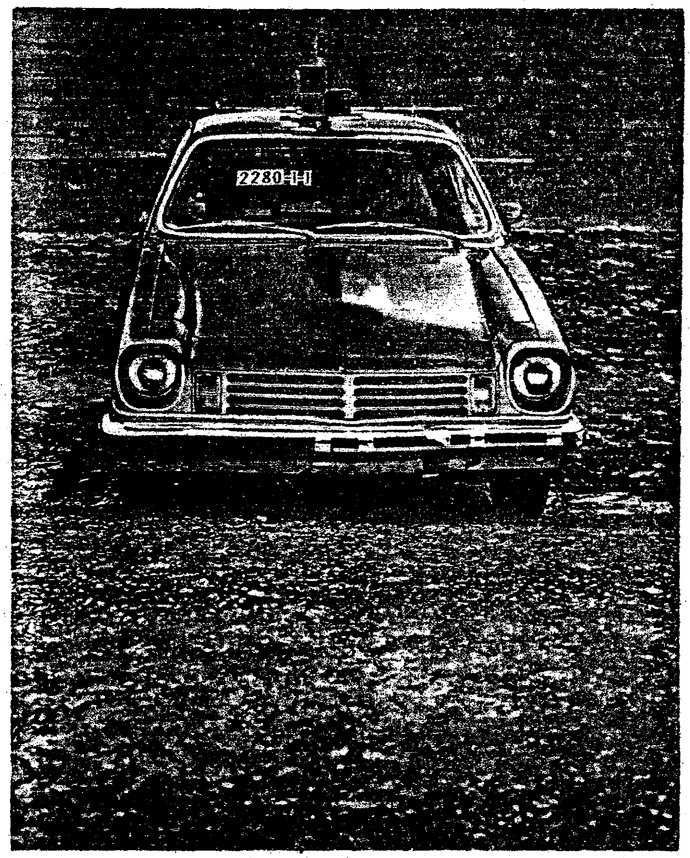
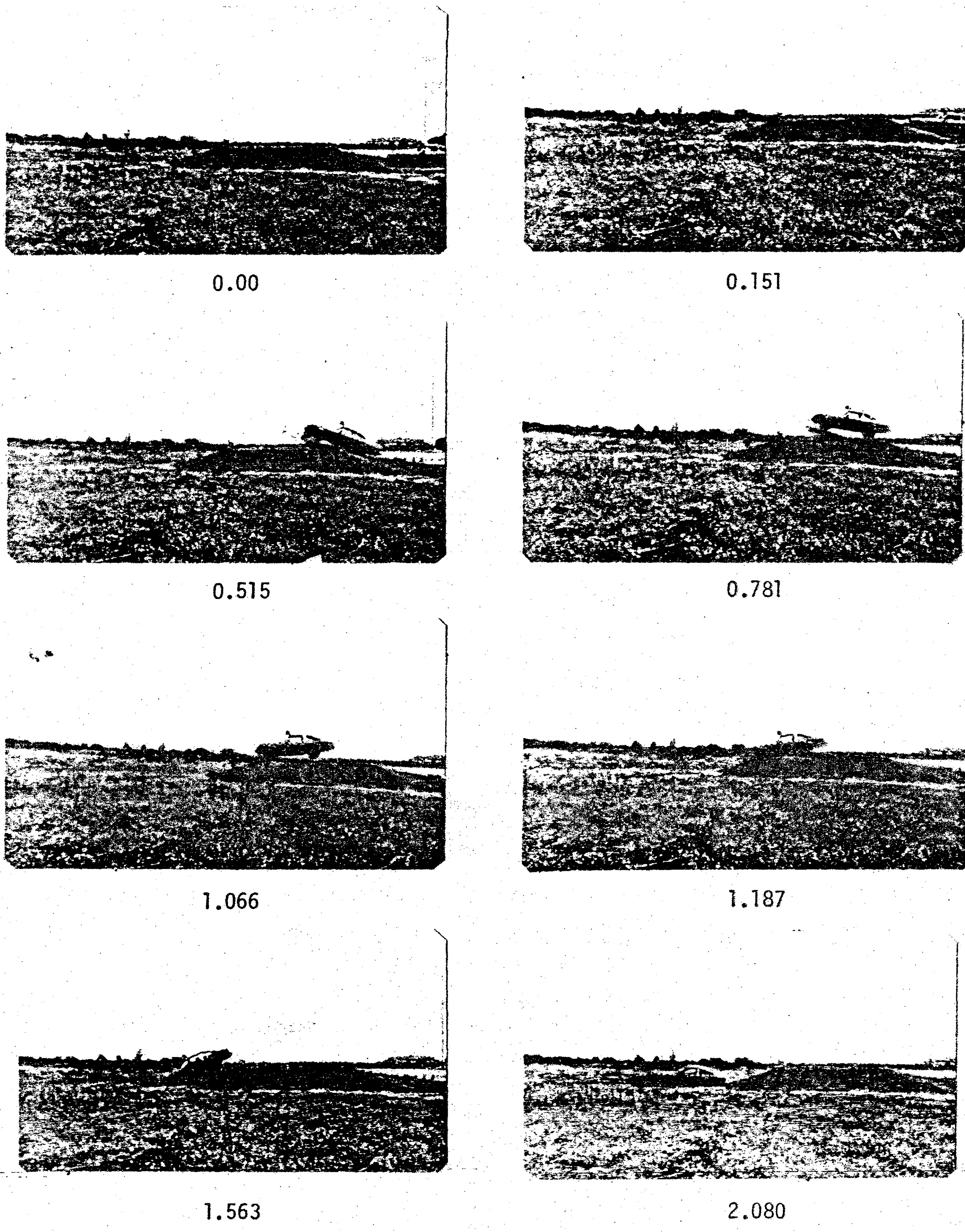


Figure B-2. Test Vehicle Before Test 1-1



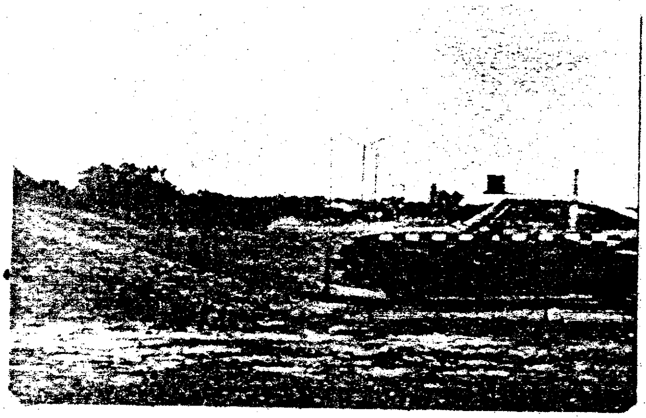
0.00 0.151

0.515 0.781

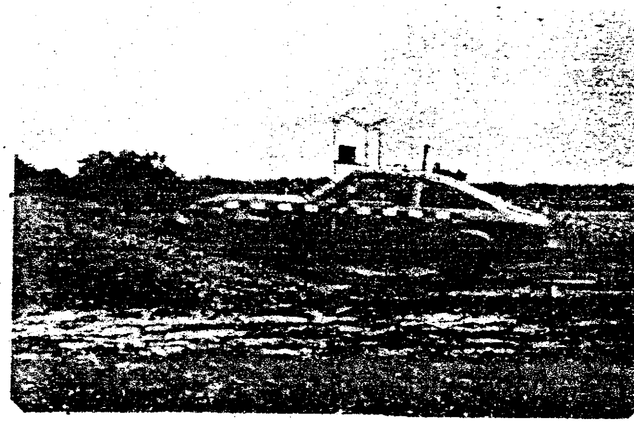
1.066 1.187

1.563 2.080

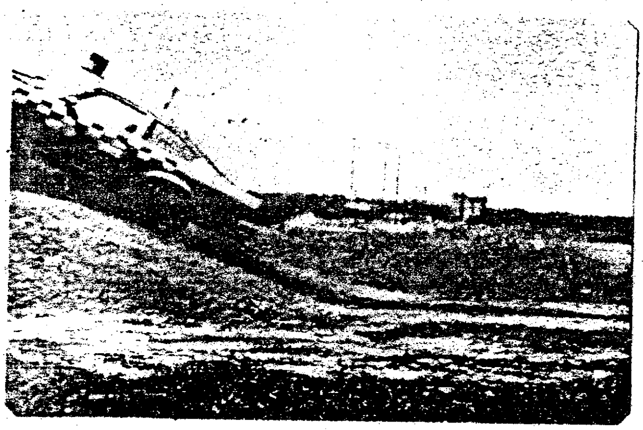
Figure B-3. Sequential Photos, Test 1-1.



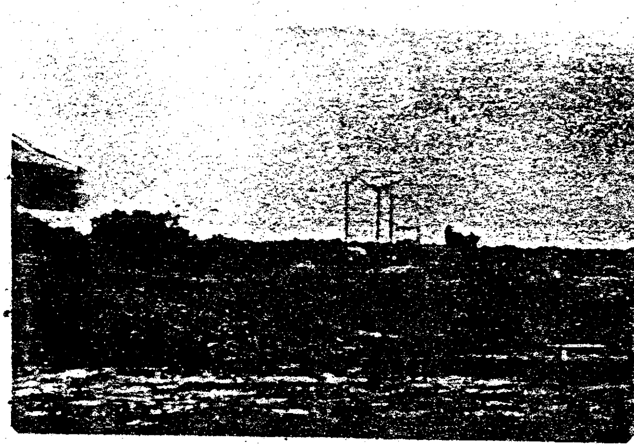
0.00



0.151



0.515



0.781

Figure B-4. Sequential Photos, Test 1-1.

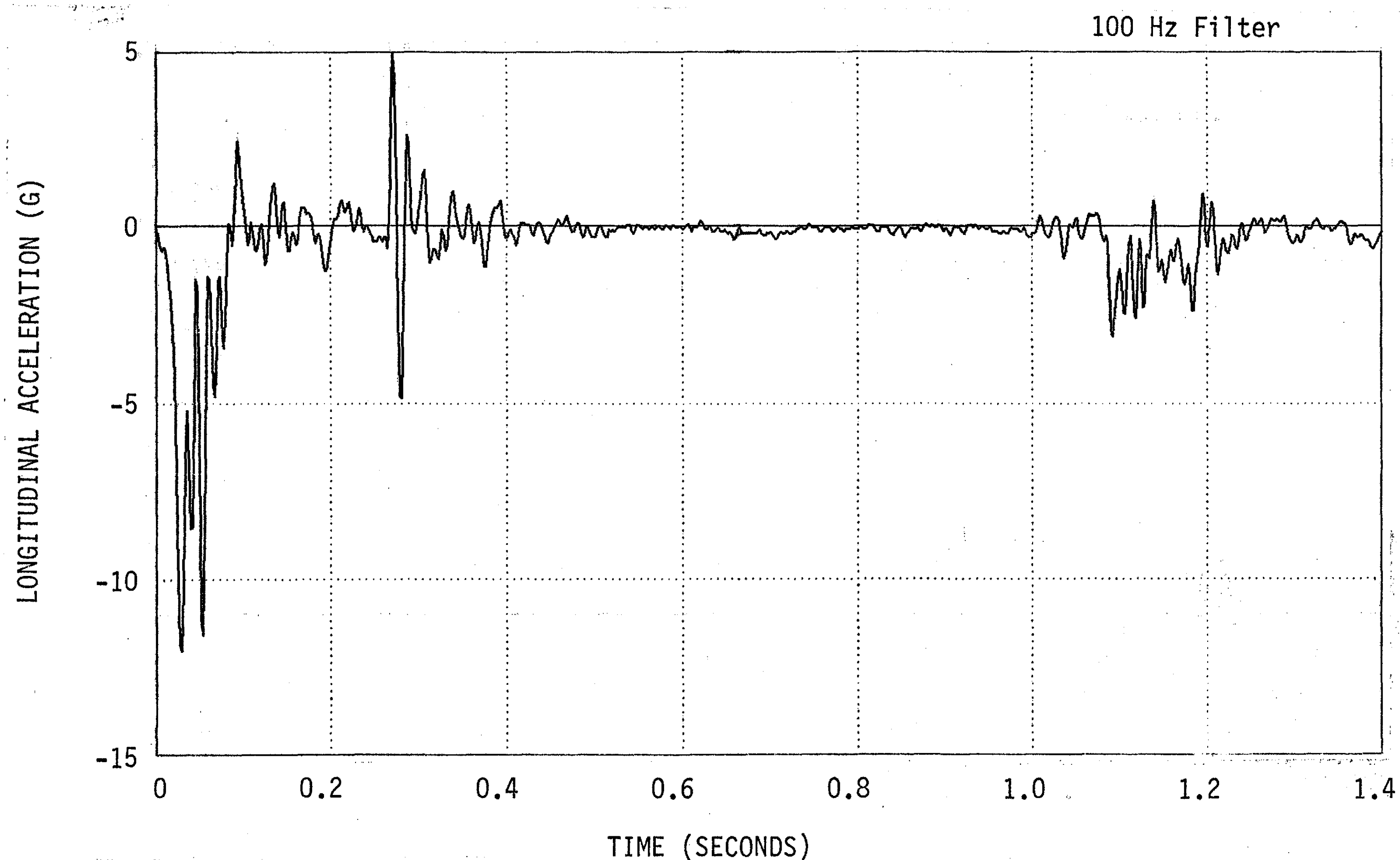


Figure B-5. Vehicle Longitudinal Acceleration, Test 1-1.

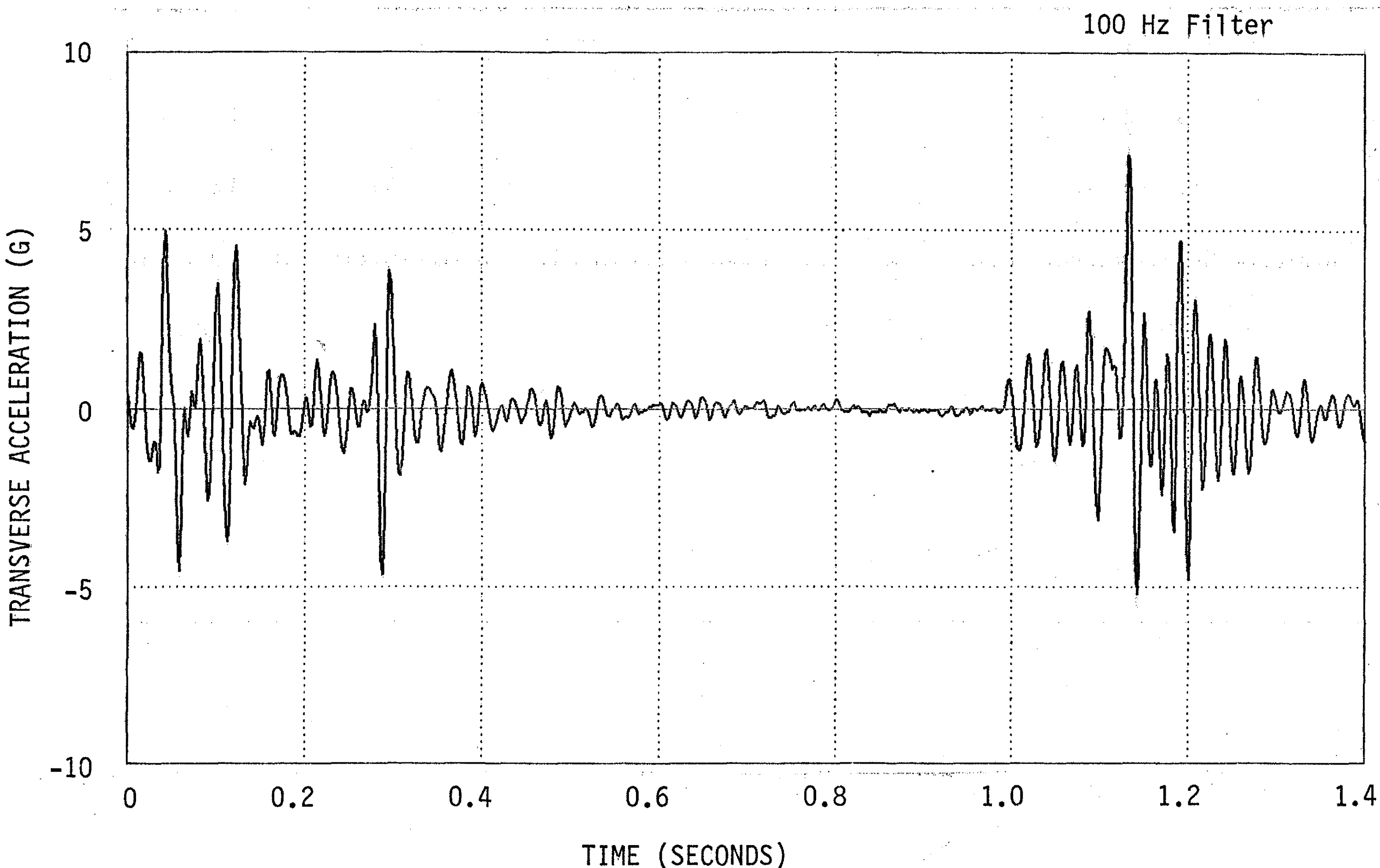


Figure B-6. Vehicle Transverse Acceleration, Test 1-1.

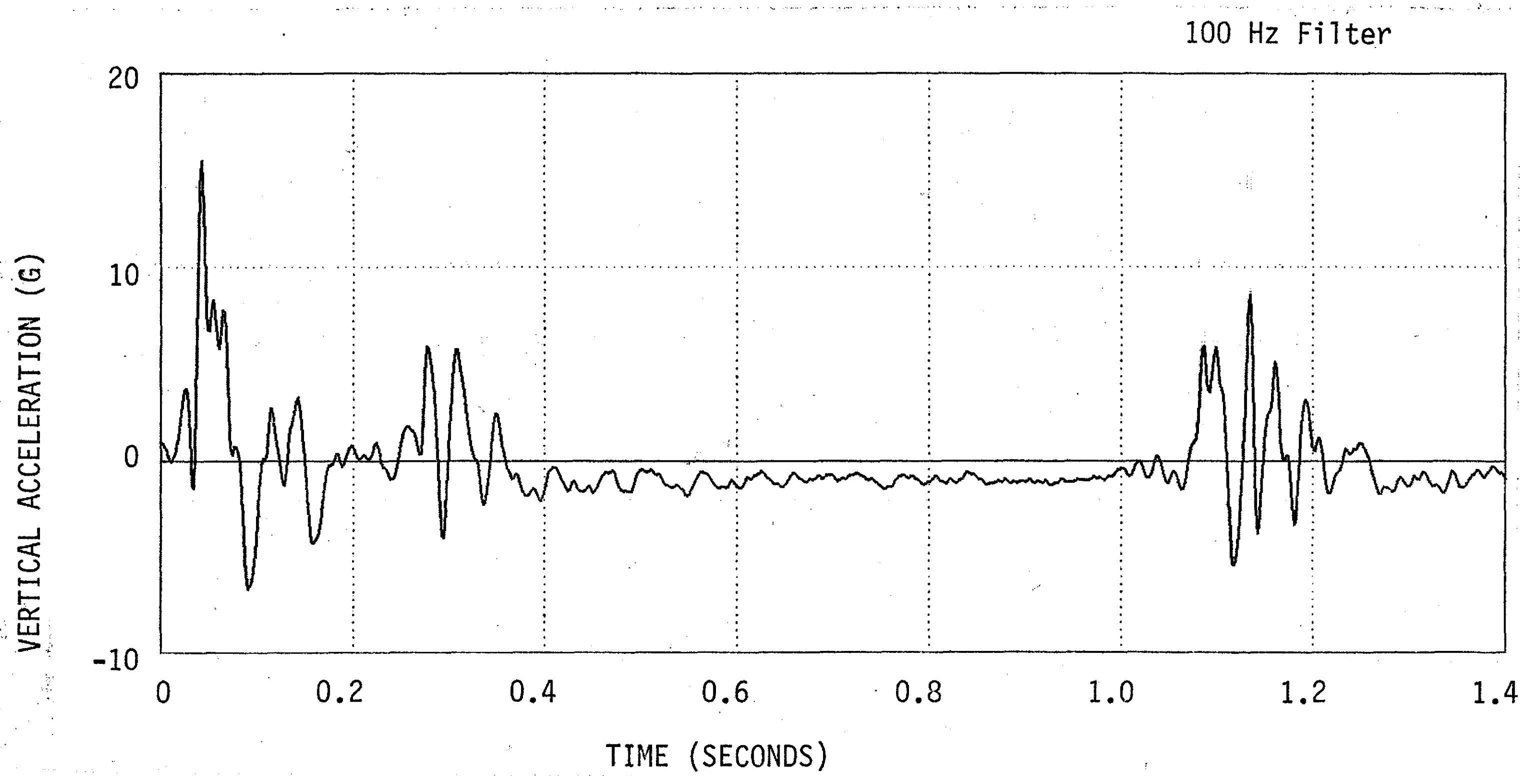


Figure B-7. Vehicle Vertical Acceleration, Test 1-1.

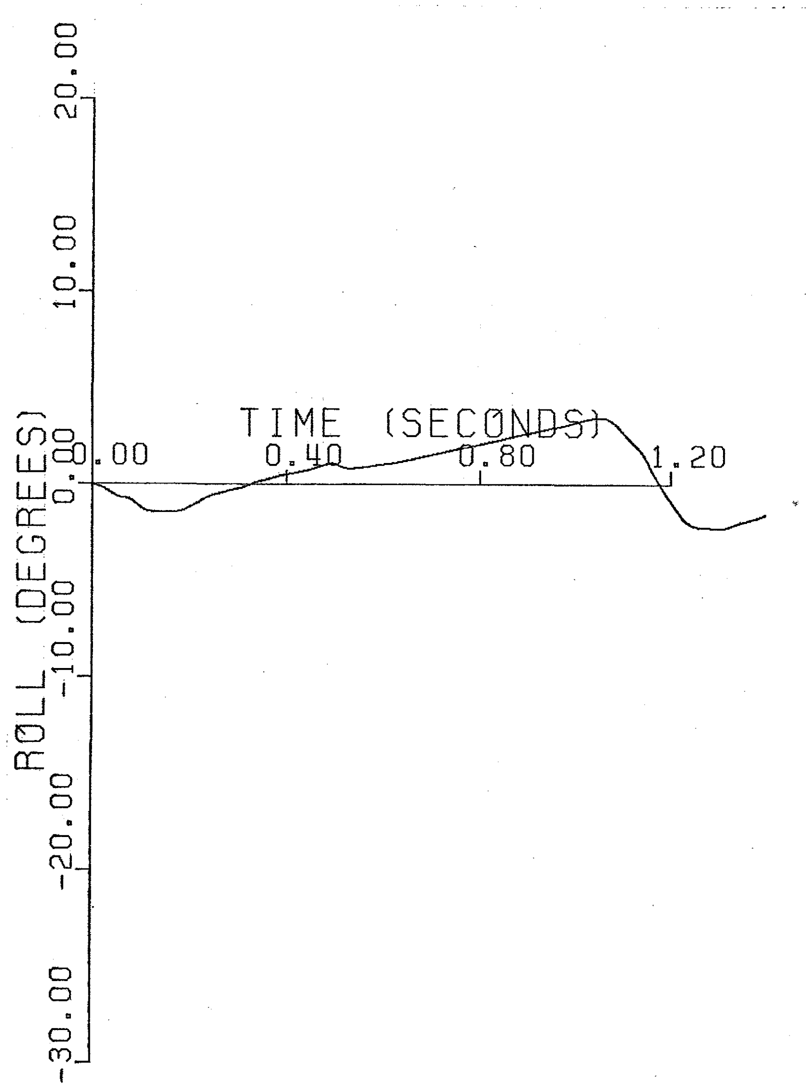


Figure B-8. Vehicle Roll, Test 1-1.

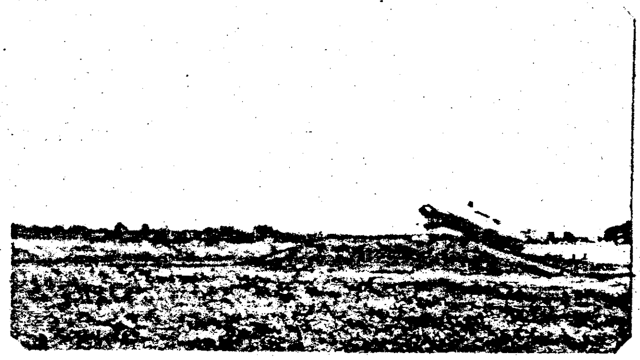
B-3-2. Test No. 1-2

Test 1-2 was the same as 1-1 except the vehicle speed was increased to 35 mph (56.3 km/h). The vehicle used in test 1-1 was also used in test 1-2. Figures B-9 and B-10 contain sequential photos taken during impact. The test vehicle launched over the earth berm and rolled approximately 15 degrees before hitting the ground. This caused some damage to the vehicle as shown in Figure B-11.

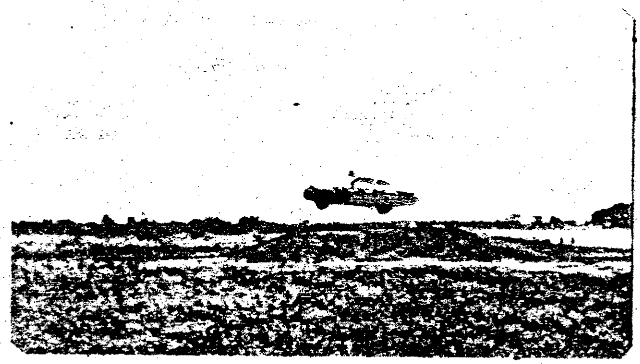
Figures B-12, B-13, and B-14 contain plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-15 is a plot of roll angle versus time.

0.00

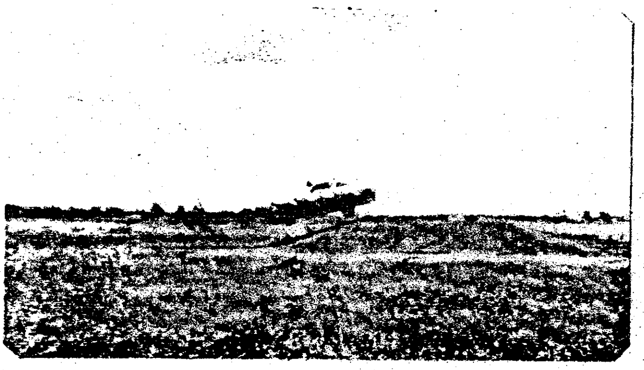
0.131



0.454

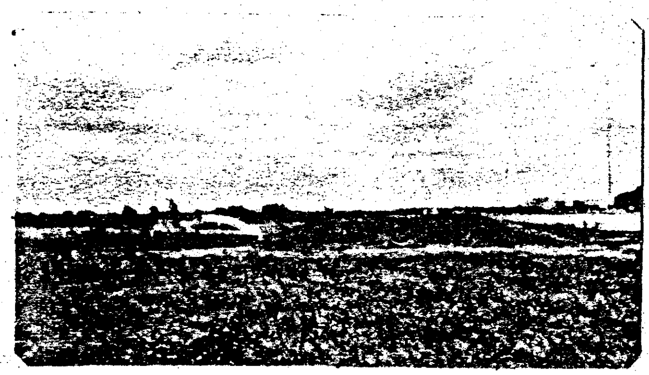


0.859



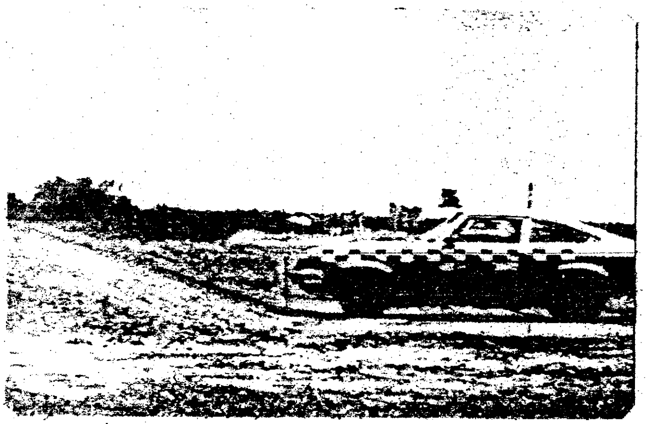
1.212

1.374

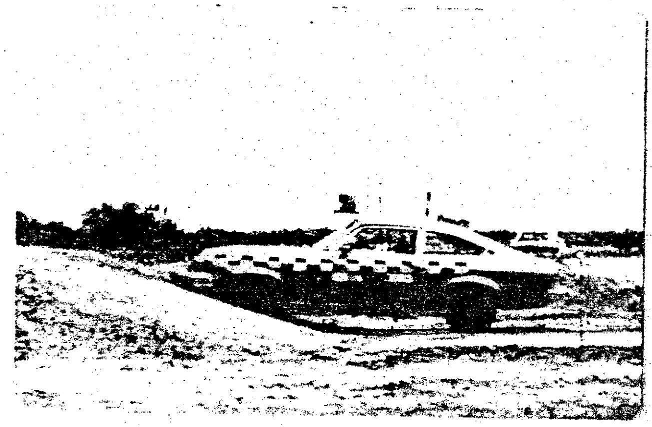


1.647

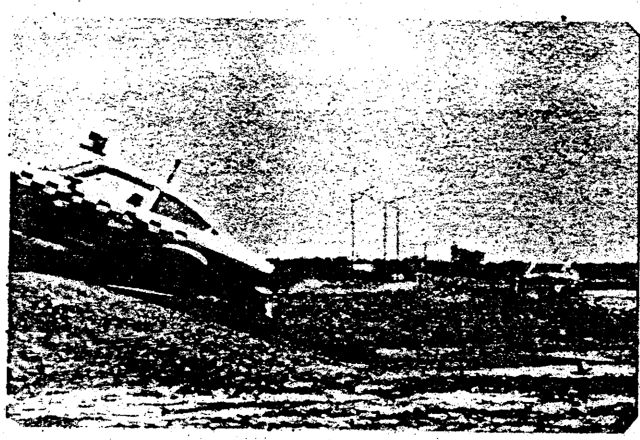
Figure B-9. Sequential Photos, Test 1-2.



0.00



0.131



0.454

Figure B-10. Sequential Photos, Test 1-2.

Figure B-11. Test Vehicle After Test 1-2.

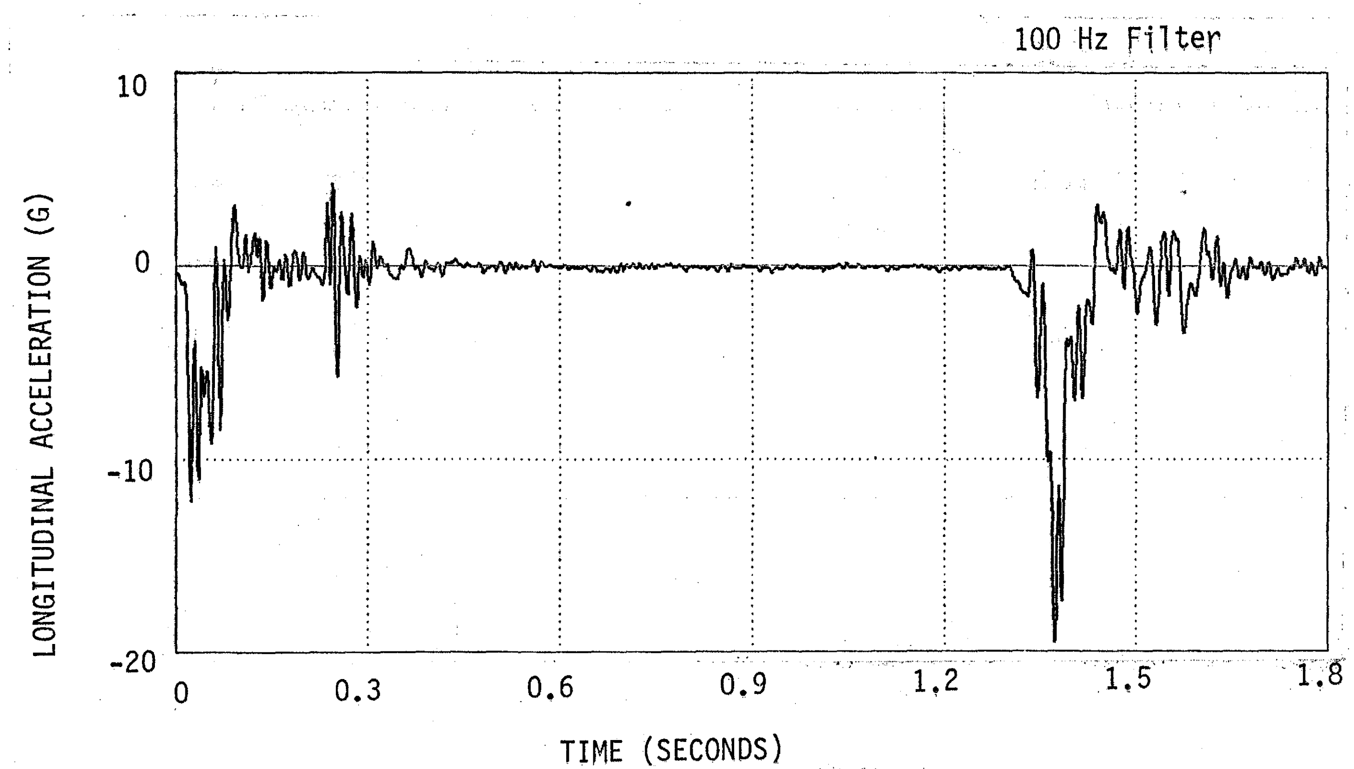


Figure B-12. Vehicle Longitudinal Acceleration, Test 1-2.

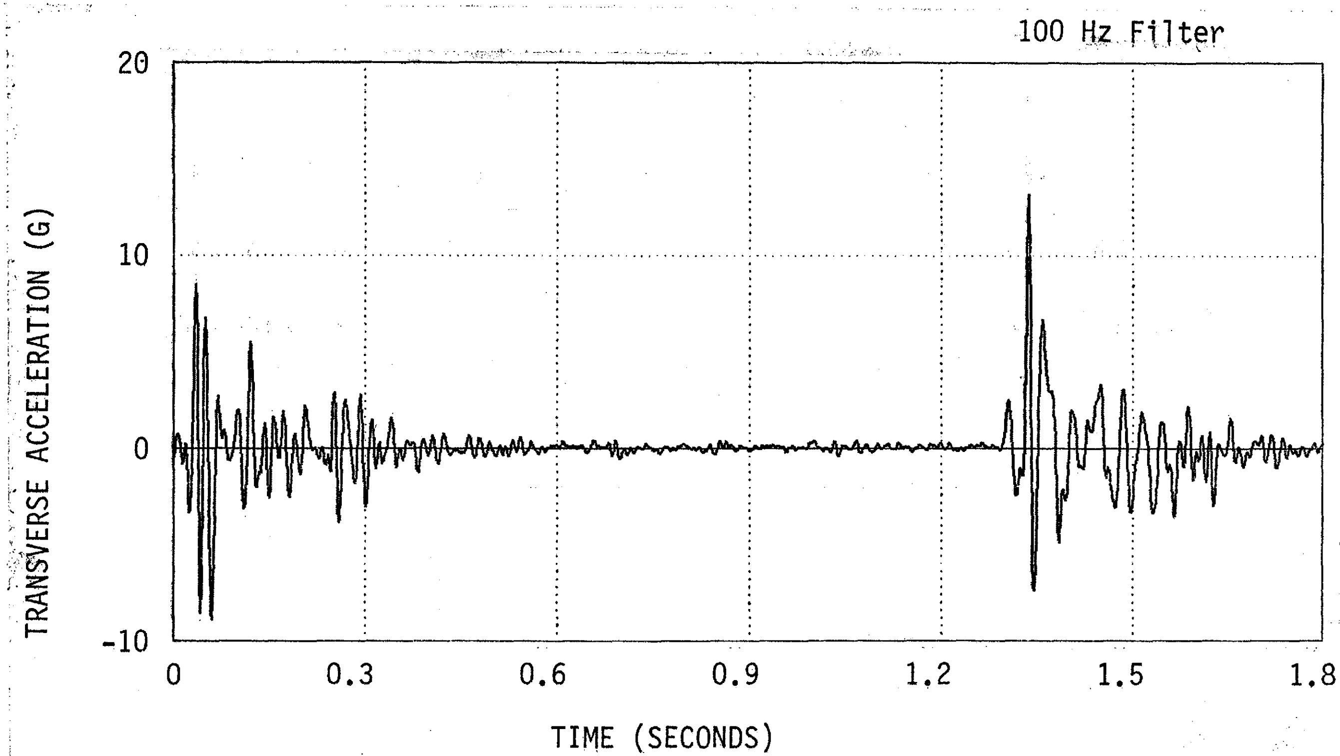


Figure B-13. Vehicle Transverse Acceleration, Test 1-2.

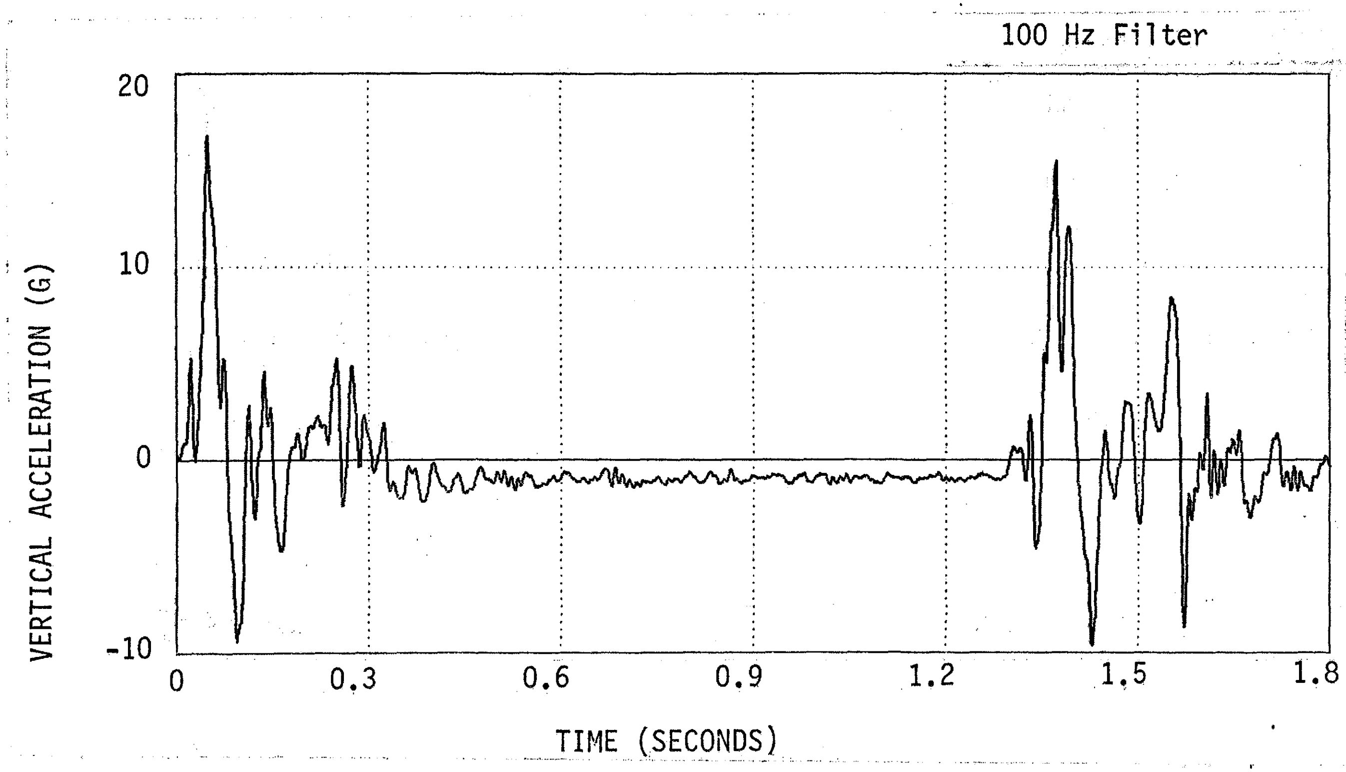


Figure B-14. Vehicle Vertical Acceleration, Test 1-2.

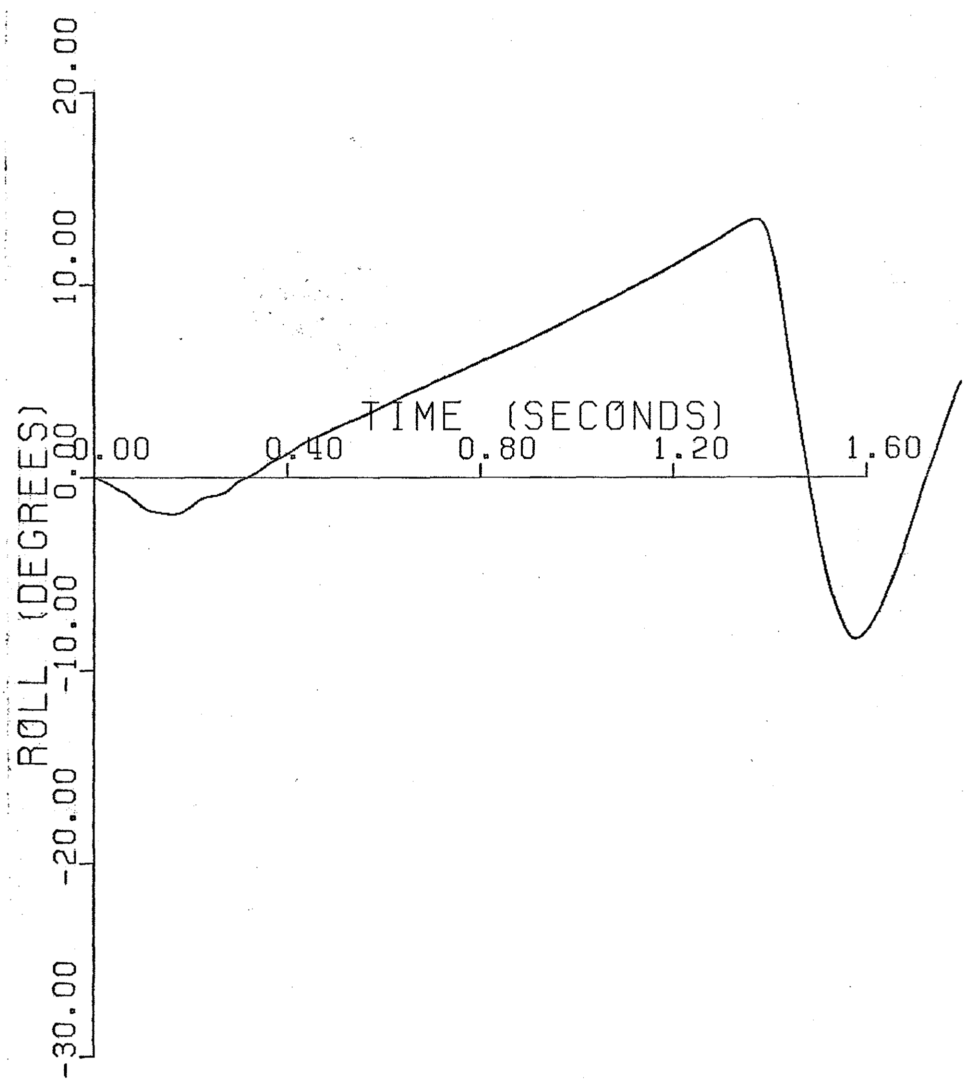


Figure B-15. Vehicle Roll, Test 1-2.

B-3-3. Test No. 1-3

Test 1-3 was a repeat of test 1-2 except the speed was increased to 40 mph (64.4 km/h). The same vehicle was used in both tests. Figure B-16 contains a photo of the test vehicle before impact. Figures B-17 and B-18 contain sequential photos taken during impact. The vehicle was launched well over the earth berm and again rolled about 20 degrees while airborne. Vehicle damage was significant as shown in Figure B-19, and the vehicle was not used again.

Plots of longitudinal, tranverse, and vertical accelerations versus time are found in Figures B-20, B-21, and B-22. Figure B-23 contains a plot of roll angle versus time.

Figure B-16. Test Vehicle Before Test 1-3.

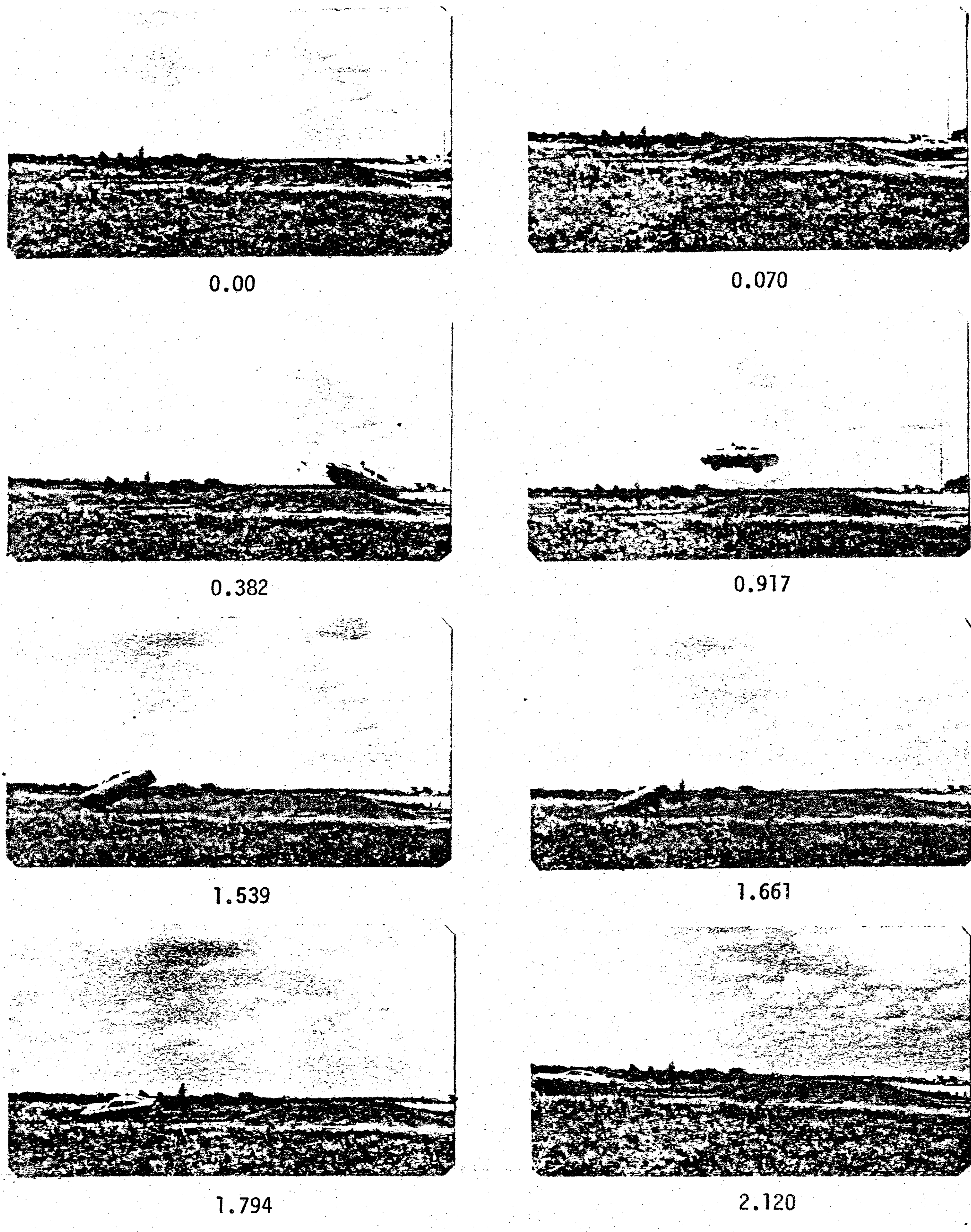
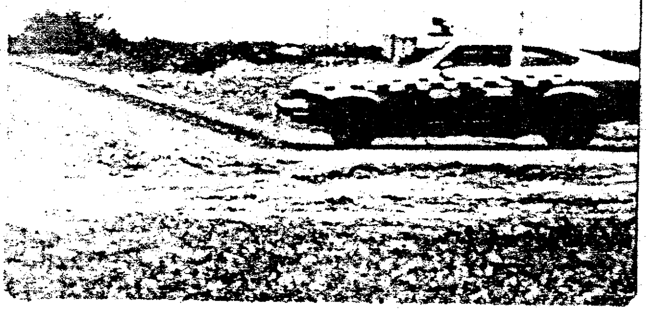
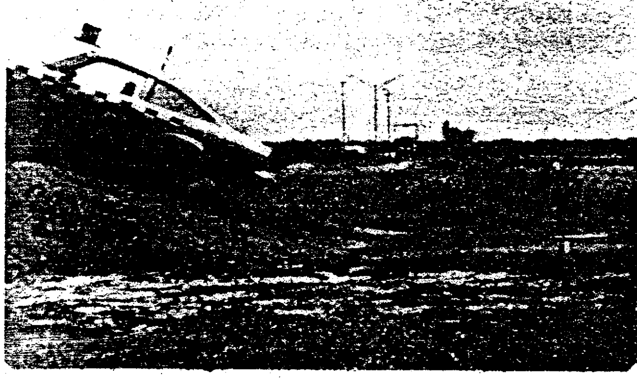


Figure B-17. Sequential Photos, Test 1-3.



0.00

0.070



0.382

Figure B-18. Sequential Photos, Test 1-3.

Figure B-19. Test Vehicle After Test 1-3.

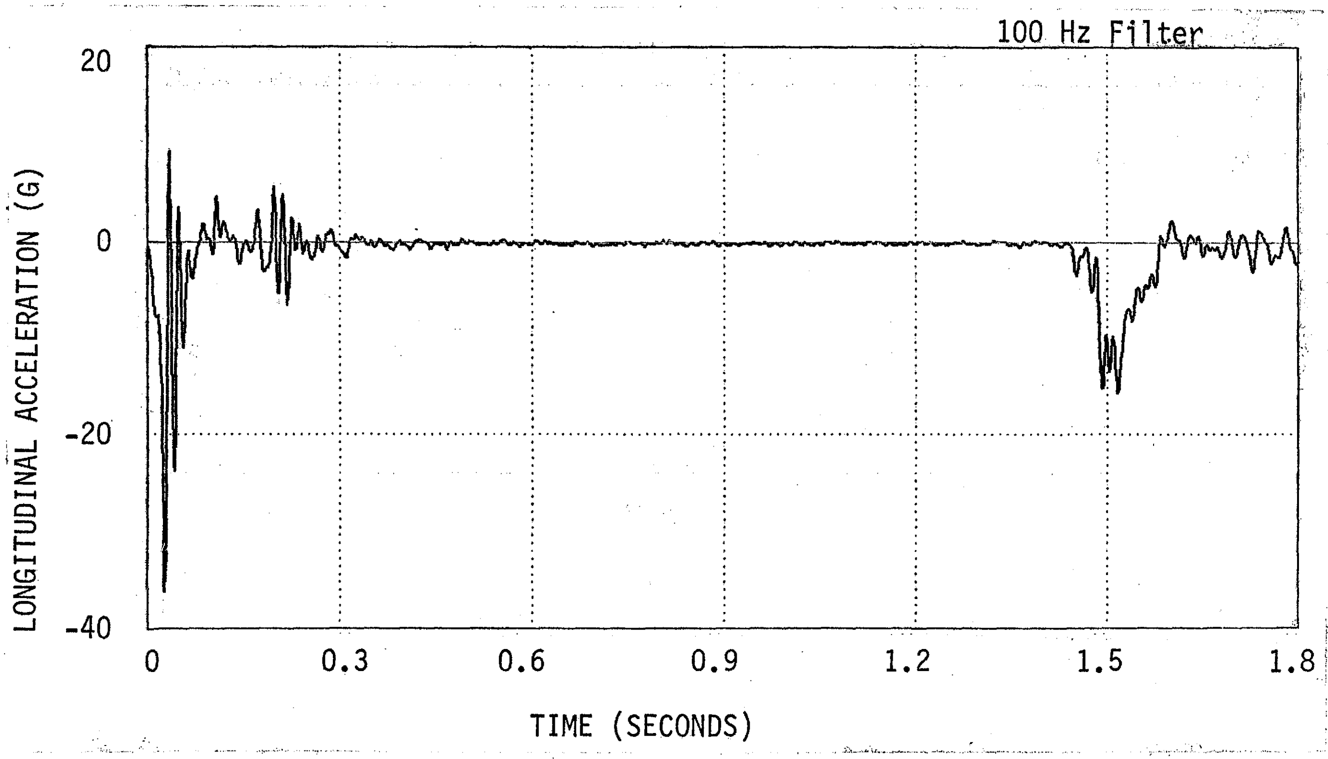


Figure B-20. Vehicle Longitudinal Acceleration, Test 1-3.

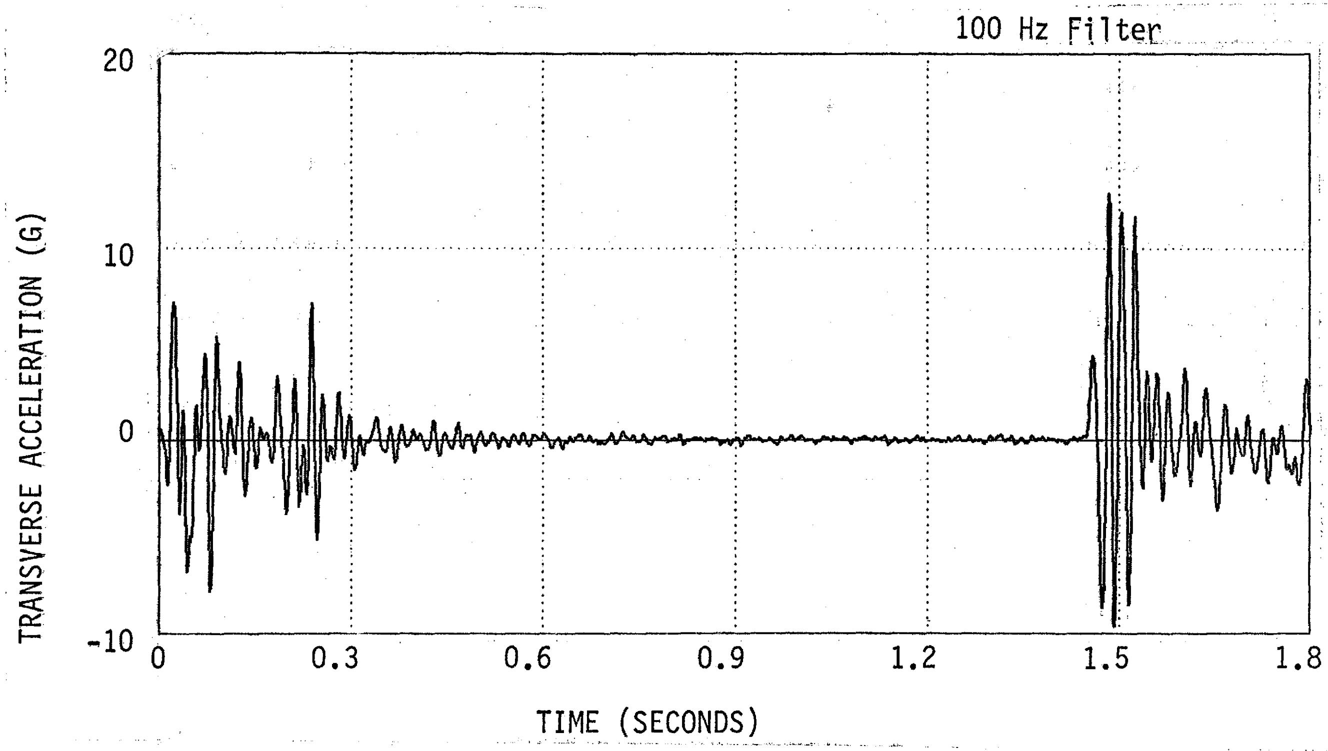


Figure B-21. Vehicle Transverse Acceleration, Test 1-3.

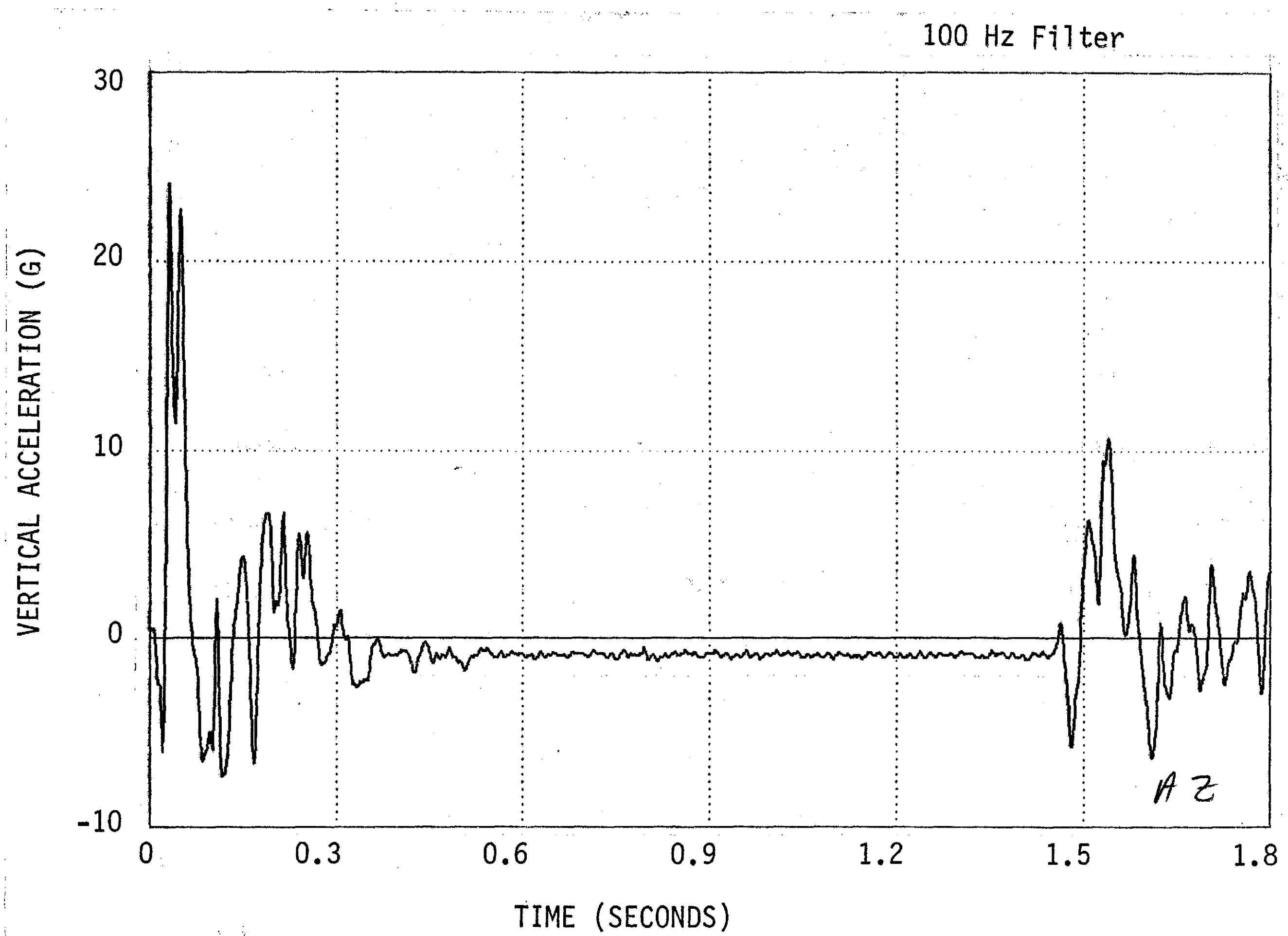


Figure B-22. Vehicle Vertical Acceleration, Test 1-3.

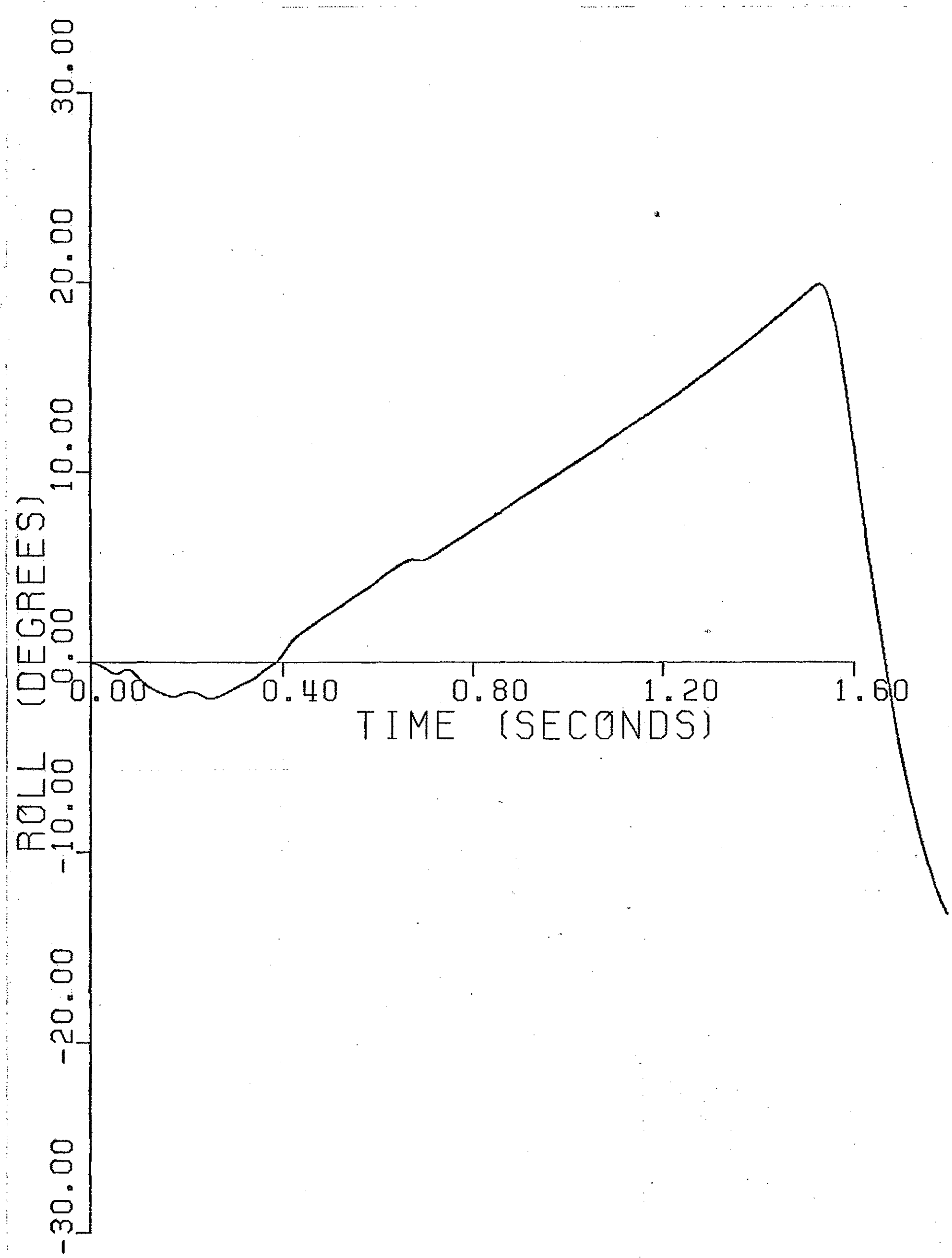


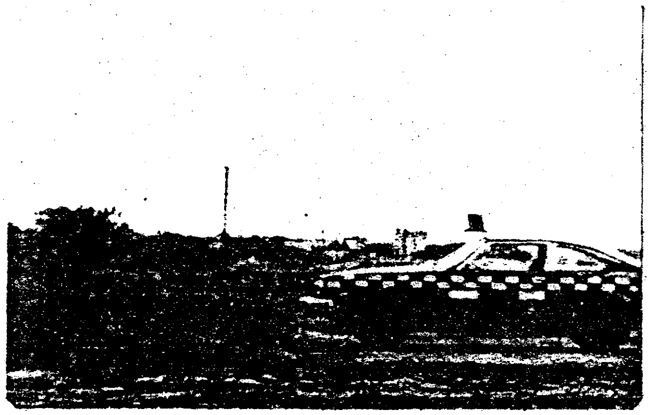
Figure B-23. Vehicle Roll, Test 1-3.

B-3-4. Test No. 1-4

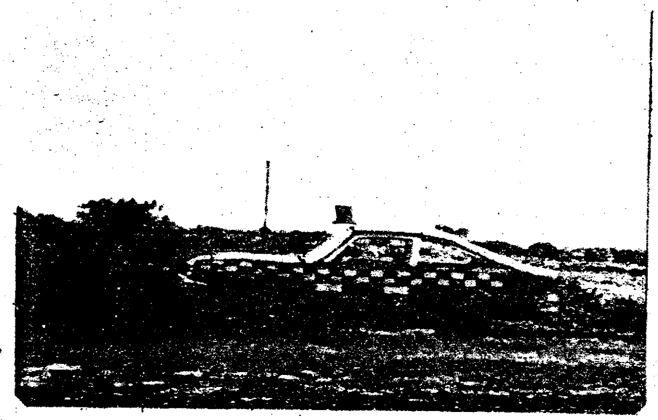
Test 1-4 was the same as 1-3 except the speed was increased to 50 mph (80.5 km/h). A different car was also used.

Figures 4 and B-24 contain sequential photos taken during impact. The vehicle was launched well over the berm and, although it rolled over only 40 degrees, the vehicle pitched over. This test was therefore a failure, and the damage was accordingly very severe. The damaged vehicle is shown in Figure B-25.

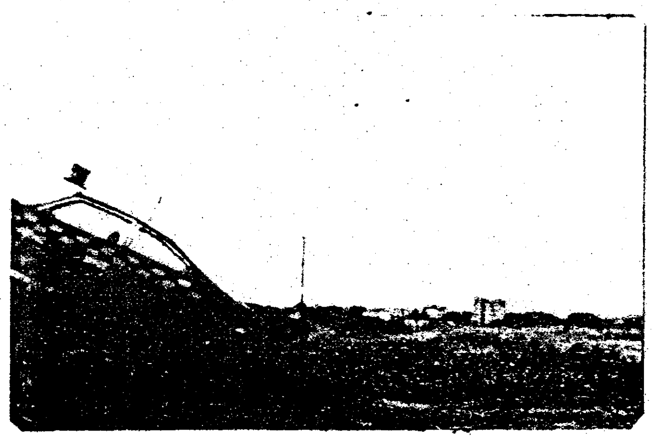
Plots of longitudinal, transverse, and vertical accelerations versus time are contained in Figures B-26, B-27, and B-28. A plot of roll angle versus time is found in Figure B-29.



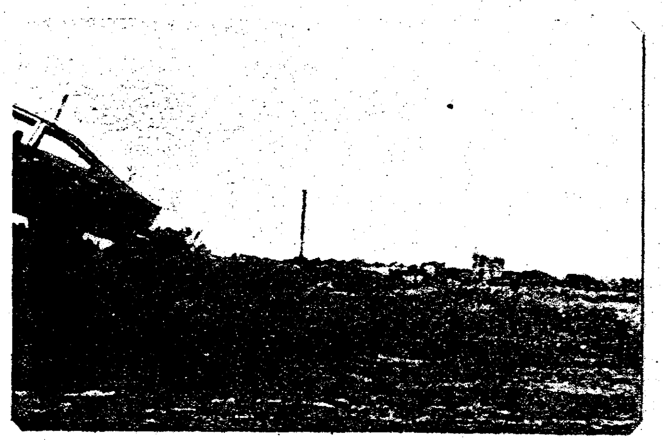
0.00



0.091



0.332



0.402

Figure B-24. Sequential Photos, Test 1-4.

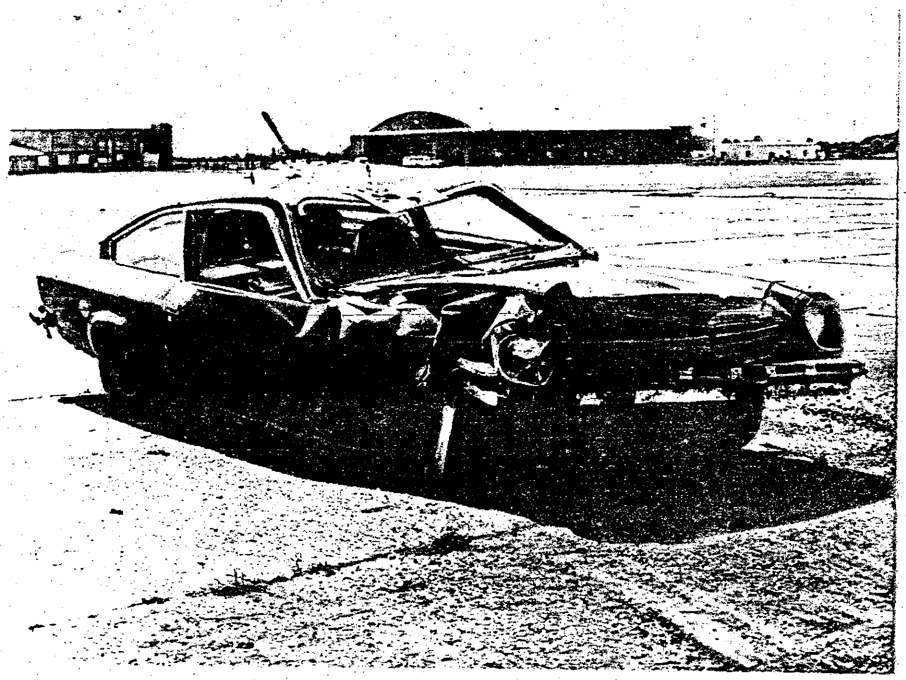


Figure B-25. Test Vehicle After Test 1-4.

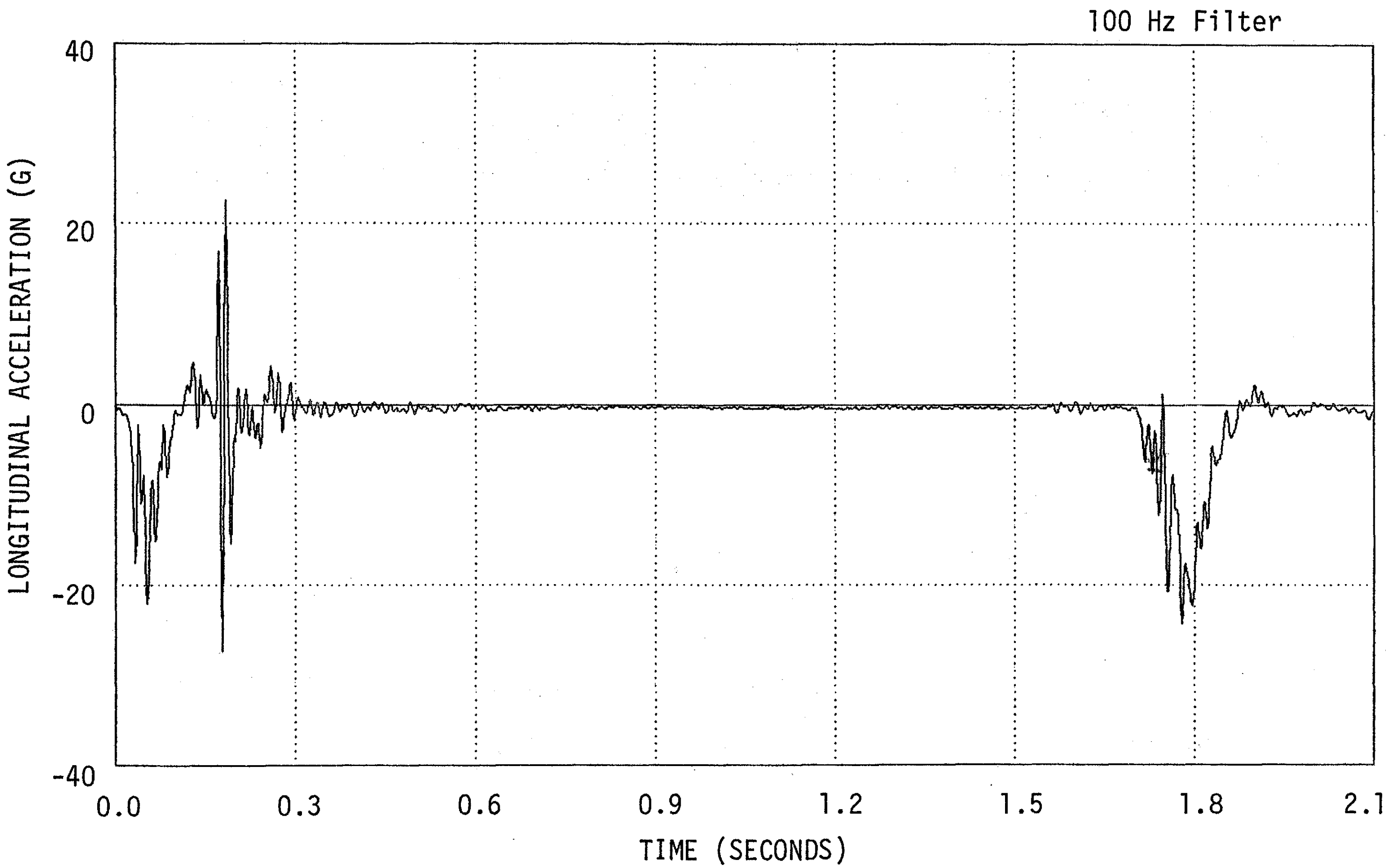


Figure B-26. Vehicle Longitudinal Acceleration, Test 1-4.

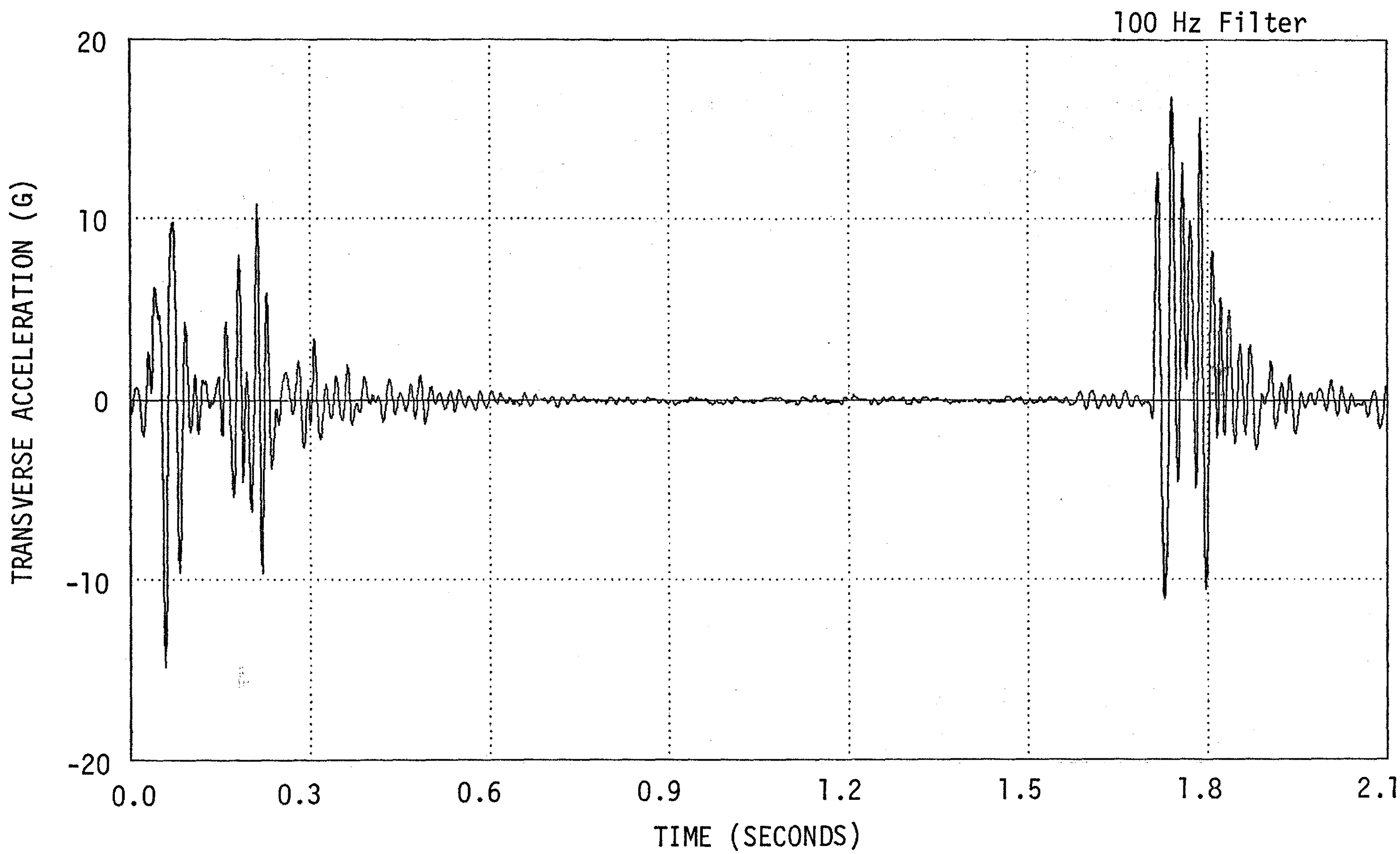


Figure B-27. Vehicle Transverse Acceleration, Test 1-4.

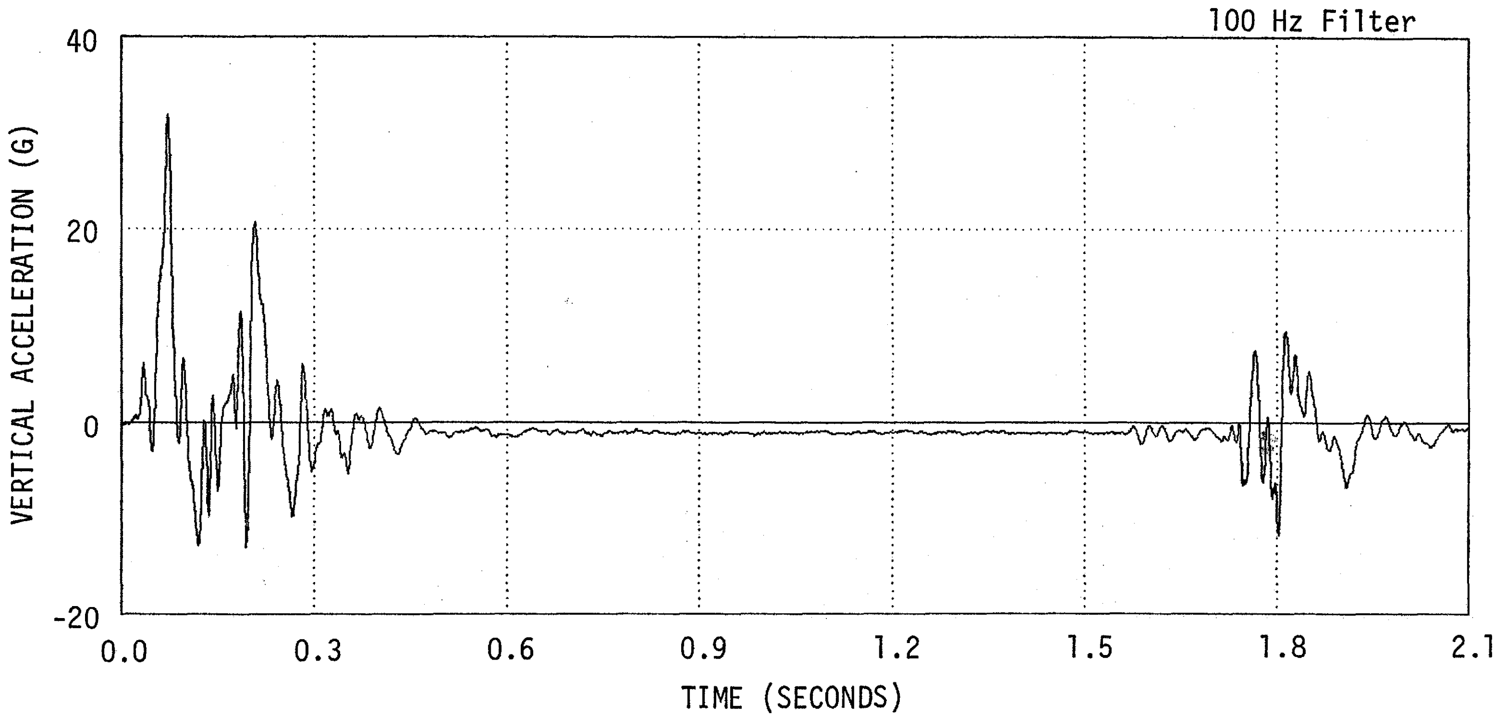


Figure B-28. Vehicle Vertical Acceleration, Test 1-4.

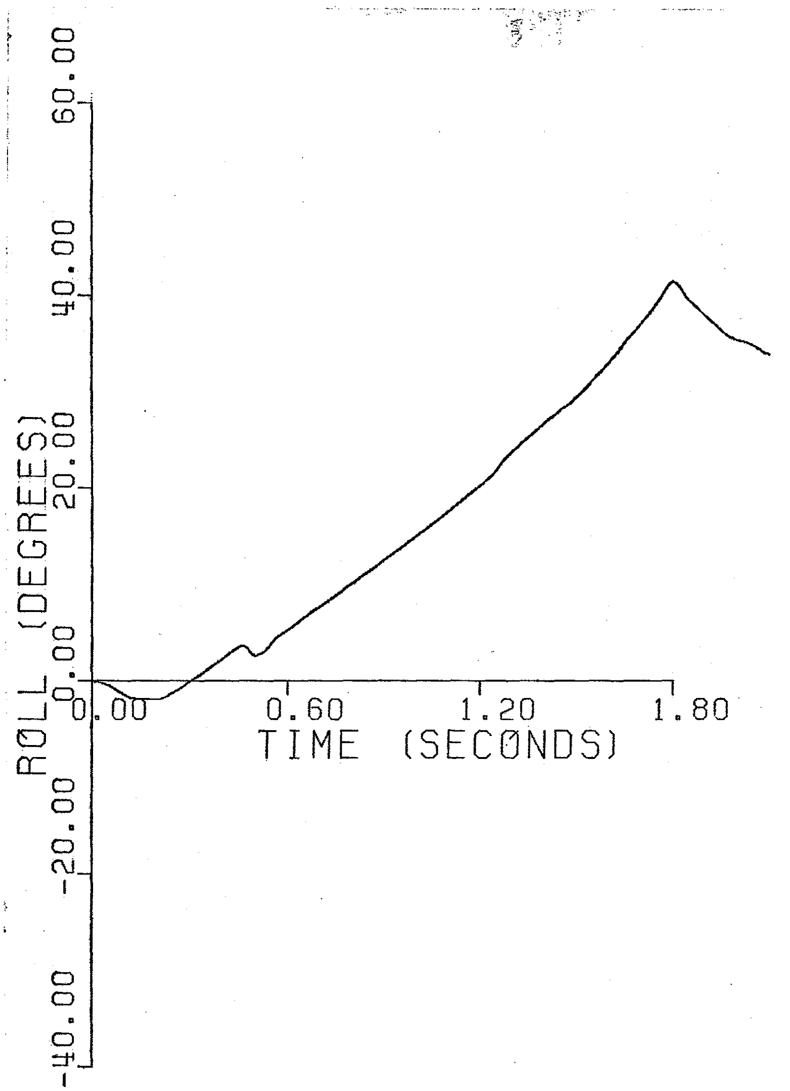


Figure B-29. Vehicle Roll, Test 1-4.

B-3-5. Test No. 5-1

For test 5-1 the earth berm was flattened to a 6 to 1 slope as shown in Figure B-30. The test speed was 50 mph (80.5 km/h). A photo of the test vehicle before impact is contained in Figure B-31. Figures 6 and B-32 contain sequential photos taken during the event. The vehicle was launched beyond the berm but landed at a low pitch angle, and the maximum roll angle was only 7 degrees. Vehicle damage was not severe, as shown in Figure B-33.

Figures B-34, B-35, and B-36 contain plots of longitudinal, transverse, and vertical accelerations, respectively. Figure B-37 contains a plot of roll angle versus time.

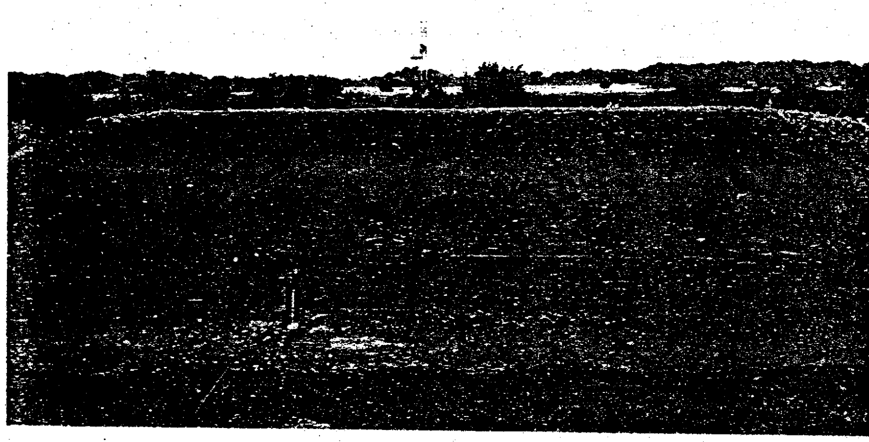


Figure B-30. 6:1 Slope Test Installation, Test 5-1.

Figure B-31. Test Vehicle Before Test 5-1.

0.00

0.086

0.268

0.490

Figure B-32. Sequential Photos, Test 5-1.

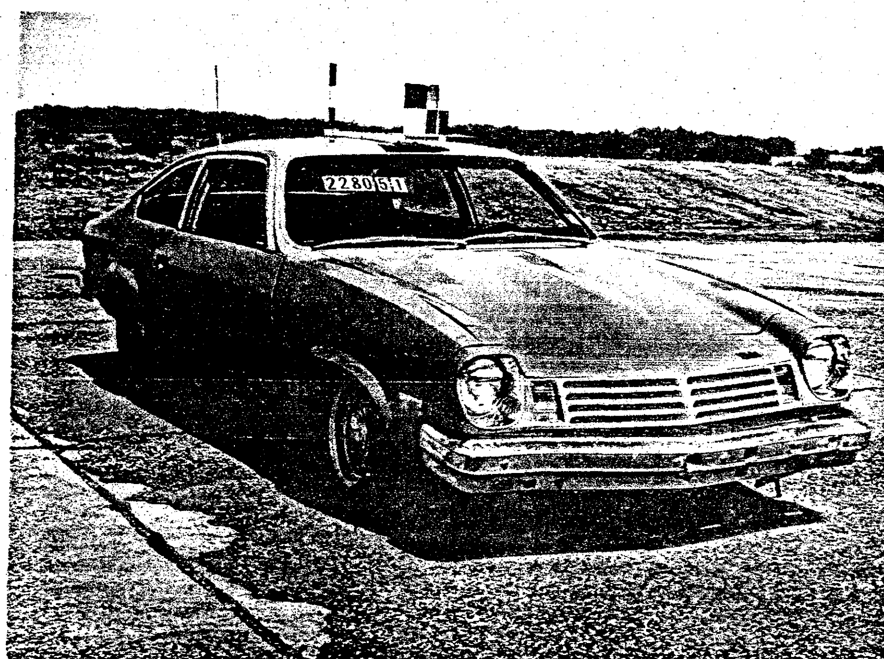


Figure B-33. Test Vehicle After Test 5-1.

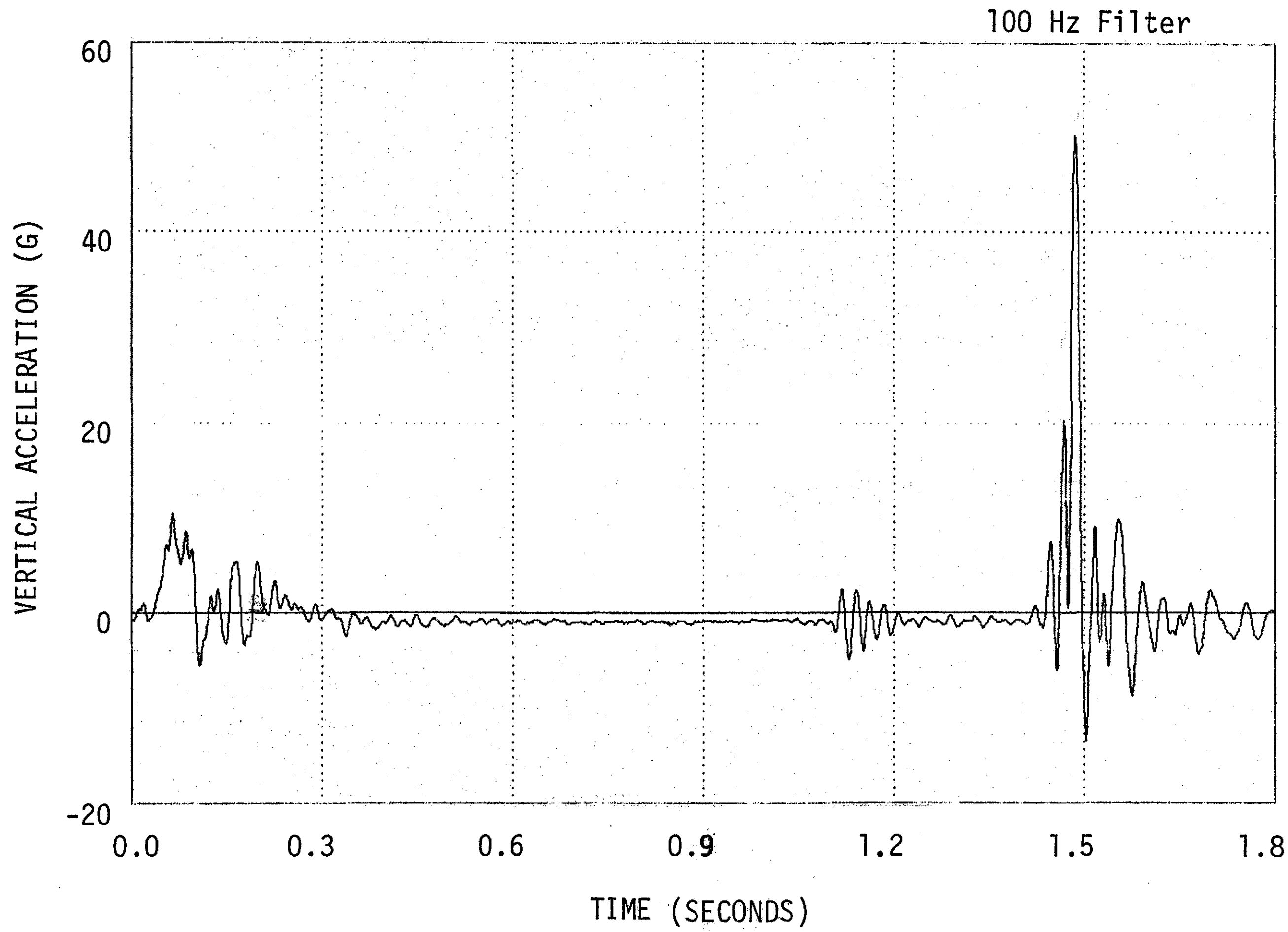


Figure B-34. Vehicle Vertical Acceleration, Test 5-1.

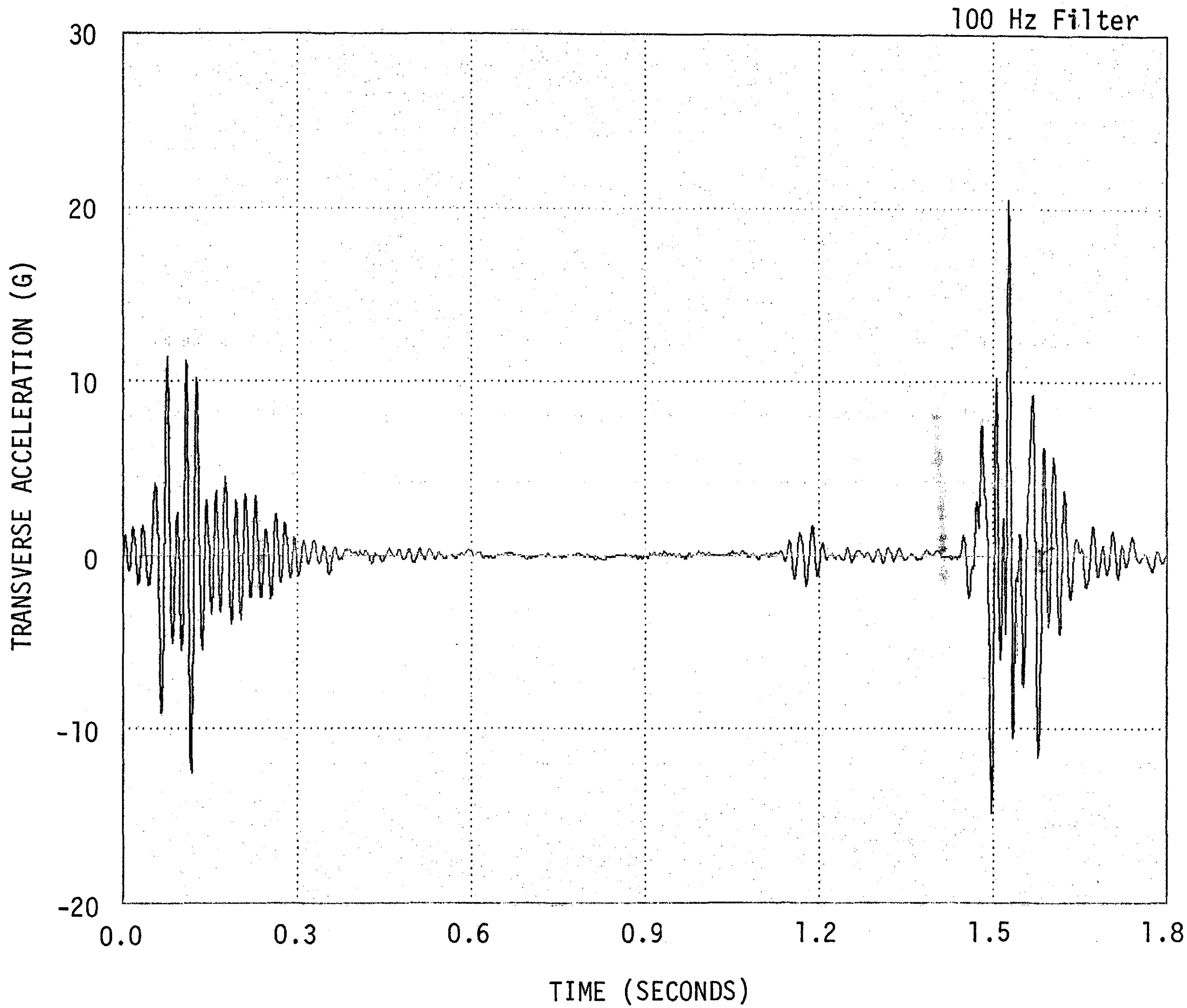


Figure B-35. Vehicle Transverse Acceleration, Test 5-1.

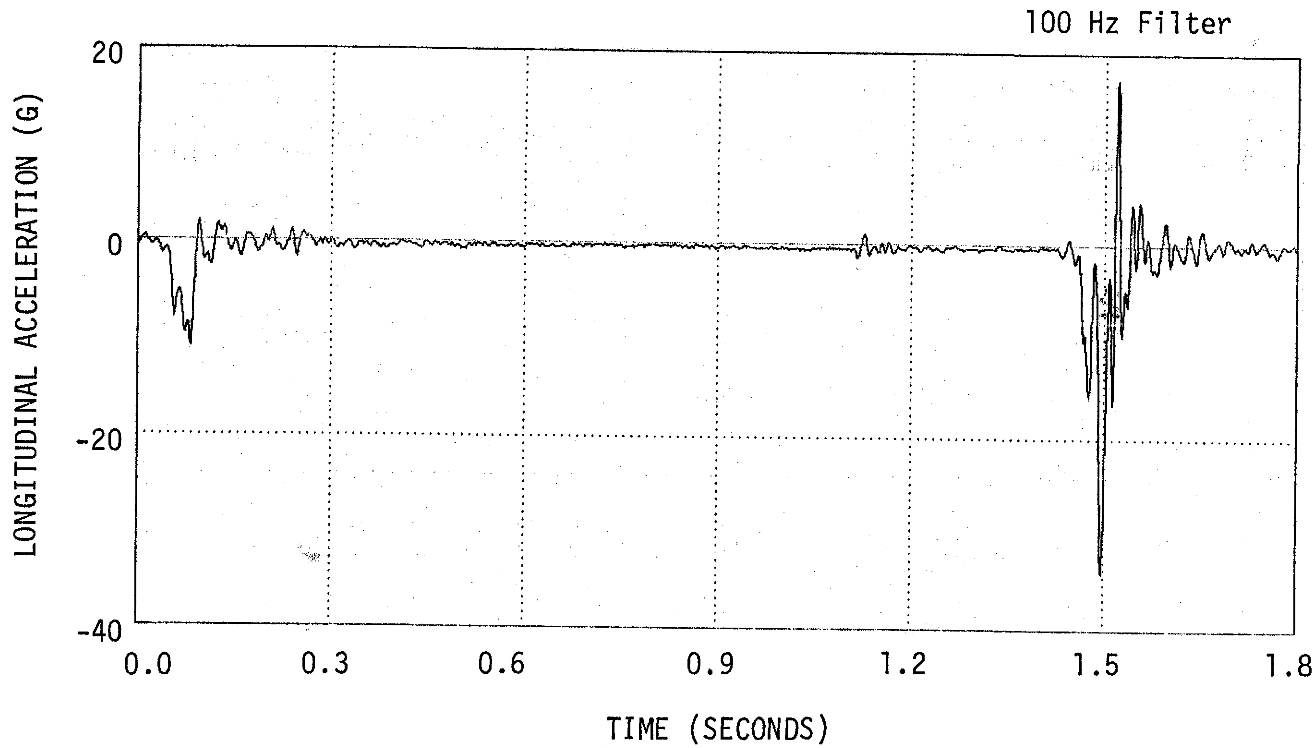


Figure B-36. Vehicle Longitudinal Acceleration, Test 5-1.

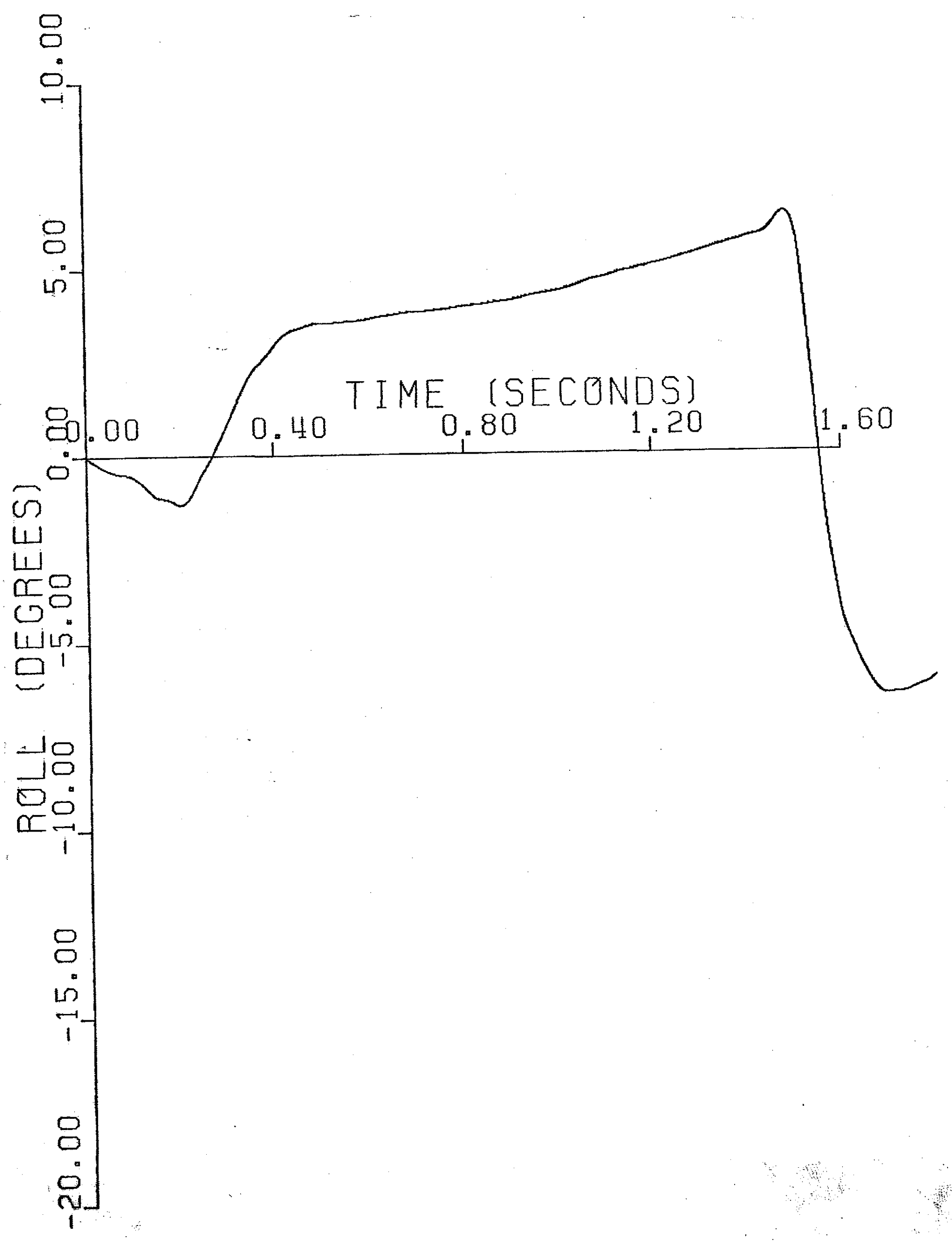


Figure B-37. Vehicle Roll, Test 5-1.

B-4. Culvert Tests

This section describes the tests conducted to determine the grate spacing required to enable an errant vehicle to safely traverse a driveway culvert. Table B-2 contains a summary of the results of these tests. A discussion of these results and the conclusions drawn therefrom can be found in Section IV-2.

All of these tests were conducted on the earth berm used in test 5-1 and described in Figure 5. A culvert was installed in the berm and the impact point was placed such that the right front wheel of the test vehicle rolled down the centerline of the culvert. The impact angle was again 0 degrees and the test speed for all of these tests except test 7-4 was 50 mph (80.5 km/h). The test speed for test 7-4 was 20 mph (32.2 km/h).

TABLE B-2. SUMMARY OF CULVERT GRATING TEST RESULTS

TEST NO.	TEST SPEED (mph)	NO. OF CROSSMEMBERS	CROSSMEMBER SPACING (in.)	TYPE OF CROSSMEMBER	DISTANCE VEHICLE AIRBORNE (ft)	VEHICLE DAMAGE CLASSIFICATION TAD	SAE	PEAK 50 MS AVG. ACCELERATION (g's)	DID VEHICLE PITCH OVER?
7-1	50	0	-	-	48.5	FL-4;BL-3	00LFM03	9.0	Yes
7-2	50	1	84	2.5 in. O.D Standard Steel Pipe	43.5	FL-4;BR-3	12FLEW4	8.2	Yes
7-4	20	4	21	2 lb/ft Billet Steel Delineator Post	0	No Damage		0.9	No
7-5	50	4	21	2 lb/ft Billet Steel Delineator Post	66.0	FL-5;BO-2	12FLAW6	14.8	Yes
7-6	50	4	24	2.5 in. O.D. Standard Steel Pipe	64.0	RFQ-3	12FLEW2	10.2	No

Metric Conversions:

1 mph = 1.609 km/h
1 ft = 0.305 m
1 in. = 2.54 cm

B-4-1. <u>Test No. 7-1</u>

The initial test involved a culvert end with no grating as shown in Figures 7 and B-38. Figures 8 and B-39 contain sequential photos of the event. The test vehicle began to roll when the right rear wheel impacted the top of the culvert. When the car hit the ground it had already rolled approximately 60 degrees and continued to roll completely over. Figure B-40 contains photos of the damage done to the culvert installation and the test vehicle.

Figures B-41, B-42, and B-43 contain plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-44 contains a plot of the roll angle versus time.

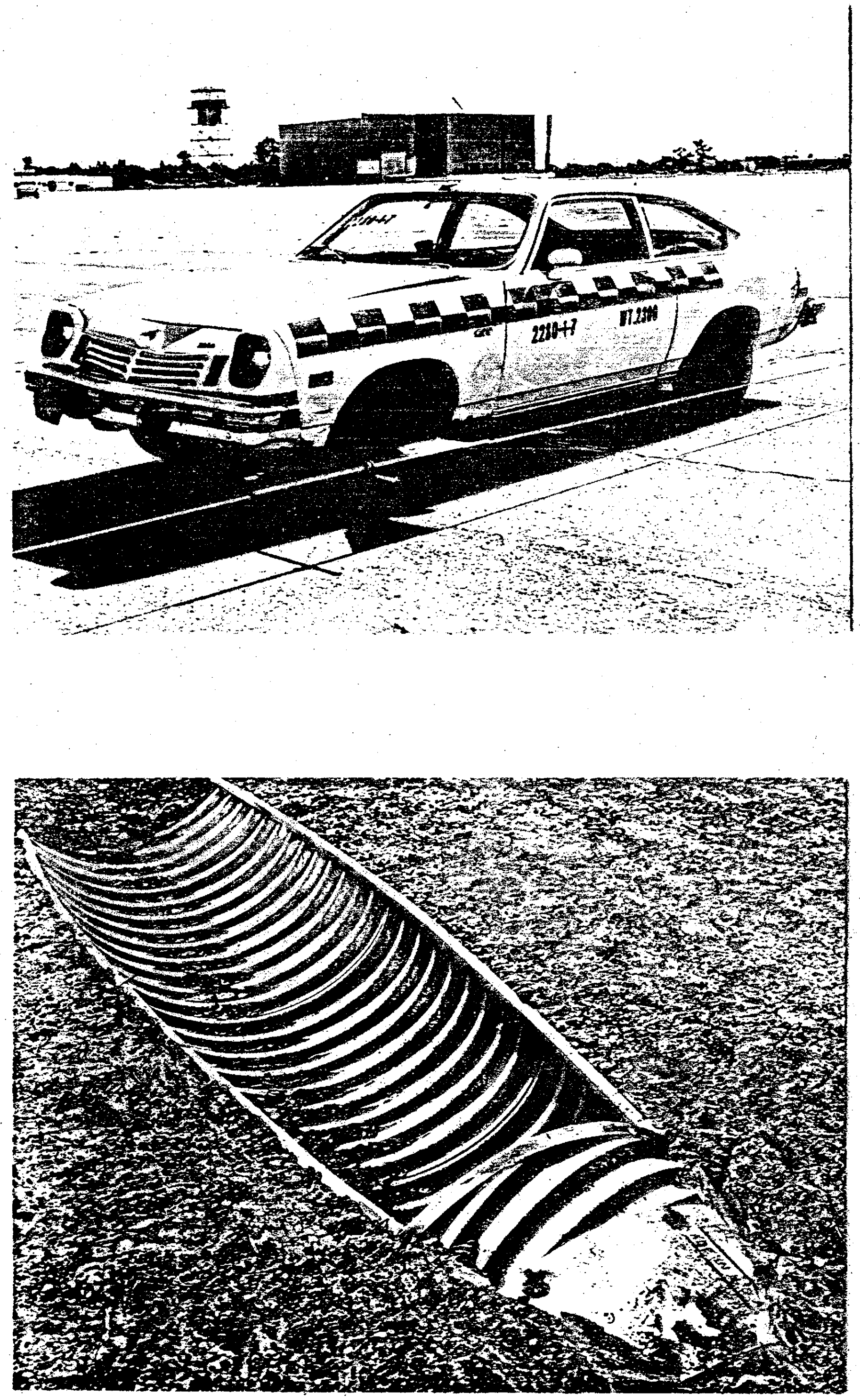


Figure B-38. Test Vehicle and Installation Before Test 7-1.

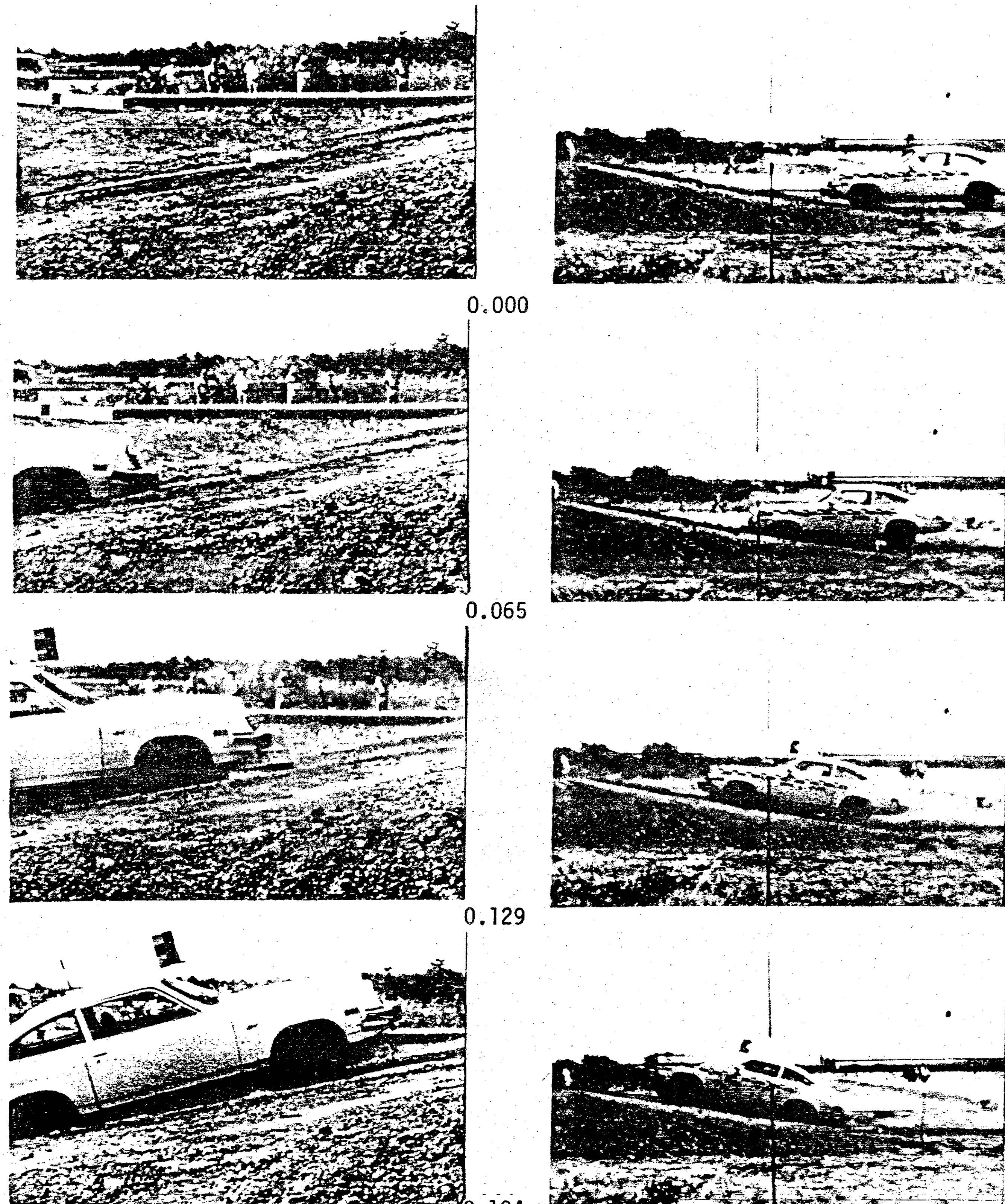


Figure B-39. Sequential Photos, Test 7-1.

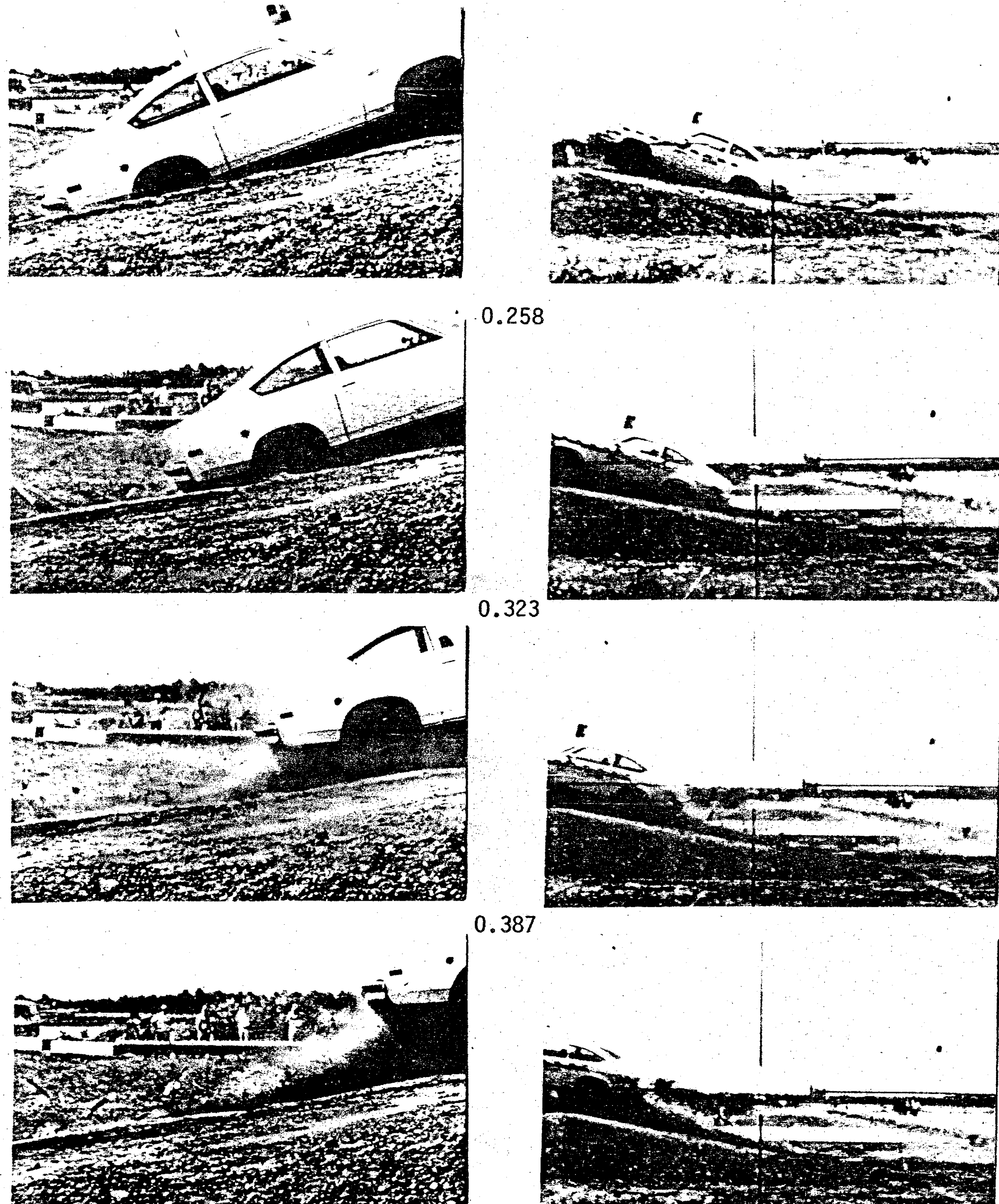


Figure B-39. Sequential Photos, Test 7-1. (cont.)

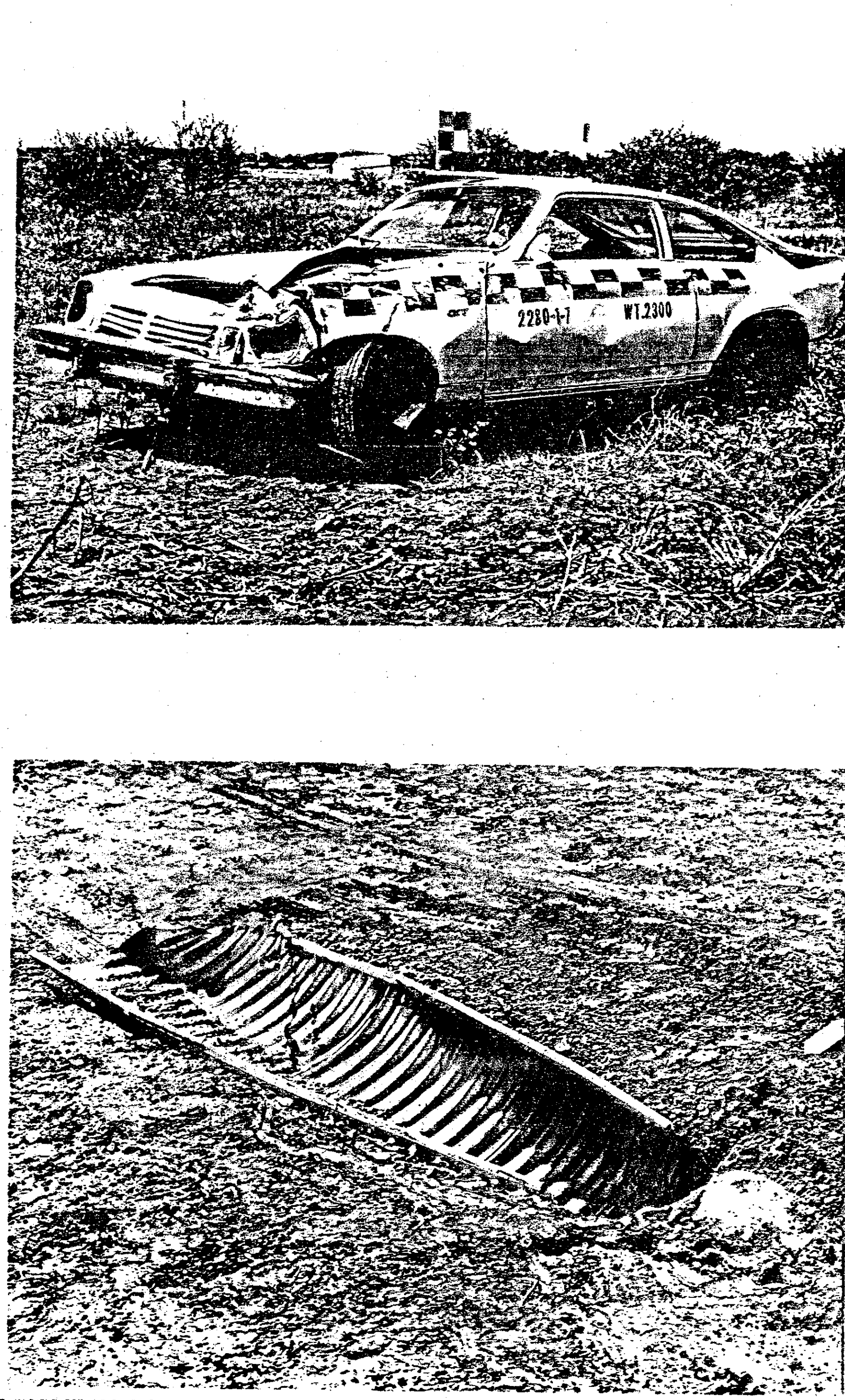


Figure B-40. Test Vehicle and Installation After Test 7-1.

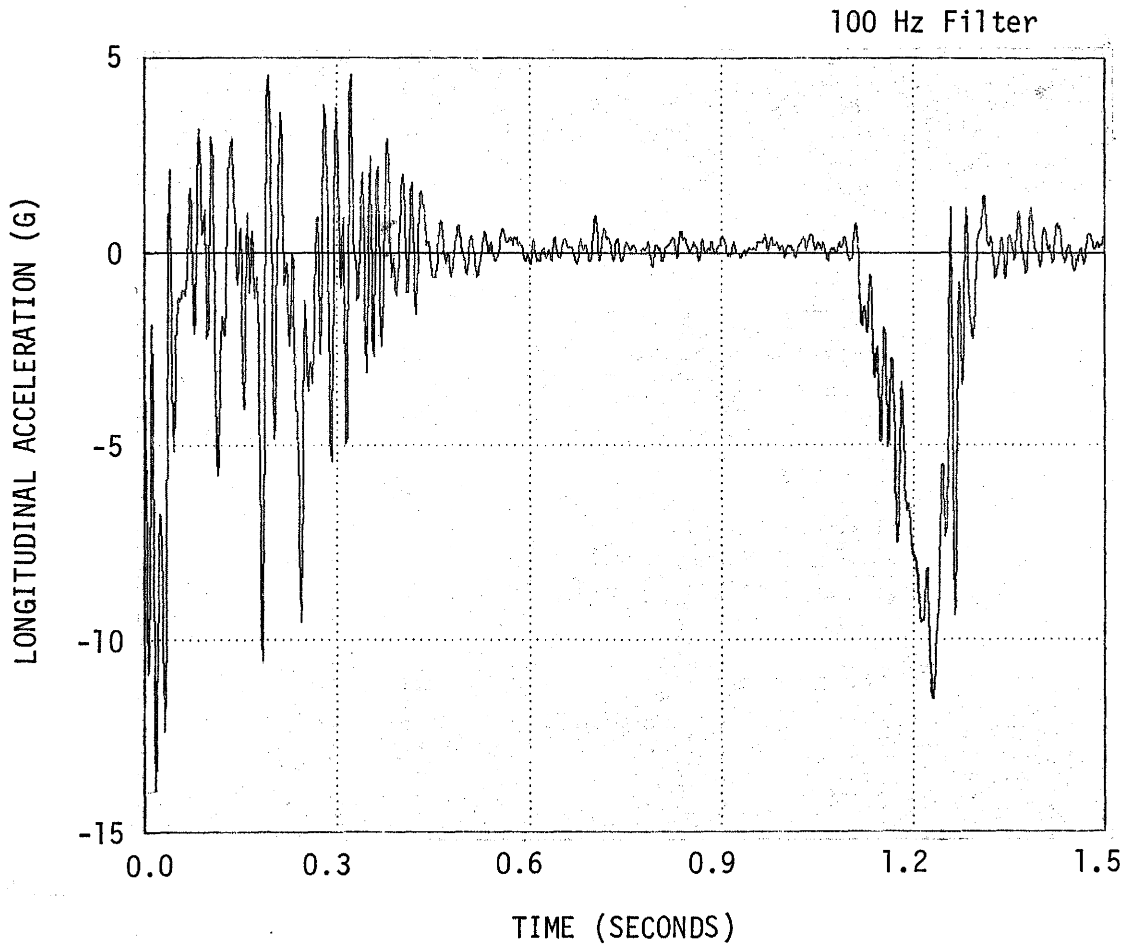


Figure B-41. Vehicle Longitudinal Acceleration, Test 7-1.

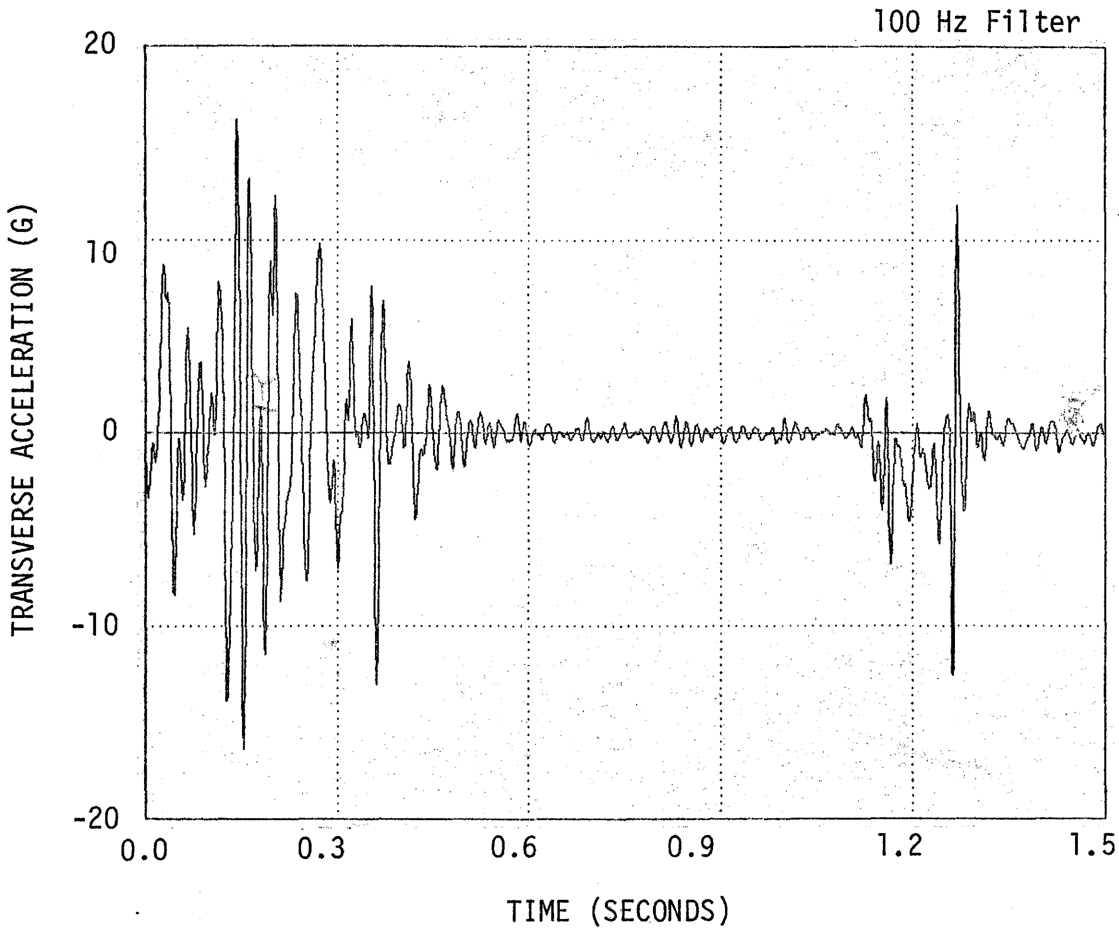


Figure B-42. Vehicle Transverse Acceleration, Test 7-1.

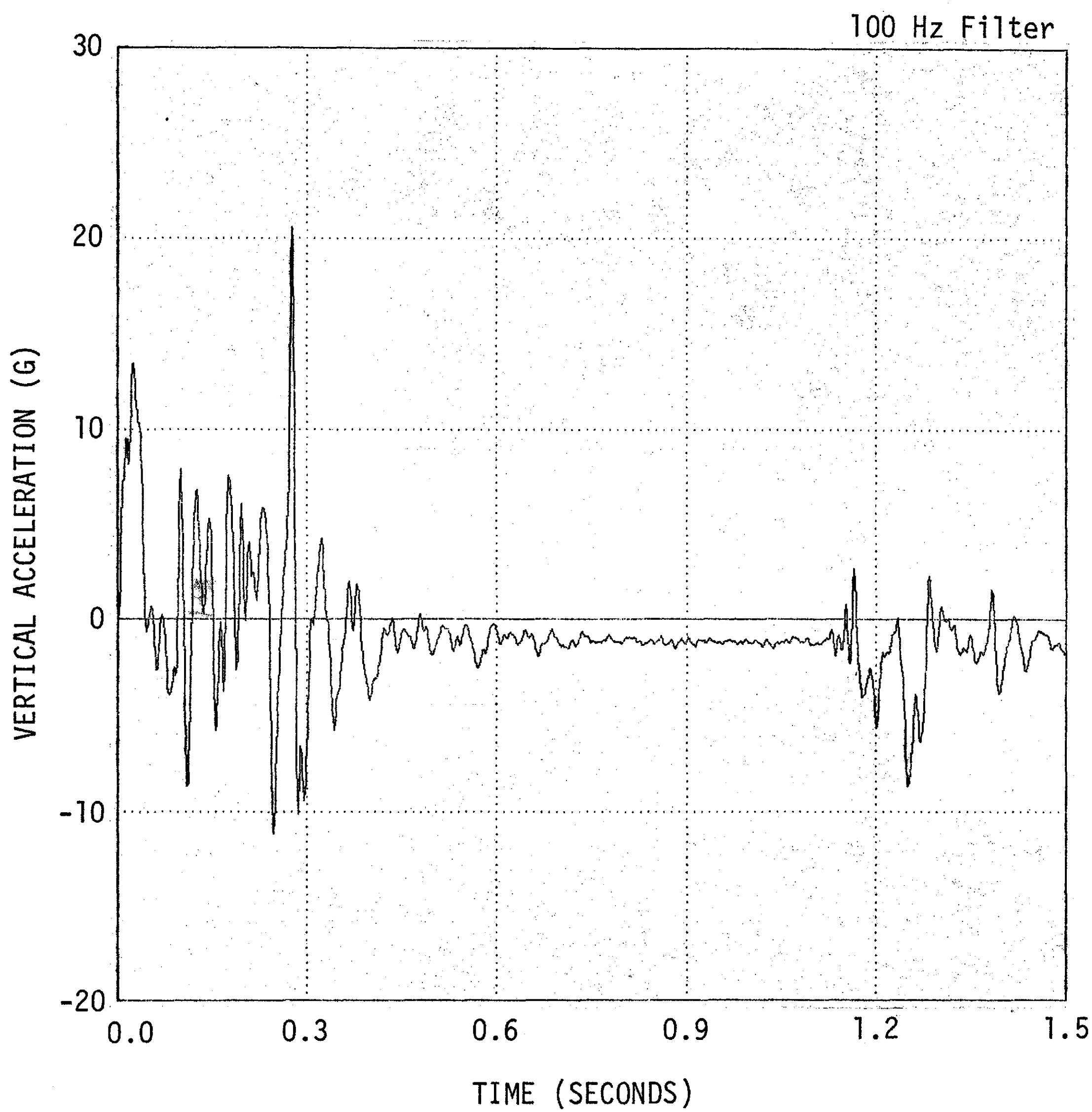


Figure B-43. Vehicle Vertical Acceleration, Test 7-1.

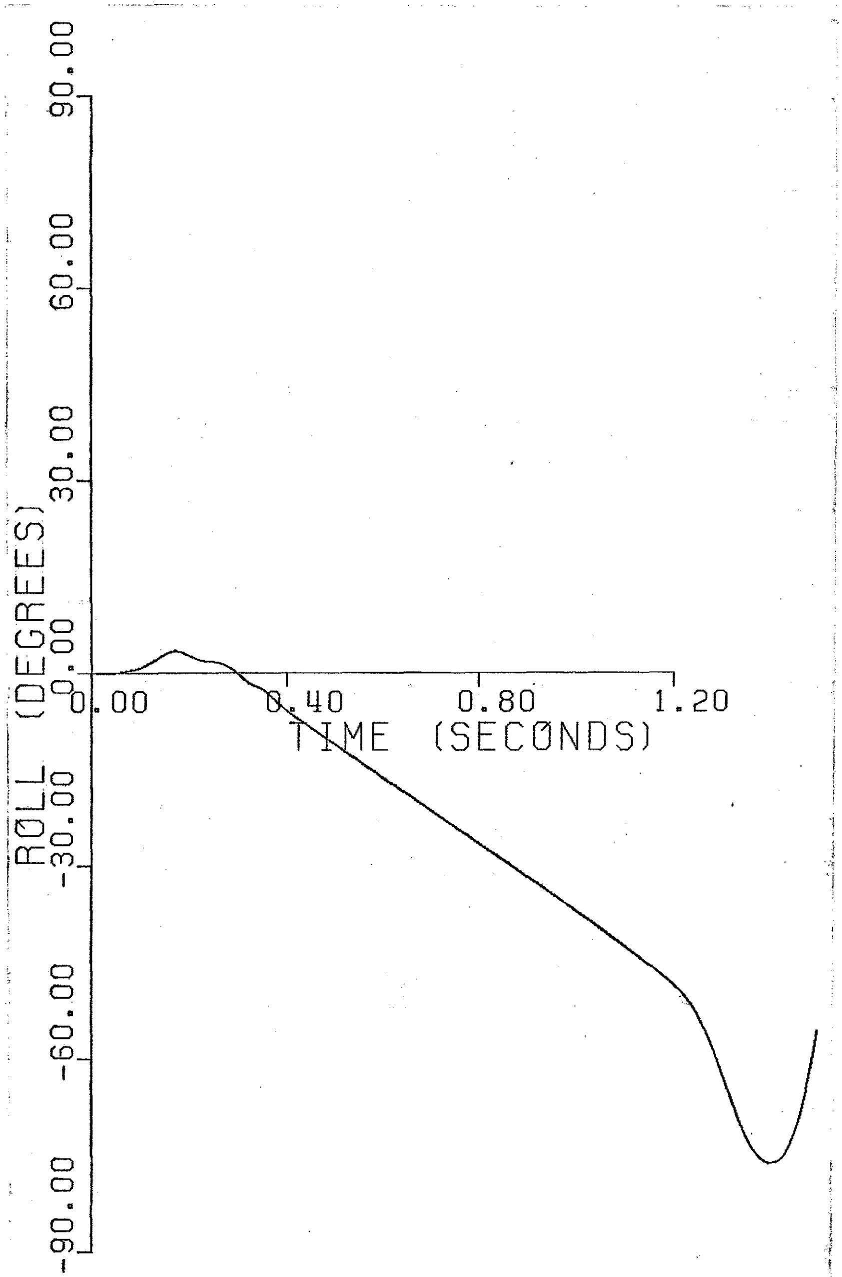
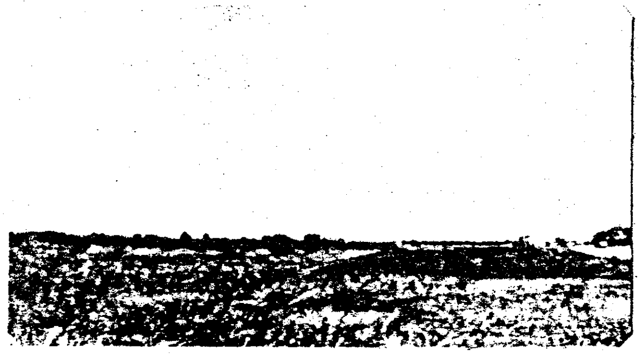


Figure B-44. Vehicle Roll, Test 7-1.

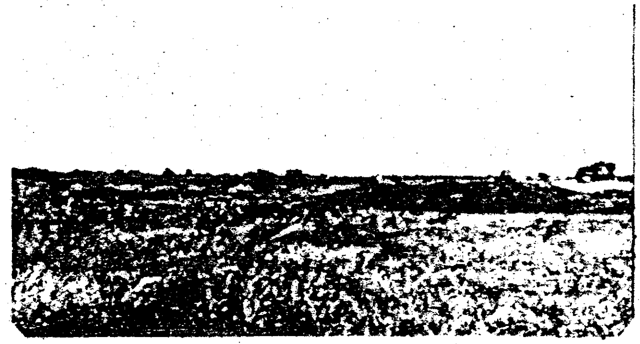
B-4-2. Test No. 7-2

For this test a single crossmember grate was installed as shown in Figure 9. Figures B-45 and B-46 contain sequential photos of the impact. The vehicle began to roll when the rear wheel impacted the top of the culvert. The vehicle subsequently rolled over. Figure B-47 contains photos of the damage to the vehicle as well as the culvert.

Plots of the longitudinal, transverse, and vertical accelerations versus time are contained in Figures B-48, B-49, and B-50. Figure B-51 contains a plot of the roll angle versus time.



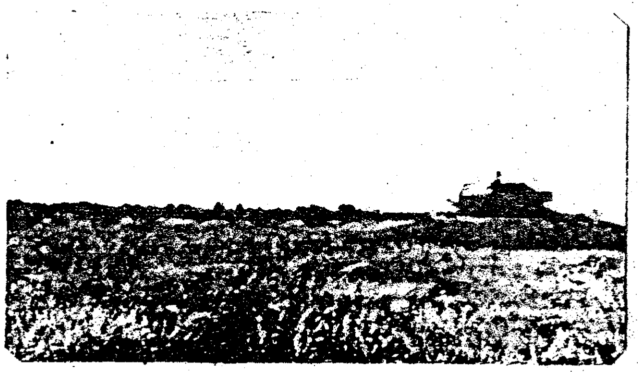
0.036



0.136

0.301

0.525



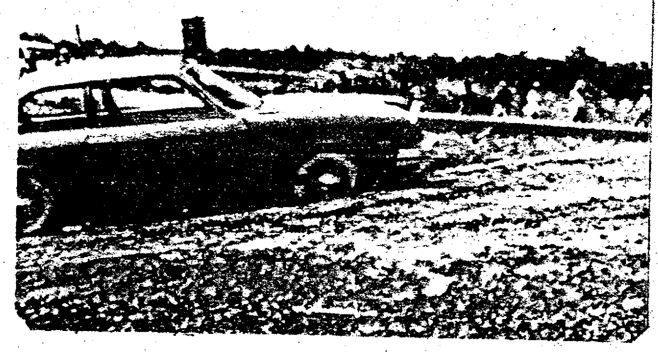
0.706

1.165

1.735

Figure B-45. Sequential Photos, Test 7-2.

0.036



0.136

0.301

Figure B-46. Sequential Photos, Test 7-2.

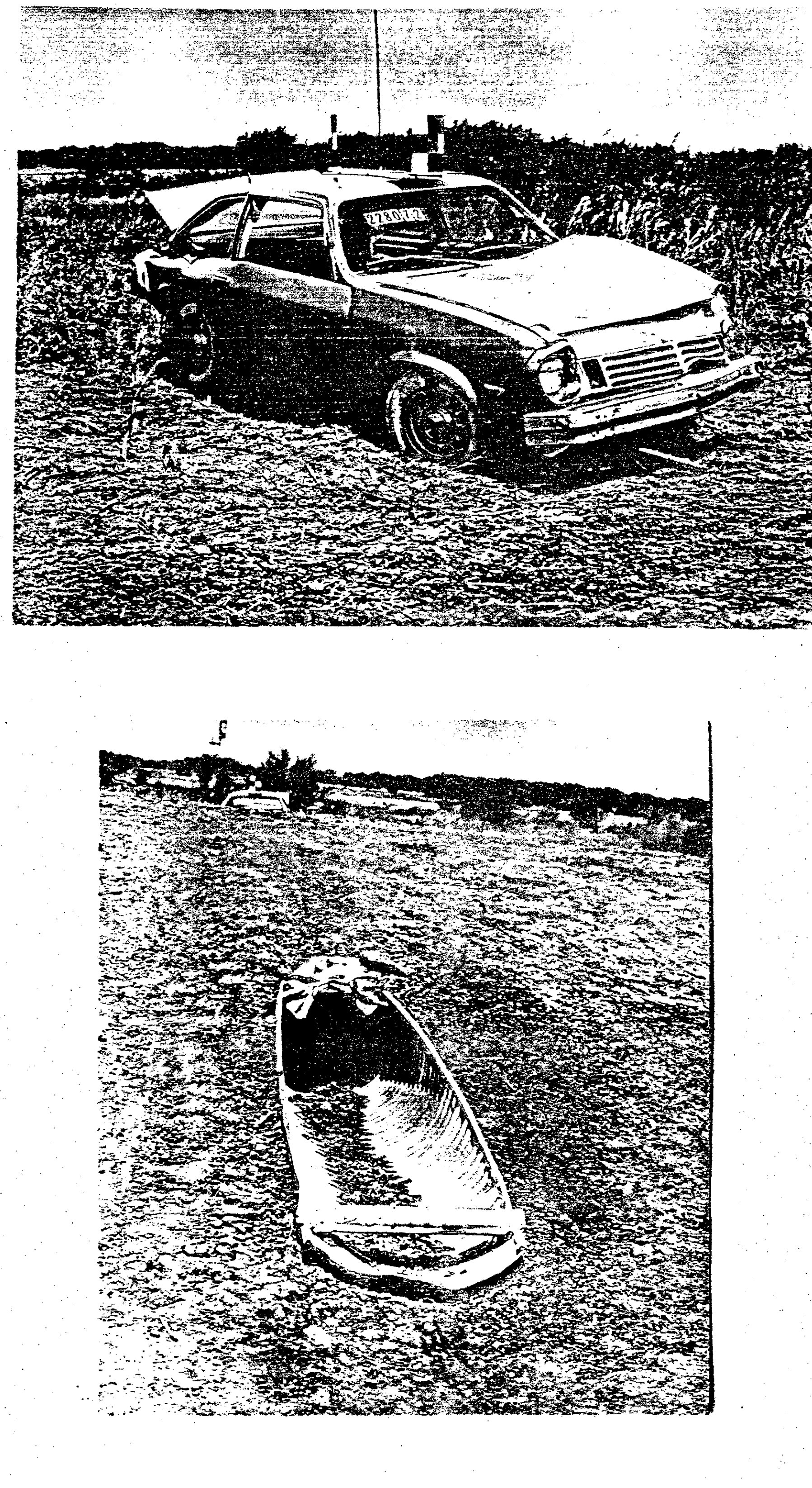


Figure B-47. Test Vehicle and Installation After Test 7-2.

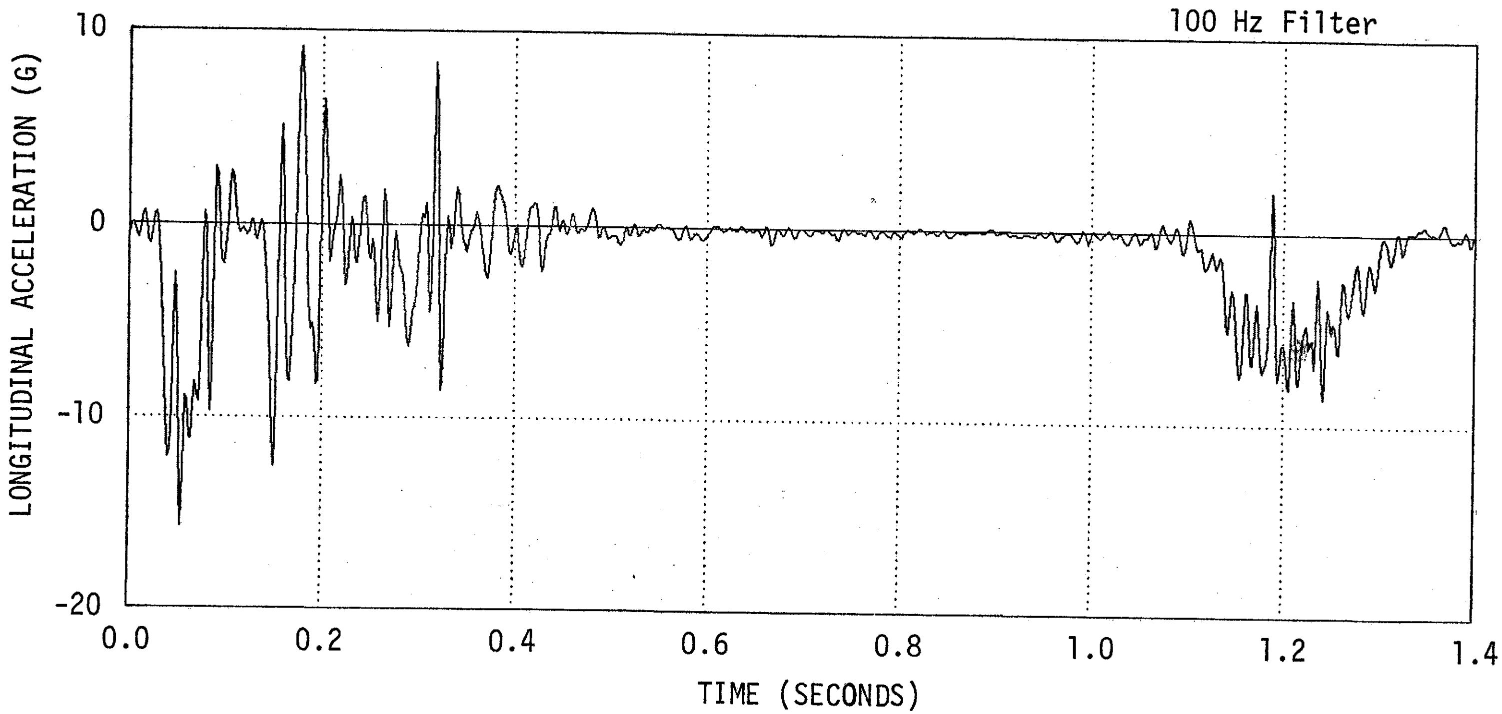


Figure B-48. Vehicle Longitudinal Acceleration, Test 7-2.

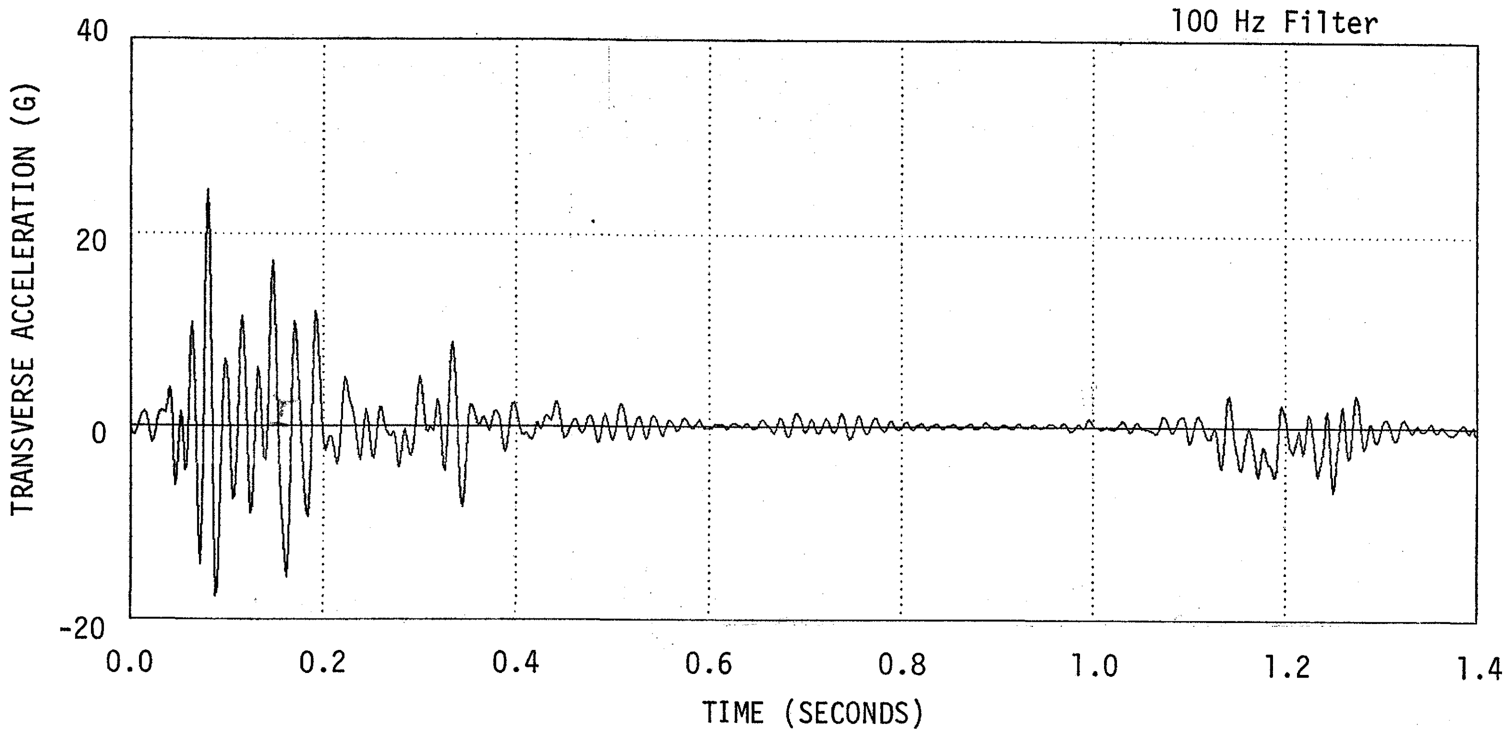


Figure B-49. Vehicle Transverse Acceleration, Test 7-2.

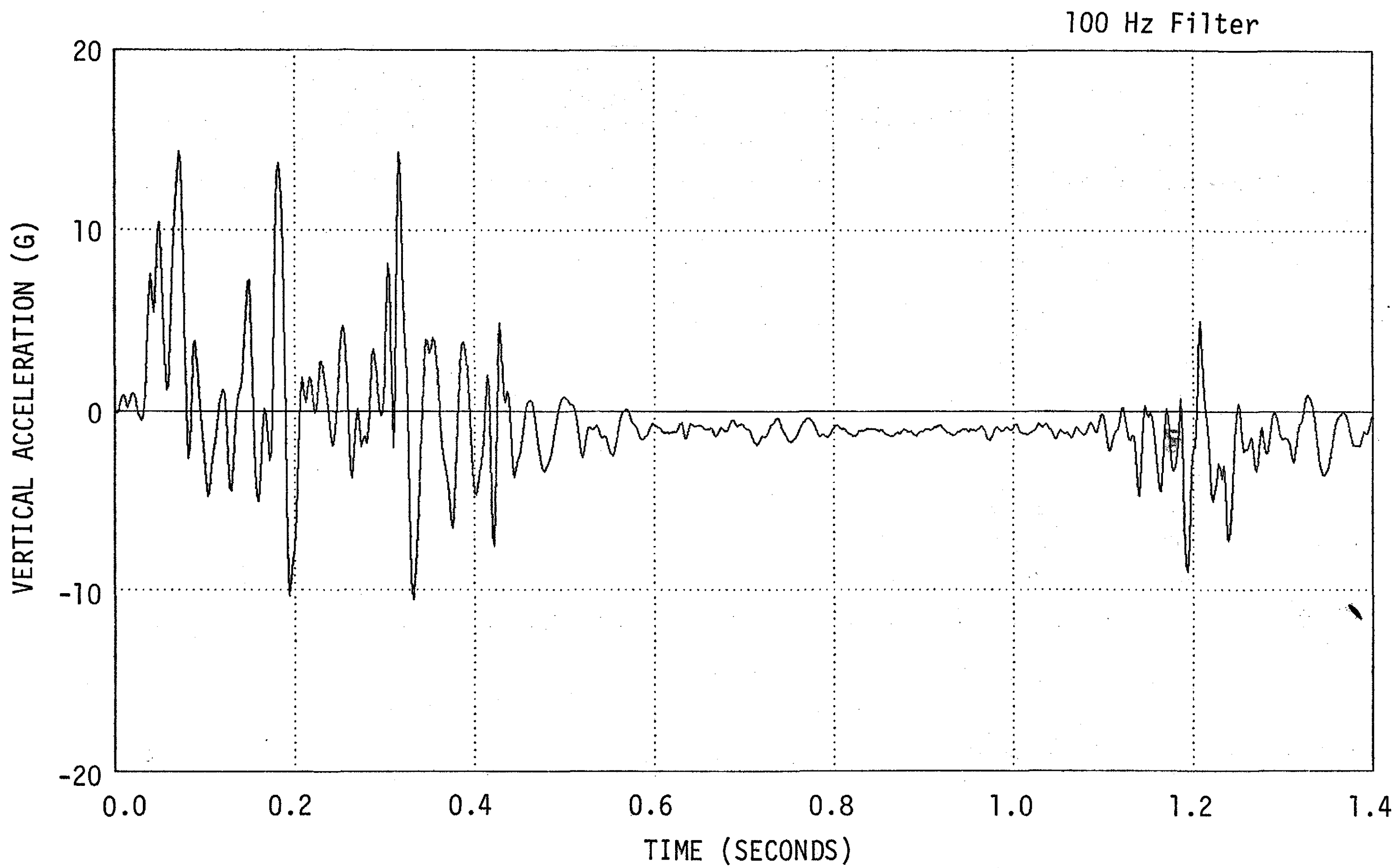


Figure B-50. Vehicle Vertical Acceleration, Test 7-2.

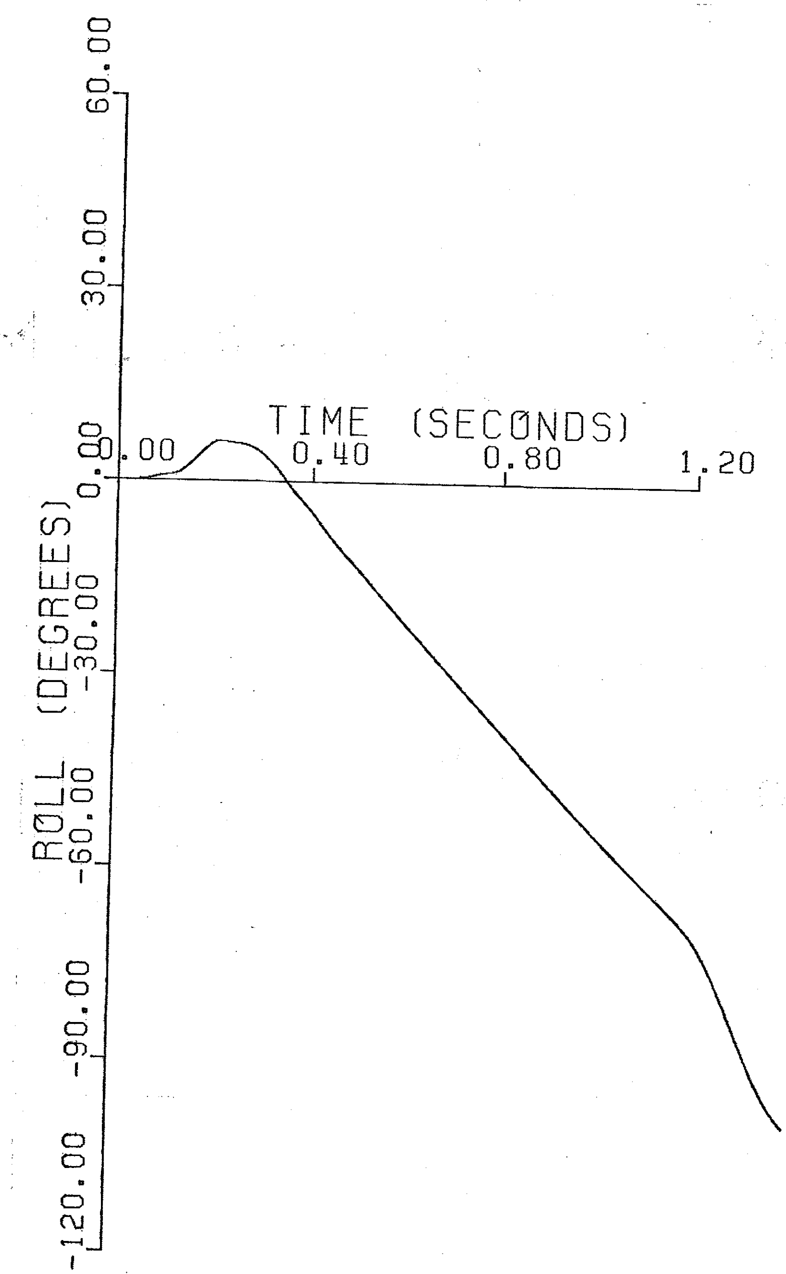


Figure B-51. Vehicle Roll, Test 7-2.

B-4-3. Test No. 7-4

Figure 10 contains photos of the vehicle and installation used in test 7-4. Four 2 lb/ft (2.98 kg/m) billet steel delineator posts were used for crossmembers. Figures B-52 and B-53 contain sequential photographs taken during impact. Due to the low impact speed of 20 mph (32.2 km/h) there was no damage to the car and little damage to the test installation. Figure B-54 shows the test vehicle and the installation after the test.

Figures B-55, B-56, and B-57 show plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-58 contains a plot of the roll angle versus time.

0.000

0.086

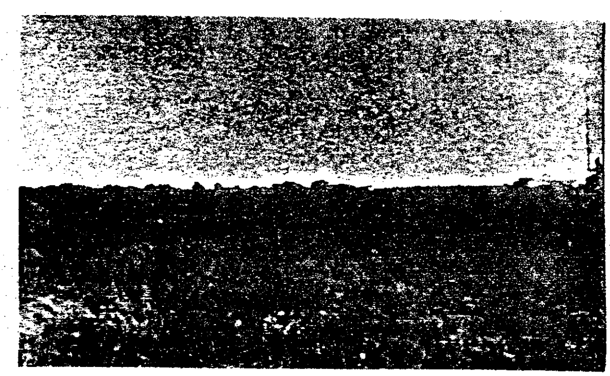
0.200

0.318

0.432

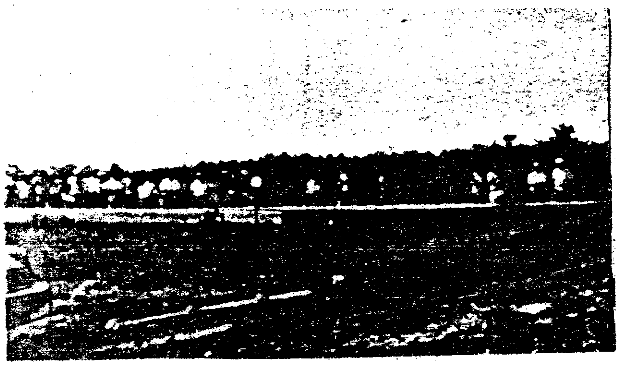
0.579

0.905

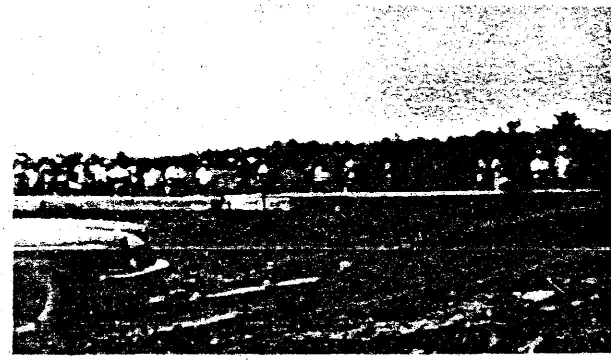


2.444

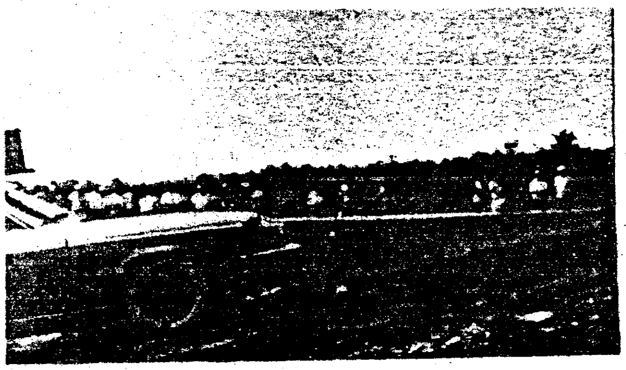
Figure B-52. Sequential Photos, Test 7-4.



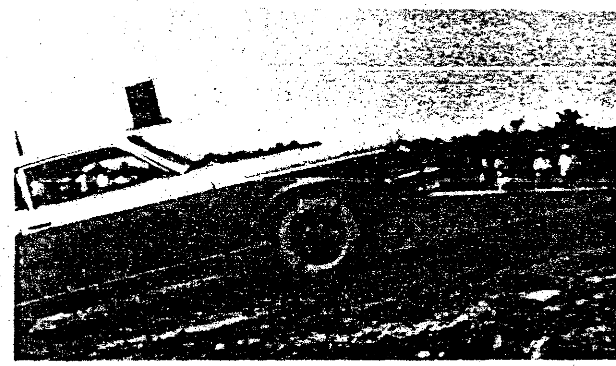
0.000



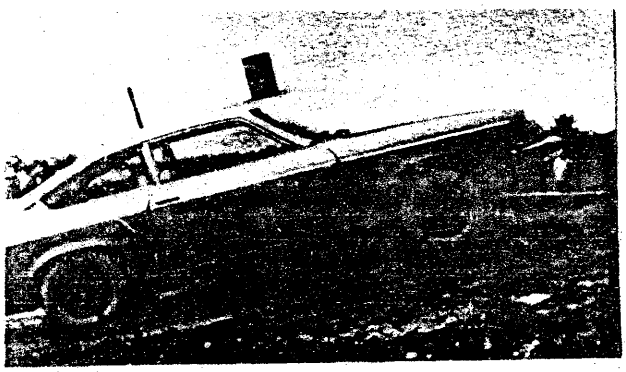
0.086



0.200



0.318



0.432

0.579

0.905

Figure B-53. Sequential Photos, Test 7-4.

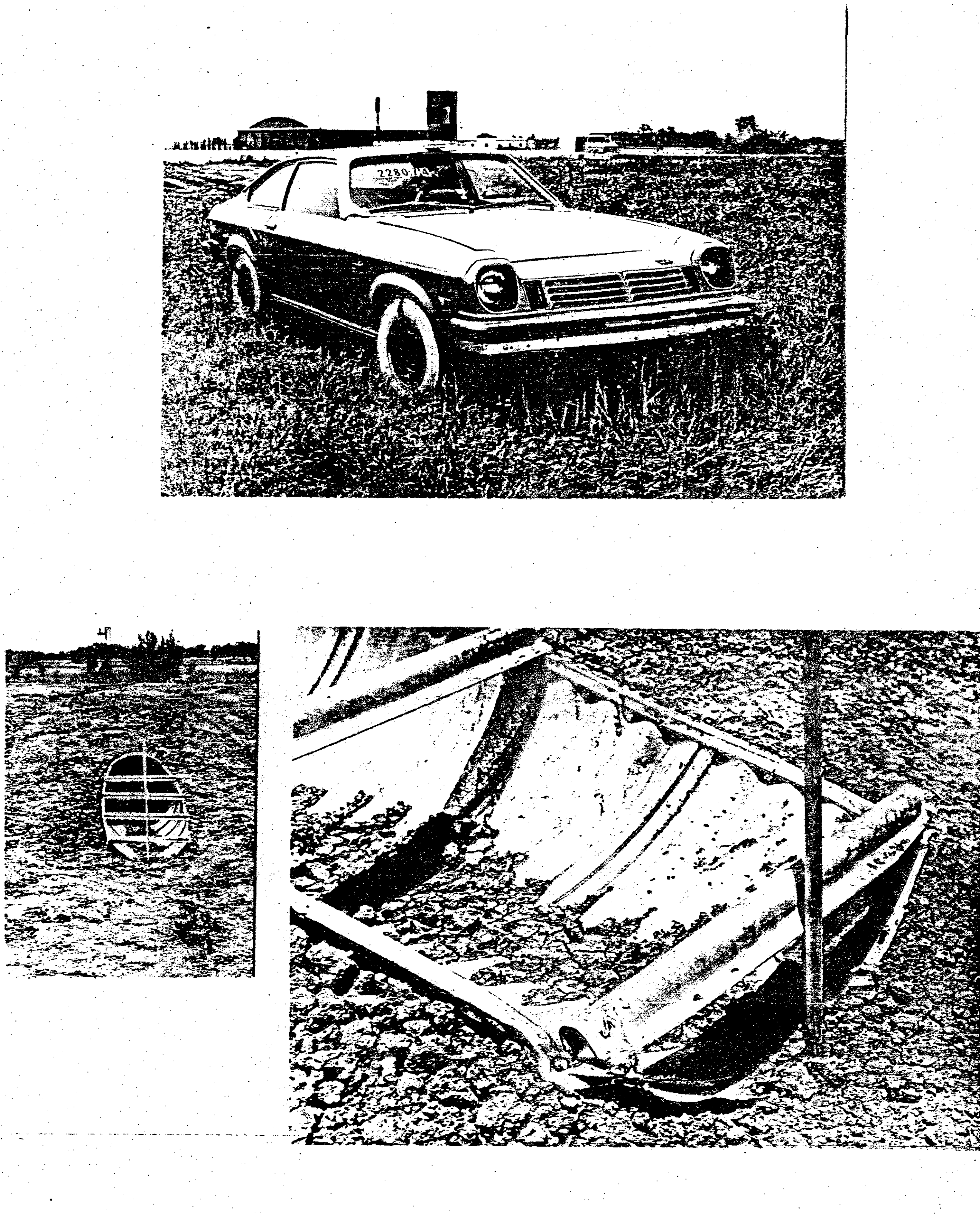


Figure B-54. Test Vehicle and Installation After Test 7-4.

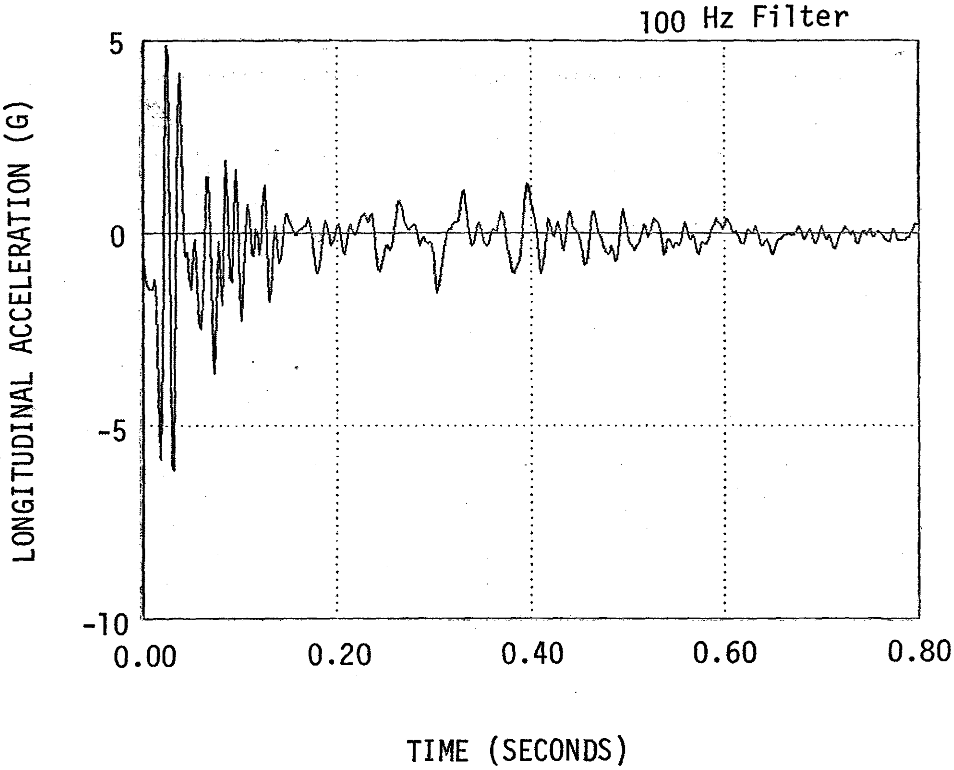


Figure B-55. Vehicle Longitudinal Acceleration, Test 7-4.

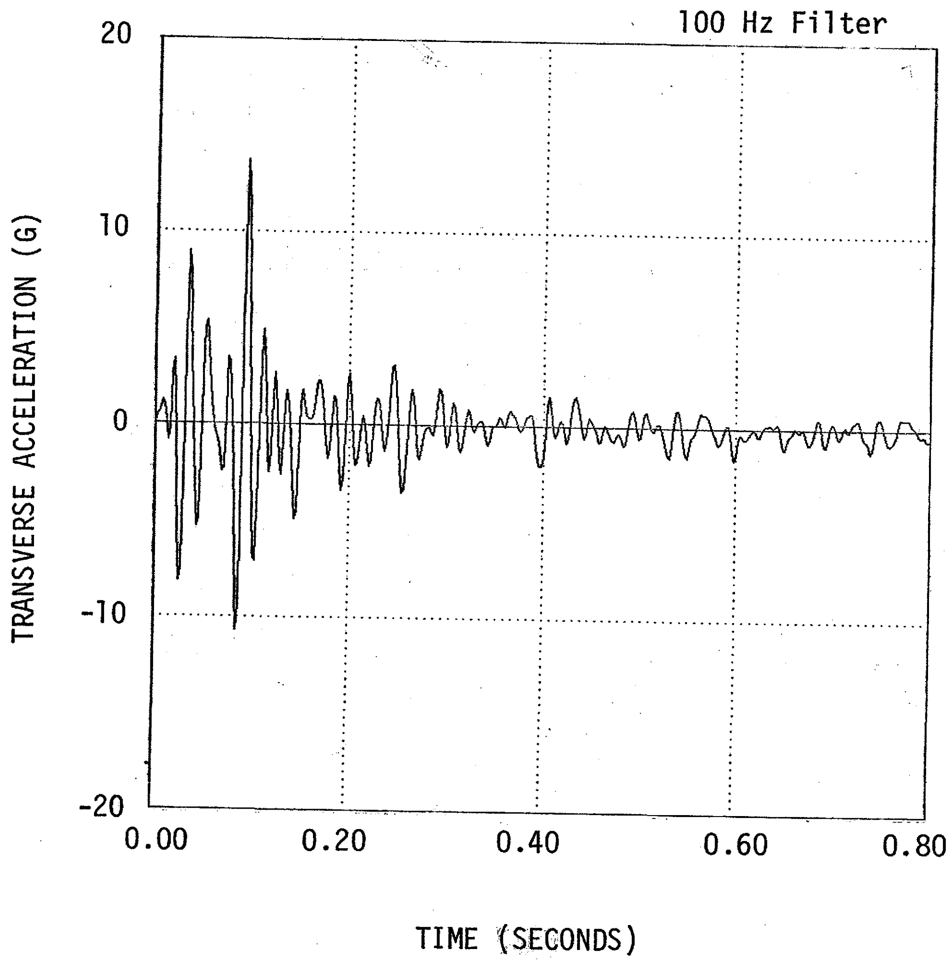


Figure B-56. Vehicle Transverse Acceleration, Test 7-4.

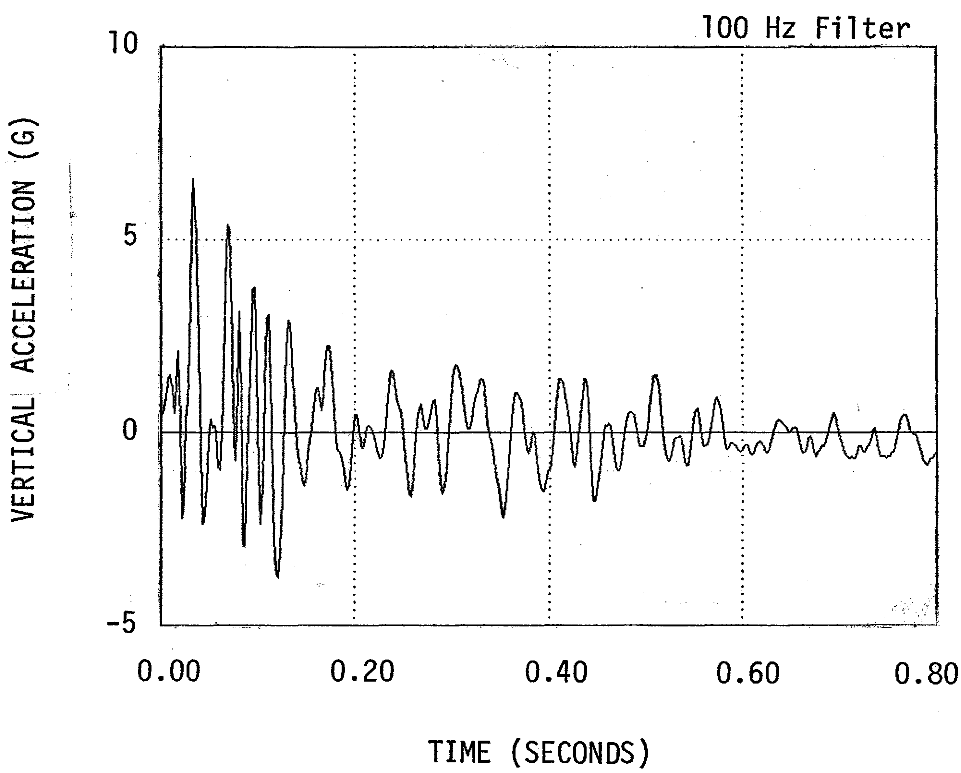


Figure B-57. Vehicle Vertical Acceleration, Test 7-4.

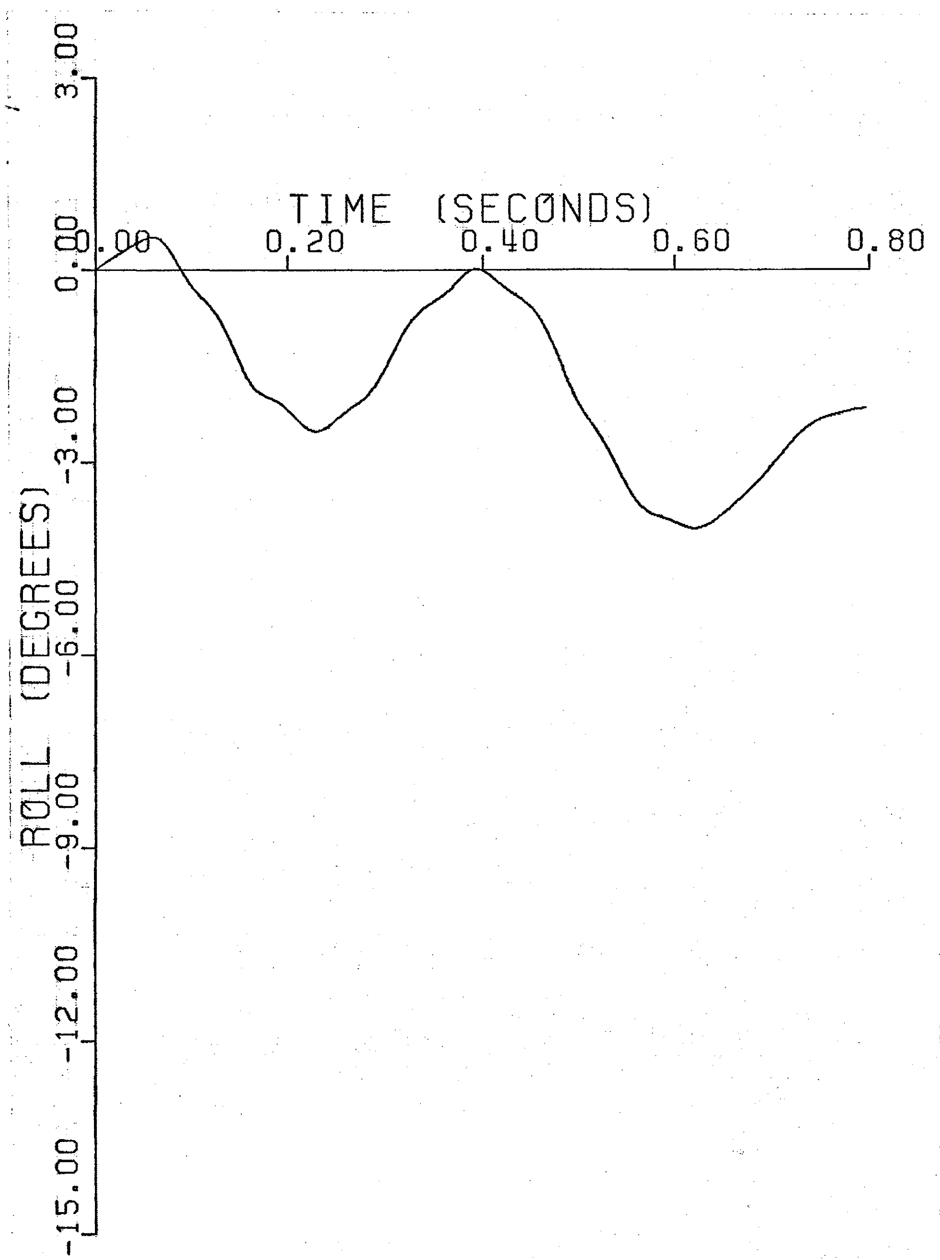


Figure B-58. Vehicle Roll, Test 7-4.

B-4-4. Test No. 7-5

Figure B-59 contains photos of the vehicle and installation before test 7-5. The same test installation and vehicle were used for test 7-5 as were used for test 7-4. Sequential photos taken during impact are shown in Figures B-60 and B-61. Two of the four crossmembers failed during this test, causing the vehicle to begin to roll when the rear tire impacted the final crossmember. The car eventually rolled completely over. Both the test vehicle and the test installation sustained significant damage as shown in Figure B-62.

Figures B-63, B-64, and B-65 contain plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-66 contains a plot of the roll angle versus time.

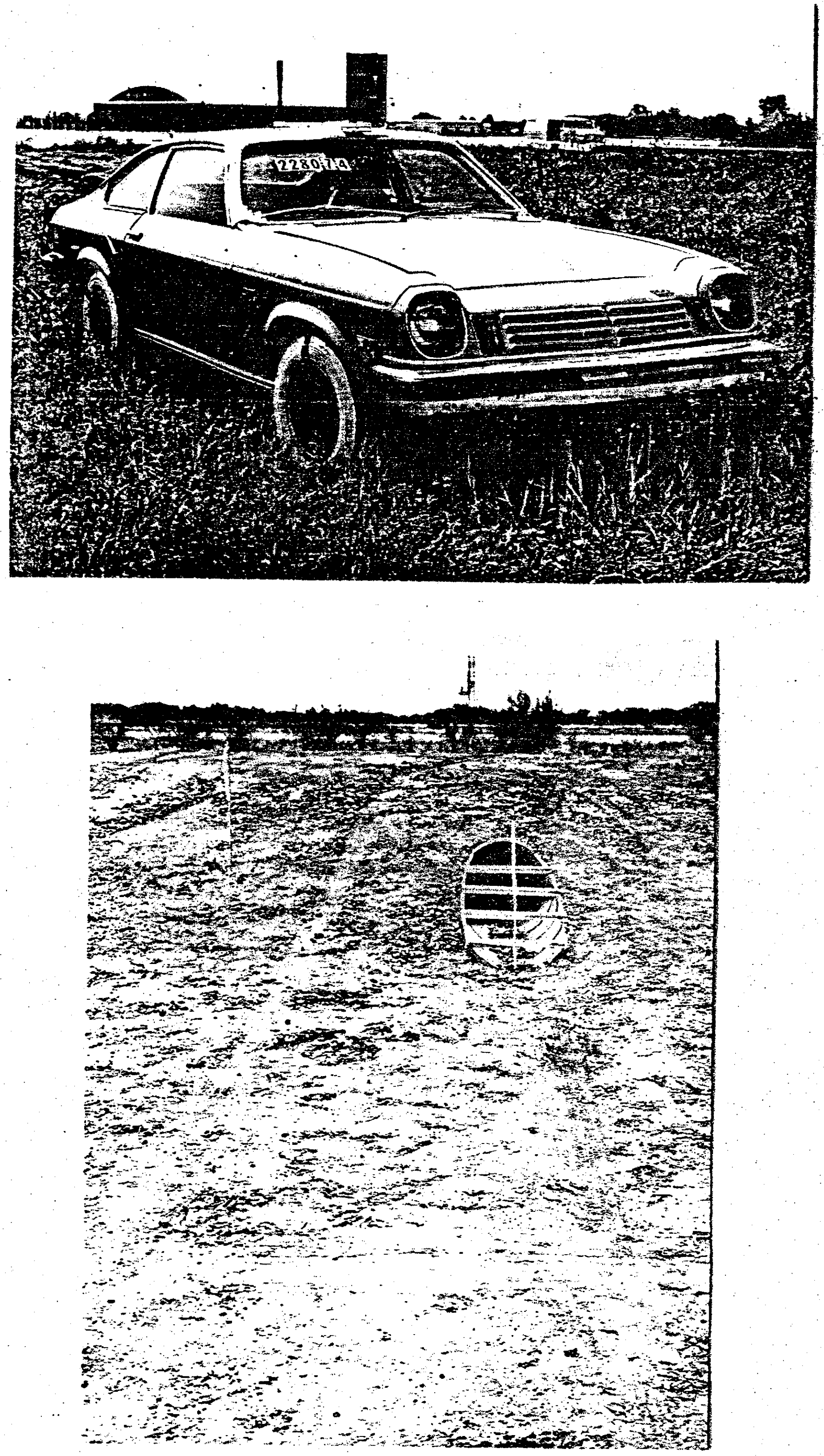
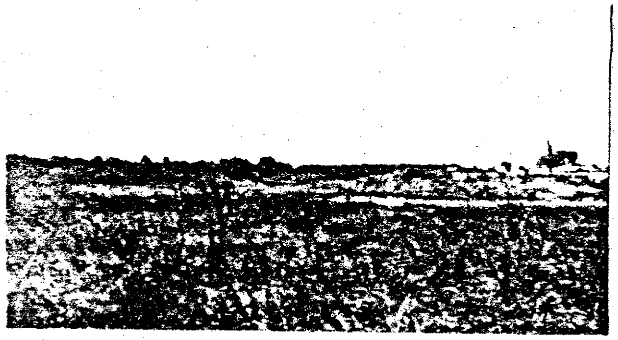


Figure B-59. Test Vehicle and Installation Before Test 7-5.



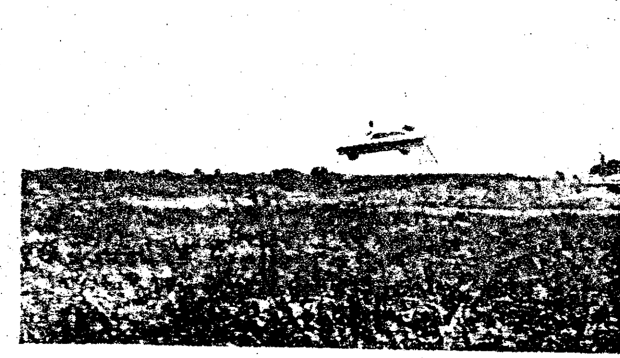
0.000

0.053

0.072

0.213

0.401



0.802

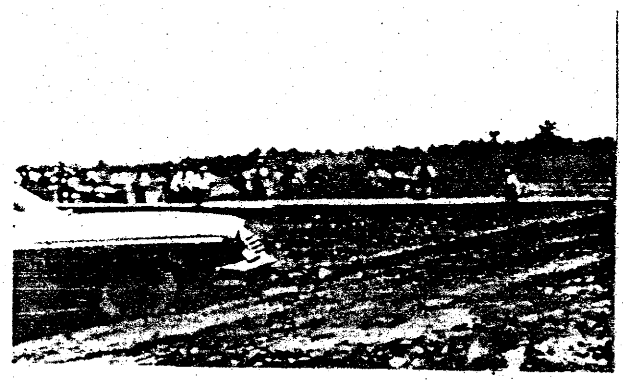
1.415

2.156

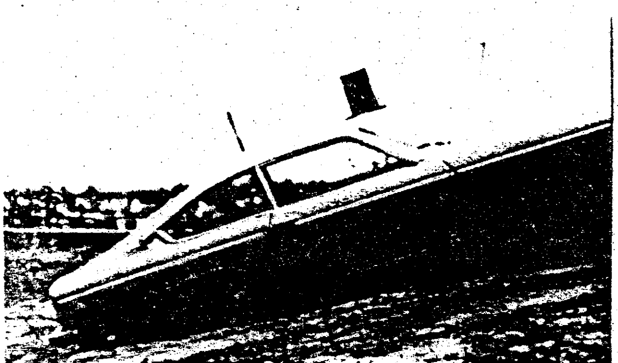
Figure B-60. Sequential Photos, Test 7-5.

0.000

0.053



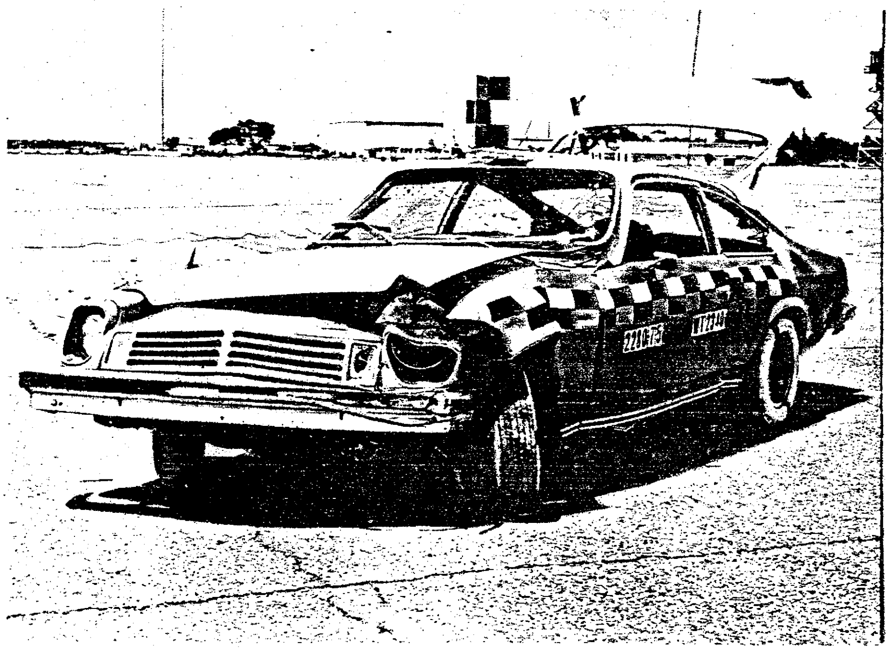
0.072



0.213

0.401

Figure B-61. Sequential Photos, Test 7-5.



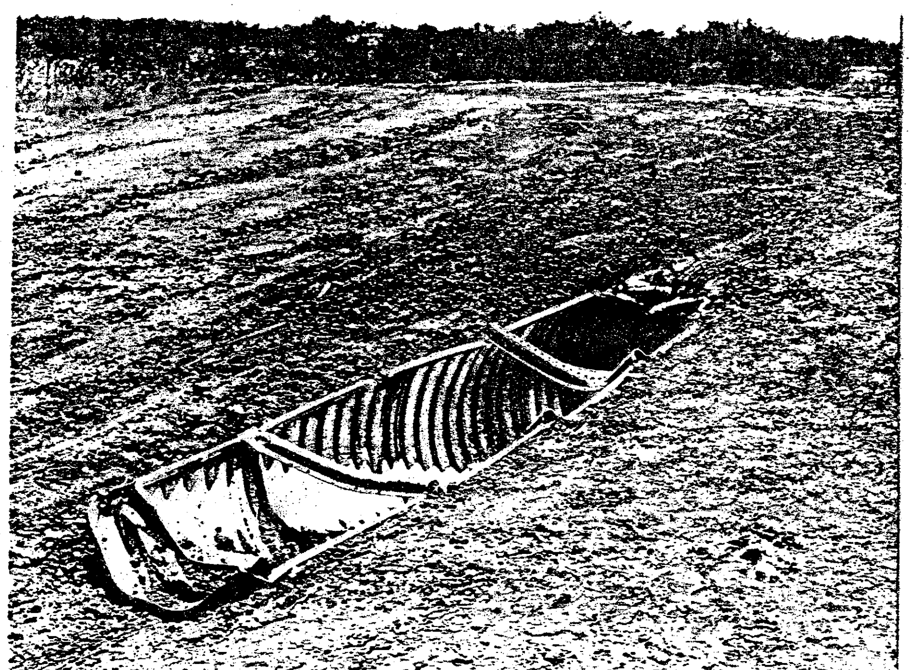


Figure B-62. Test Vehicle and Installation After Test 7-5.

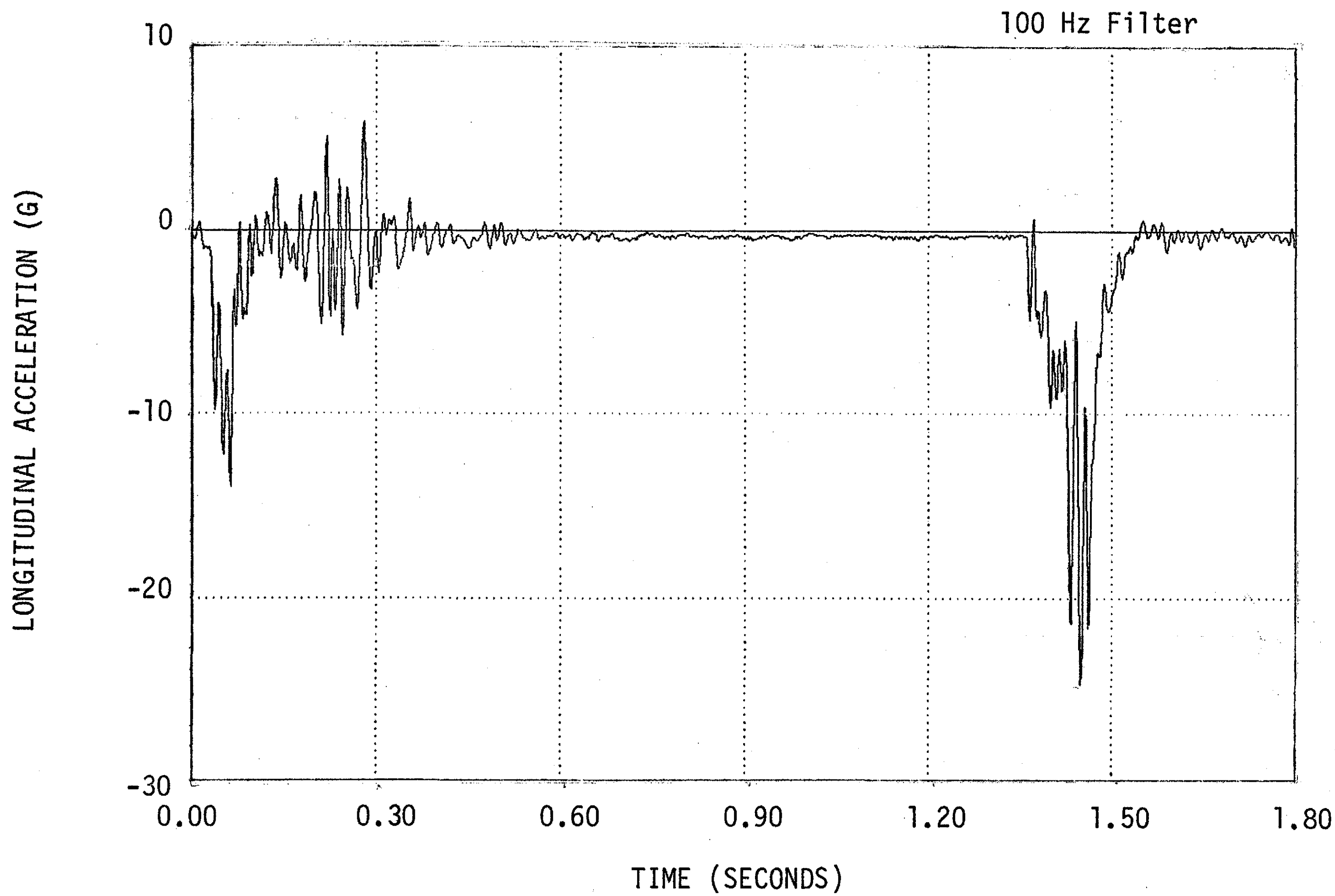


Figure B-63. Vehicle Longitudinal Acceleration, Test 7-5.

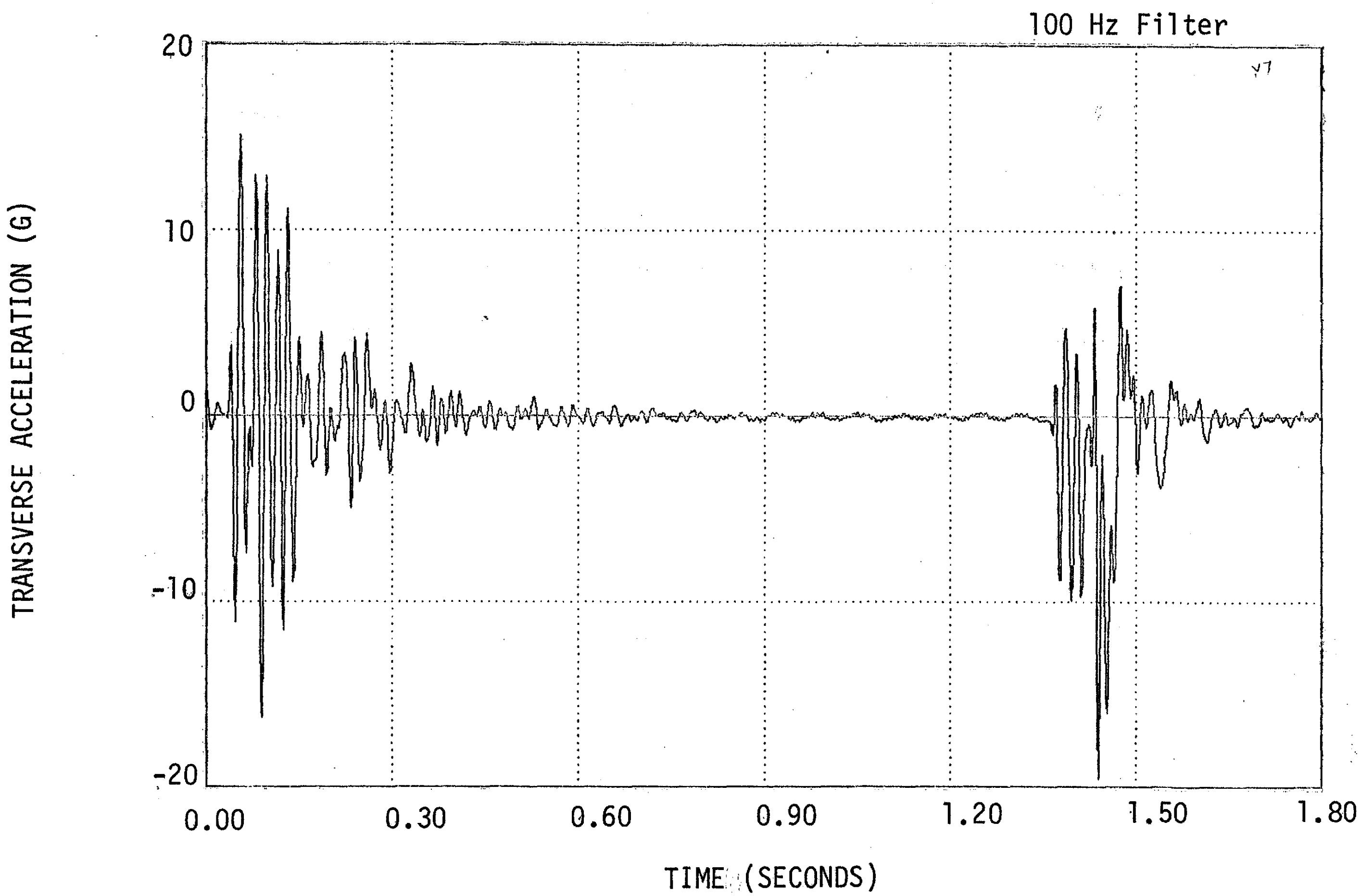


Figure B-64. Vehicle Transverse Acceleration, Test 7-5.

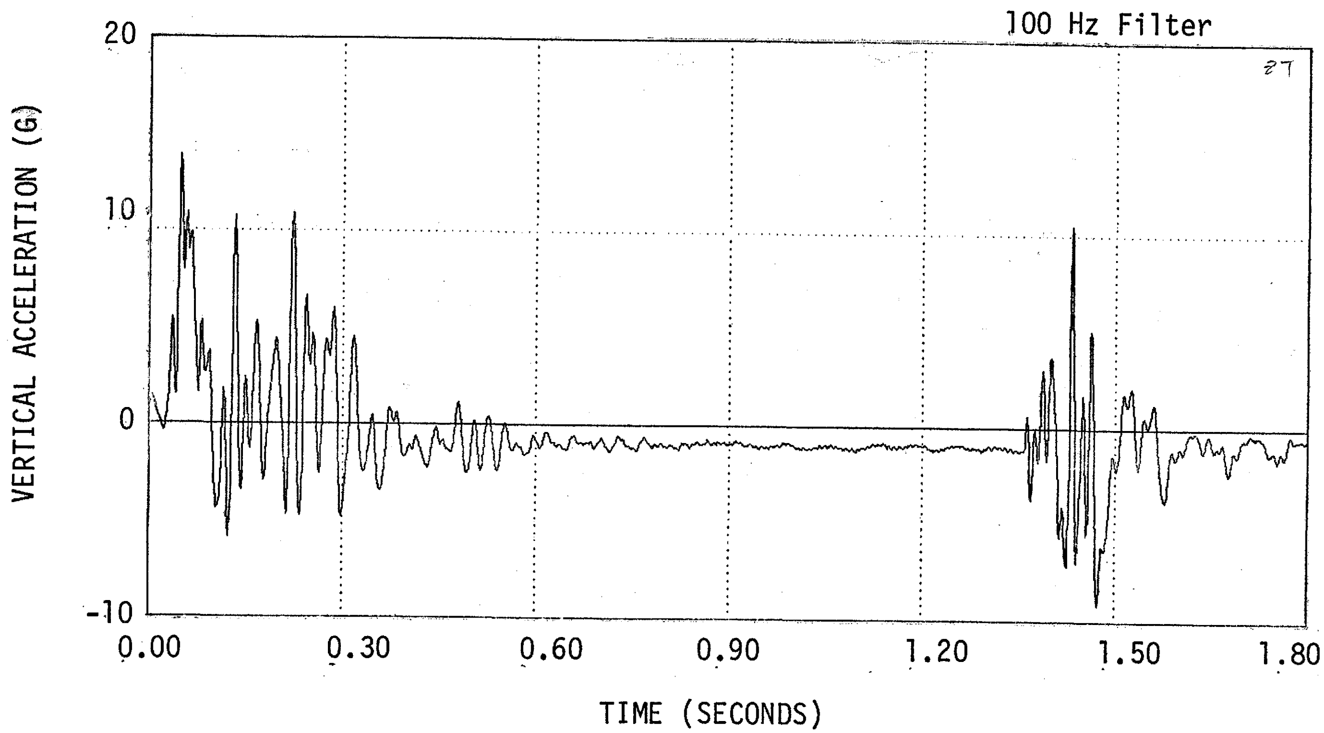


Figure B-65. Vehicle Vertical Acceleration, Test 7-5.

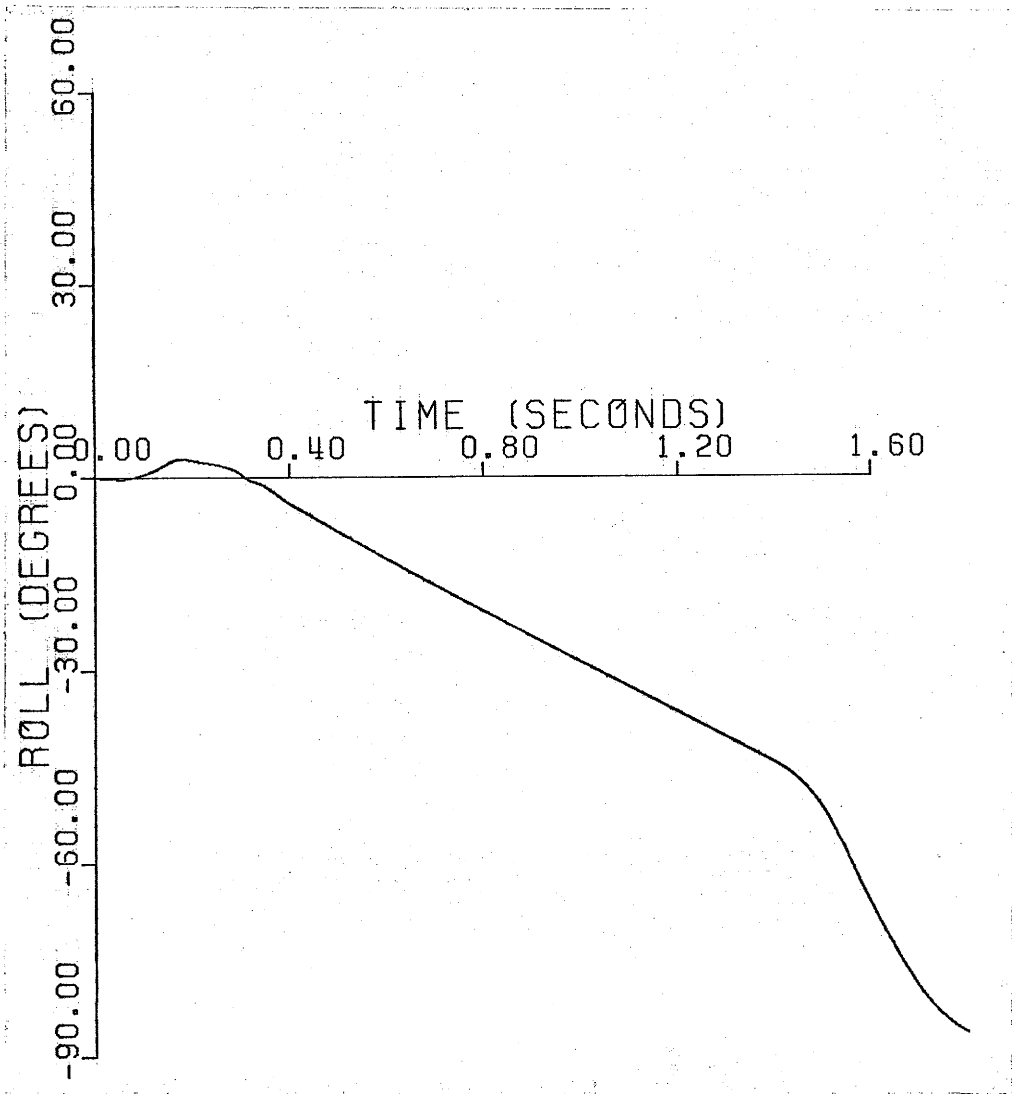
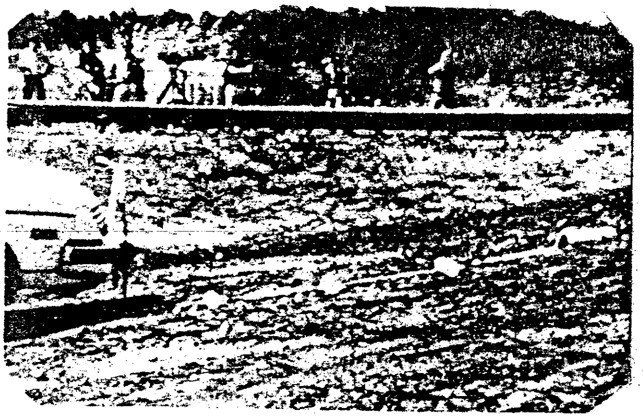


Figure B-66. Vehicle Roll, Test 7-5.

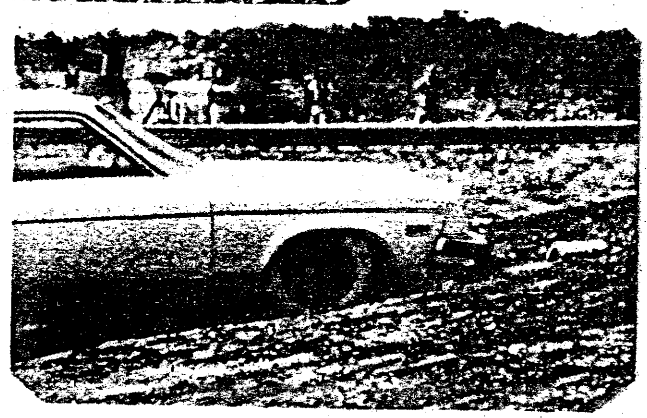
B-4-5. Test No. 7-6

In this test the culvert grating consisted of four 2.5 in. (6.35 cm) I.D. schedule 40 steel pipe spaced 24 in. (61 cm) apart. Figure 10 contains photos of the test vehicle and test installation before impact. Further details of this treatment are given in Figure 5. Figures 11 and B-67 contain sequential photos taken during the event. The car traversed the culvert and landed without rollover. It did, however, attain a roll angle of 40 degrees while the vehicle was airborne. Figure B-68 shows the damage done to the test vehicle as well as the test installation.

Figures B-69, B-70, and B-71 contain plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-72 shows a plot of the roll angle versus time.



0.000



0.084

0.220

0.274

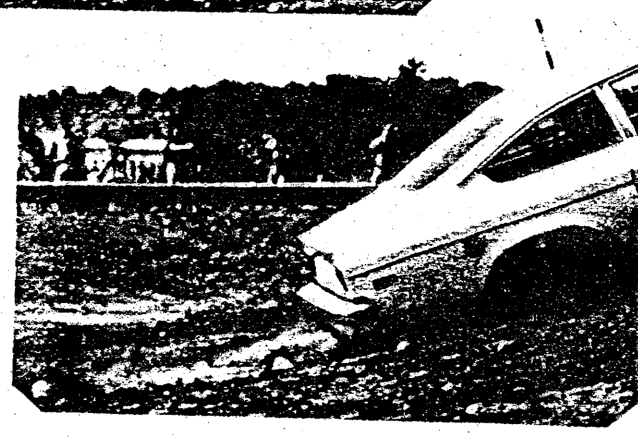


Figure B-67. Sequential Photos, Test 7-6.

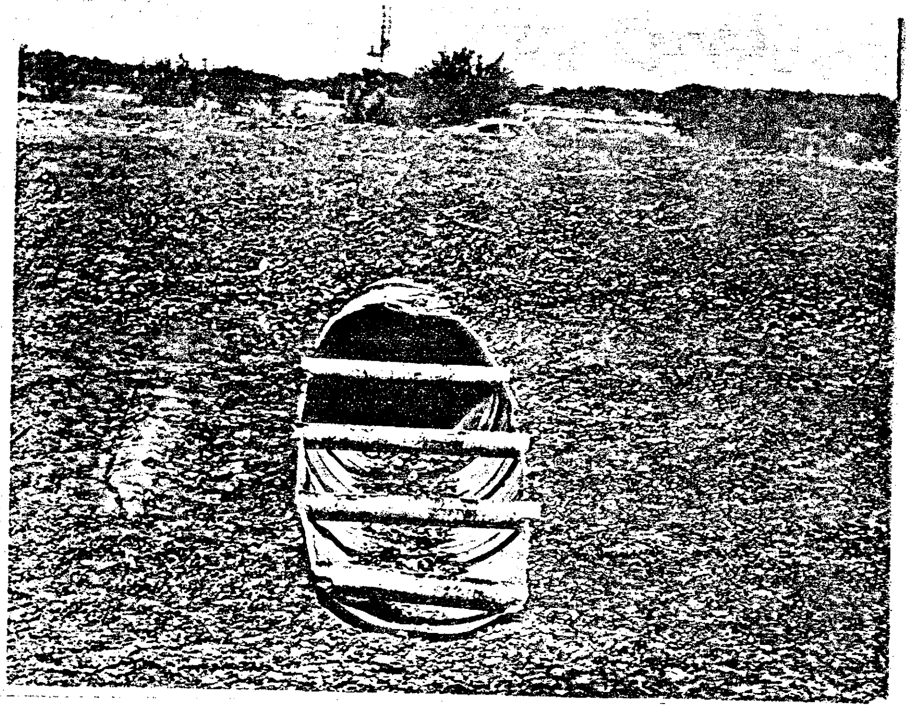


Figure B-68. Test Vehicle and Installation After Test 7-6.

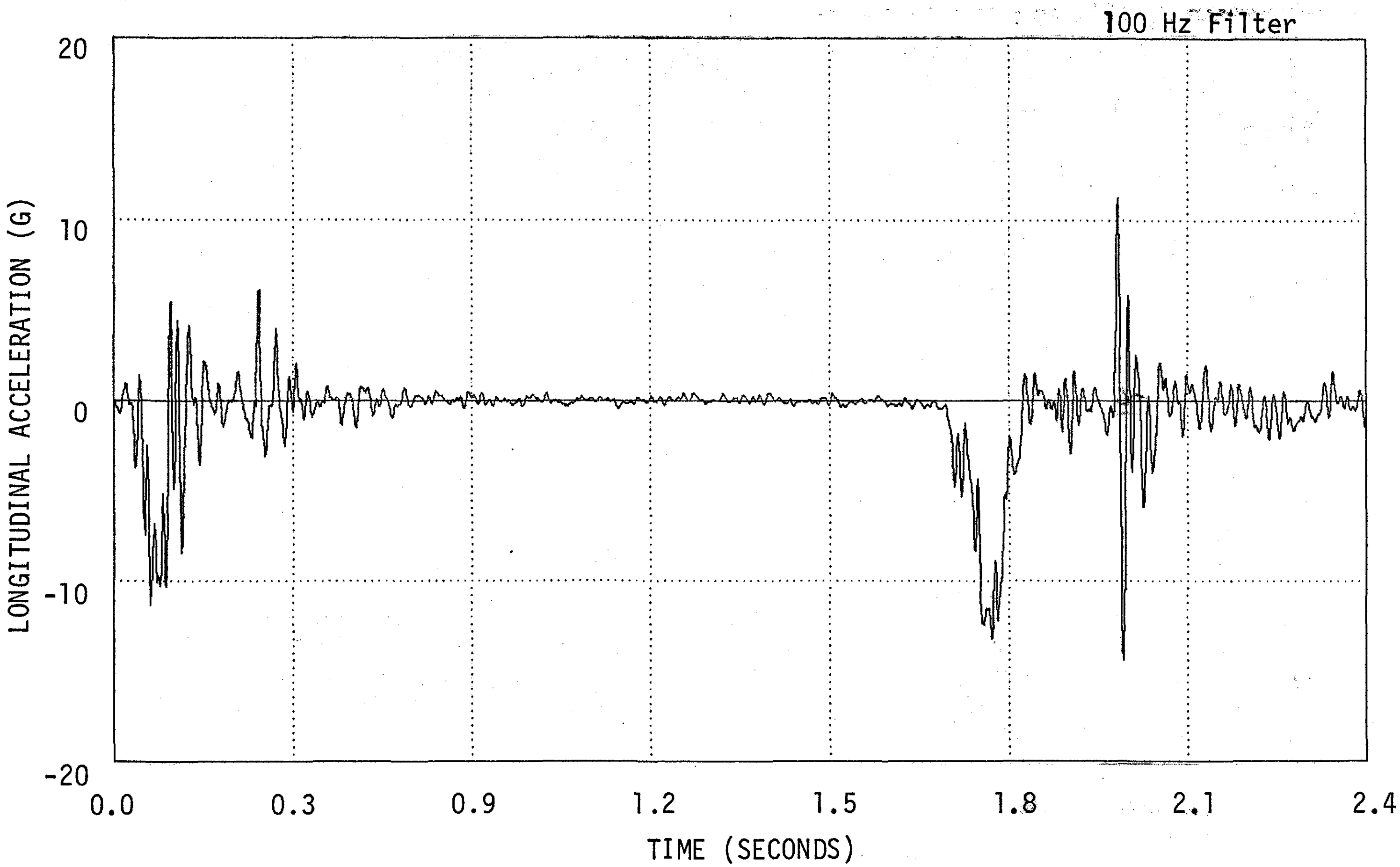


Figure B-69. Vehicle Longitudinal Acceleration, Test 7-6.

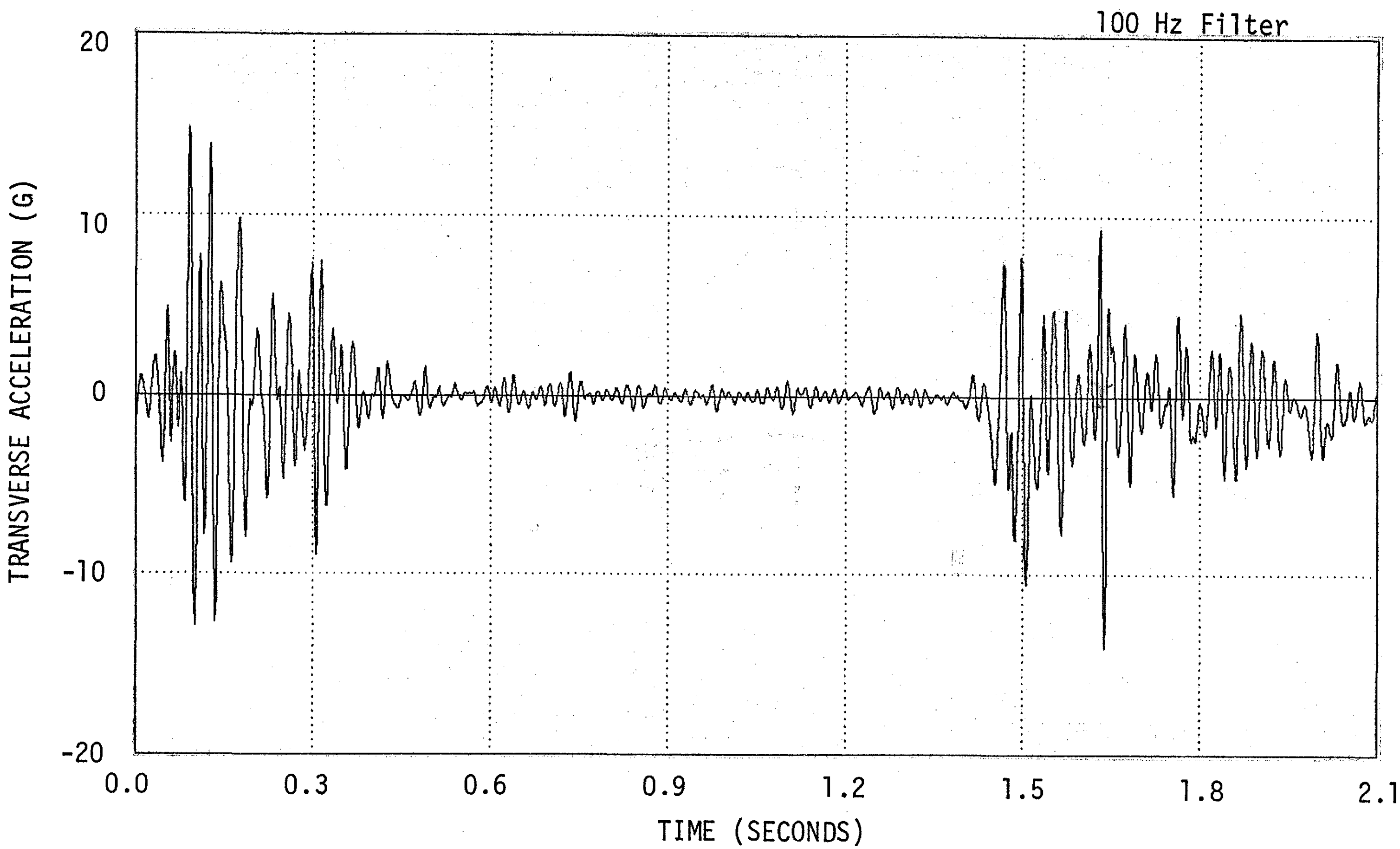


Figure B-70. Vehicle Transverse Acceleration, Test 7-6.

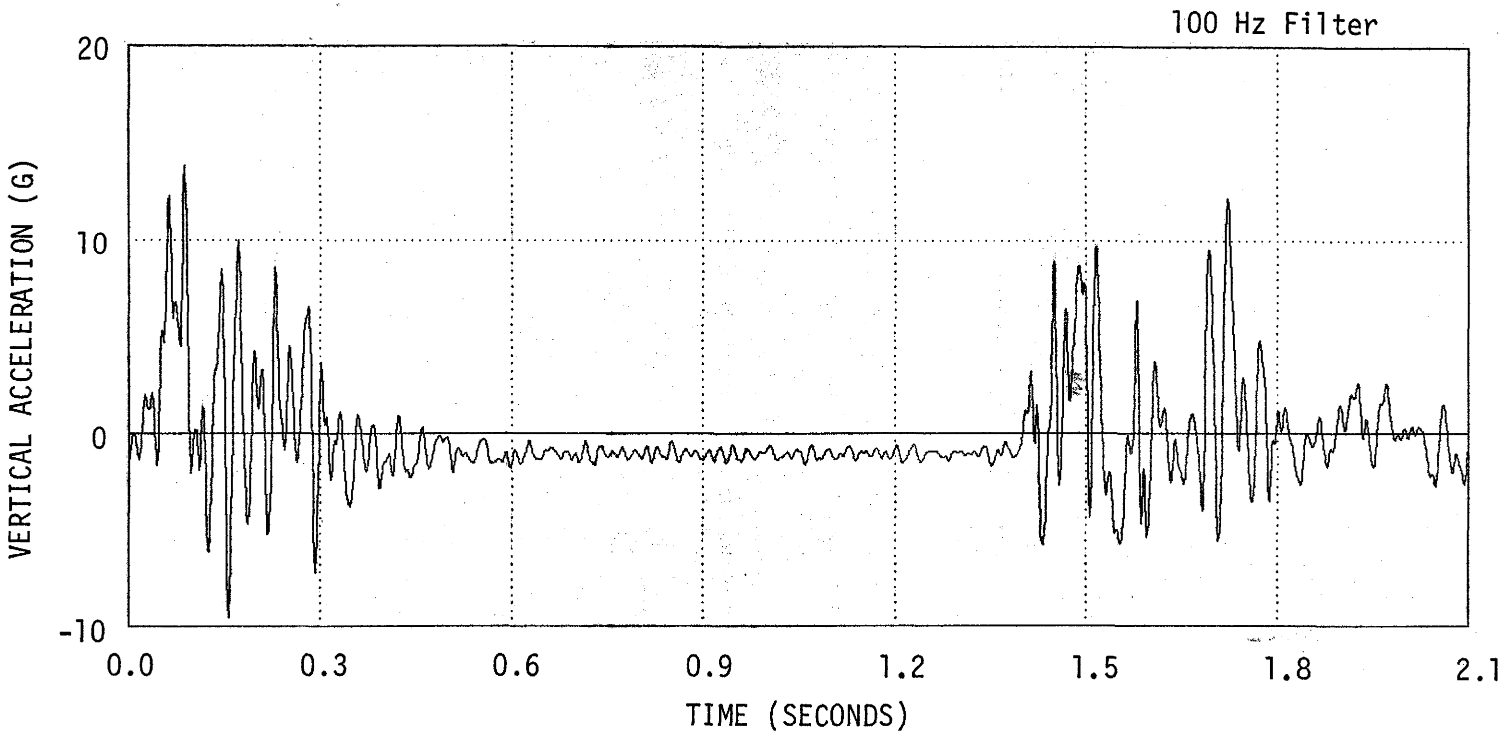


Figure B-71. Vehicle Vertical Acceleration, Test 7-6.

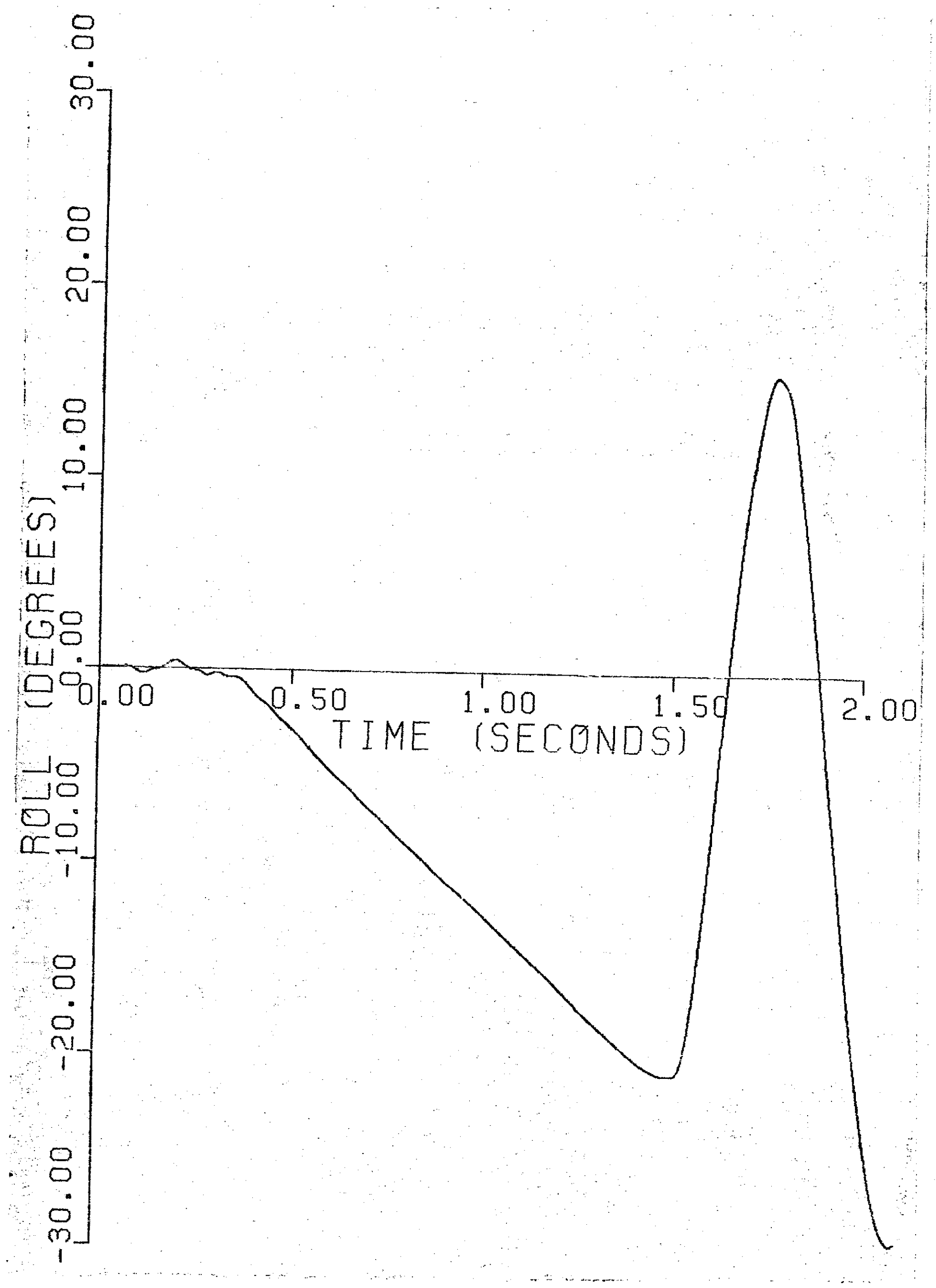


Figure B-72. Vehicle Roll, Test 7-6.

B-5. Prototype Tests

This section describes two tests conducted to verify results of the slope tests and the grating tests. Table B-3 summarizes the results of these tests. A discussion of these results and the conclusions drawn therefrom can be found in Section IV-3.

The test installation for these tests consisted of a driveway constructed across a drainage ditch. The ditch and driveway slopes were near 6 to 1. The culvert and grating tested in test 7-6 were installed in the driveway. Details of th ditch-driveway geometry are given in Figure 12. The encroachment angle was 15 degrees, measured from the centerline of the ditch. The impact point is shown in Figure 12.

TABLE B-3. SUMMARY OF PROTOTYPE TESTS

TEST NO.	TEST SPEED (mph)	DITCH SLOPE	DRIVEWAY SLOPE	CROSSMEMBER SPACING (in.)	VEHICLE DAMAGE CLASSIFICATION TAD	SAE	PEAK 50 MS AVG. ACCELERATION (g's)	DID VEHICLE ROLL OVER?
9-1	40	7:1	6.5:1	24	FD-1	12VDXW1	8.0	No
9-2	50	7:1	6.5:1	24	FD-3	12VDSW2	7.4	No

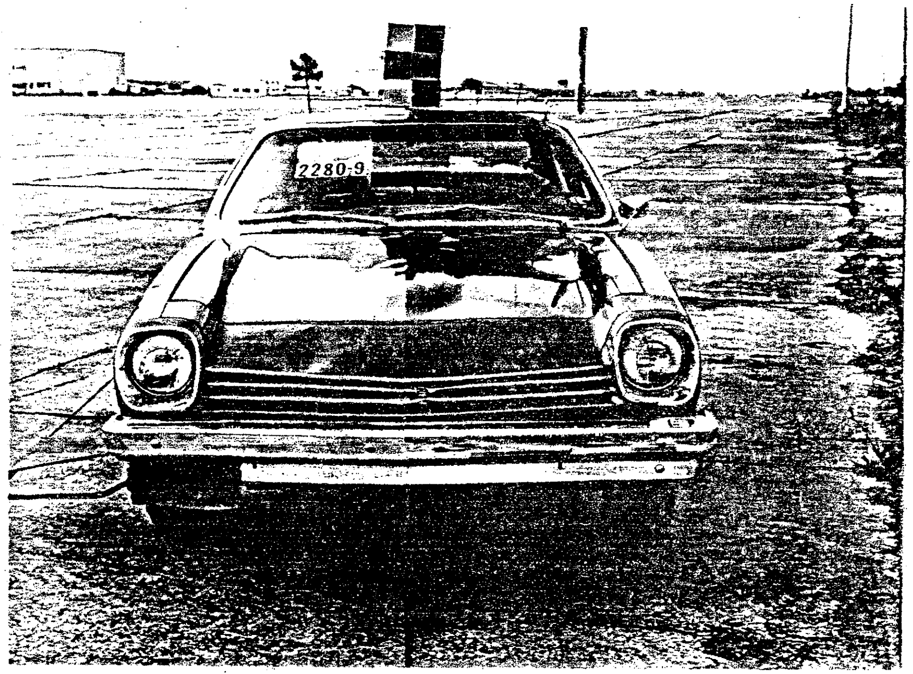
Metric Conversions:

1 mph = 1.609 km/h
1 in. = 2.54 cm

B-5-1. Test No. 9-1

Figure B-73 contains photos of the test vehicle and installation before impact. Figures B-74, B-75, and B-76 contain sequential photos during the event. The test vehicle was airborne for only a short distance and landed without rolling over. Neither the car nor the test installation sustained major damage as shown in Figure B-77. Both were reused for test 9-2.

Figures B-78, B-79, and B-80 contain plots of longitudinal, transverse, and vertical accelerations versus time. Figure B-81 contains a plot of the roll angle versus time.



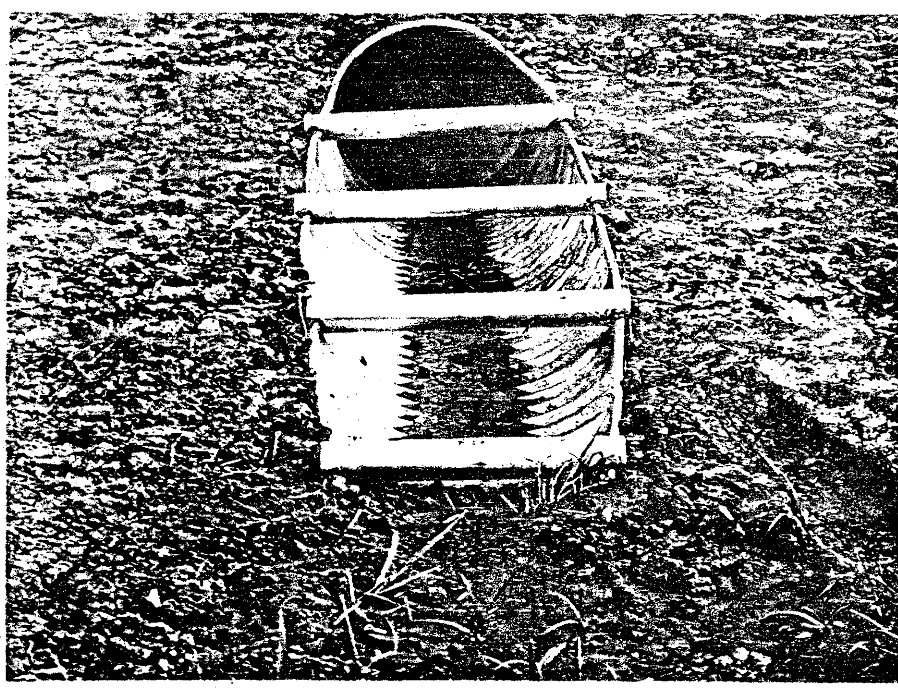


Figure B-73. Test Vehicle and Installation Before Test 9-1.

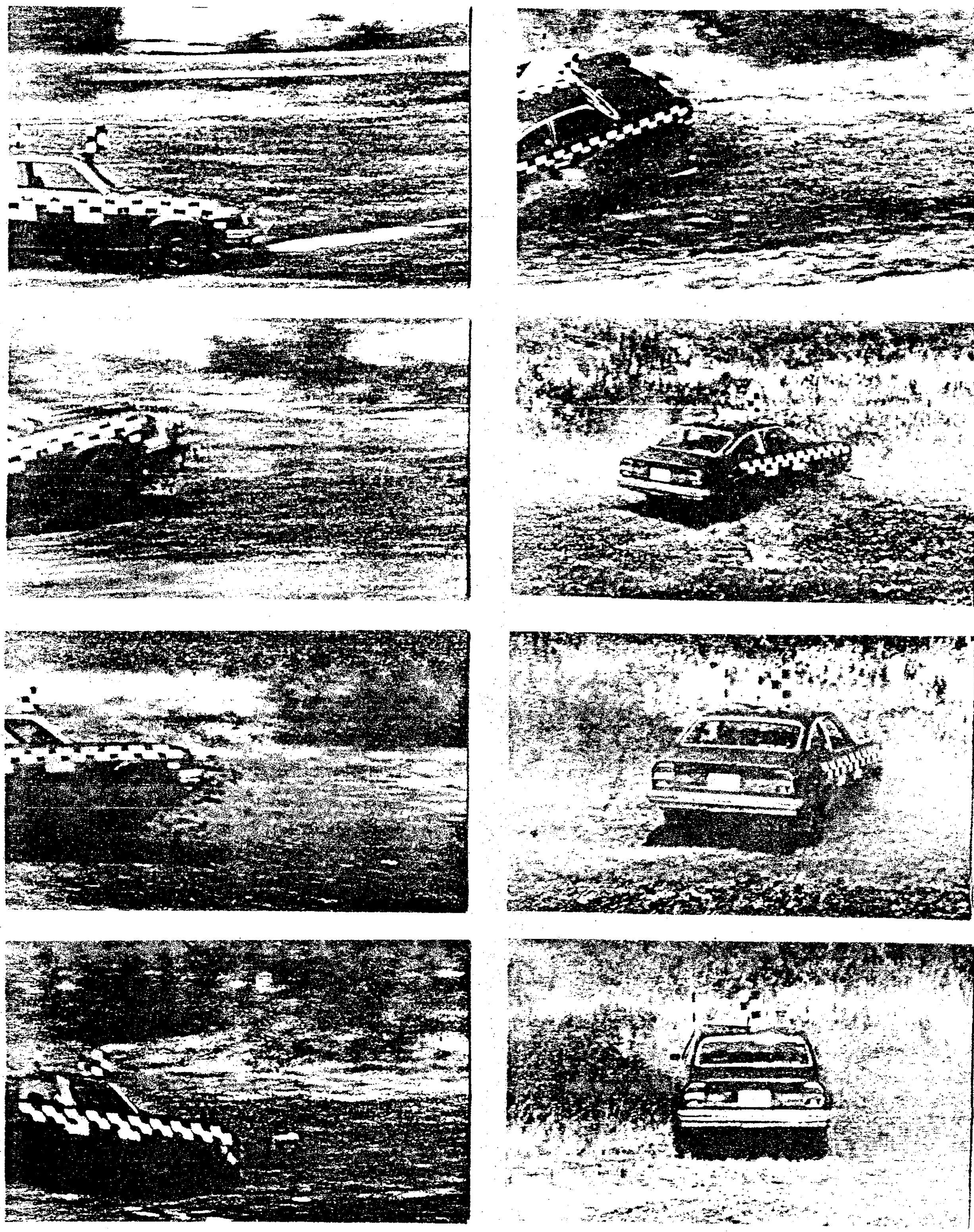
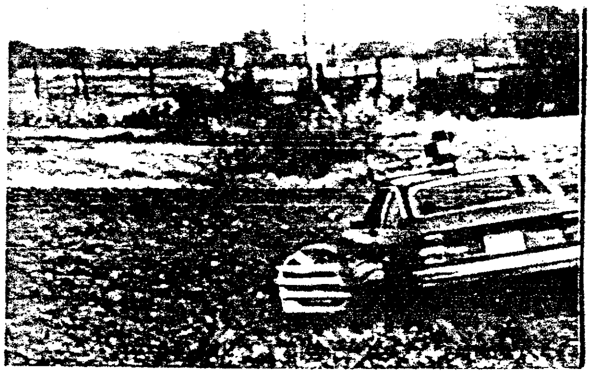


Figure B-74. Sequential Photos, Test 9-1; Pan Shot.



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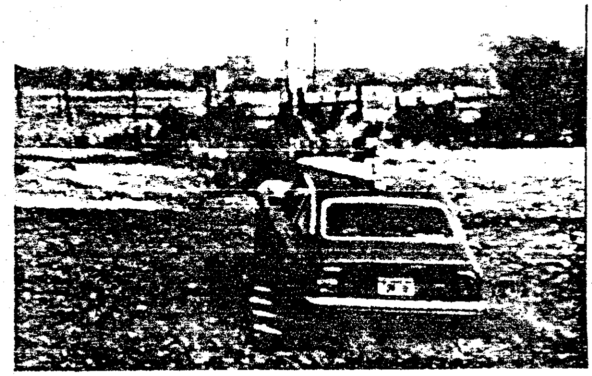
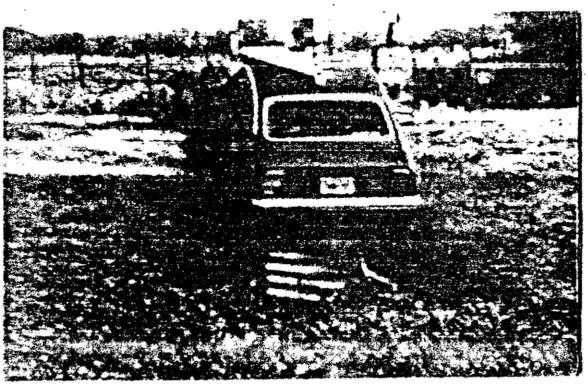


0.150

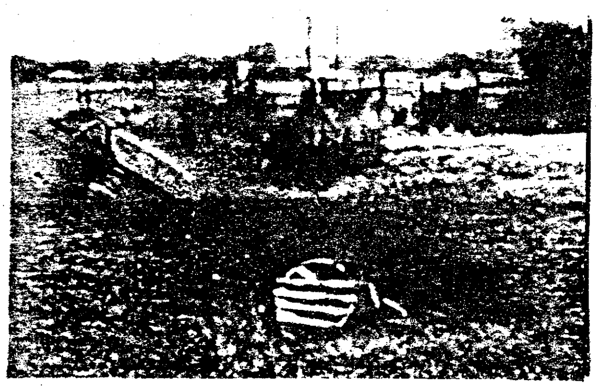


0.375

0.588

0.838

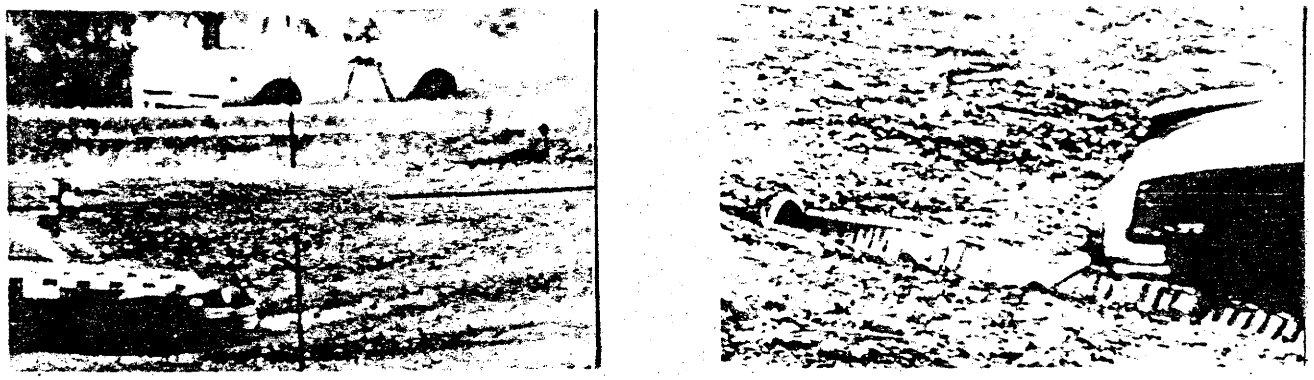
1.126



1.426

1.876

Figure B-75. Sequential Photos, Test 9-1; End View.



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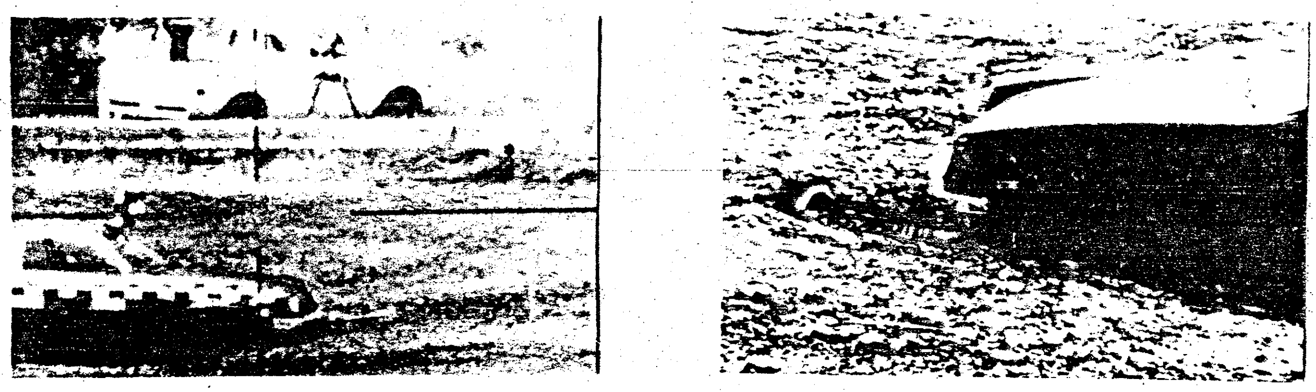

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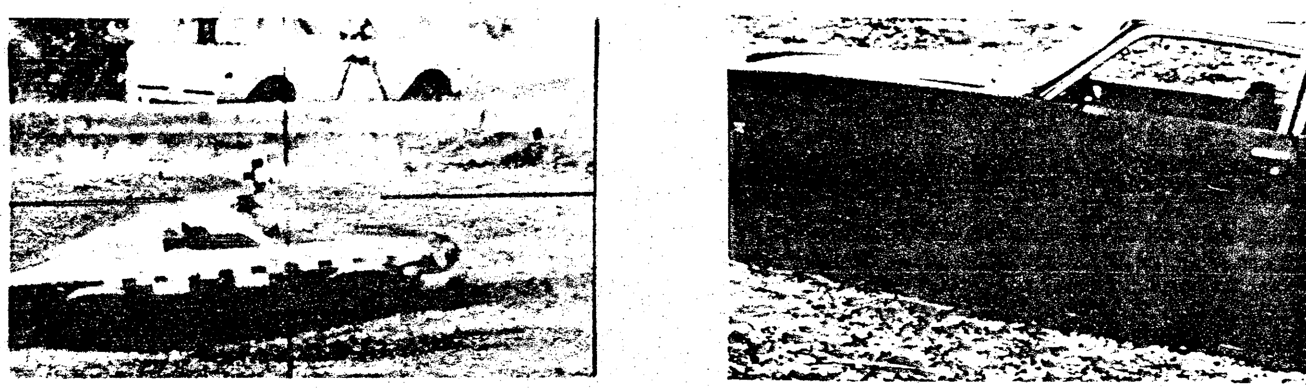

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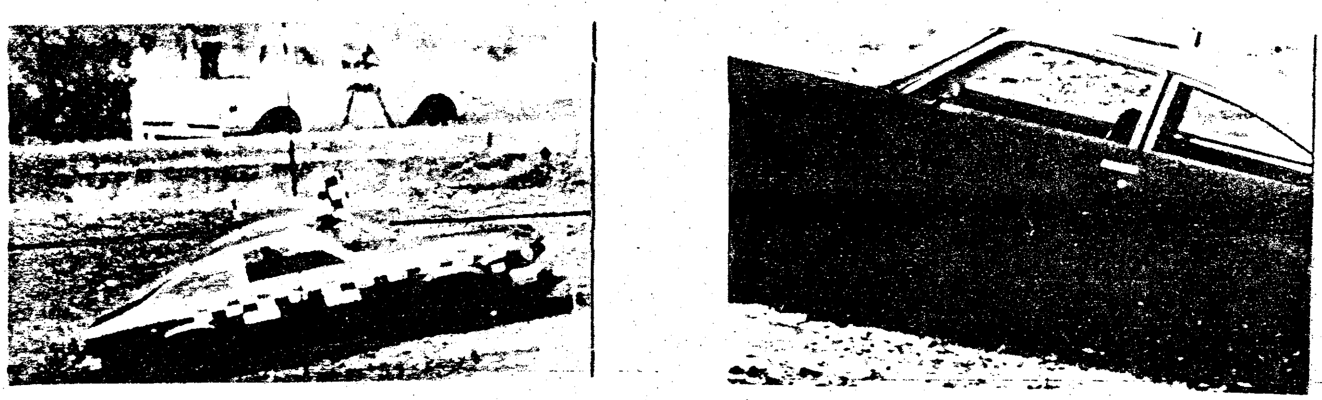
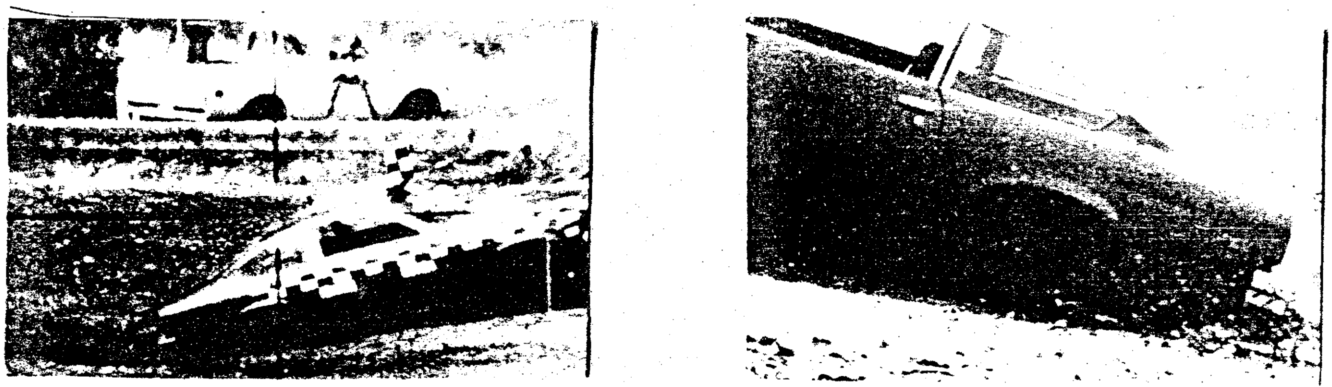
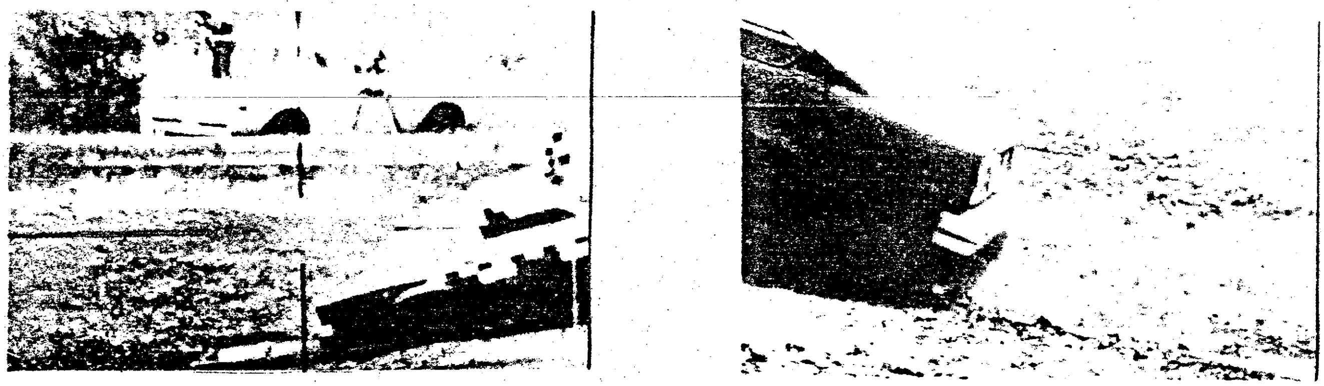


0.177

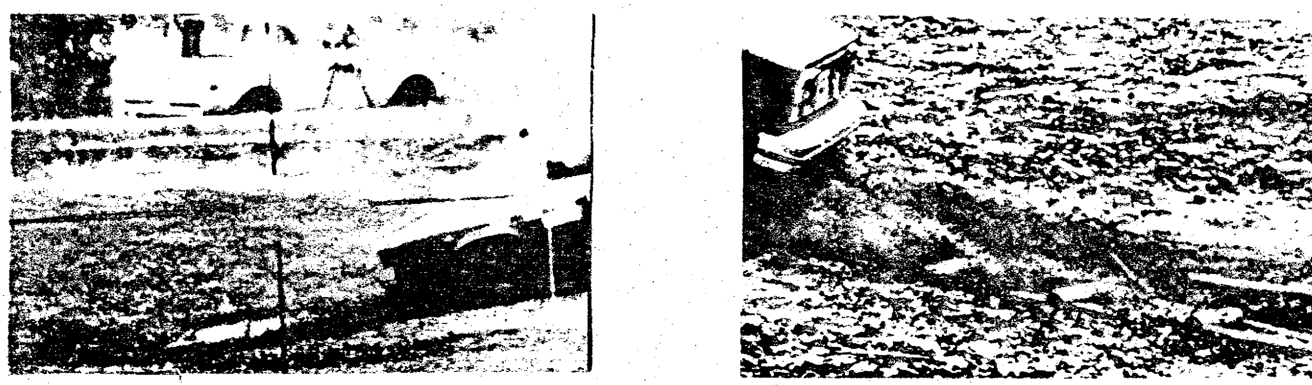
Figure B-76. Sequential Photos, Test 9-1; Side View.



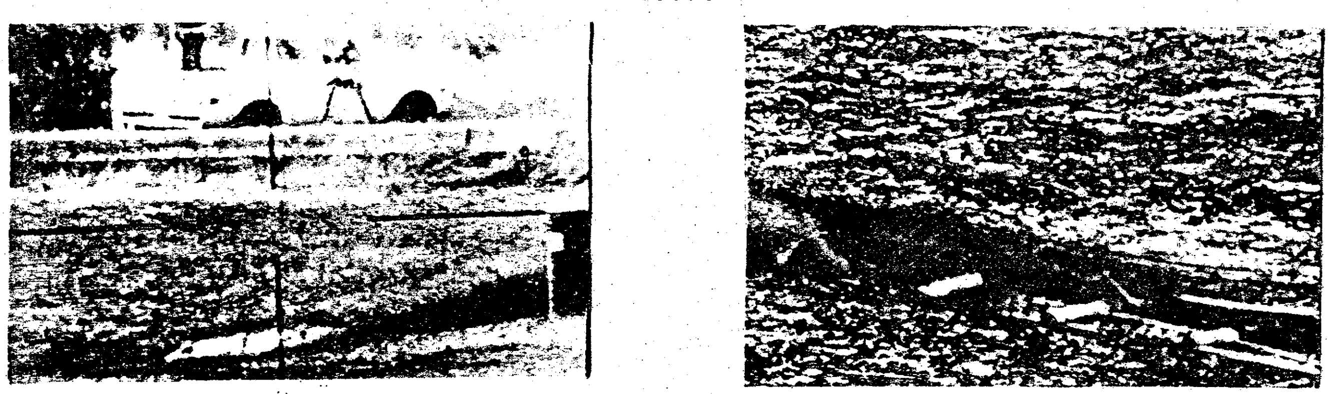
0.241



0.333



0.395



0.518

Figure B-76. Sequential Photos, Test 9-1; Side View (continued)

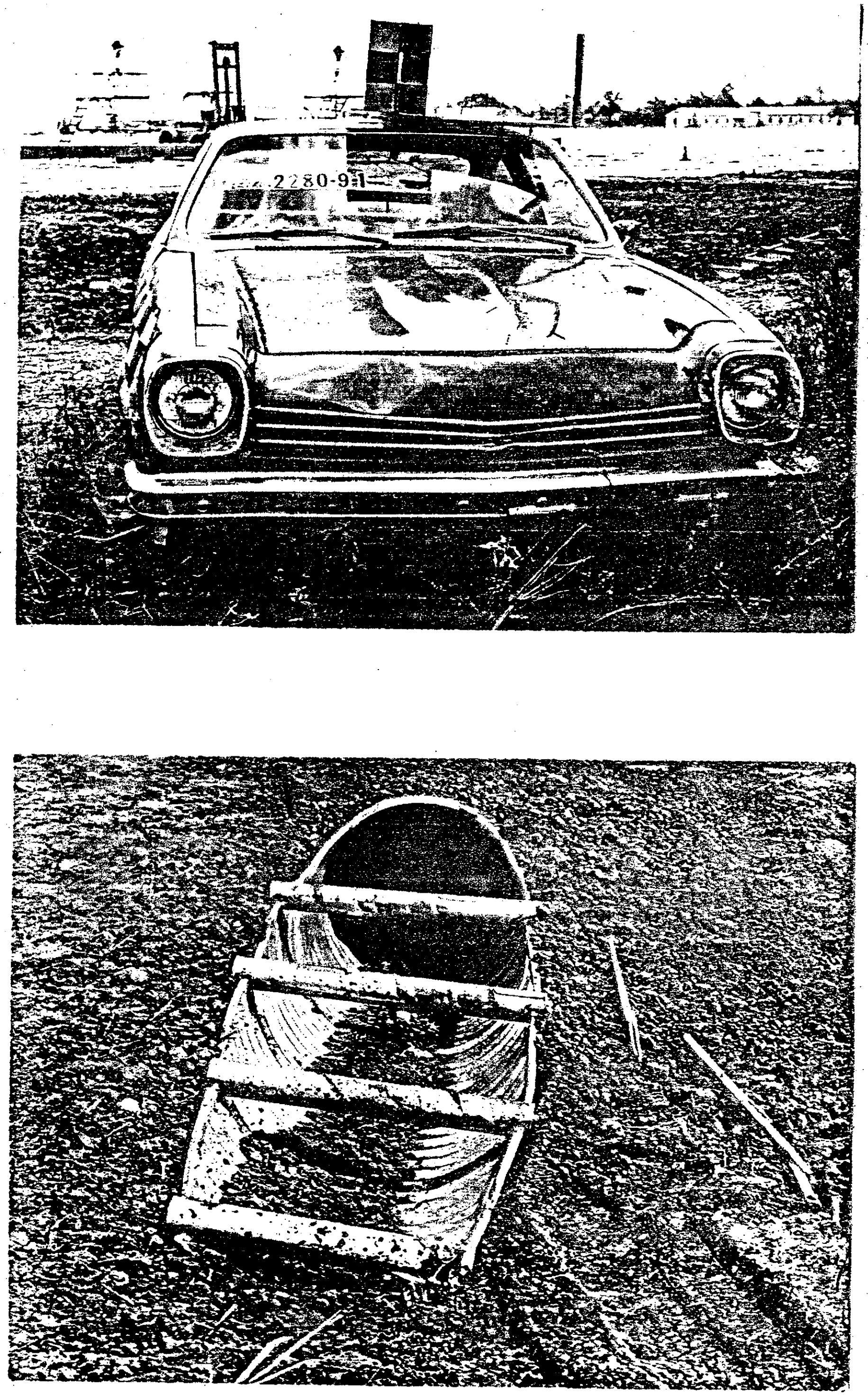


Figure B-77. Test Vehicle and Installation After Test 9-1.

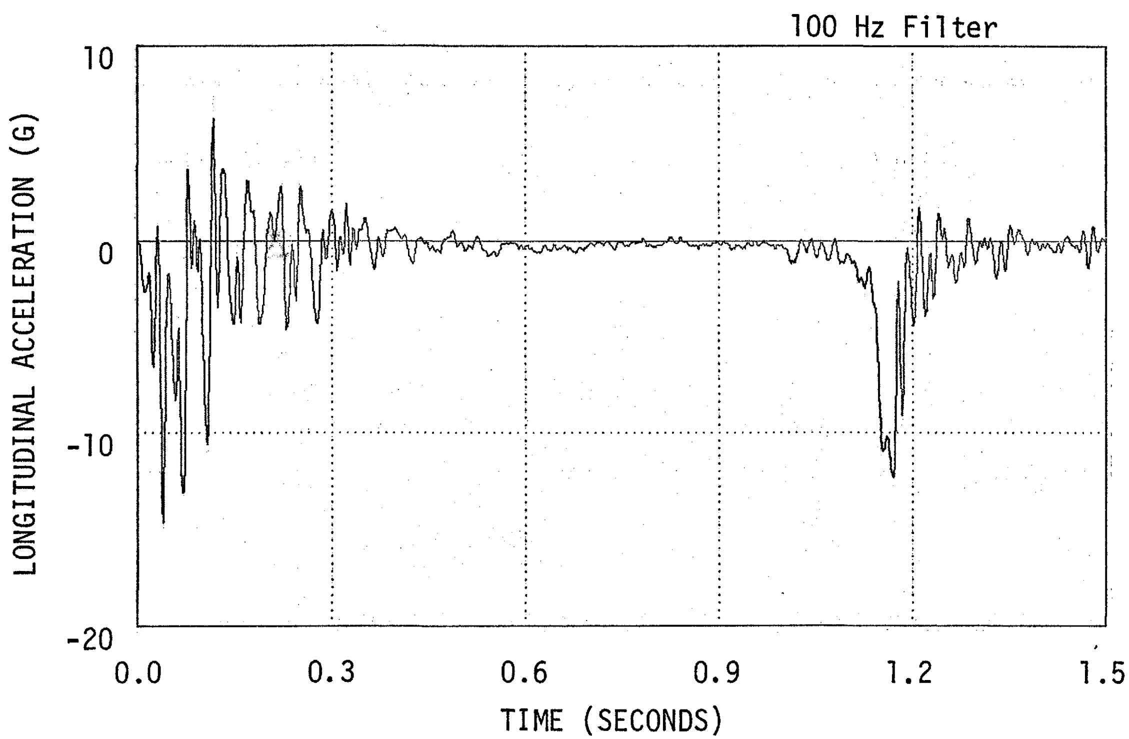


Figure B-78. Vehicle Longitudinal Acceleration, Test 9-1.

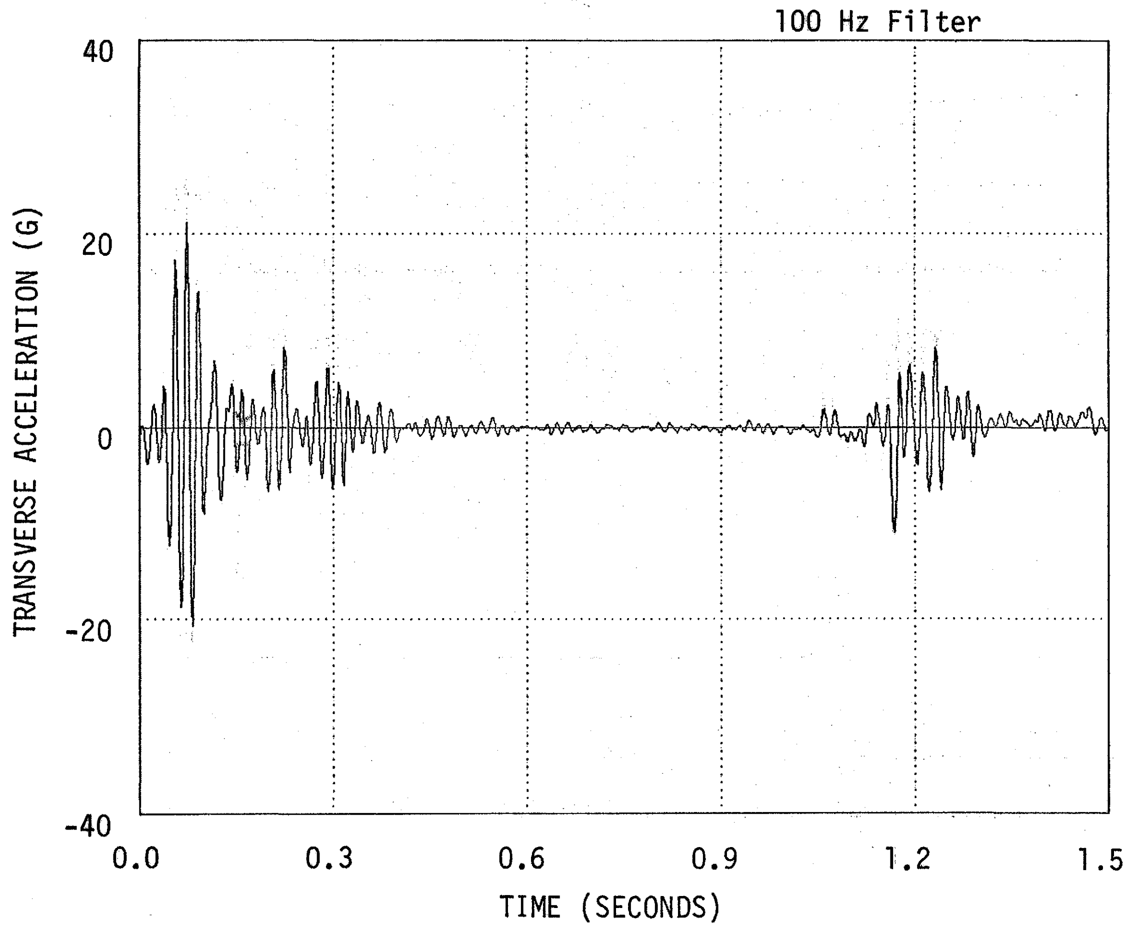


Figure B-79. Vehicle Transverse Acceleration, Test 9-1.

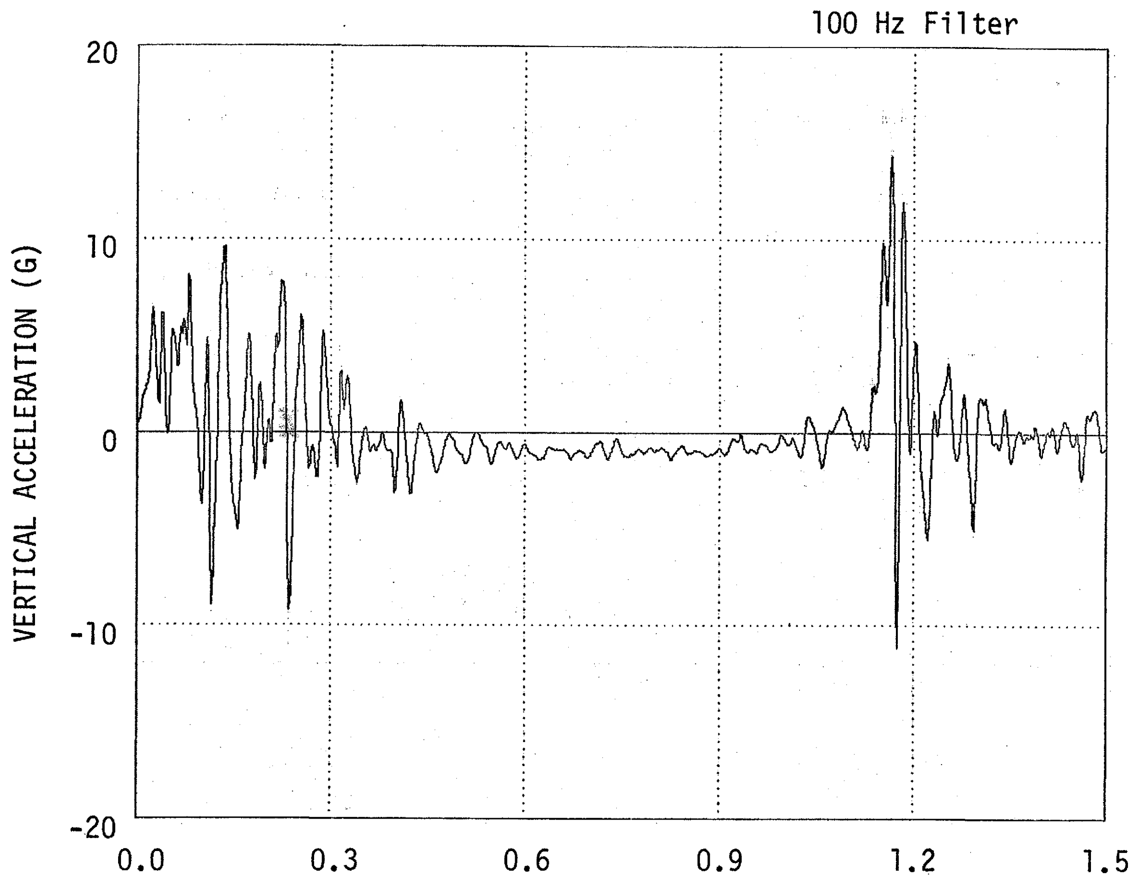


Figure B-80. Vehicle Vertical Acceleration, Test 9-1.

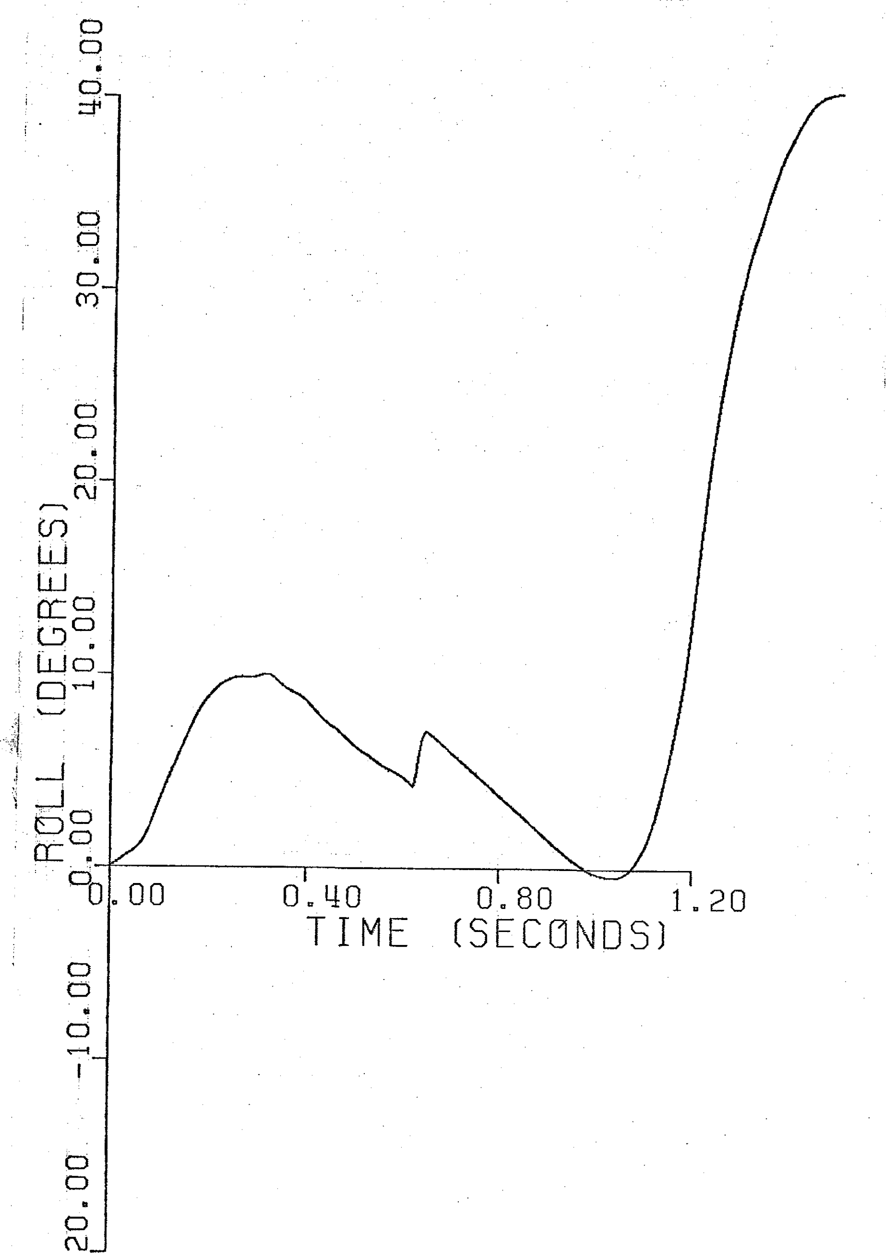
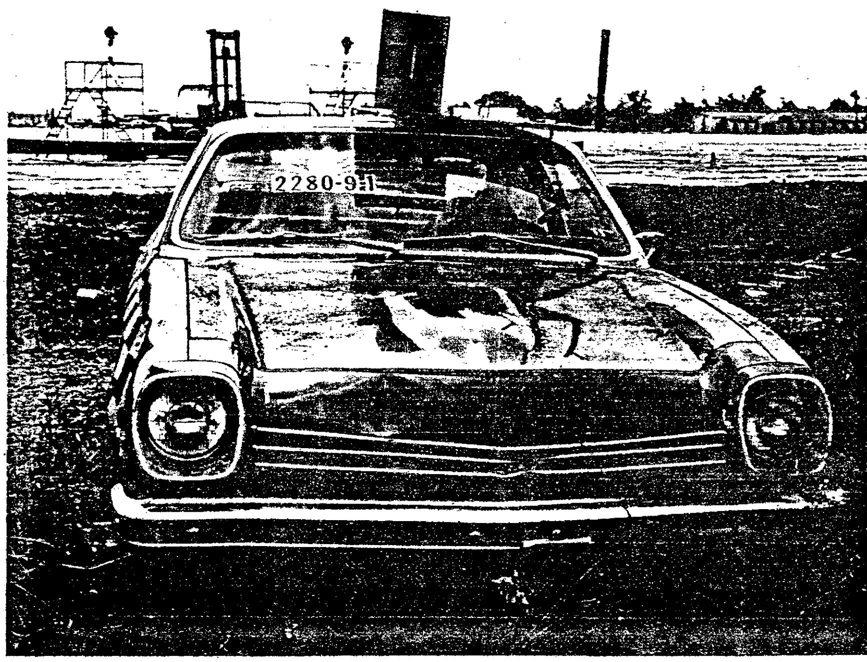


Figure B-81. Vehicle Roll, Test 9-1.

B-5-2. <u>Test No. 9-2</u>

Figure B-82 shows the test vehicle and installation before impact. Sequential photos of the impact are contained in Figures 14, B-83, and B-84. The vehicle traversed the driveway without rolling over. Damage to the vehicle and to the test installation was slightly more than in test 9-2 but, as shown in Figure 15, the test installation required no maintenance and the vehicle was repairable.

Figures B-85, B-86, and B-87 contain plots of the longitudinal, transverse, and vertical accelerations versus time. Figure B-88 contains a plot of the roll angle as a function of time.



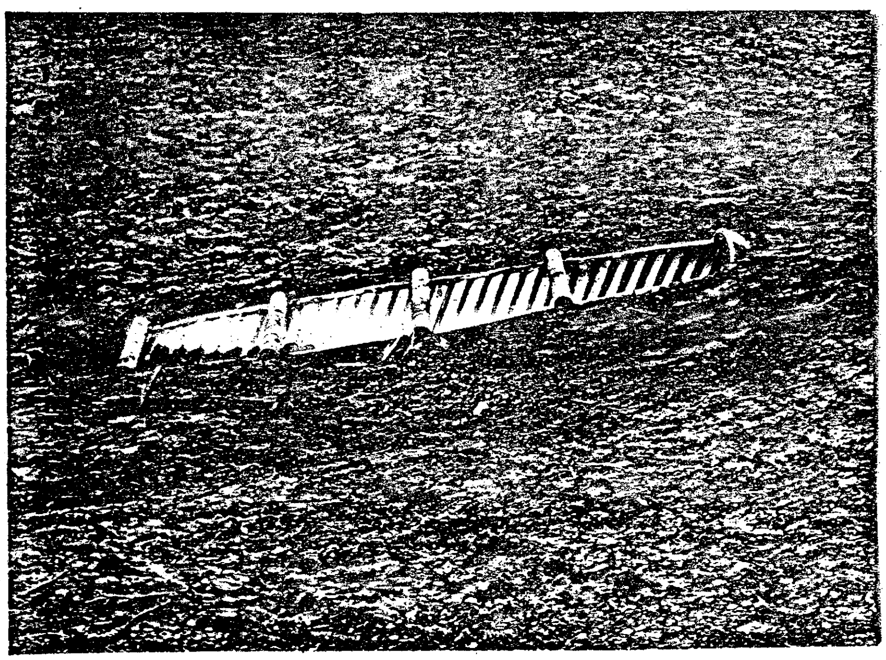


Figure B-82. Test Vehicle and Installation Before Test 9-2.

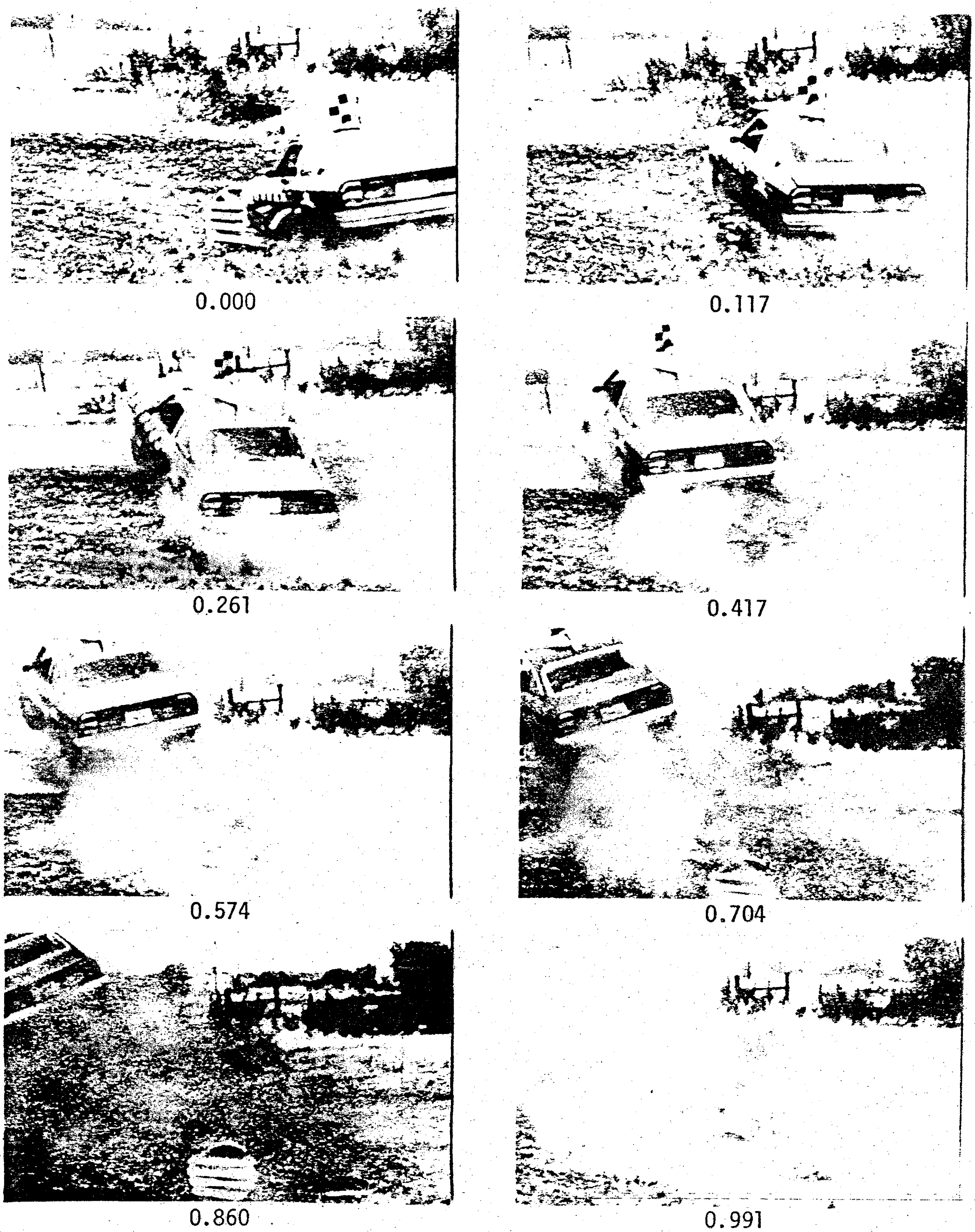
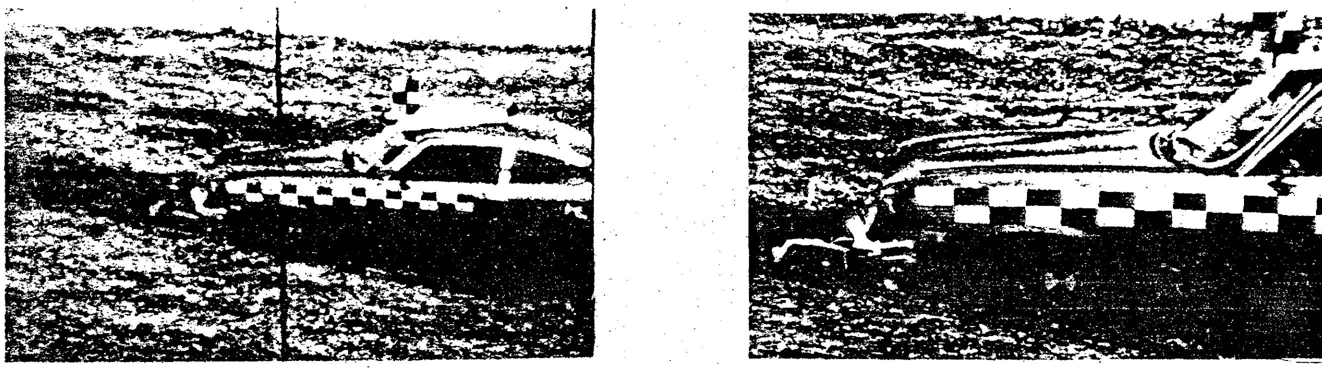


Figure B-83. Sequential Photos, Test 9-2; End View.



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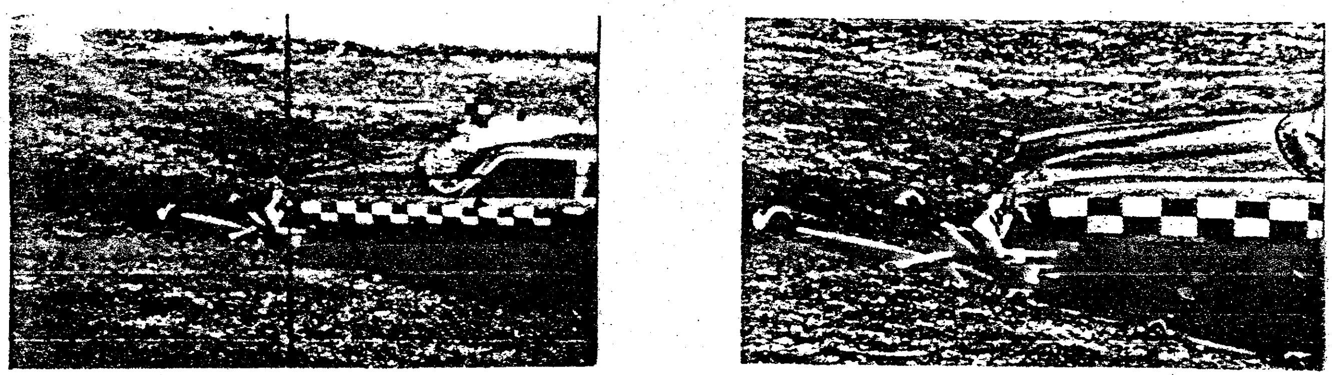
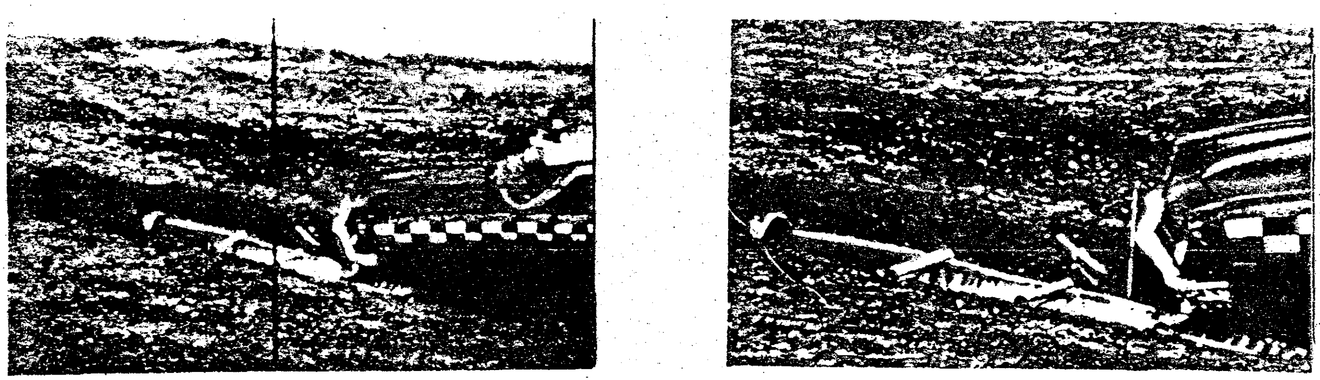


0.247



0.296

Figure B-84. Sequential Photos, Test 9-2; Side View.

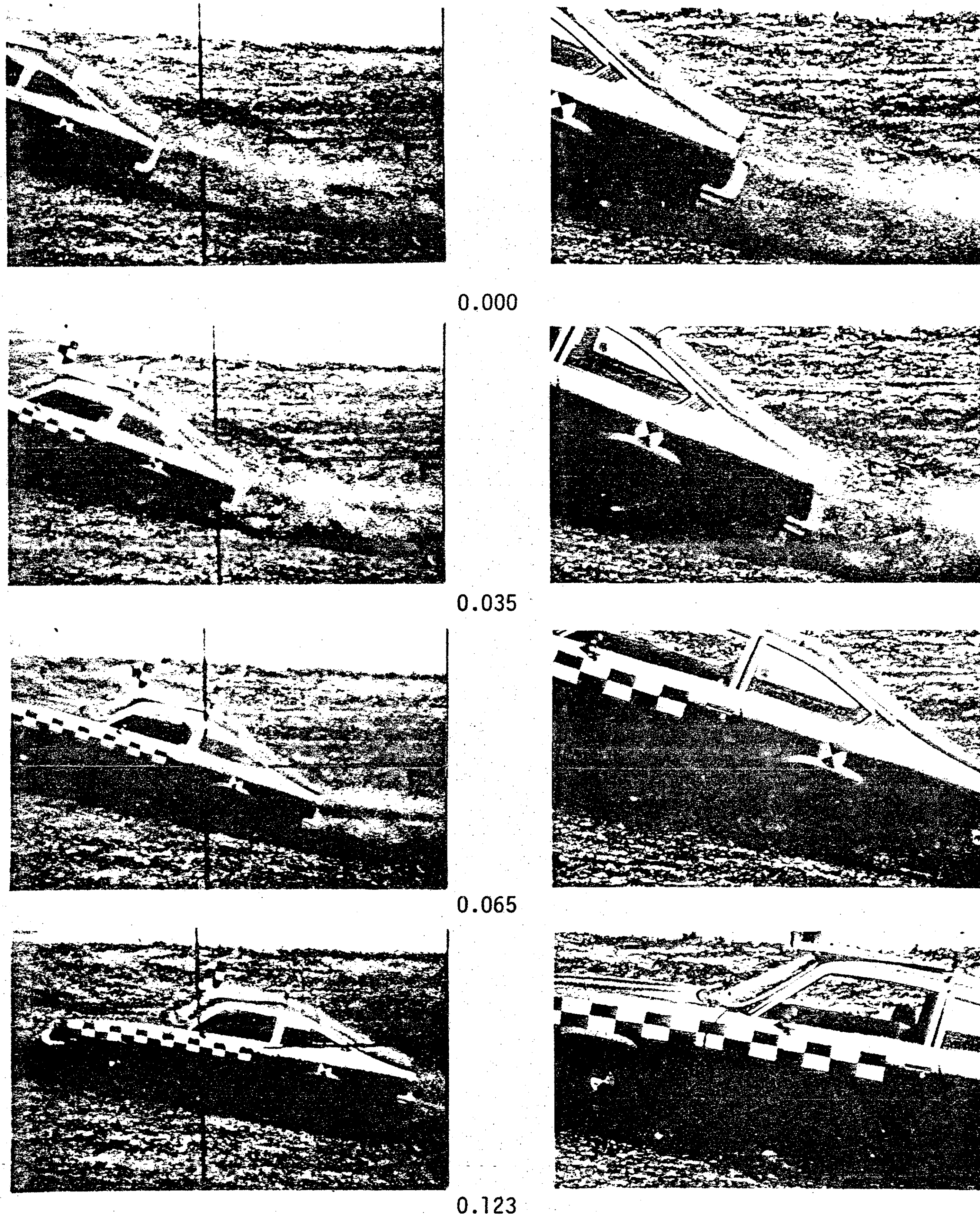


Figure B-84. Sequential Photos, Test 9-2; Side View. (continued)

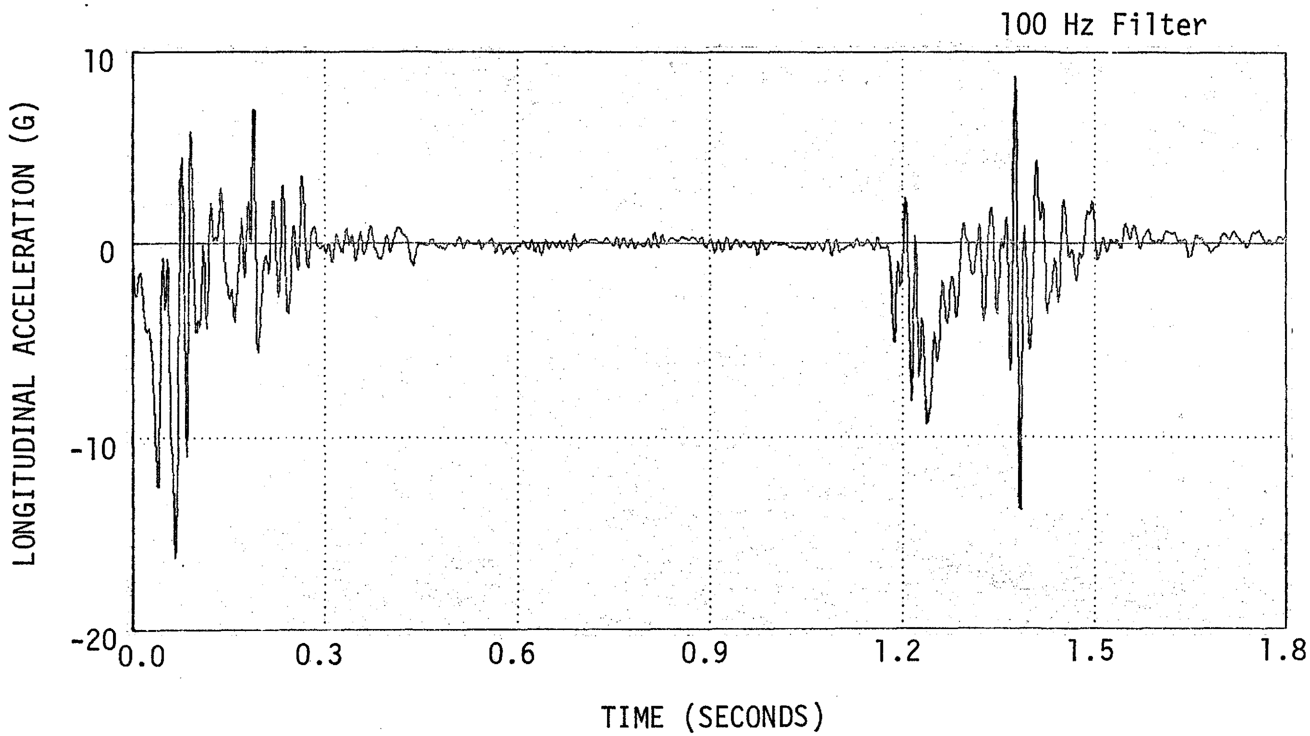


Figure B-85. Vehicle Longitudinal Acceleration, Test 9-2.

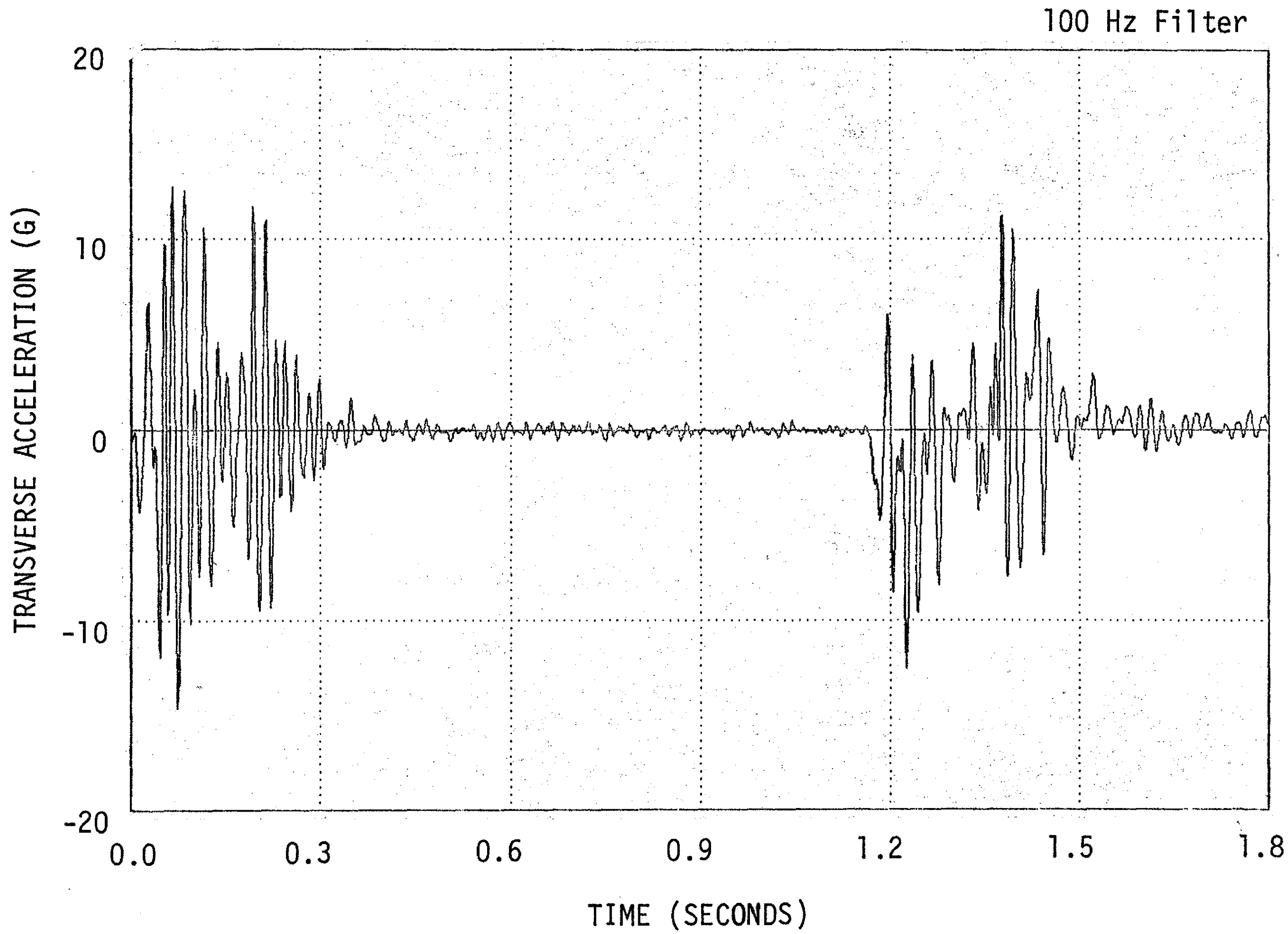


Figure B-86. Vehicle Transverse Acceleration, Test 9-2.

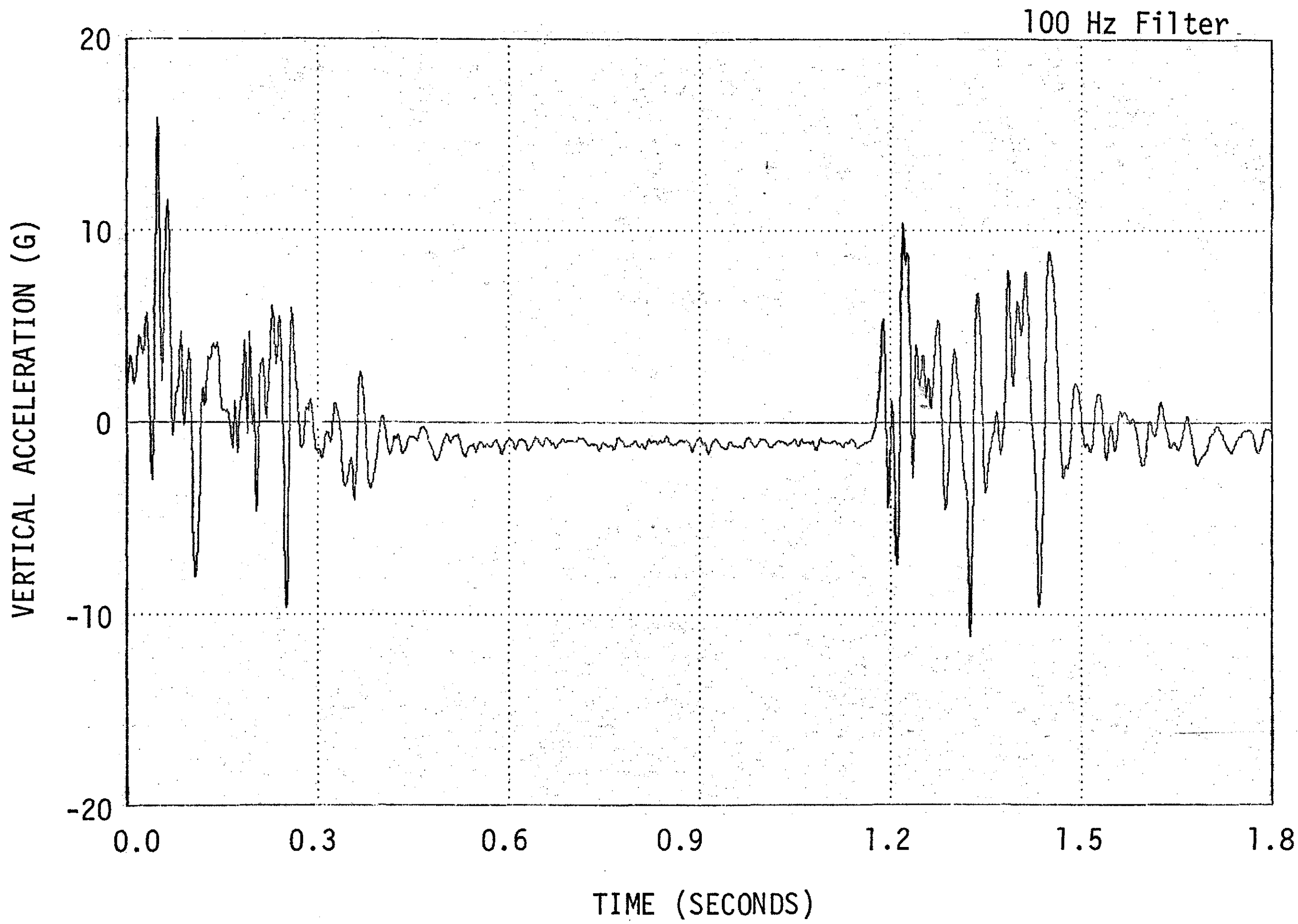


Figure B-87. Vehicle Vertical Acceleration, Test 9-2.

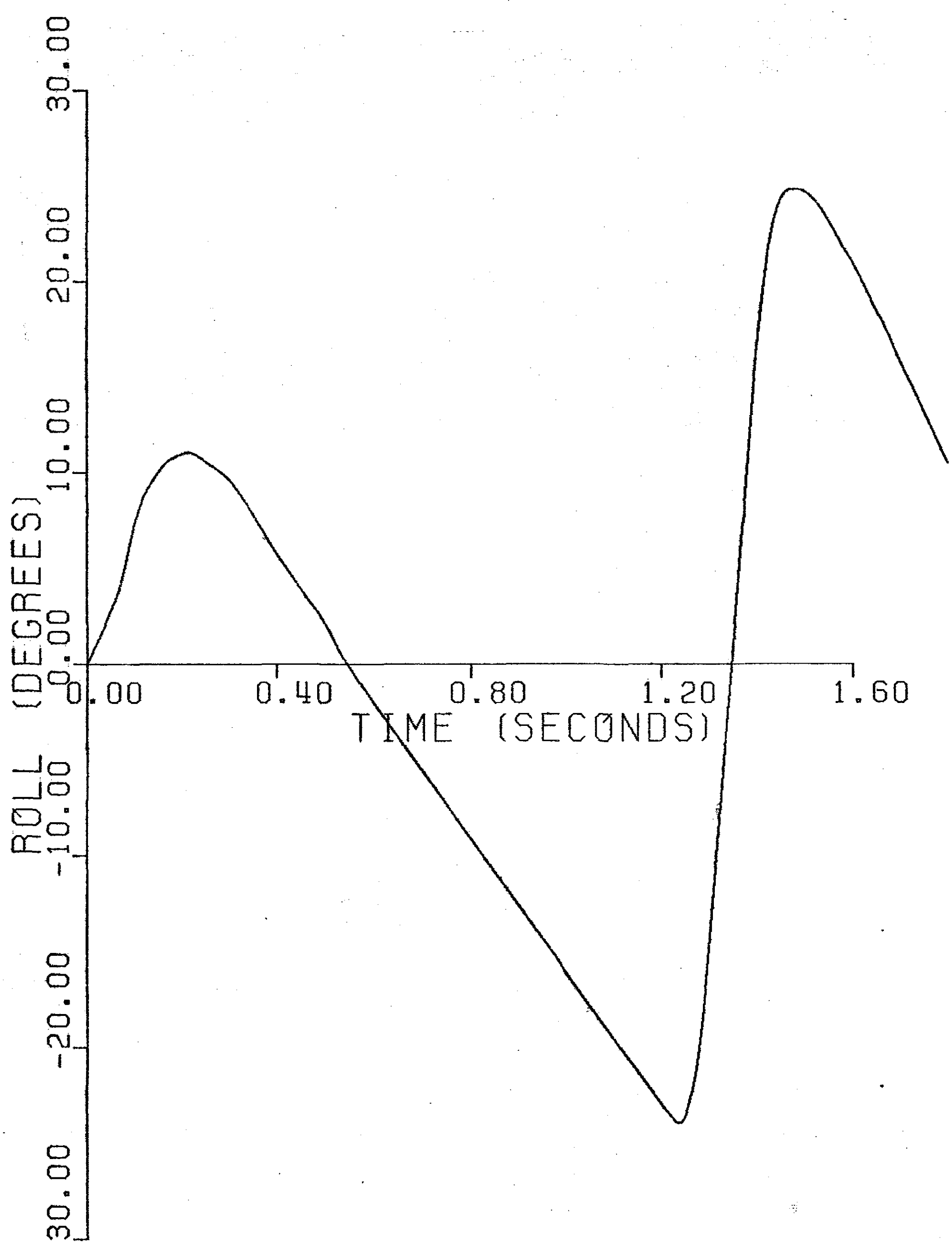


Figure B-88. Vehicle Roll, Test 9-2.

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