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16. Abstract

The purpose of the research was to develop traffic-safe end treatments for cross-drainage structures that would not appreciably restrict water flow. Cross-drainage culverts are used to convey water under the highway.

Preliminary designs were first evaluated in a test pit in which the culvert clear open space could be varied. The pit was also used to determine an acceptable spacing for grates on larger culvert openings. Subcompact and full-size automobiles were used in each test pit run.

Tentative end treatments developed in the test pit runs were then subjected to full-scale prototype testing. These tests involved evaluation of the end treatments on a 5:1 side slope with both a subcompact automobile and a full-size automobile. The end treatments were subjected to tests at both 20 mph and 60 mph.

A cost/benefit analysis was conducted to develop guidelines that identify conditions warranting culvert safety treatment.

17. Key Words Culvert(s), Drainage, Safety, Roadside, Test(s), Treatment	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

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SAFETY TREATMENT OF ROADSIDE CROSS-DRAINAGE STRUCTURES

by

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Dean Sicking

Research Report 280-1
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

March 1981

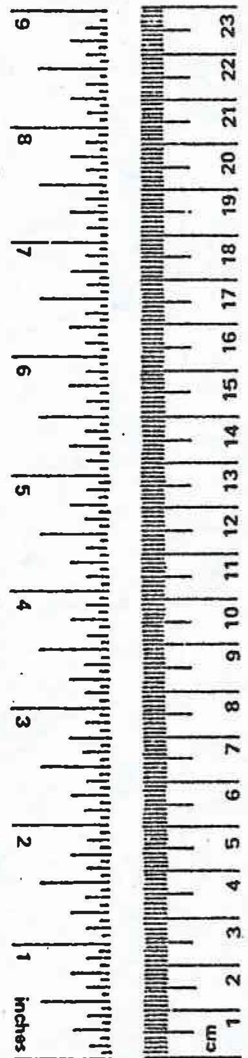
Texas Transportation Institute
The Texas A&M University System
College Station, Texas

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

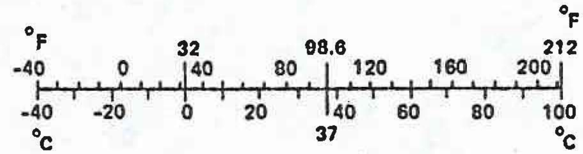
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

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 cross-drainage structures that would not appreciably restrict water flow. Guidelines or warrants for use of the end treatments and other safety treatments were also developed. Cross-drainage culverts are used to convey water under the highway.

Preliminary designs were first evaluated in a test pit in which the culvert clear open space could be varied. The pit was also used to determine an acceptable spacing for grates on larger culvert openings. Subcompact and full-size automobiles were used in each test pit run.

Tentative end treatments developed in the test pit runs were then subjected to full-scale prototype testing. These tests involved evaluation of the end treatments on a 5:1 side slope with both a subcompact automobile and a full-size automobile. The end treatments were subjected to tests at both 20 mph and 60 mph. A benefit/cost analysis was conducted to determine warrants for the use of the treatments.

Conclusions drawn as a result of this research are:

1. All culvert ends regardless of size should be made to match the existing side slope if they terminate within the clear zone. Protrusions of the culvert and adjoining wing walls and head wall above the terrain in excess of 3 to 4 inches should be avoided.
2. Round culverts with diameters of 30 inches or less need no end treatment other than as mentioned in 1 above. Elliptic or oval shaped culverts with major axes 30 inches or less need no end treatment other than as mentioned in 1 above. Rectangular shaped culverts with a horizontal clear distance 30 inches or less need

no end treatment other than as mentioned in Conclusion 1.

3. Culverts having dimensions greater than those given in Conclusion 2 can be safety treated with grate members, placed on 30-inch centers, that are oriented parallel to the water flow and in the plane of the surface of the side slope.

4. Grate member sizes depend on the span of the grates, the manner in which the grates are supported and the design vehicle weight. To support a full-size automobile, the following sizes are suggested (or their equivalent).

SPAN LENGTH (ft)	SUGGESTED STANDARD SCHEDULE 40 PIPE SIZE I.D. (in.)
up to 12	3.0
12 to 16	3.5
16 through 20	4.0

In addition, if midspan vertical supports are incorporated for the larger span lengths, 3.0 in. (7.62 cm) I.D. standard schedule 40 pipe can be used for spans up to 20 ft (6.1 m).

5. Safety treatment of cross-drainage structures is warranted on roadways having traffic volumes of approximately 750 vehicles per day or more. Treatment may consist of grates or the culvert end can be extended to the edge of the clear zone. The more appropriate treatment depends on the culvert type being treated and the distance the culvert end is from the travelway.

IMPLEMENTATION STATEMENT

Results of this study have been implemented by the Texas State Department of Highways and Public Transportation (SDHPT). The Highway Design Division has issued policy statements and has updated the SDHPT design manual. The Bridge Division has issued new standards for safety grate treatment of culverts. Implementation of this study has resulted in reduced costs, improved safety, and improved culvert hydraulics as compared with previous grate designs. Numerous other states are also implementing the results of the study.

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INTRODUCTION

Since highways cross many natural drainage channels, provision for conveying the water carried by these channels across the highway right-of-way is necessary. This cross drainage is accomplished with culverts as shown in Figure 1 (1)*.

In designing drainage culverts, the primary objective is to properly accommodate surface runoff along the highway right-of-way through the application of sound hydraulic principles. However, a second, important goal is that of incorporating safety into the design of drainage appurtenances. The best design would be one which would efficiently accommodate drainage and be traversable by an out-of-control vehicle without rollover or abrupt change in speed.

The Texas State Department of Highways and Public Transportation (TSDHPT) issued guidelines for drainage structure design for improved safety early in 1979 (2). Recent field reviews of drainage culverts revealed that improvements and some modification of design details could improve on both drainage and safety. Many of the safety grates used to cover the open ends of culverts have such a fine mesh or such small openings that they are easily stopped up with trash or debris. This causes water to back up, flow over the roadway and damage adjacent property. In some cases safety grates were being used on small culvert pipe entrances where no grate was needed.

The purpose of the research was therefore to develop traffic-safe end treatments for cross-drainage structures that would not appreciably restrict water flow.

*Underlined numbers in parentheses are references listed at the end of the report.

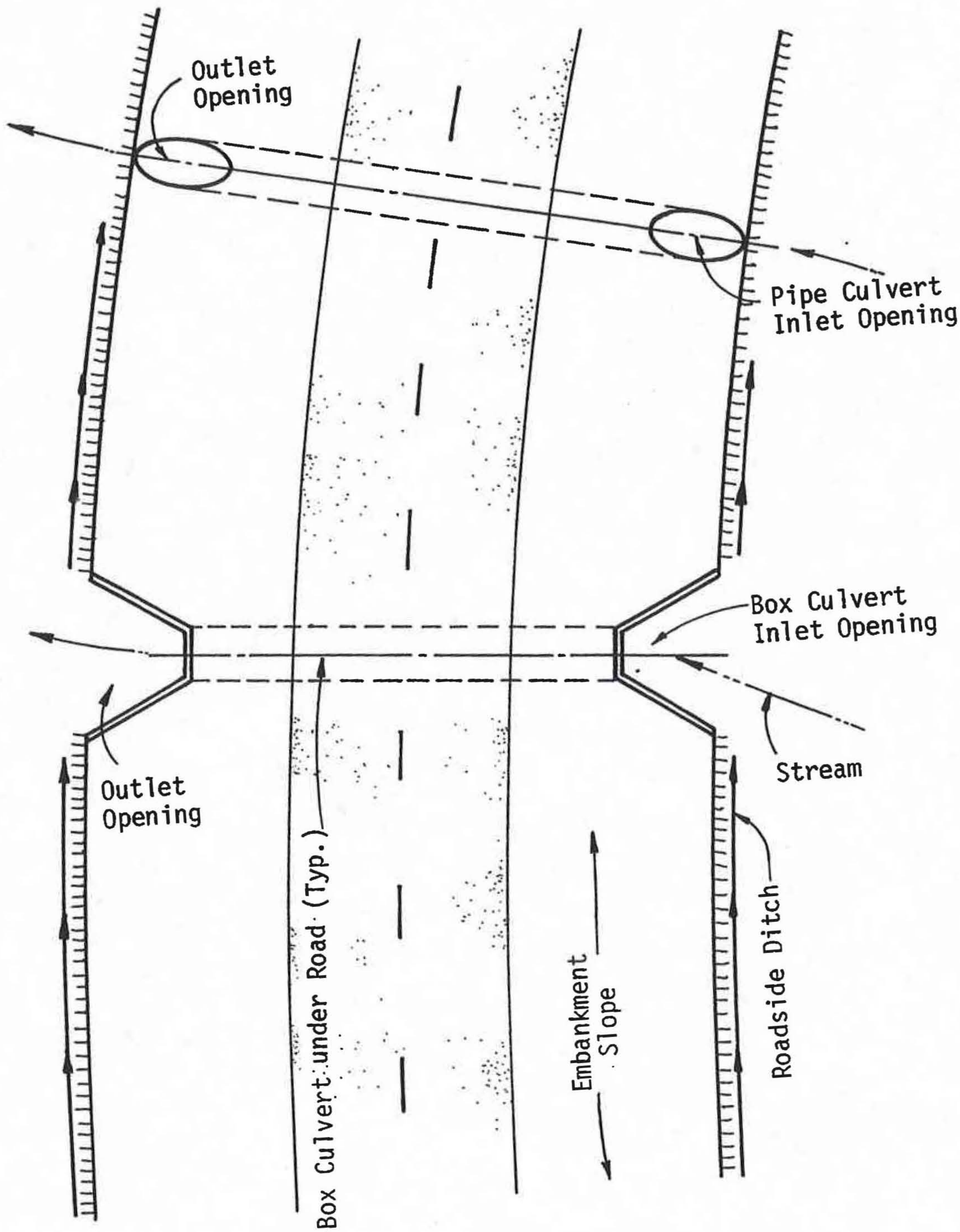


Figure 1. Drainage Plan for a Highway

Figures 2 and 3 are examples of cross-drainage culverts. It was assumed that the best grate from a hydraulic standpoint will be one with the least members possible and hence the largest clear opening. This study was limited to culverts with openings of approximately 25 ft^2 (2.33 m^2) or less. It is estimated that 90 to 95% of all culverts fall in this size category. No hydraulic research was undertaken in this study.

Investigation of parallel-drainage culverts such as those installed at driveways, side roads, and median crossovers will be conducted later under a separate TSDHPT research study. Figure 4 shows an example of a parallel-drainage culvert.

The research program was carried out in two major stages. First, a preliminary full-scale vehicular test program was conducted on a test pit to arrive at an optimum clear opening and an optimum grate spacing that could be safely traversed. Some computer simulation work was done prior to the preliminary crash test to observe the wheel drop into an ungrated opening on flat terrain. The simulation work was also used to study the effect of a curb at the leading edge of the opening. In the second stage prototype culverts were constructed on a side slope and subjected to full-scale crash testing. The culverts tested were a 30-inch (76.2-cm) diameter corrugated metal pipe culvert and a 3-ft (0.92-m) by 5-ft (1.53-m) concrete box culvert with grating on a 5:1 drainage ditch side slope. This report describes the tests and results obtained therefrom along with the major conclusions gathered from the test program. These results will then be the basis for selecting an efficient and safe design of end treatments for cross-drainage culverts.

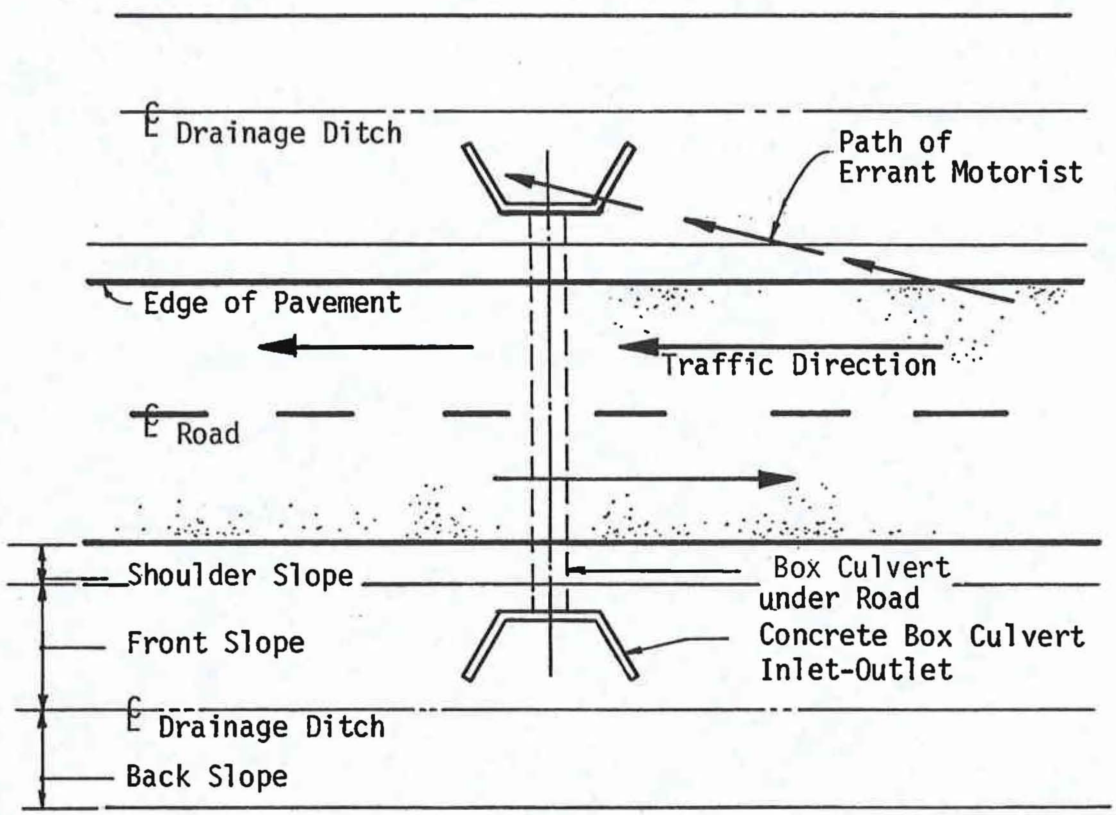


Figure 2. Cross-Drainage Box Culvert

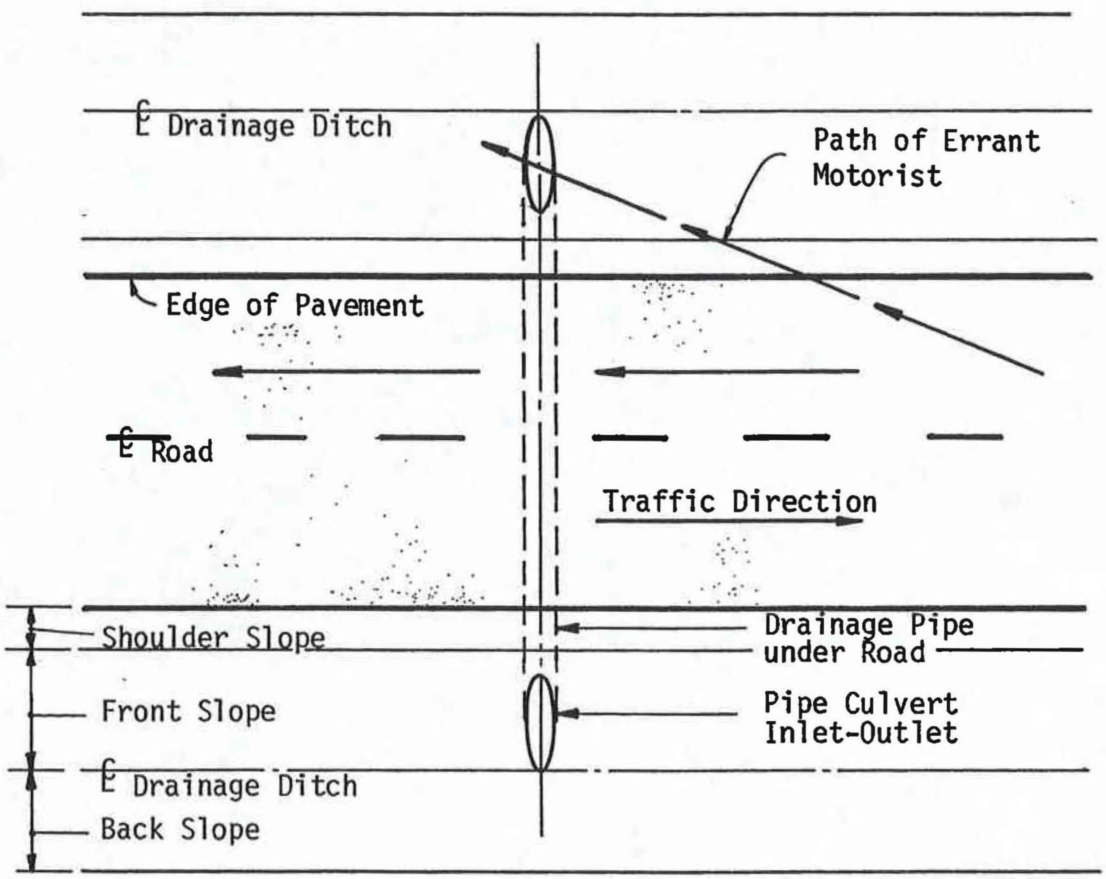


Figure 3. Cross-Drainage Pipe Culvert

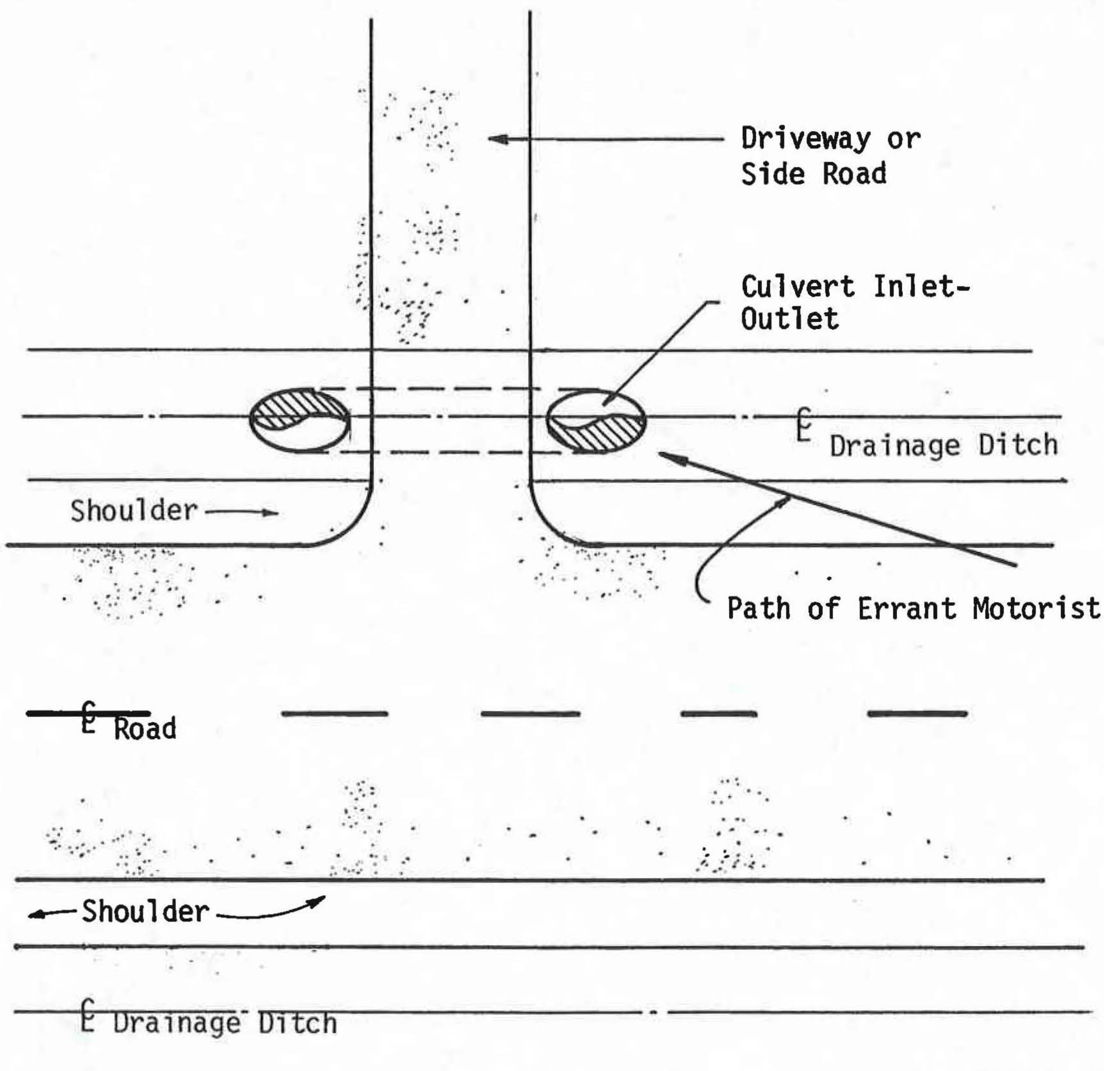


Figure 4. Parallel-Drainage Culvert

PRELIMINARY TESTS AND VEHICLE SIMULATION

Several questions had to be answered before safety end treatments could be developed. (1) What is the largest culvert that can be safely traversed without a safety grate? (2) For those culverts that have to be safety treated, what is the maximum spacing of bars such that a passenger vehicle can still traverse it safely? (3) For cross-drainage culverts, what is the effect of slope on grate bar spacing? (4) Will the use of a curb or a raised sloped face at the edge of the culvert opening help the car get across more easily?

To provide tentative answers to these questions, a computer simulation program was used to study a passenger car's response in traversing an opening on flat terrain. Also, full-scale vehicular tests were conducted on a test pit to observe the vehicle's behavior in crossing various clear openings and grate bar spacings. These tests were conducted at various encroachment angles. Finally, computer simulation and full-scale test runs were made using an 1800 lb (817.2 kg) and 4500 lb (2043 kg) vehicle to observe the response of the vehicle after impacting a curb with a ramp-like cross section. The computer simulation work and preliminary crash tests are discussed in subsequent sections along with the results of the same.

Computer Simulation

The Highway-Vehicle-Object-Simulation Model (HVOSM) (4) was used to gain insight on the behavior of a vehicle as it traversed various culvert configurations. It was also used to investigate the effect a ramp or curb would have on vehicle response as the vehicle traversed the culvert opening.

Figures 5 and 6 show the cross sections of the opening and curbs simulated along with the sprung mass center of gravity (cg) positions of the car as it traversed the opening. Note that a curb was simulated at each end of the

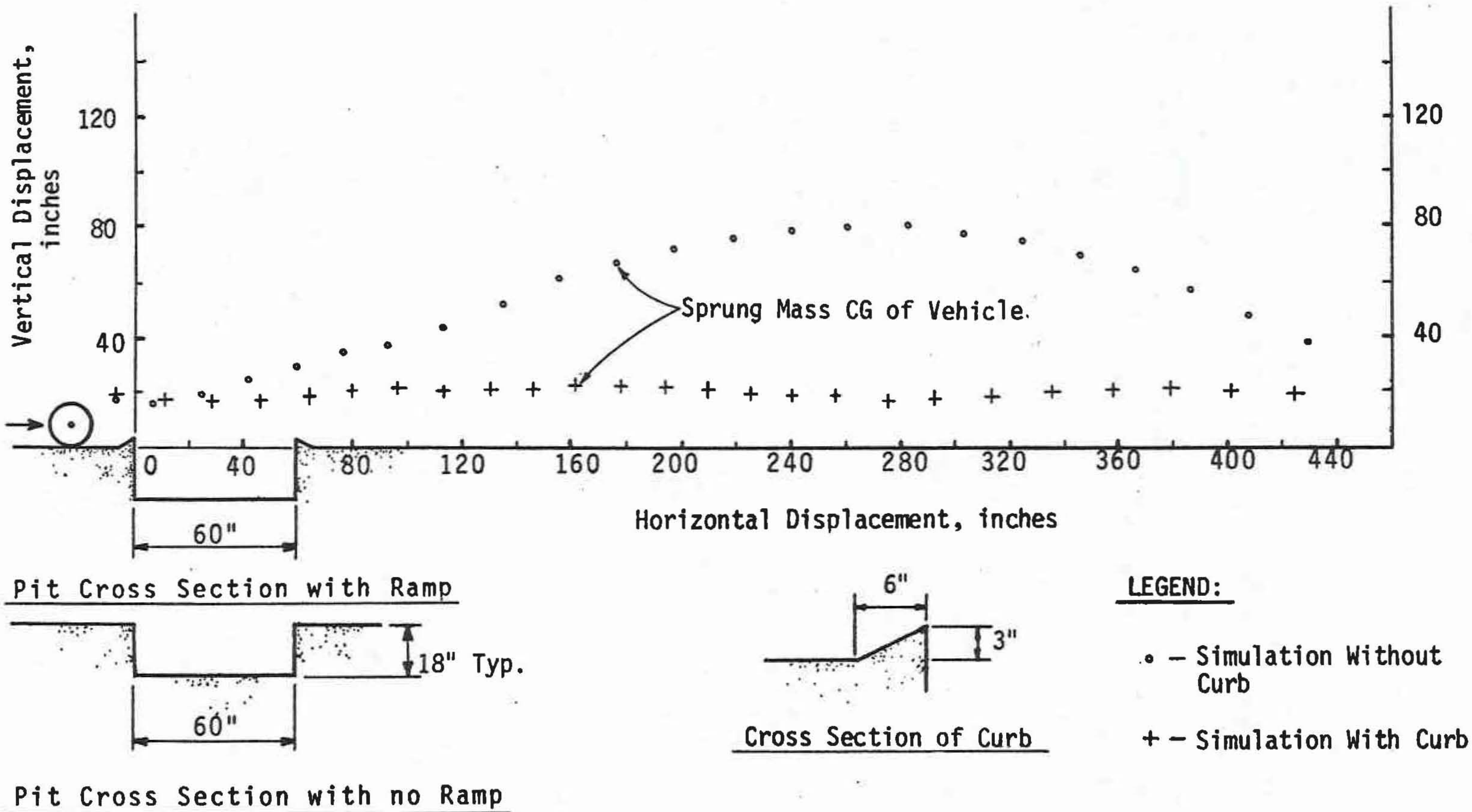


Figure 5. Simulation Results of Curb Impact Study with a 1971 Vega, 20 mph

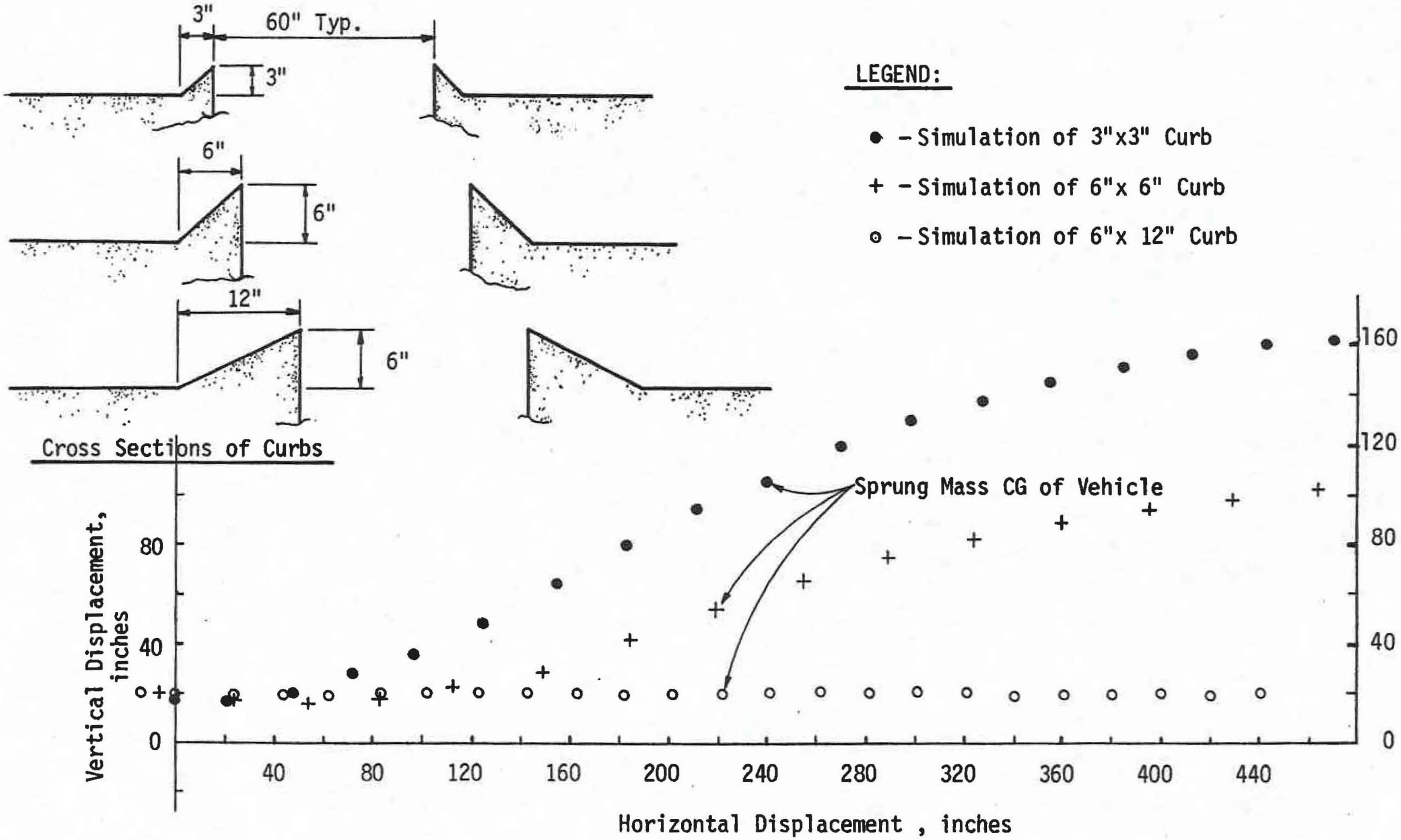


Figure 6. Simulation Results of Curb Impact Study with a 1971 Vega, 20 mph

opening. A test speed of 20 mph (32.18 km/hr) was used since it was deemed to be the most critical. At higher speeds the vehicle would clear the opening more readily and at lower speeds, although the vehicle would tend to drop more and possibly snag, velocity changes would be tolerable. When first reviewing Figure 5 one may erroneously conclude that the vehicle ramps over the opening are better without a ramp. In truth, the front wheels drop considerably more in the "no-ramp" configuration, causing very large vertical and horizontal forces (snagging) on the front of the simulated vehicle, which in turn causes the vehicle to pitch up rapidly. The vehicle experienced no appreciable lifting in the ramped condition of Figure 5 as it easily traversed the opening with no snagging. From Figures 5 and 6 it can be seen that a ramp having a 2:1 longitudinal-to-vertical dimension ratio provides the more optimum configuration.

Culvert Test Pit Program

A test pit was constructed on flat terrain as shown in Figure 7 to study the behavior of a vehicle as it traverses various openings. The objectives of these preliminary tests were to determine (1) the maximum clear opening permissible on a grated culvert end (box culvert, for example) that could be traversed safely by both subcompact and full-size automobiles. All runs in this preliminary program were live-driver tests at various speeds and encroachment angles. Appendix A contains a working drawing giving details for the installation of the test pit. Figure 8 is a photograph of the test pit after installation. A layout of the test site for the preliminary test program is shown in Figure 9 along with vehicle test data. A discussion of the nongrated culvert and grated culvert tests follows.

Nongrated Culvert. The purpose of the initial phase of the program was to find the maximum diameter of a sloped end culvert, such as that of Figure 10, Note: Appendix B contains a working drawing of the test pit.

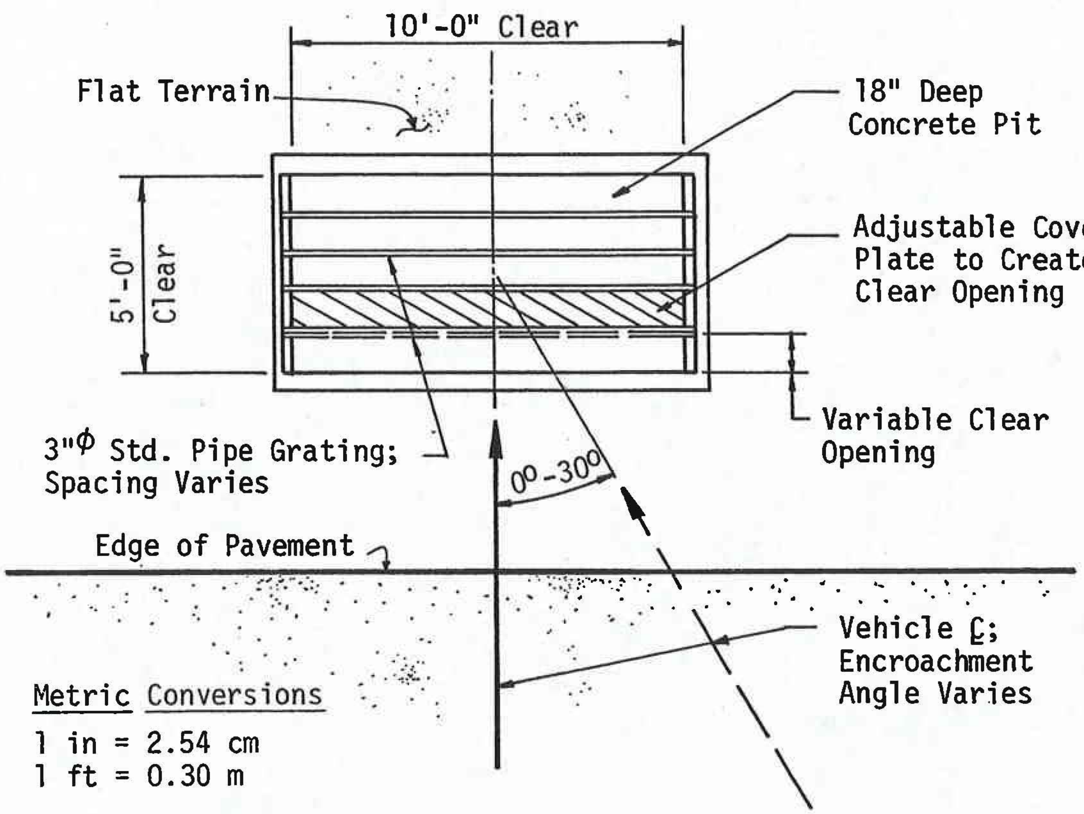
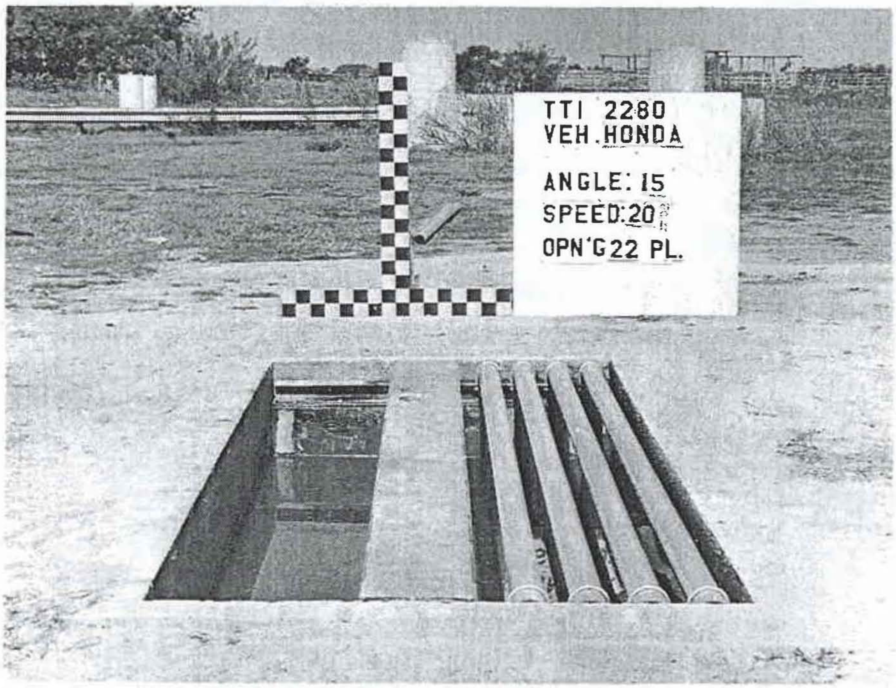
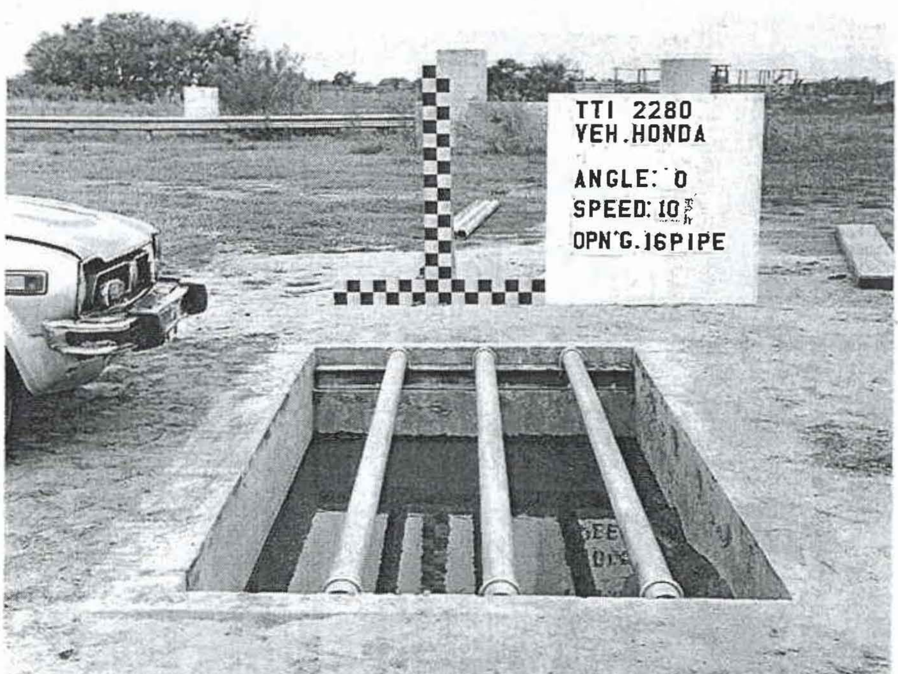


Figure 7. Plan View of Culvert Test Pit



a) Nongrated Culvert Setup



b) Grated Culvert Setup

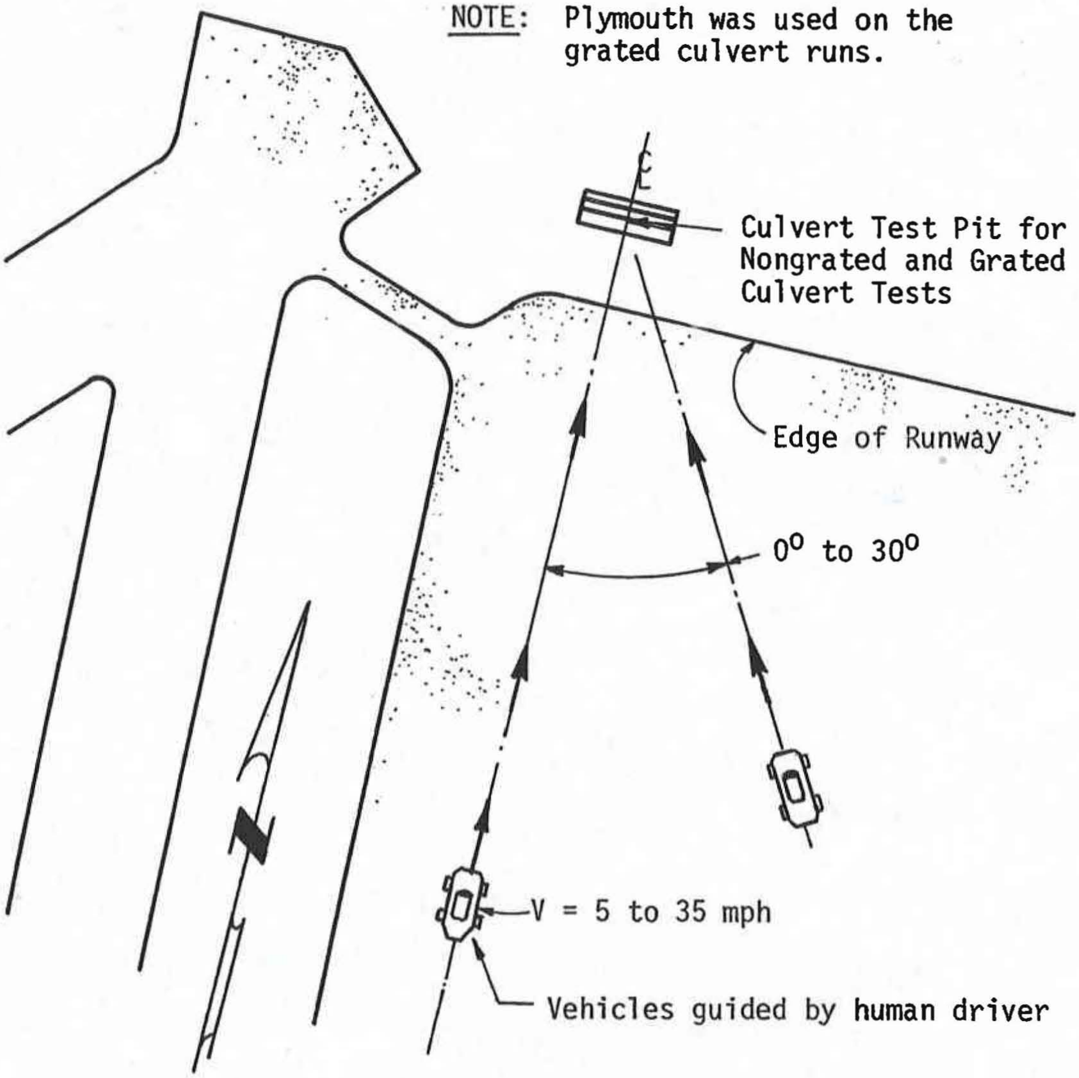
Figure 8. Culvert Test Pit

VEHICLE DATA

	Car 1	Car 2
Make	Honda	Plymouth
Model	Civic	Fury
Year	1974	1975
Test Weight (lb)	1970*	4500
Velocity (mph)	5-35	20,25

*Included weight of driver

NOTE: Plymouth was used on the grated culvert runs.

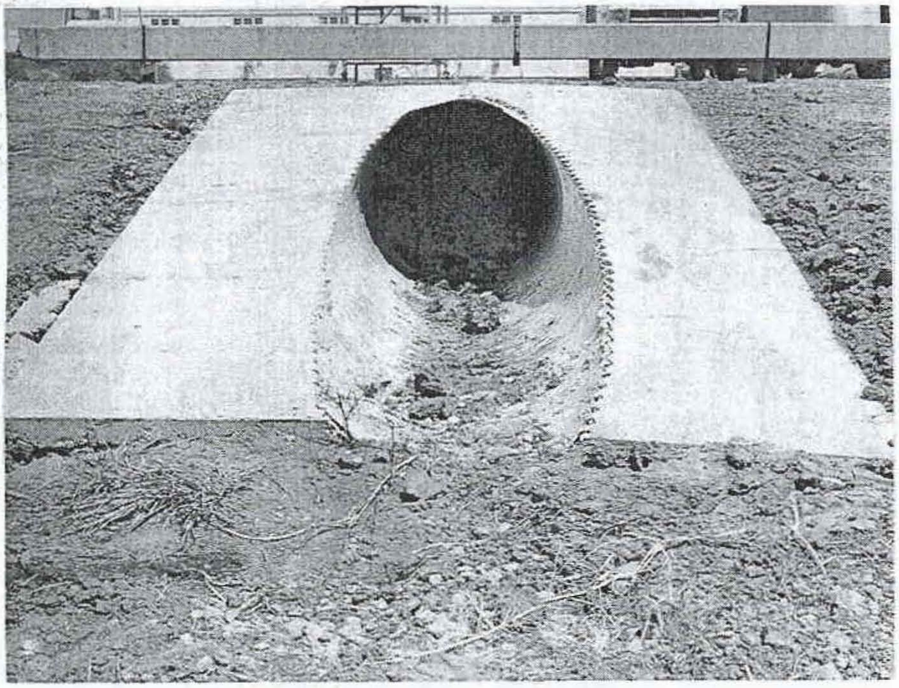


Metric Conversions:

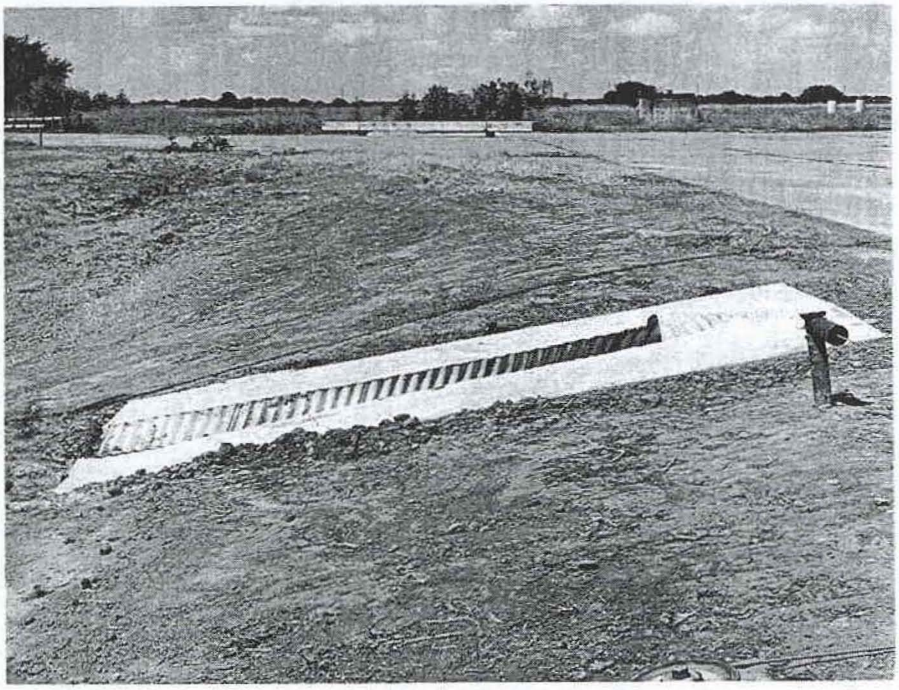
$1\ lb_m = 0.454\ kg$

$1\ mph = 1.609\ km/h$

Figure 9. Plan View of Site for Test Pit



a) Front View



b) Side View

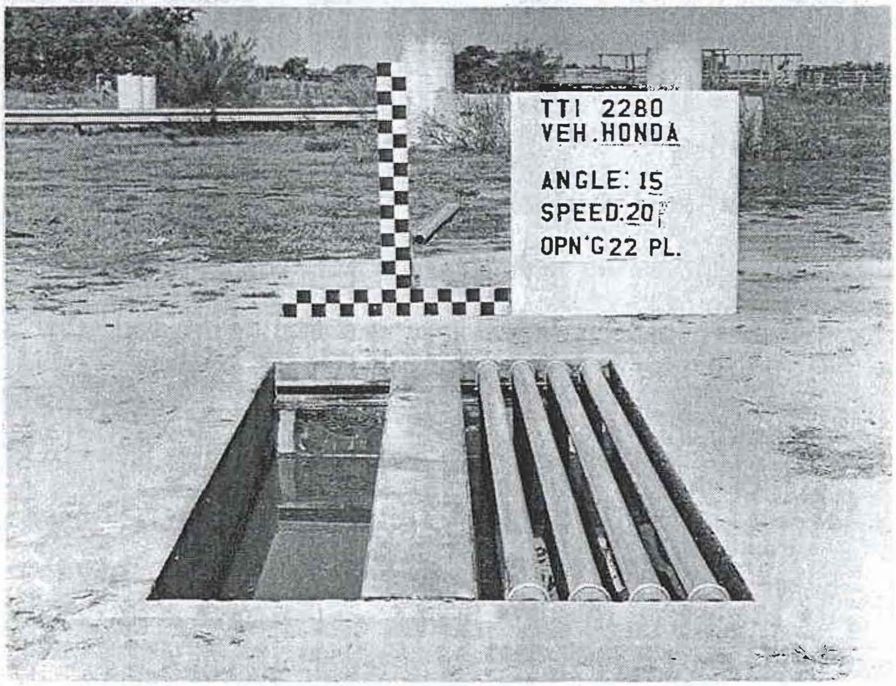
Figure 10. Corrugated Metal Pipe Culvert

that could be traversed safely by a car. Note that the pipe culvert has been cut to match the given ditch front slope. To simulate this clear opening in the test pit, a steel plate was welded onto a steel channel frame (see Appendix A) that could be adjusted to various opening widths as shown in Figure 11. The pipes behind the plate assembly were merely to help the vehicle get across the pit once the tires had cleared the opening being tested. Once a certain opening had been tested, a new one was set up by removing a pipe or pipes and moving the plate assembly back to the desired clear opening width.

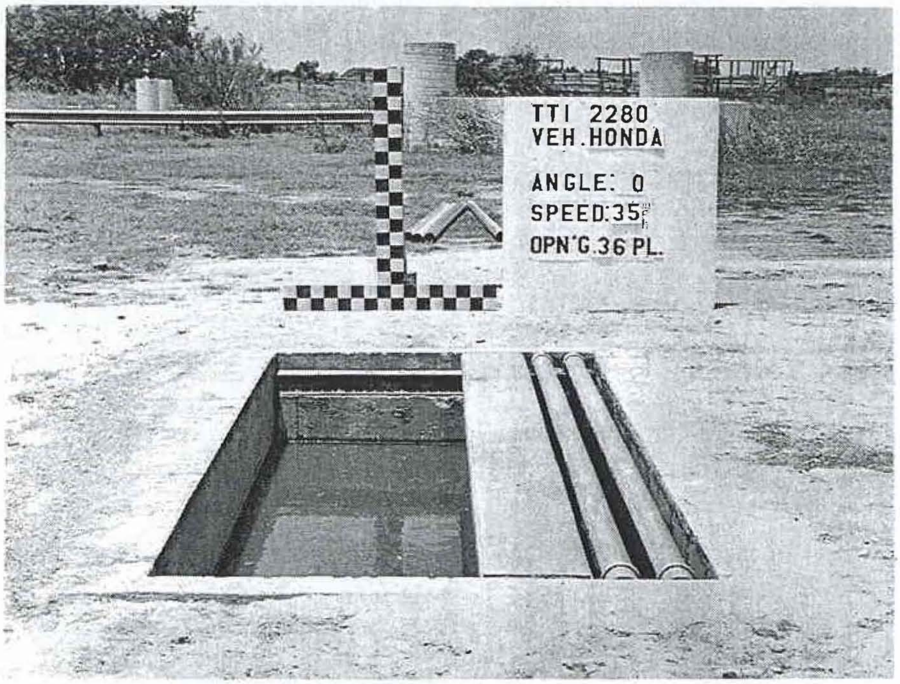
The test vehicle for this set of runs was a 1974 Honda Civic which is shown in Figure 12. The vehicle was accelerated to test speeds and kept on line with the test pit by a driver.

A total of 29 full-scale test runs were conducted on the clear opening setup. General details of the test runs are given in Table 1. Limiting values were determined by the severity of the ride as experienced by the driver in traversing each opening. In other words, the lowest speed shown for a given opening represents the lowest speed judged to be "traversable" by the driver. Sequential photos from high-speed film of two test runs are shown in Figures 13 and 14, picturing the second largest and largest clear openings tested, respectively. Figure 15 shows the amount the wheel would drop into an 18 in. (45.72 cm) clear opening under static or very low-speed traversals. Wheel hub and car displacement versus time data are plotted in Figure 16 for a 36 in. (91.44 cm) clear opening. The maximum wheel hub displacement values for the 22 in. and larger openings are shown in Table 2.

Grated Culvert. Based on the results of tests previously described, openings greater than 30 in. (76.2 cm) require a safety grate. The purpose of this phase of the study was therefore to find the maximum spacing of safety grate members on culverts greater than 30 in. (76.3 cm) in diameter. Figure 17



a) 22 in. Clear Opening



b) 36 in. Clear Opening

Figure 11. Test Pit Setup for Simulation of Nongrated Culvert

a) Front View

b) Side View

Figure 12. 1974 Honda Civic

Table 1. Matrix of Clear Opening Test Runs on Pit

Speed, mph	Clear Opening, inches								
	16	18	20	22	24	26	28	30	36
5	X								
10		X	X 0	X 0					
15				X 0	X 0	X 0			
20			X 0	X 0	X 0	X 0	X 0	X 0	
25								X 0	X 0
30									X
35									X

Metric Conversions: 1 in. = 2.54 cm; 1 mph = 1.609 km/h
1 lb_m = 0.454 kg

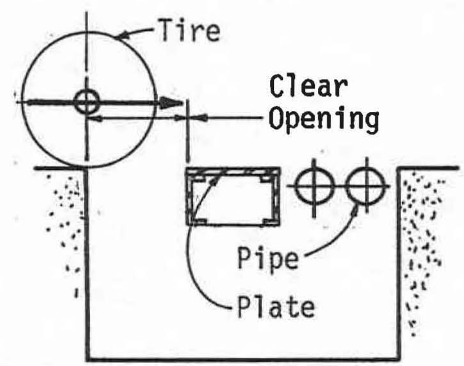
VEHICLE:

1974 Honda
1800 lb
13" Wheel
22" Tire (Diameter)

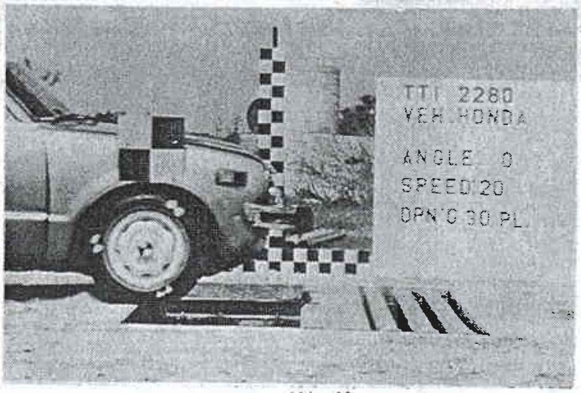
LEGEND:

x – 0^{0} Encroachment Angle

o – 15^{0} Encroachment Angle



Test Pit Cross Section



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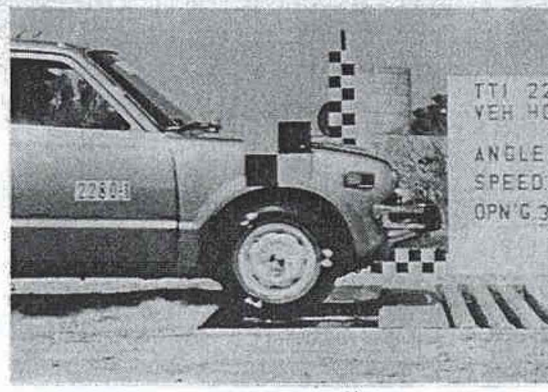

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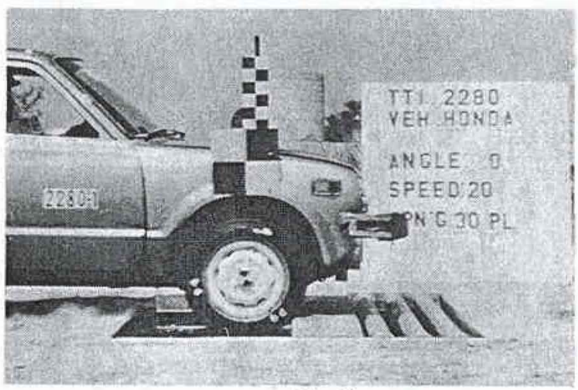

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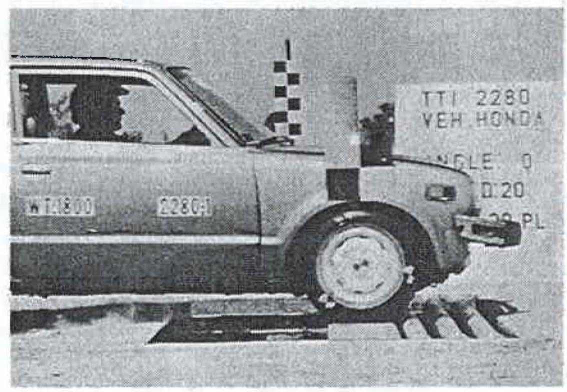

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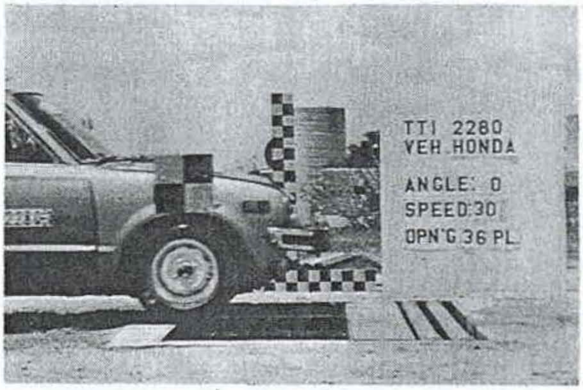
Figure 13. Sequential Photos of Nongrated Culvert Test,
30 in. (76.2 cm) Clear Opening, 1974 Honda Civic.



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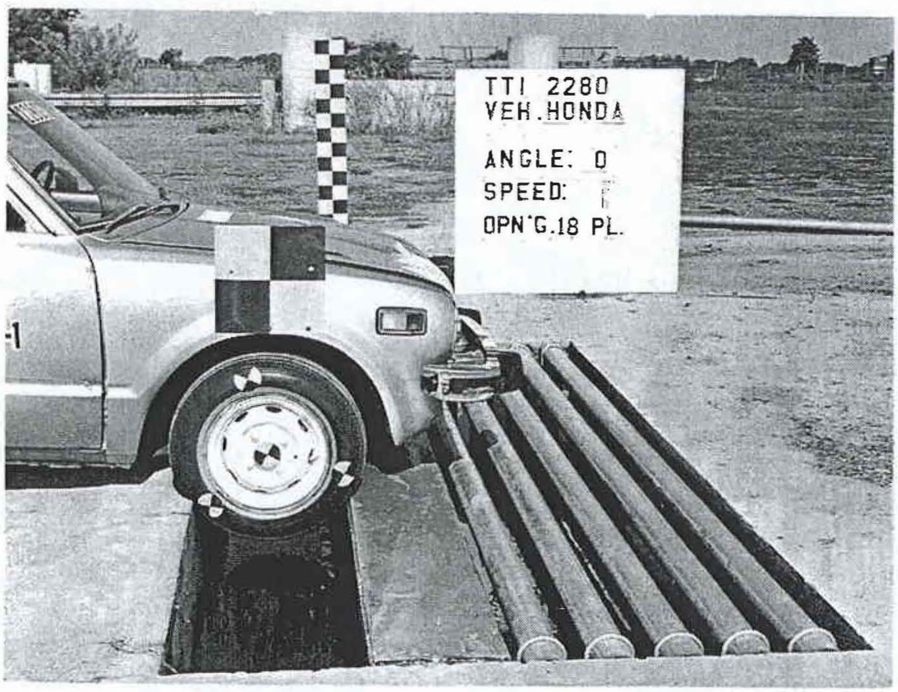
Metric Conversions:

1 in. = 2.54 cm

Figure 14. Sequential Photos of Nongrated Culvert Test, 36 in. Clear Opening, 1974 Honda Civic

a) Front Wheel Drop



b) Closeup of Front Wheel Drop

Figure 15. Wheel Drop into Clear Opening Setup

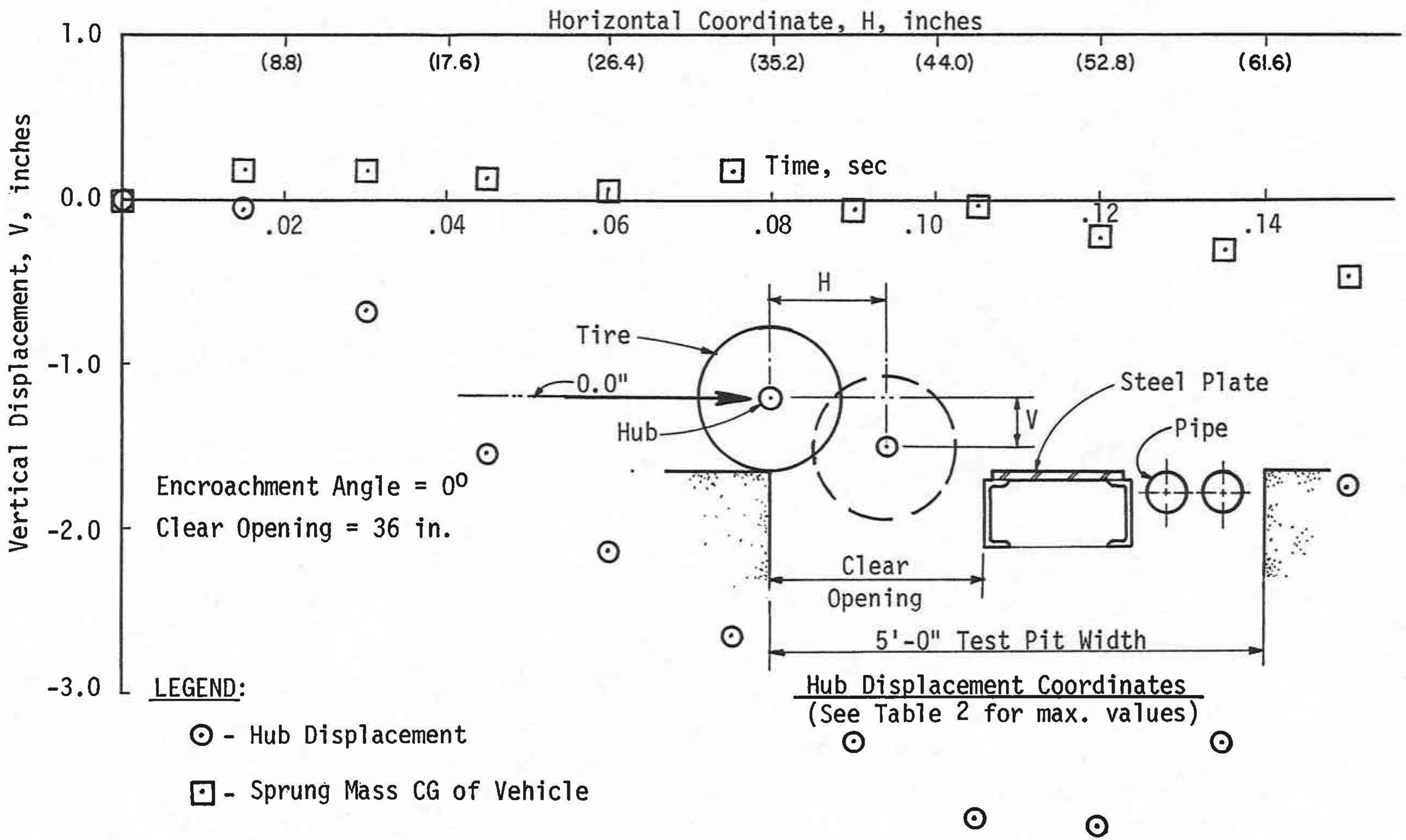


Figure 16. Wheel Hub and Car Displacement vs. Time for Clear Plate Opening Run, 25 mph,1974 Honda Civic

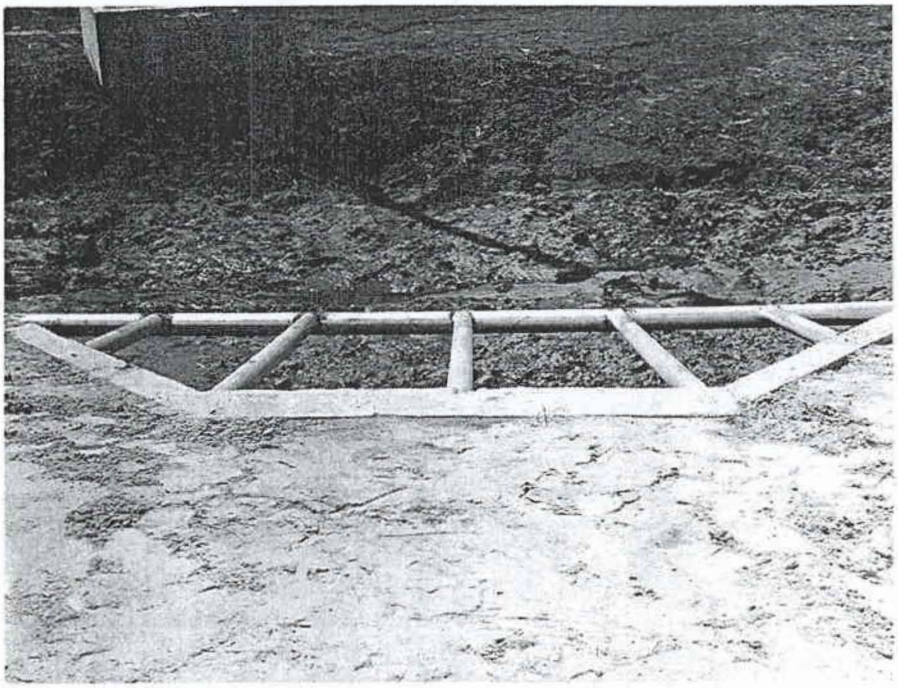
Table 2. Maximum Wheel Hub Displacement for Clear Opening Runs.[a]

Velocity (mph)	Encroachment Angle (degrees)	Clear Opening (inches)	Vertical Hub Displacement, V (inches)	Horizontal Coordinate from Edge, H (inches)
20	0	22	-2.2	21.1
15	0	22	-2.3	15.8
10	0	22	-2.9	15.8
20	15	22	-2.2	20.4
15	15	22	-2.6	19.1
10	15	22	-2.9	17.9
20	0	24	-2.7	21.1
15	0	24	-2.8	19.8
20	15	24	-2.9	20.4
15	15	24	-3.0	23.0
20	0	26	-2.8	21.1
20	15	26	-2.5	25.5
15	0	26	-2.9	19.8
15	15	26	-3.3	23.0
20	0	28	-3.1	26.0
20	15	28	-2.7	25.5
25	0	30	-3.4	26.4
20	0	30	-3.4	26.4
25	15	30	-3.1	26.4
20	15	30	-3.6	25.5
35	0	36	-1.2	27.7
30	0	36	-2.6	31.7
25	0	36	-2.7	28.6

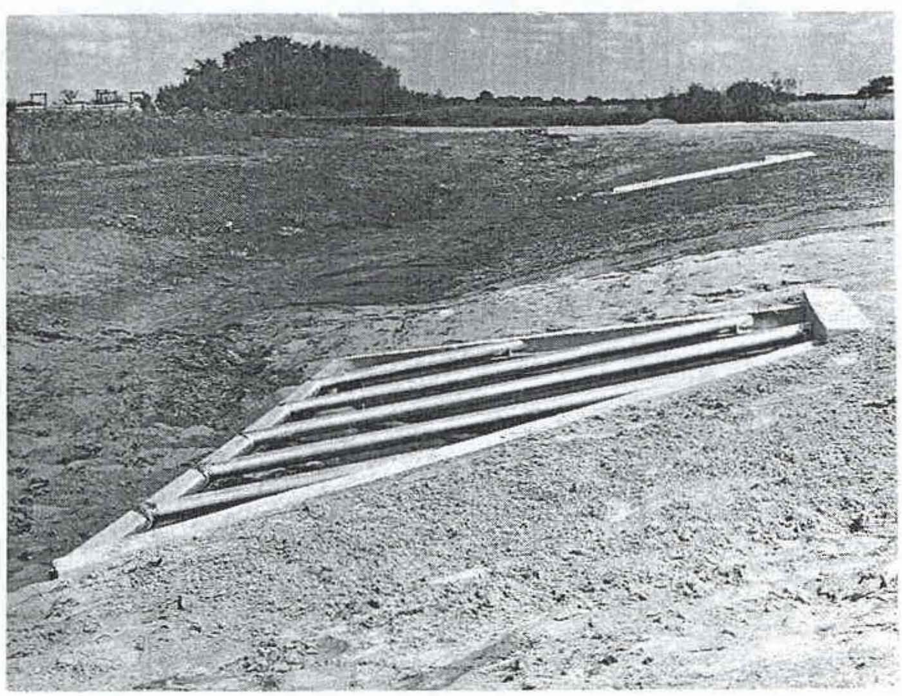
[a] All clear opening test runs were made with a 1974 Honda Civic.

Metric Conversions:

1 in. = 2.54 cm
1 mph = 1.609 km/h
1 lb_m = 0.454 kg



a) Rear View



b) Side View

Figure 17. Concrete Drainage Culvert with Safety Grate

shows a large culvert with a safety treatment. To simulate this safety grate, 3 inch (7.62 cm) schedule 40 steel pipe were anchored onto a steel beam (see Appendix A) with provisions to allow adjustment of the pipe to any desired spacing. Figure 18 shows two of the safety grate spacings that were tested.

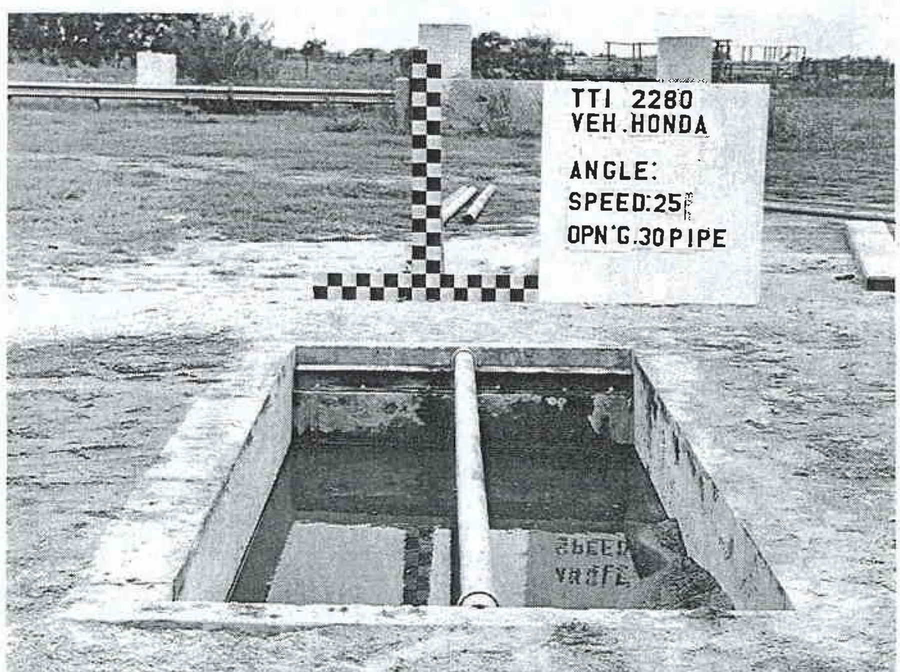
The test vehicles for this set of runs were a 1974 Honda Civic, used previously in the nongrated culvert test (see Figure 12), and a 1975 Plymouth Fury, shown in Figure 19. Both vehicles were accelerated to test speeds and kept on line with the test pit by a driver.

A total of 22 full-scale test runs were conducted on the grated culvert setup. General details of the test runs are given in Table 3 with limiting values determined as previously discussed for the nongrated condition. Sequential photos from high-speed film of two test runs are shown in Figures 20 and 21, picturing the two test vehicles traversing a 30 in. (76.2 cm) grate spacing. Figure 22 shows the amount the wheel would drop into a safety grate with a 16 in. (40.64 cm) center-to-center spacing under static or very low speed traversals. Wheel hub and car displacement versus time data are plotted in Figures 23 and 24 for the two vehicles mentioned above. The maximum wheel hub displacement values for all the test runs are shown in Table 4.

Curb Impact Study. A curb with a ramp-like cross section was constructed to further investigate the effect a curb would have on vehicle trajectory. Based on the results of the computer simulation work, a curb with a 2:1 slope helped to maintain a fairly uniform vertical position of the sprung mass cg, and thus was the one chosen for use in this curb impact study. The curb was constructed of 3/4 in. (1.905 cm) plywood as shown in Figure 25. Note that the area behind the ramp was flat earthen soil.

The test vehicles for this study were the same ones used for the grated culvert test. The vehicles were accelerated to test speeds and kept on line with the test pit by a driver.

a) 16 in. Grate Spacing



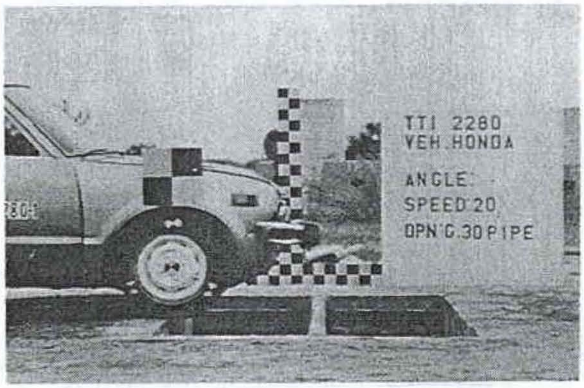
b) 30 in. Grate Spacing

Figure 18. Test Pit Setup for Simulation of Grated Culvert

a) Front View

b) Side View

Figure 19. 1975 Plymouth Fury



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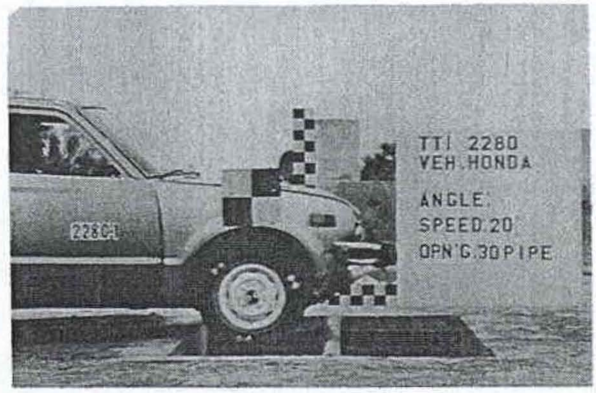

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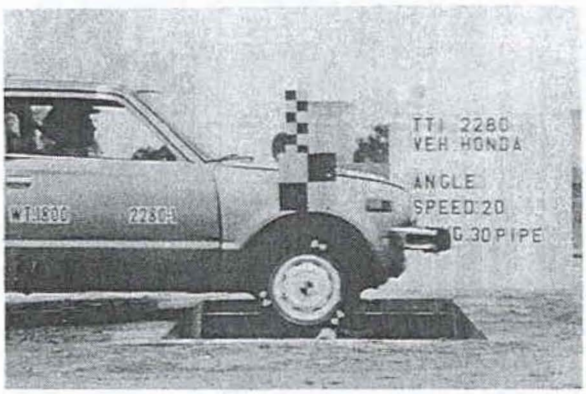


0.079 sec.

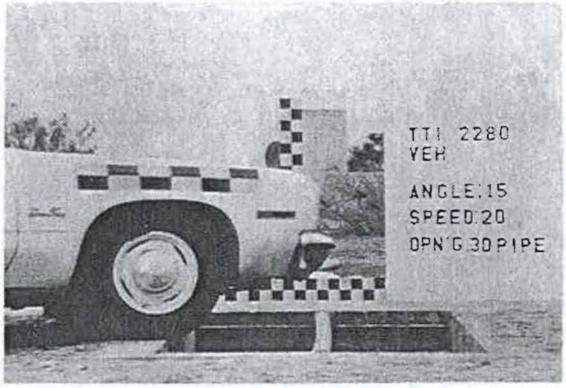
0.139 sec.

0.198 sec.

Metric Conversion:

1 in. = 2.54 cm

Figure 20. Sequential Photos of Grated Culvert Test, 30 in. Pipe Spacing, 1974 Honda Civic



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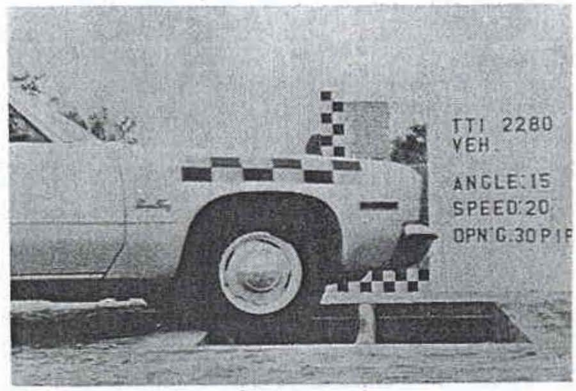

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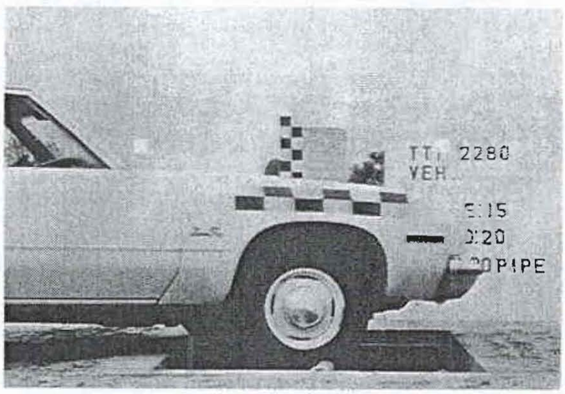

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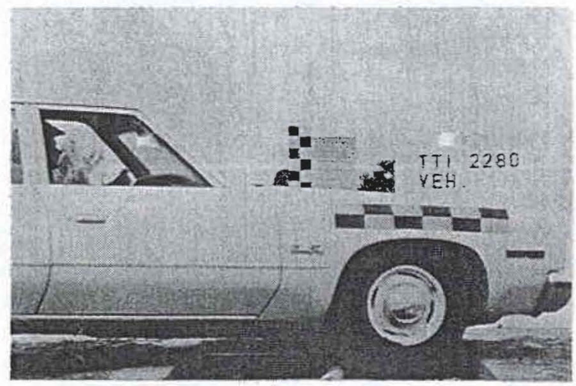


0.159 sec.

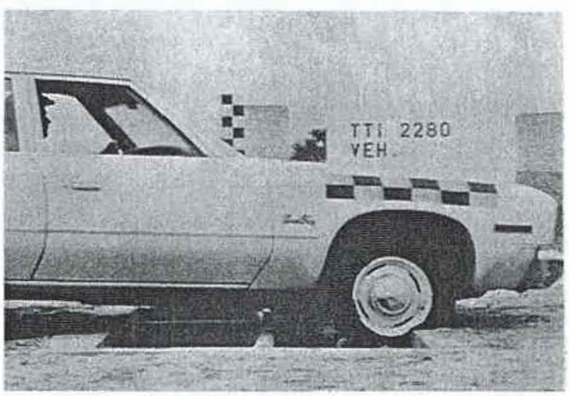


Figure 21. Sequential Photos of Grated Culvert Test, 30 in. Pipe Spacing, 1975 Plymouth Fury

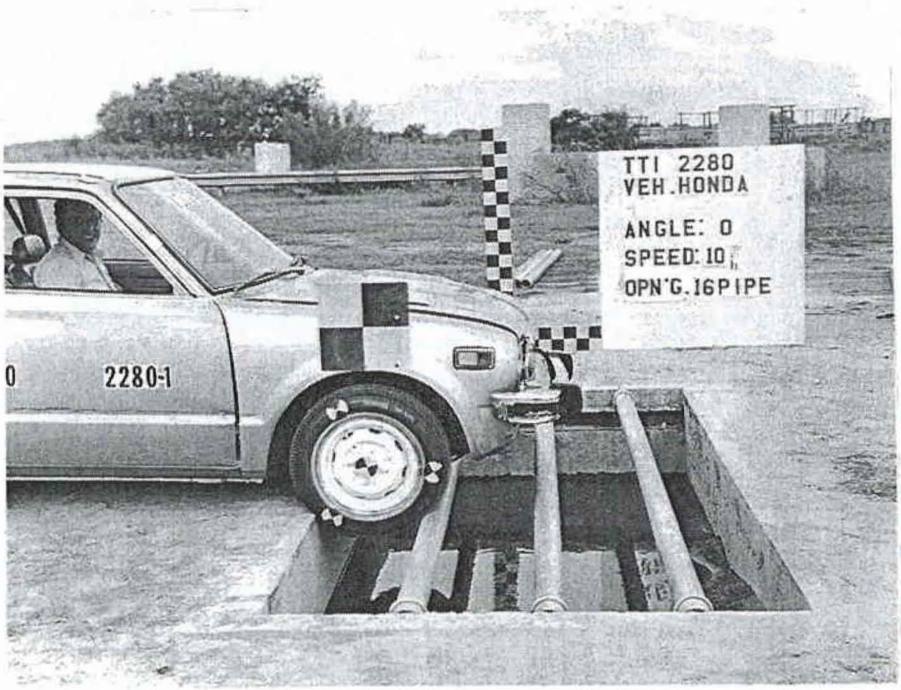


Figure 22. Front Wheel Drop into Grated Culvert Setup

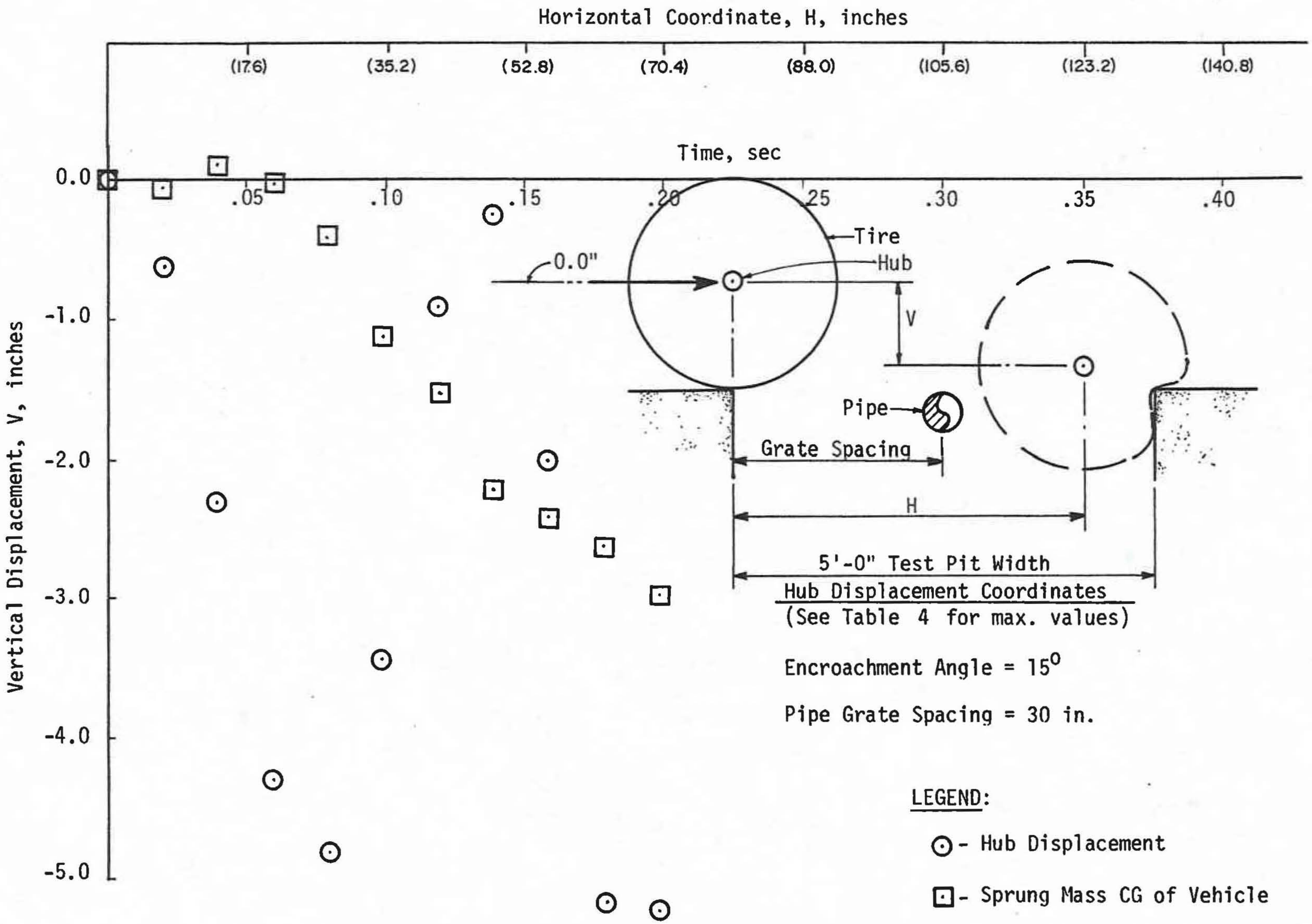


Figure 23. Wheel Hub and Car Displacement vs. Time for Pipe Grating Run, 20 mph, 1975 Plymouth Fury

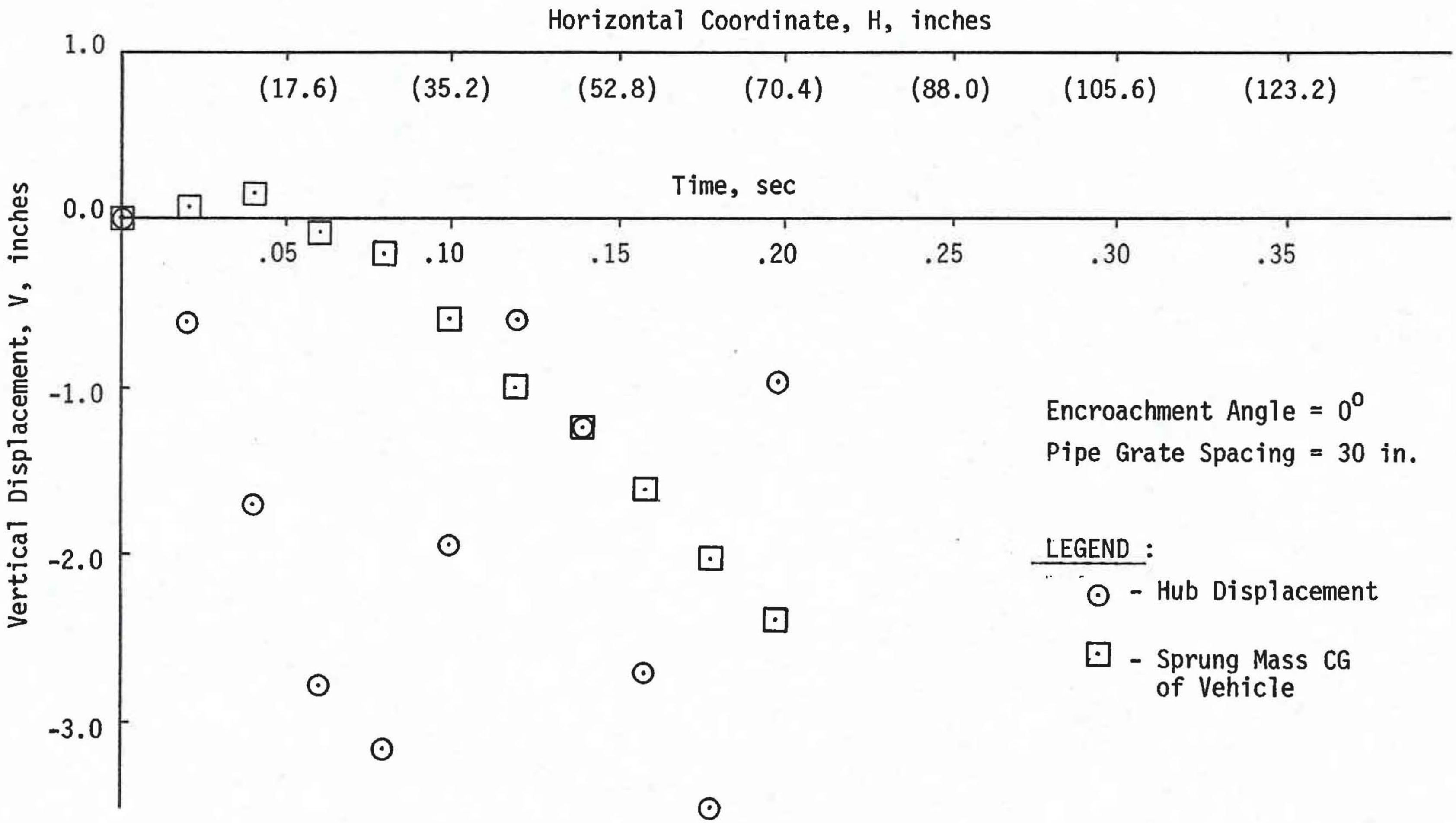
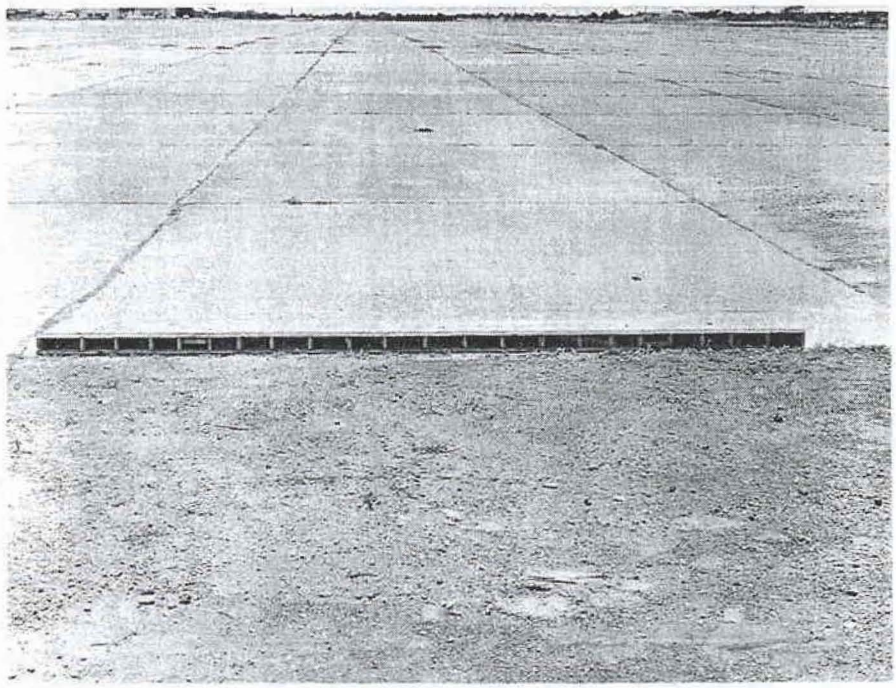


Figure 24. Wheel Hub and Car Displacement vs. Time for Pipe Grating Run, 20 mph, 1974 Honda Civic.



a) Front View

b) Side View

Figure 25. Ramp Installation for Curb Impact Study.

Table 3. Matrix of Pipe Grating Test Runs.

Speed, mph	Center-to-Center Pipe Spacing, inches			
	16	20	24	30
5	x o			
10	x o □	x o		
15		x o	x o	
20		x o	x o	x-P o-P
25				x-P o
Metric Conversions: 1 in. = 2.54 cm; 1 mph = 1.609 km/h 1 lb_m = 0.454 kg				

NOTE: The 1975 Plymouth Fury had 3 tires blown out and 4 wheels bent at a vehicle speed of 20 mph, 15° encroachment angle with a 30" center-to-center pipe grate spacing.

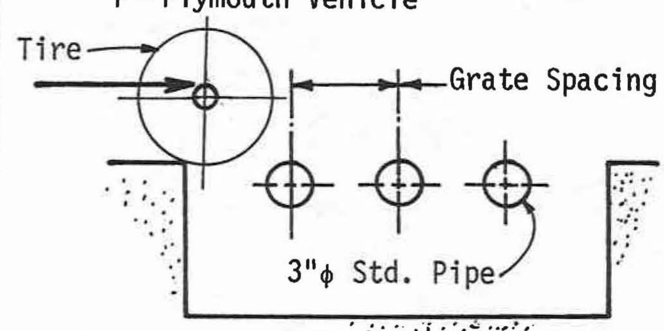
VEHICLES:

1974 Honda
1970 lb
13" Wheel
22" Tire Diameter

1975 Plymouth Fury
4500 lb

LEGEND:

x – 0° Encroachment Angle
o – 15° Encroachment Angle
□ – 30° Encroachment Angle
P – Plymouth Vehicle



Test Pit Cross Section

Table 4. Maximum Wheel Hub Displacement for Pipe Grating Runs.

Velocity (mph)	Encroachment Angle (degrees)	Pipe Grate Spacing (inches)	Vertical Hub Displacement, V (inches)	Horizontal Coordinate from Edge, H (inches)
10	0	16	-2.8	46.2
5	0	16	-2.5	20.9
10	15	16	-2.0	13.6
10	30	16	-1.5	13.2
5	15	16	-2.2	16.7
15	0	20	-3.3	52.5
10	0	20	-3.7	55.4
20	0	20	-2.6	52.5
20	15	20	-1.4	20.4
15	15	20	-2.0	19.9
10	15	20	-2.9	53.6
20	0	24	-2.8	49.3
15	0	24	-2.8	47.5
15	15	24	-2.7	20.2
20	15	24	-2.2	40.8
25	15	30	-2.4	33.6
25	0	30	-3.4	52.5
20	15	30	-3.1	26.9
20	0	30	-3.5	52.5
Note: Above data are for runs made with a 1974 Honda Civic.				
20	15	30	-5.3	52.5
20	0	30	-4.4	21.1
25	0	30	-4.2	26.4
Note: Above data are for runs made with a 1975 Plymouth Fury.				

Metric Conversions:

1 in. = 2.54 cm
1 mph = 1.609 km/h
1 lb_m = 0.454 kg

A total of nine test runs were made for the curb impact study. Wheel hub and car displacement versus time data are plotted in Figures 26 and 27 for the Plymouth and Honda vehicles, respectively. The maximum wheel hub displacement values for the test runs are shown in Table 5. The results of these tests were inconclusive, i.e., the benefits of a ramp or curb in allowing a vehicle to safely clear a culvert opening were not obvious. This was due in part to the test setup. Since the area behind the ramp was not excavated (as would be the case for a culvert opening) one could not determine the wheel drop that would have occurred otherwise. Further tests and evaluation of the potential benefit of such ramps may be desirable.

Summary of Preliminary Studies

The only installation damage occurred in the form of permanent deformation of the pipe at midspan for the 30 in. (76.2 cm) spacing setup. This deformation resulted from the run made with the Plymouth vehicle impacting at 25 mph and a 0^{o} encroachment angle. This deformation can be seen in Figure 21 just prior to the 15^{o} encroachment angle run. This deformation could be reduced or eliminated by using a larger pipe or a fixed-end type connection (rather than a pinned-end type) as was used for the final test discussed in subsequent sections.

Of the two vehicles used throughout the preliminary studies only the Plymouth was damaged as indicated in Figure 28. Damage was light, and only the wheels and tires were involved. Three tires were blown out and all four wheel rims were deformed as the rear edge of the test pit was impacted at a test speed of 20 mph and 15^{o} encroachment angle.

The following tentative conclusions were drawn from the preliminary investigation:

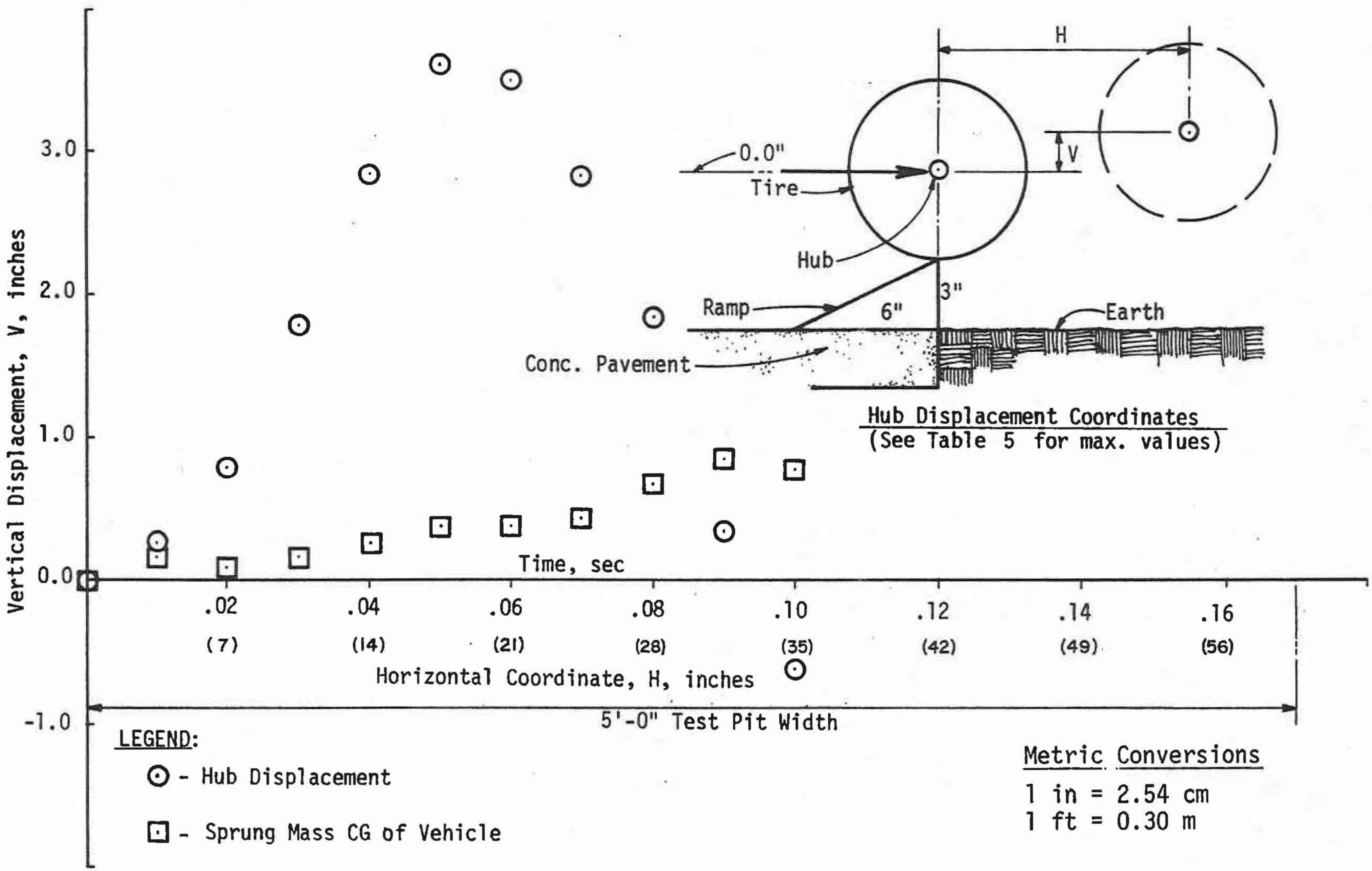


Figure 26. Wheel Hub and Car Displacement vs. Time for Ramp Run, 20 mph, 1975 Plymouth Fury

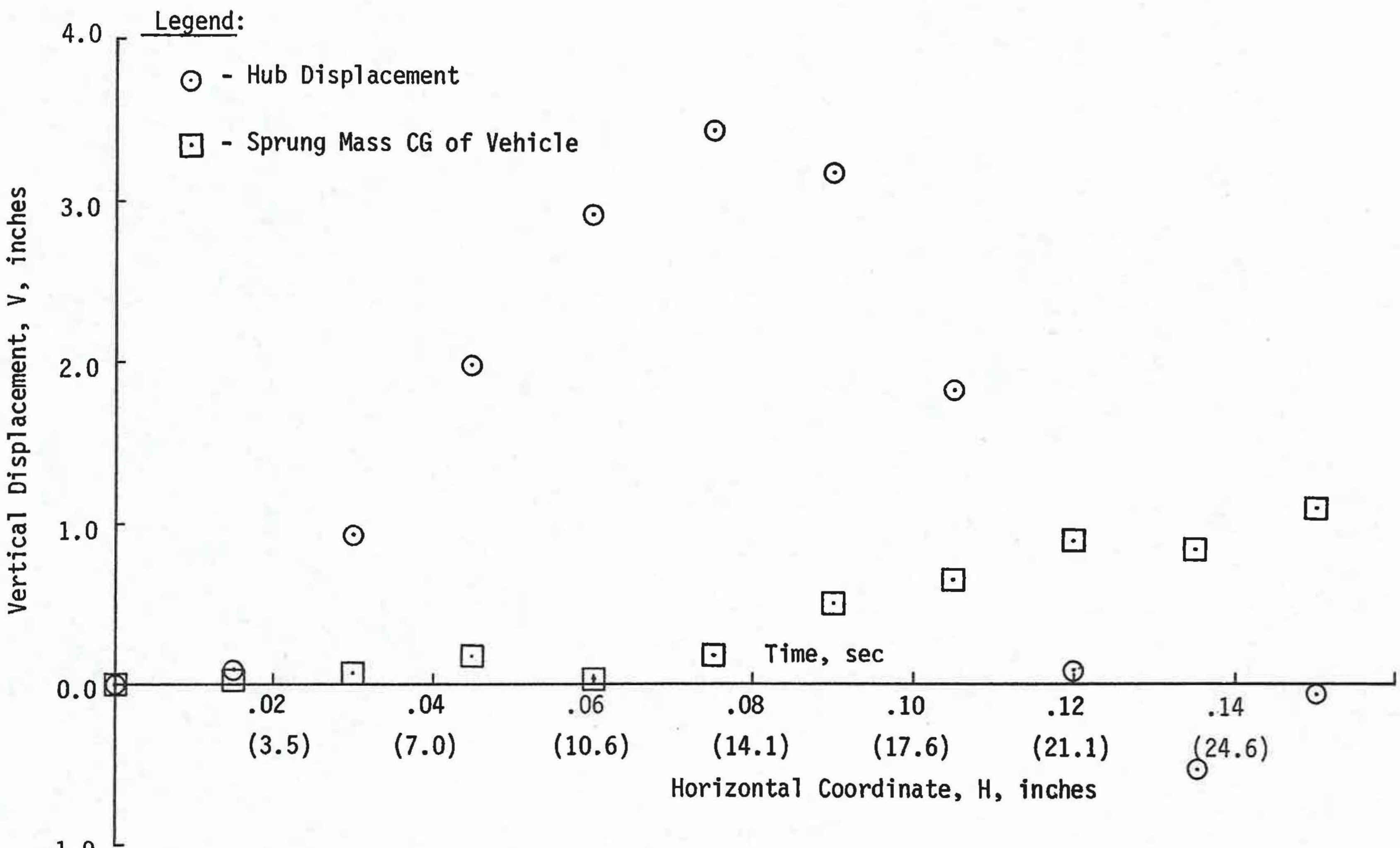


Figure 27. Wheel Hub and Car Displacement vs. Time for Ramp Run, 10 mph, 1974 Honda Civic

a) Front Tire Blown Out; Wheels Slightly Bent

b) Both Tires Blown Out; Both Wheels Bent

Figure 28. Vehicle Damage, Test 1

Table 5. Maximum Wheel Hub Displacement for Ramp Runs.[a]

Velocity (mph)	Vertical Hub Displacement, V (inches)	Horizontal Coordinate from Edge, H (inches)
5	2.9	10.6
10	2.9	10.6
20	3.1	14.1
30	3.0	21.1
40	2.6	24.6
10	3.4	13.2
Note: Above data are for runs made with a 1974 Honda Civic.		
20	3.6	17.6
30	3.1	26.4
40	2.9	28.2
Note: Above data are for runs made with a 1975 Plymouth Fury.		

[a]All encroachment angles were 0^{o}.

Metric Conversions:

1 in. = 2.54 cm
1 mph = 1.609 km/h
1 lb_m = 0.454 kg

1. Both small and large automobiles can safely traverse culverts with a clear opening 30 in. (76.2 cm) in width.
2. Pipe grates spaced on 30 in. (76.2 cm) centers provide a safe treatment for culverts with openings in excess of 30 in. (76.2 cm).
3. Although test results were inconclusive, a ramp (or curb) placed along the edge of a culvert opening appears of benefit in terms of increasing the potential of a vehicle to clear the opening without significant snagging. Further simulation and testing of this concept may be desirable.

VALIDATION OF PRELIMINARY RESULTS
BY FULL-SCALE CRASH TESTS

Based on the results obtained from the preliminary runs, two culvert structures were constructed for full-scale testing. A total of six full-scale crash tests were conducted. General details of the test program are given in Figure 29. Complete details of each test are given in subsequent sections. Each test was conducted in accordance with recommended guidelines (3).

Test Vehicles

The test vehicles used in the preliminary tests were also used in the full-scale tests. These vehicles are shown in Figures 12 and 19. The vehicle was accelerated to test speed with a reverse tow system, and kept on line with the test structure by a cable guidance system as shown in Figure 30.

Test Structures

As shown in Figure 29, two different drainage structures were constructed to test the selected clear opening and safety grate spacing. Figures 31 and 32 show the pipe culvert and concrete box culvert test installations. Figures 33 and 34 are photographs of the pipe culvert and concrete box culvert, respectively, after installation. Appendix B contains a working drawing giving details for the installation of the concrete box culvert.

Test Results

Data acquisition and data reduction procedures were in accordance with recognized guidelines (3). Test results consist of photos of the impact phase and photos of damage, if any, to the culvert installations and vehicles.

All tests were conducted with the vehicle impacting the culvert installation at a 5^{o} encroachment angle. With the exception of test 6, the vehicle

VEHICLE DATA

	Car 1	Car 2
Make	Honda	Plymouth
Model	CVCC	Fury
Year	1974	1975
Test Weight (lb)	1800	4500
Test No.	2, 3, 5	1, 4, 6
Velocity (mph)	20, 60	20, 60

Metric Conversions:

$1 \; lb_m = 0.454$ kg

1 mph = 1.609 km/h

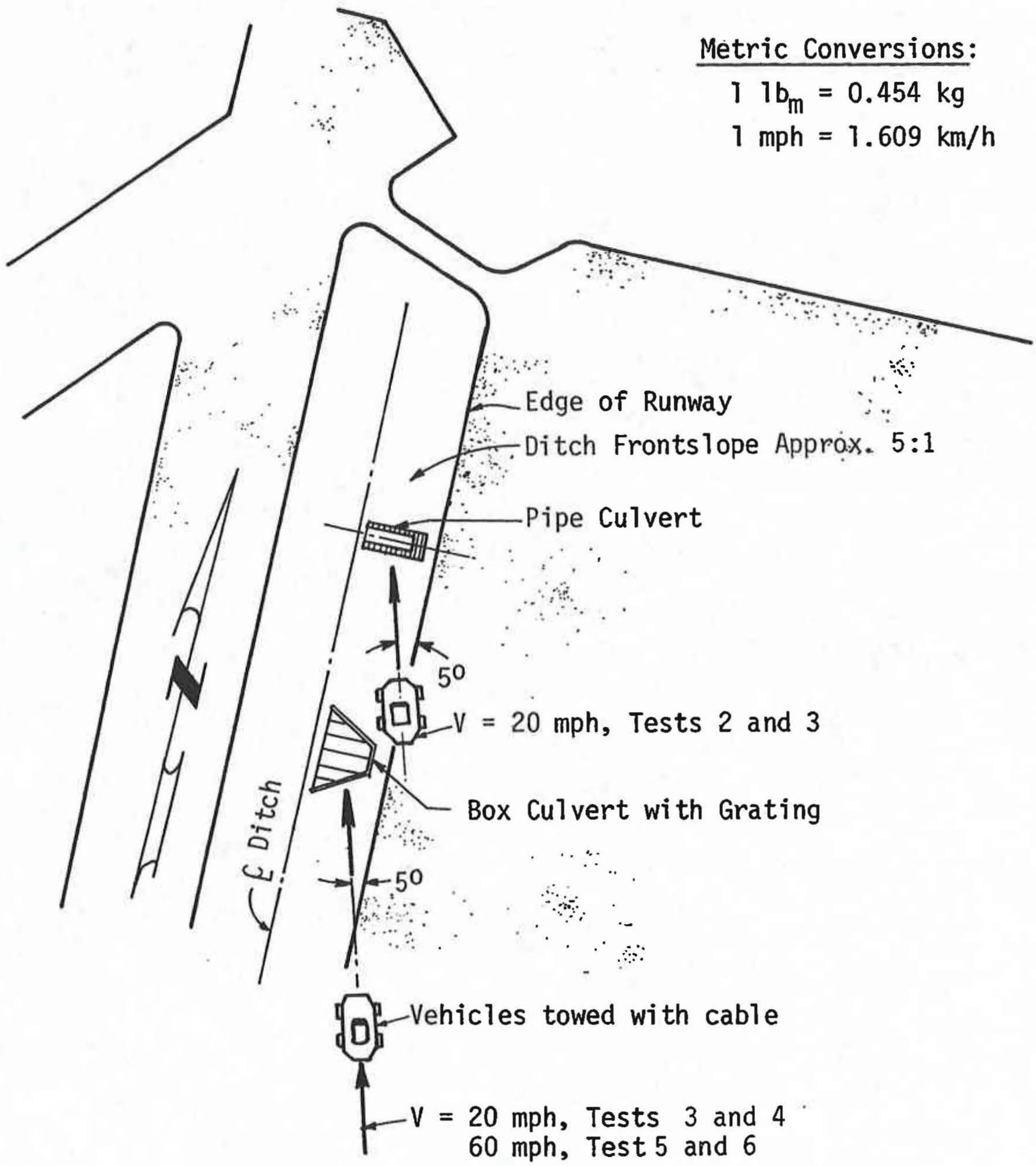
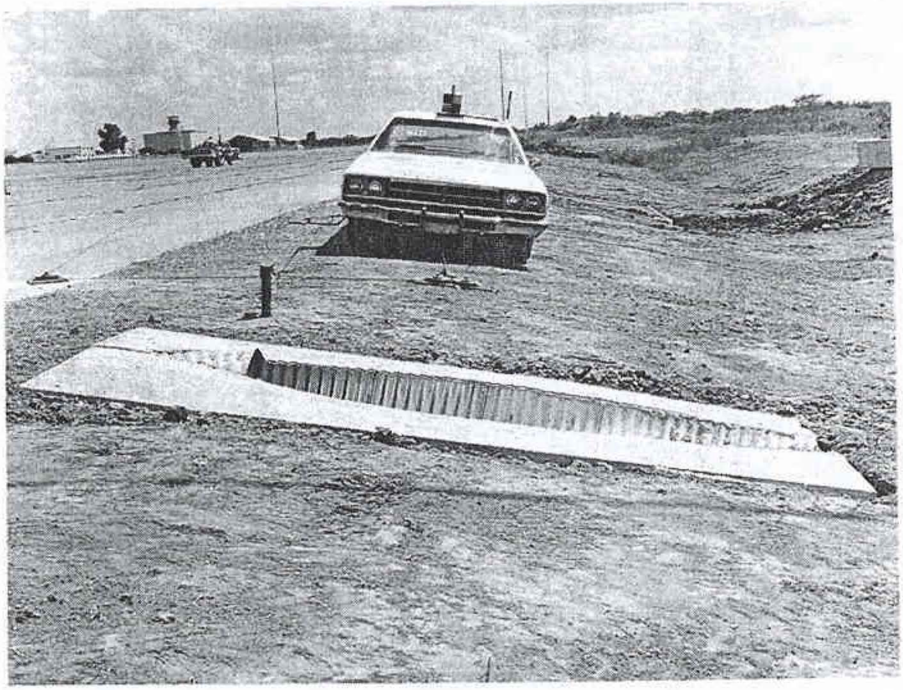


Figure 29. Plan View of Site for Tests 2, 3, 4, 5, 6, and 7



a) Front View

b) Side View

Figure 30. Example of Reverse Tow and Cable Guidance System for Tests 2, 3, 4, 5, 6, and 7

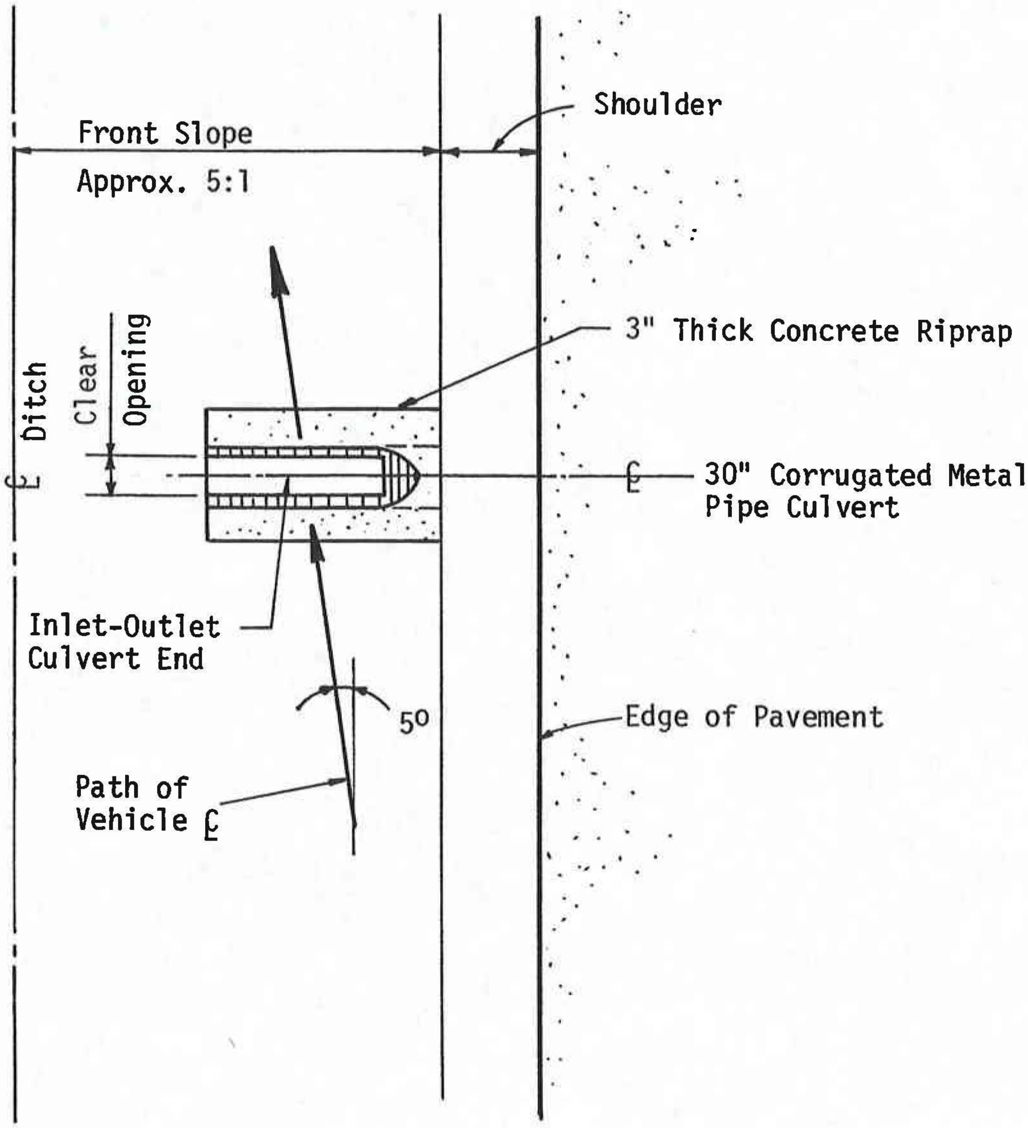


Figure 31. Plan View of Pipe Culvert for Tests 2 and 3

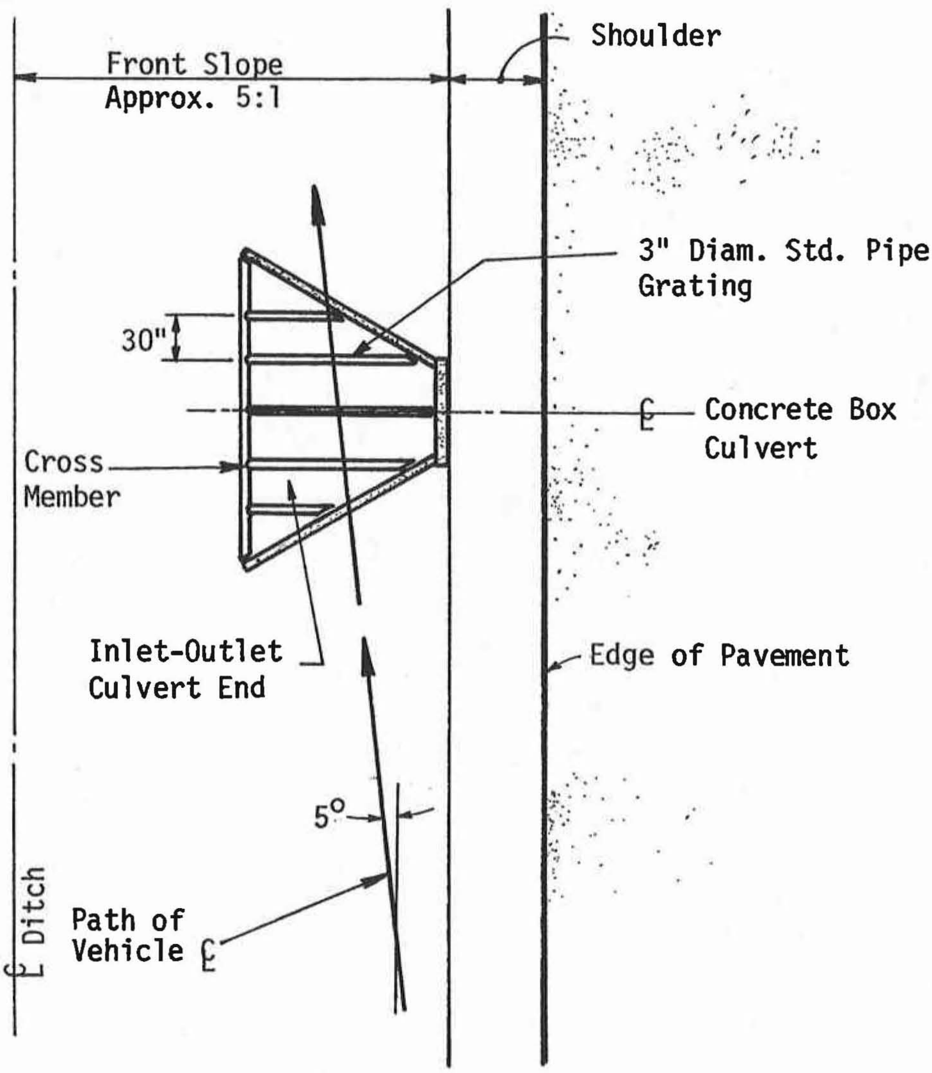
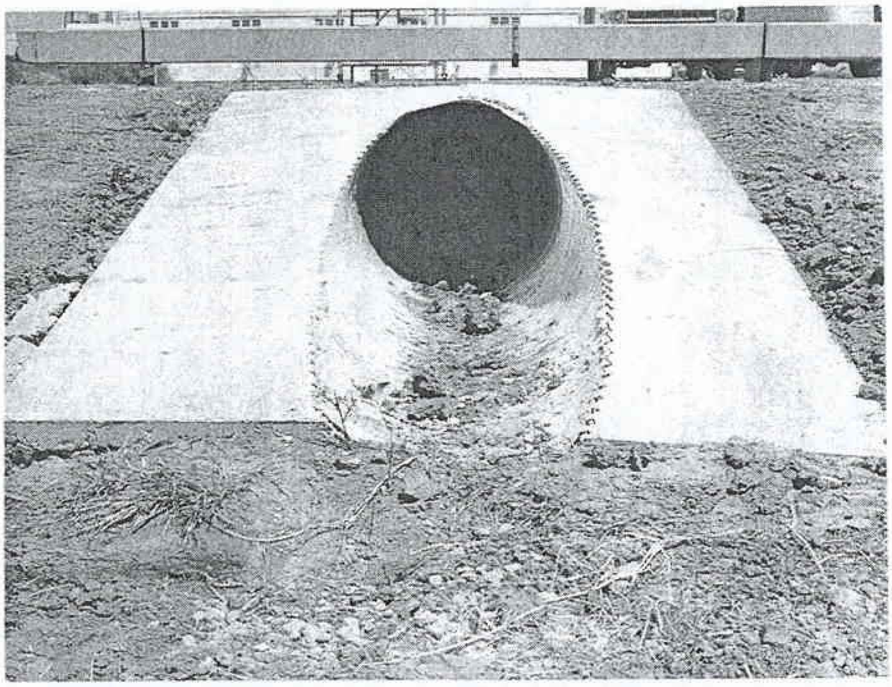
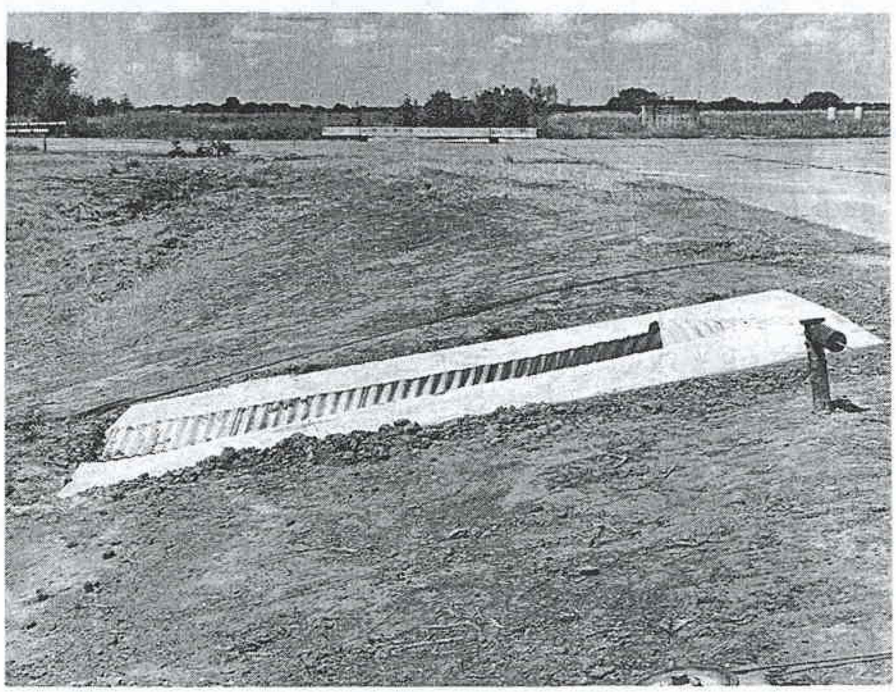


Figure 32. Plan View of Concrete Box Culvert
for Tests 4, 5, 6, and 7

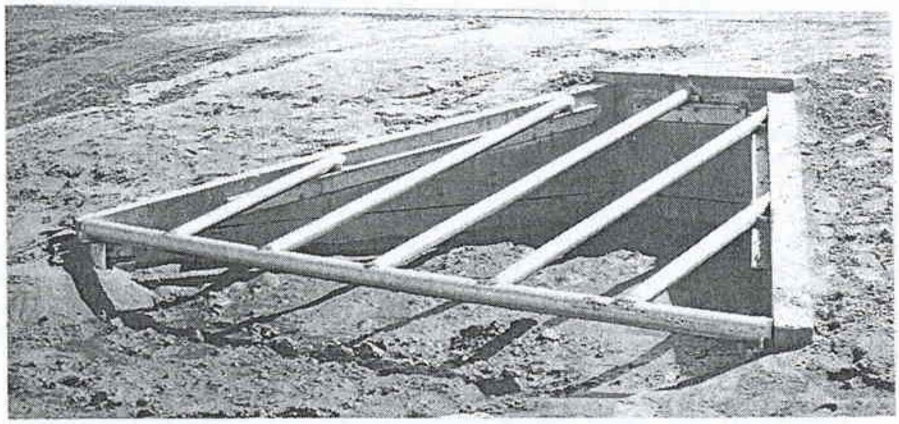


a) Front View

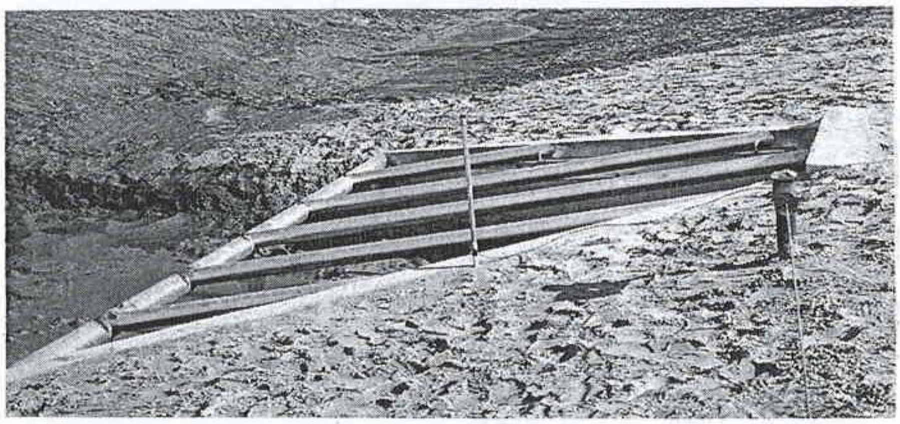


b) Side View

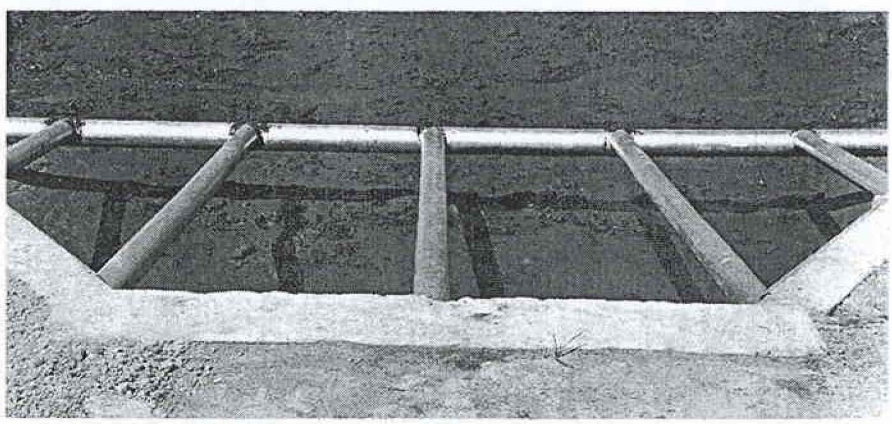
Figure 33. 30 in. Diameter Corrugated Metal Pipe Culvert on 5:1 Drainage Ditch Slope, Tests 2 and 3



a) Front View



b) Side View



c) Rear View

Figure 34. Concrete Box Culvert with Safety Grates on 5:1 Drainage Ditch Slope, Tests 4, 5, 6, and 7

was aligned so that all four tires would come in contact with the culvert as it was traversed. In test 6, the vehicle was straddled over the safety grate cross member as shown in Figure 35.

Test 2.* In test 2, the 30 in. (46.2 cm) diameter culvert was impacted at 20 mph (32.18 km/h) and easily traversed by the vehicle. Sequential photos from high-speed film of the impact are shown in Figure 36. Due to the low test speed, the vehicle tended to travel towards the ditch centerline and up the back slope where it finally came to rest as shown in Figure 37.

The culvert installation and the vehicle were not damaged and could be reused.

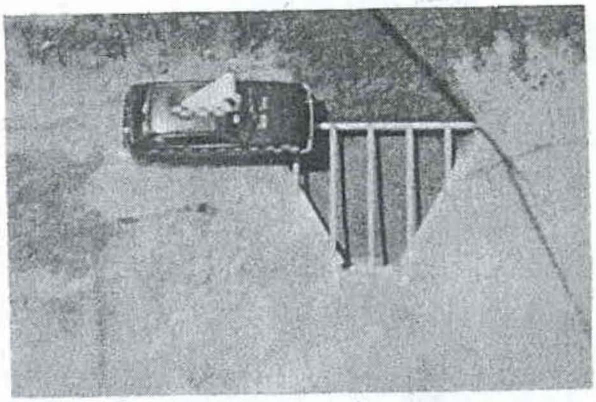
Test 3. In test 3, the 30 in. (46.2 cm) diameter culvert was once again impacted at 20 mph (32.18 km/h) but with the subcompact vehicle. The results were very similar to those reported in test 2. The high-speed film sequential photos are given in Figure 38.

Test 4. The concrete box culvert with safety grates was impacted by the Honda at 20 mph (32.18 km/h) and easily traversed by the vehicle. Figure 39 shows the sequential photos for this run. The vehicle and culvert installation were undamaged and could be reused.

Test 5. Test 5 was a repeat of test 4 with the large automobile. The box culvert was easily traversed, although more wheel hop was observed than in test 4. The sequential photos for this run appear in Figure 40. No damage to the vehicle or culvert was noted as a result of this run.

Test 6. In this test the box culvert was impacted at a speed of 60 mph (80.45 km/h) with the vehicle straddled over the culvert cross member at the end of the safety grate. The high-speed film sequential photos are given in

*"Test 1" was used to designate all tests conducted in the preliminary studies.



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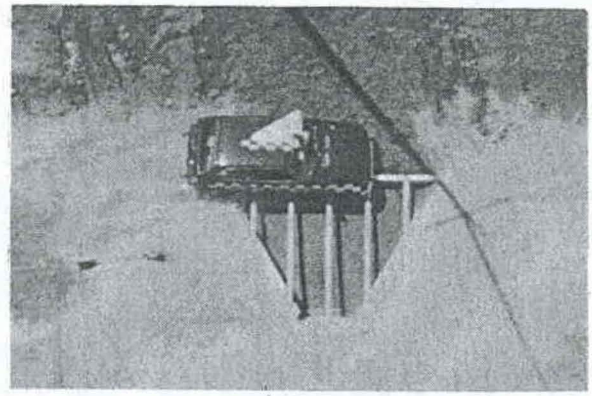

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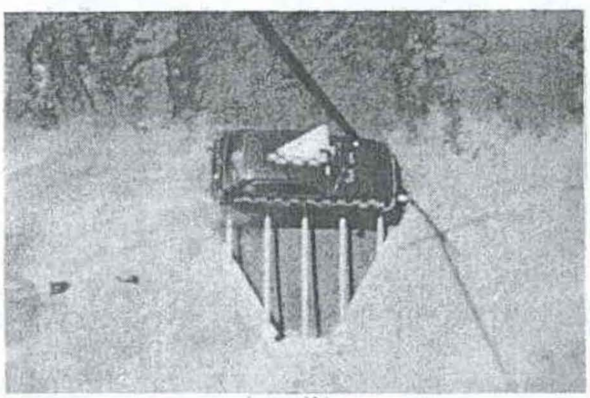

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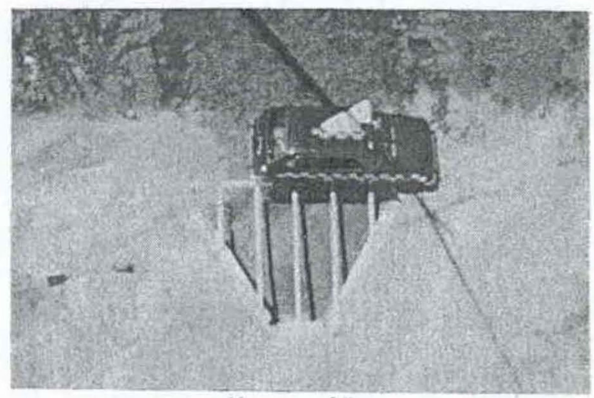

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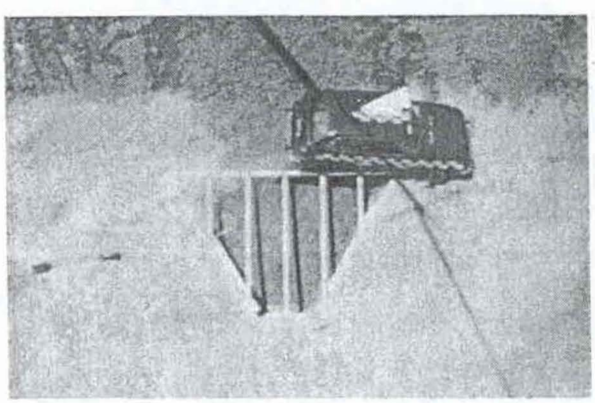

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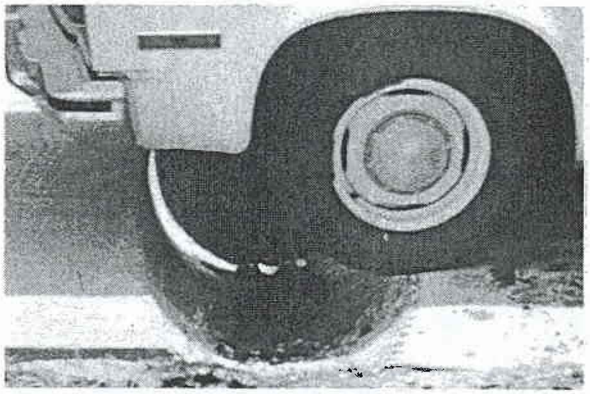
Figure 35. Sequential Photos for Straddled Run on Test 6



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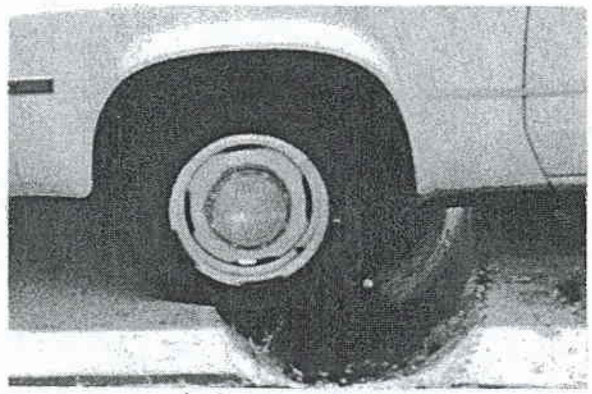

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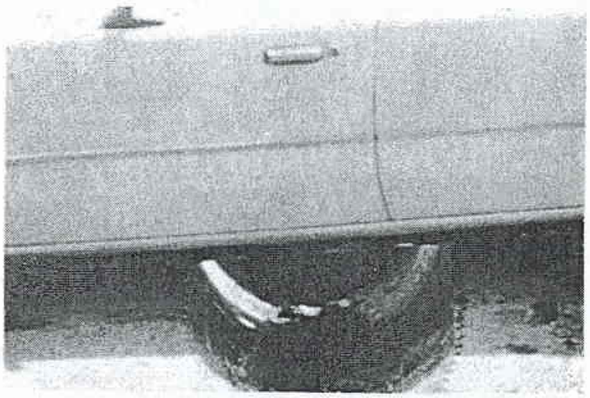

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Figure 36. Sequential Photos, Test 2

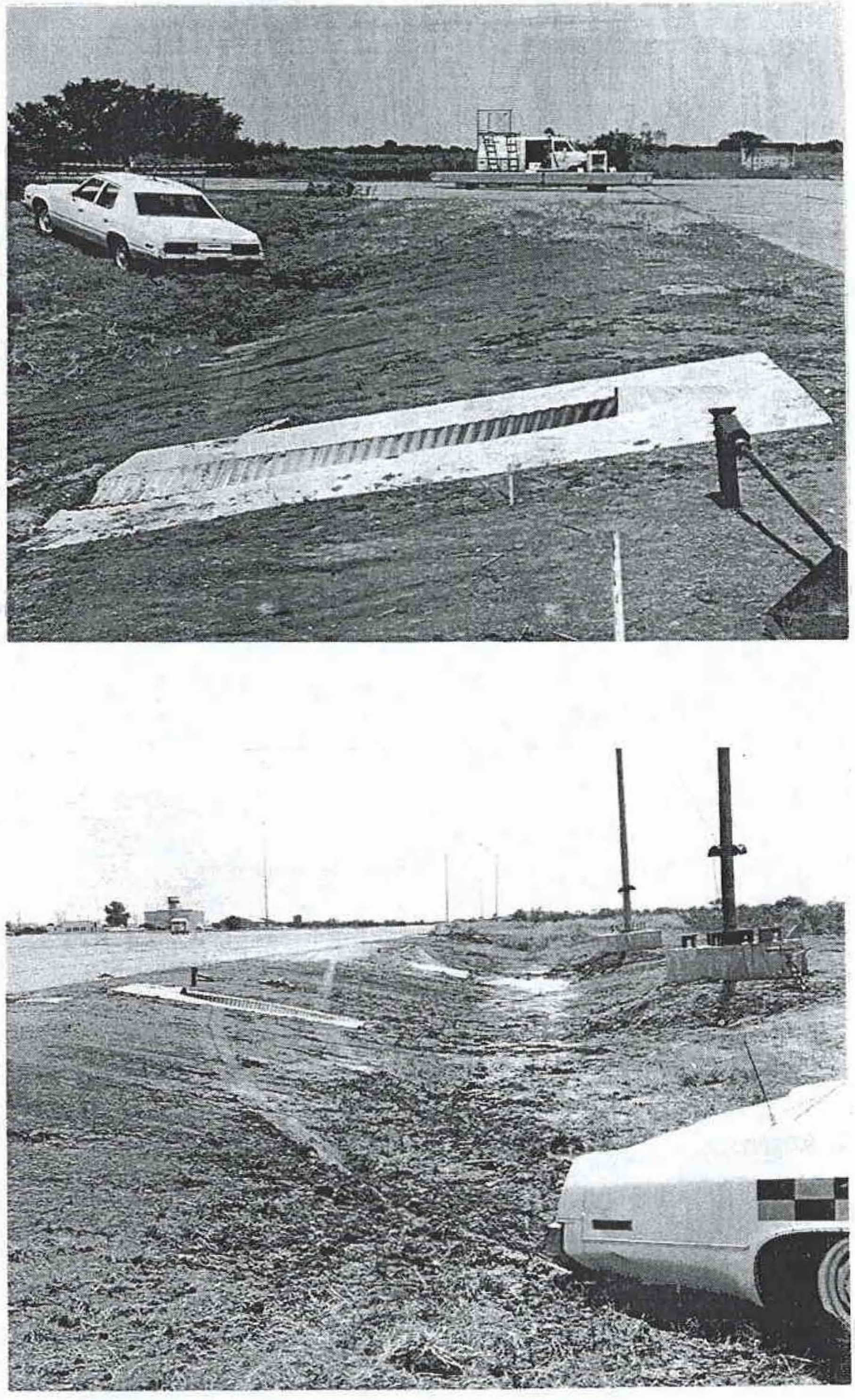
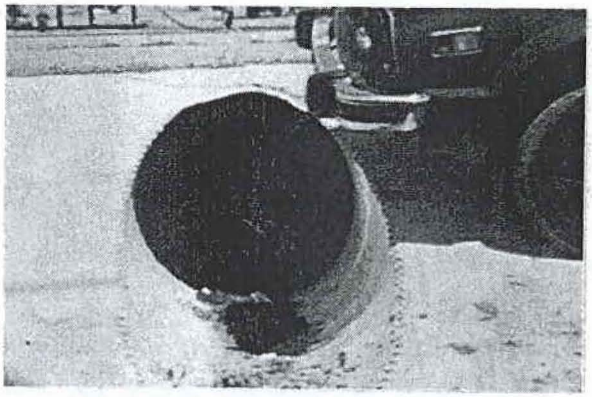


Figure 37. Resting Position of Vehicle after Traversing Pipe Culvert, Test 2



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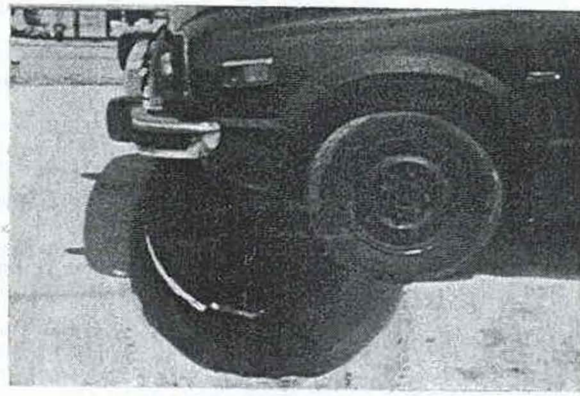

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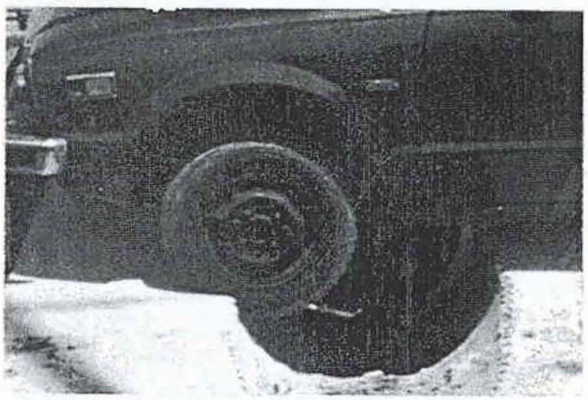

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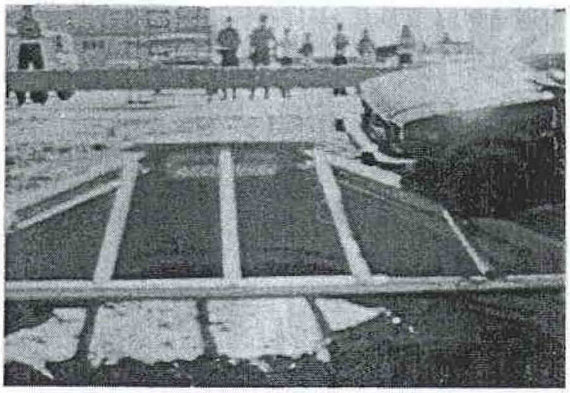
Figure 38. Sequential Photos, Test 3



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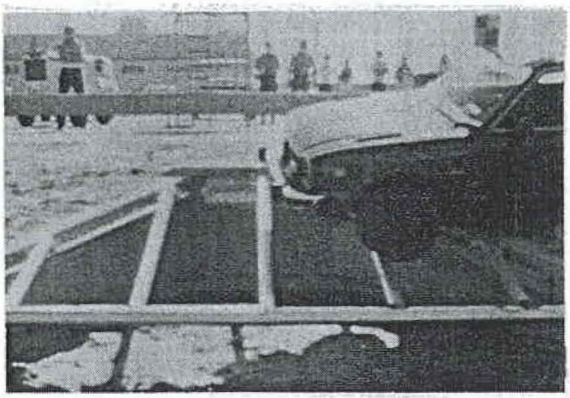

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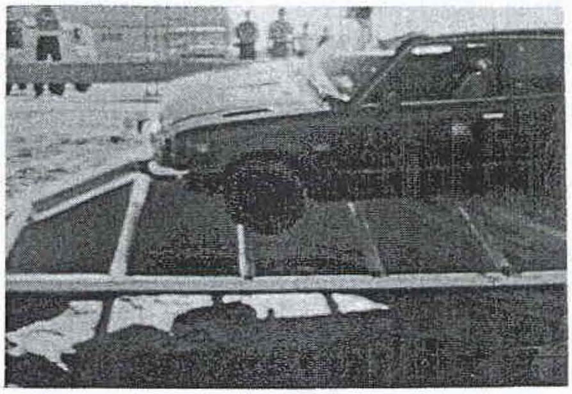

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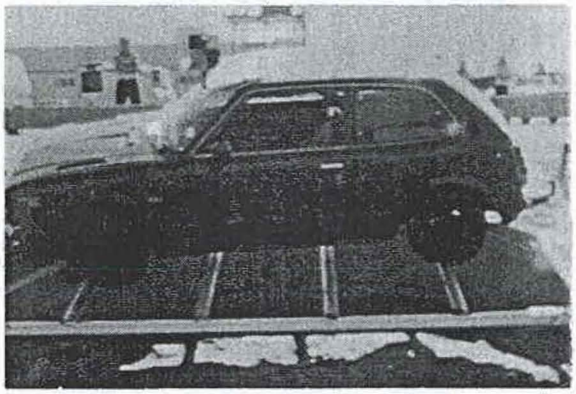

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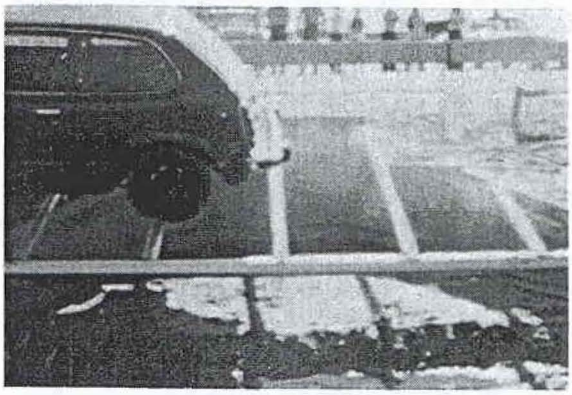
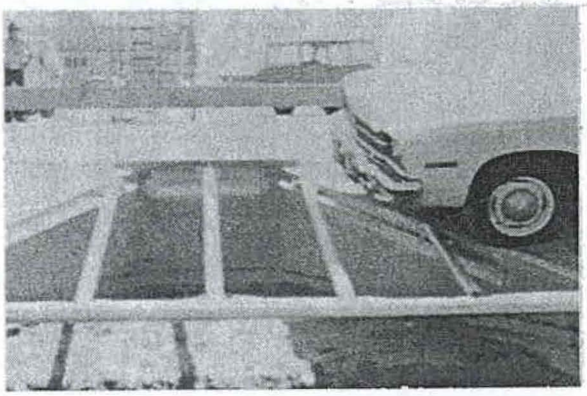


0.530 sec

Figure 39. Sequential Photos, Test 4



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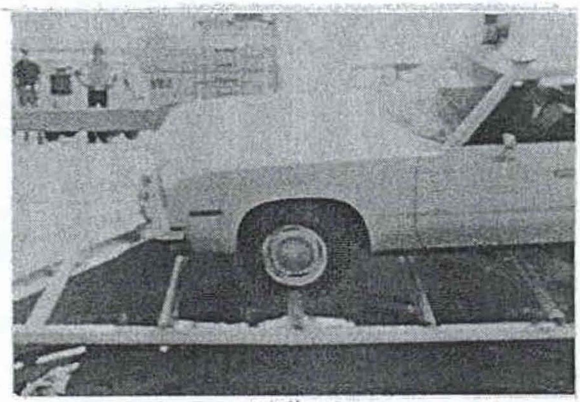

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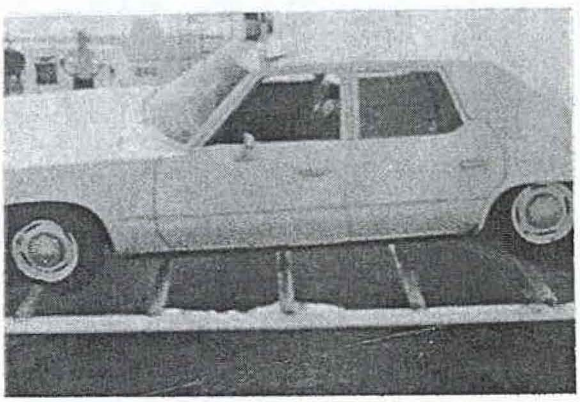

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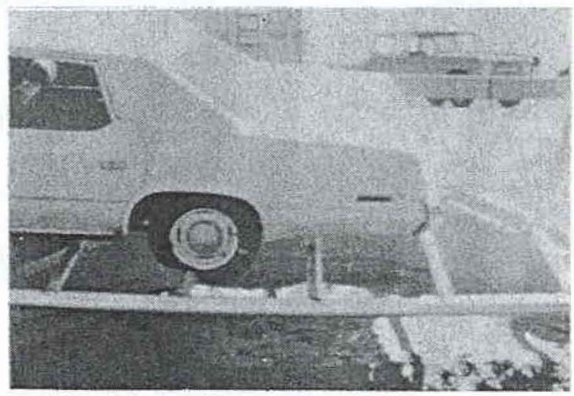

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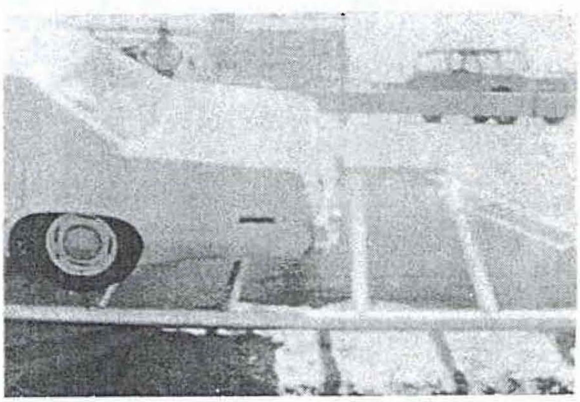


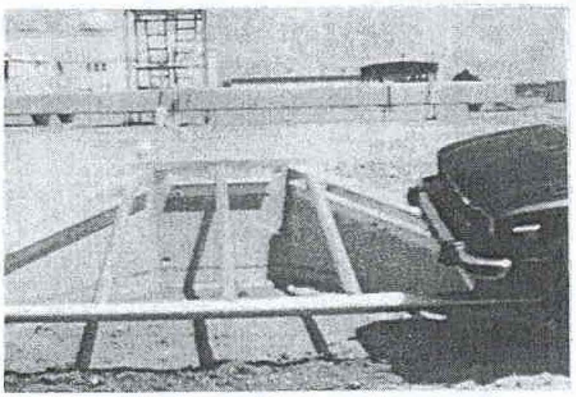
0.828 sec

Figure 40. Sequential Photos, Test 5

Figure 41. Upon contact with the grate the vehicle began to roll towards the ditch centerline. As impact continued, the vehicle's left-front tire and fender dug into the ditch and caused the vehicle to roll over as shown in Figure 42. Damage to the vehicle was extensive and it was considered a total loss. The culvert installation did not receive any damage since the right side tire kept the underside of the vehicle from contact with the safety grates.

As a result of this test it was apparent that the grate members should be extended and anchored at the flow line of the culvert to eliminate the dropoff at the end of the culvert.

<u>Test 7</u>. This test was identical to test 5 except that the impact speed was increased from 20 mph (32.18 km/h) to 60 mph (96.54 km/h). The purpose of this test was to demonstrate that a vehicle could safely traverse the safety grate at a high speed. High-speed sequential photos are given in Figure 43. The box culvert was in fact safely traversed by the full-size vehicle. There was no damage to the culvert installation. Figure 44 pictures the resting position of the vehicle and damage to the vehicle involving the left-front tire and wheel.



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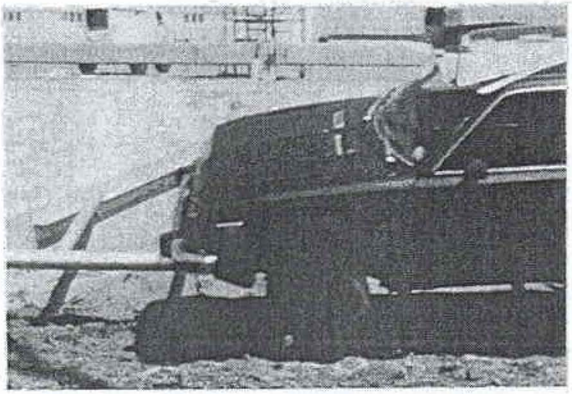

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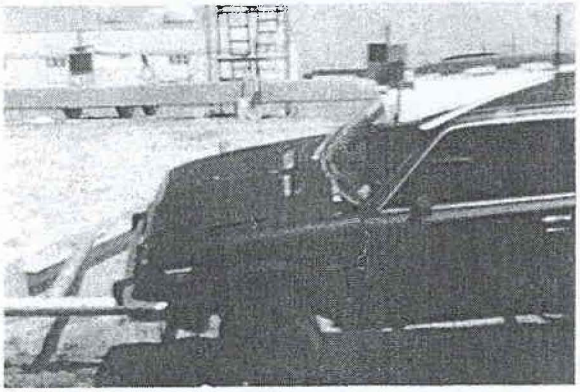

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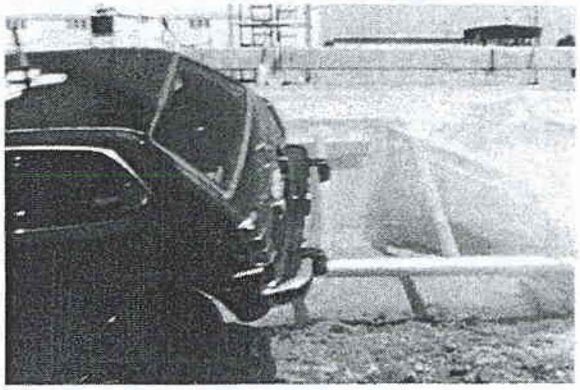
0.139 sec



0.175 sec

Figure 41. Sequential Photos, Test 6

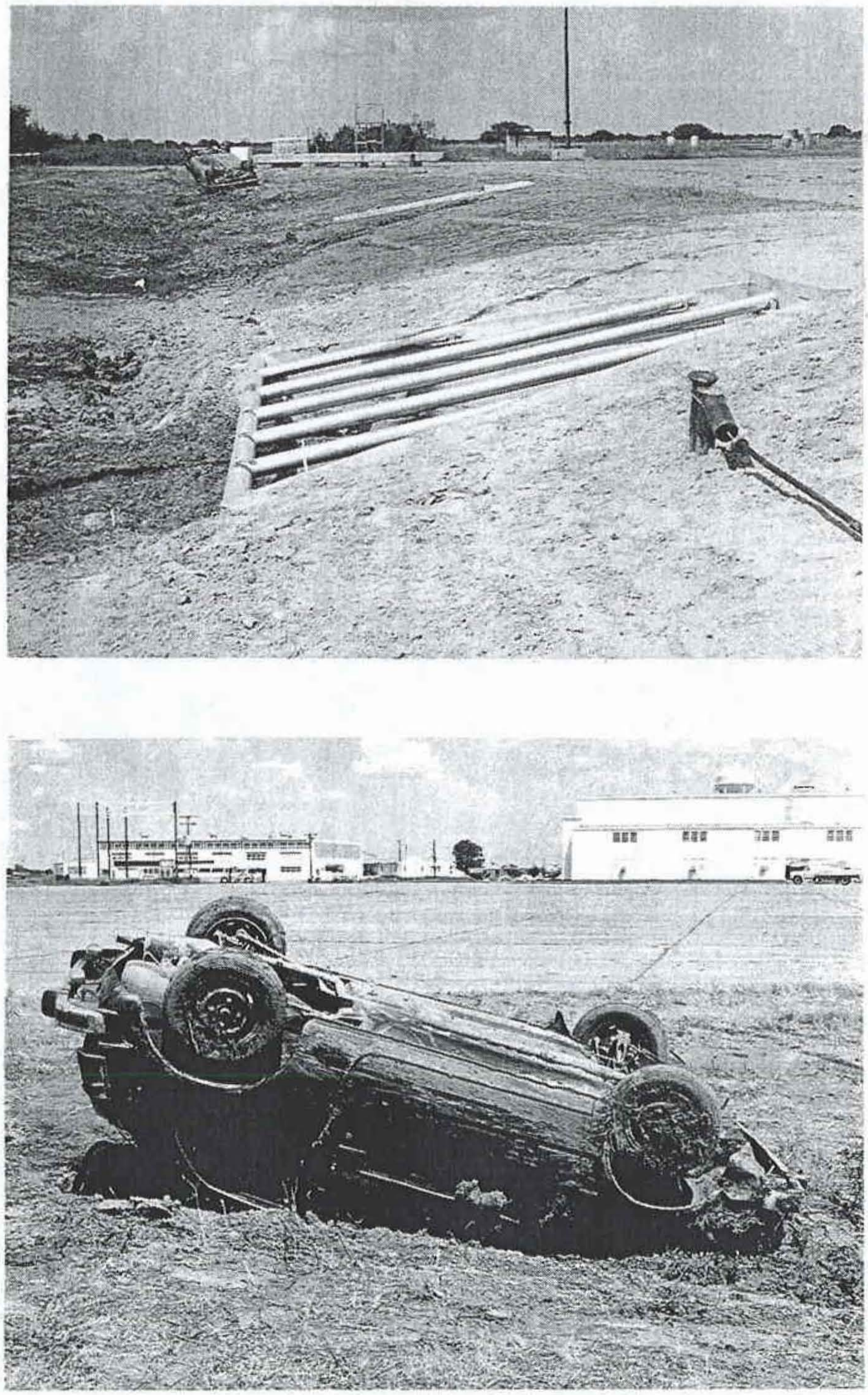
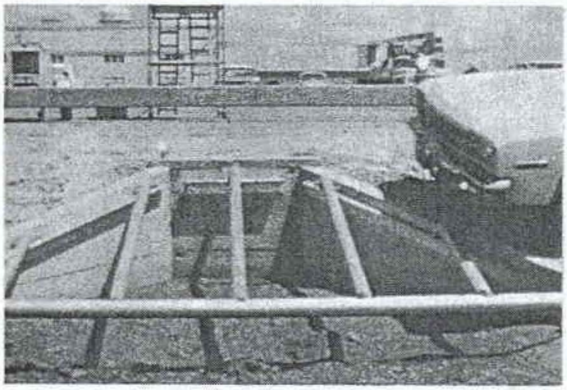


Figure 42. Resting Position of Vehicle after Impacting Box Culvert in Straddled Position, Test 6



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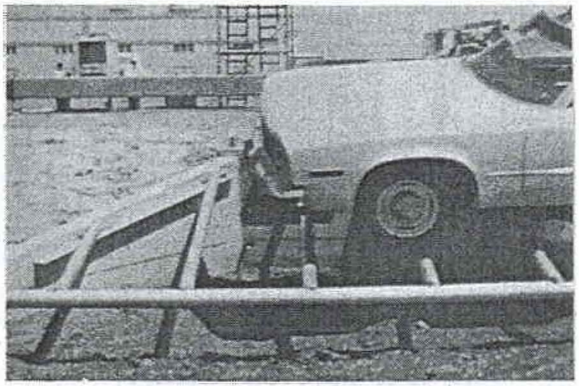

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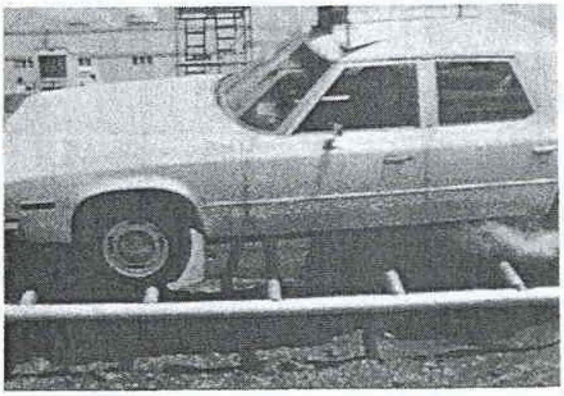


0.125 sec

0.158 sec

0.213 sec

Figure 43. Sequential Photos, Test 7

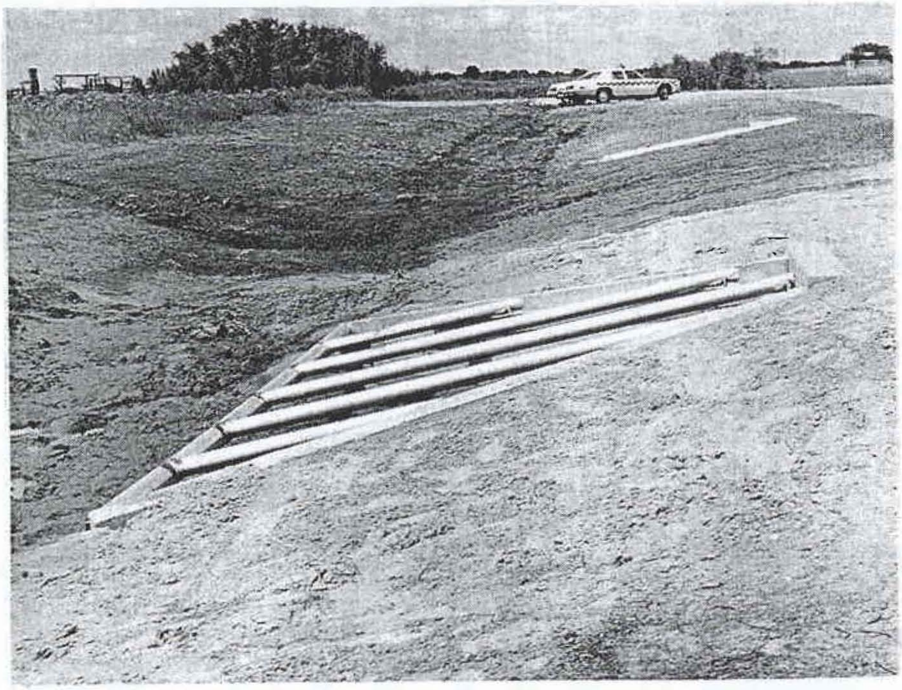


Figure 44. Resting Position and Damage to Vehicle after Traversing Box Culvert, Test 7

STRENGTH REQUIREMENTS OF GRATES

The 3 in. (7.62 cm) diameter schedule 40 steel pipe used in the test program proved of sufficient strength for the box culvert tested. The maximum span of the culvert was approximately 10 ft (3.05 m). However, analysis indicated the 3 in. (7.62 cm) pipe was not strong enough for spans in excess of 12 ft (3.7 m). A test program was therefore undertaken to determine size requirements for larger spans.

Shown in Figure 45 is the test pit constructed to evaluate various grate sizes across a 20 ft (6.10 m) span. Details of the pit are shown in Figure 46. The grate-to-pit attachments shown in Figure 46 were fabricated according to tentative standard SDHPT plans. Five full-scale crash tests were conducted on the test pit. All of the crash tests incorporated a 4500 lb (2043 kg) vehicle, an impact velocity of 20 mph (32 km/hr), and an impact angle of zero degrees.

For the first test, test 8-1, 5.0 in. (12.7 cm) I.D. standard schedule 40 steel pipe was installed in the test pit as shown in Figure 45. Sequential photos from high-speed film of this test, shown in Figure 47, reveal that the vehicle easily traversed the pit and there were no major permanent deformations of the pipes. Therefore this test was very successful.

As shown in Figure 48, 4.0 in. (10.16 cm) I.D. standard schedule 40 steel pipe was installed in the test pit for test 8-2. Figure 49 shows sequential photos from high-speed film for this test. Both of these figures again show that the test vehicle traversed the pit easily and was damaged only lightly. Also, the permanent deformations of the grates were small. Thus the 4.0 in. (10.16 cm) steel pipe grates are adequate for a 20 ft (6.1 m) span.

In test 8-3, 3.5 in. (8.89 cm) I.D. standard schedule 40 steel pipe grates were used. From the high-speed film sequential photos shown in Figure 50, it can be seen that the test vehicle did not completely traverse the test pit.

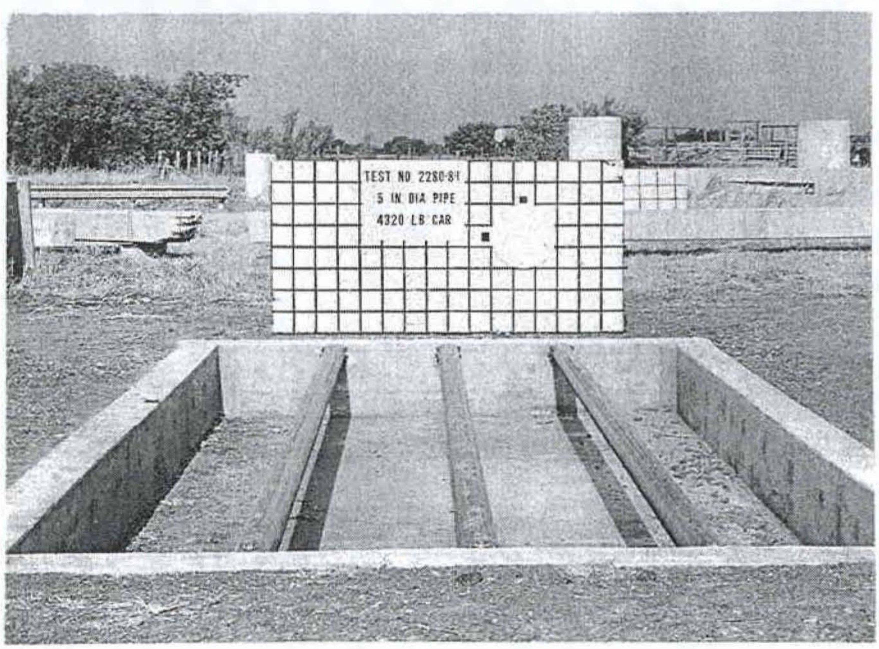


Figure 45. Test Vehicle and Installation before Test 8-1.

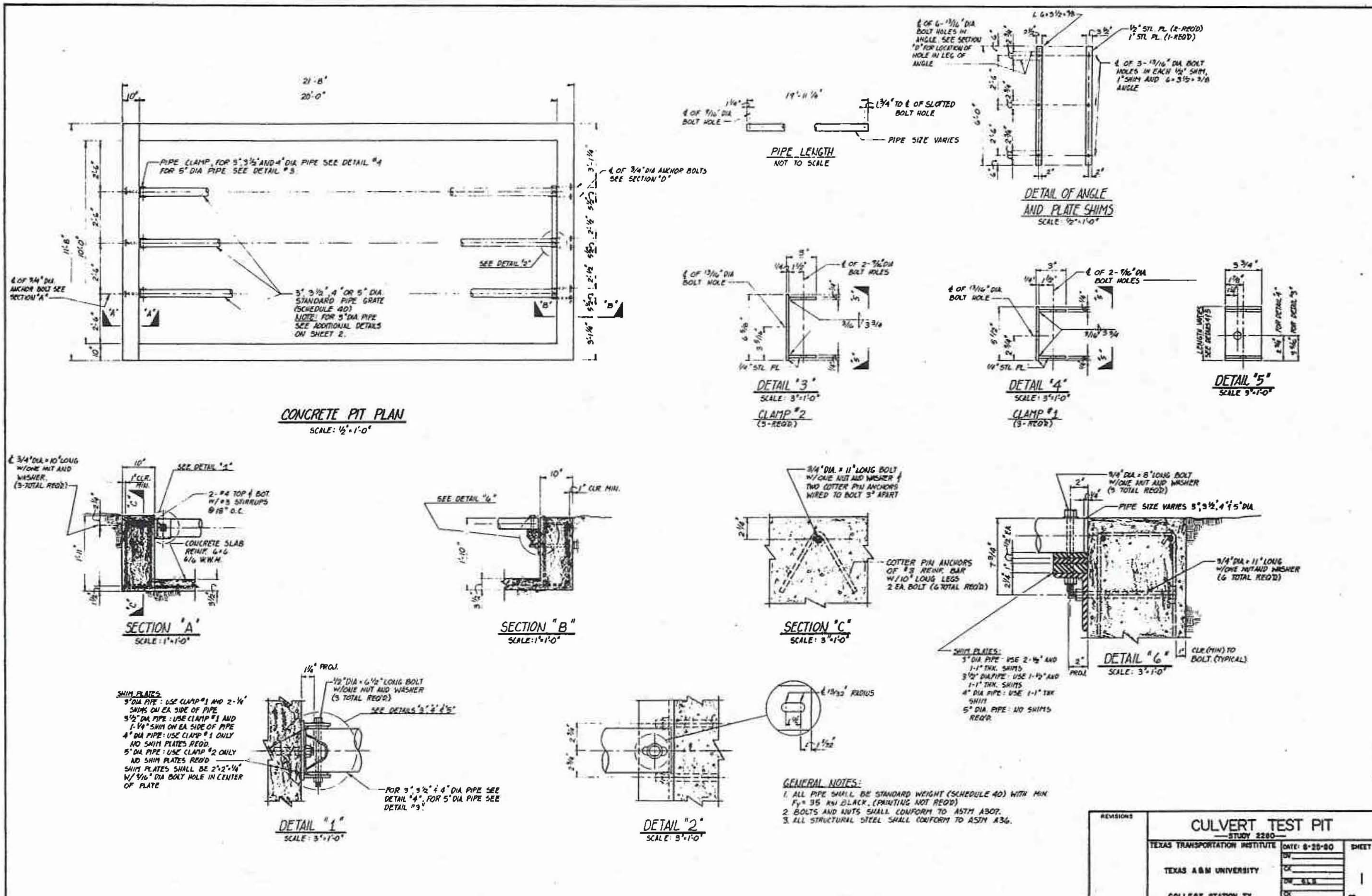
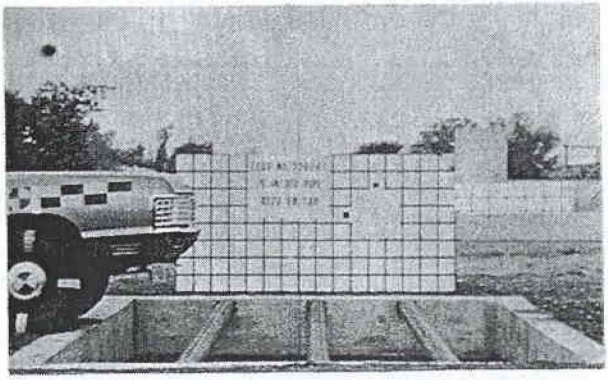


Figure 46. Test Pit Drawing



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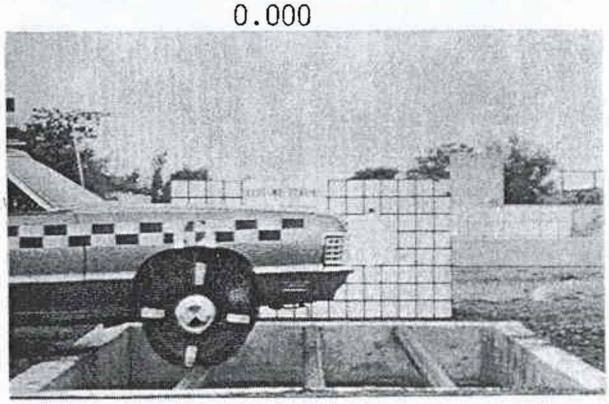

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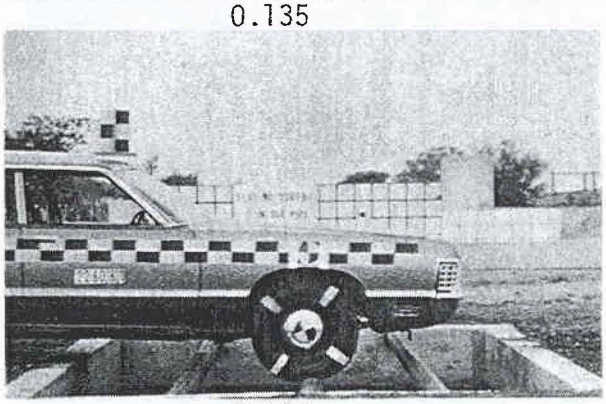

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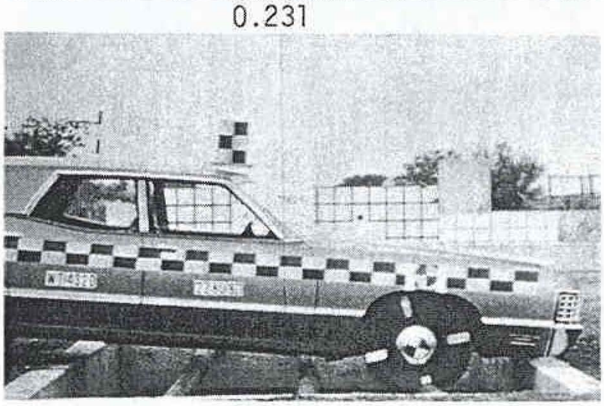

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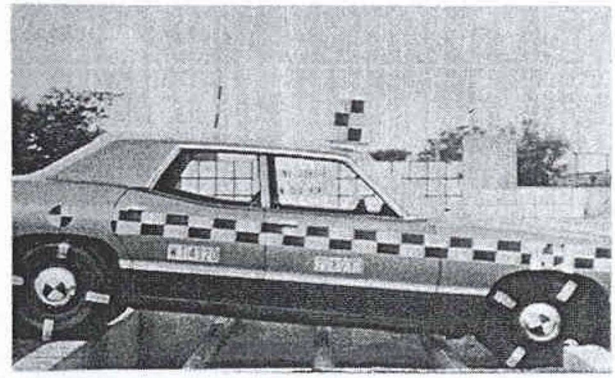

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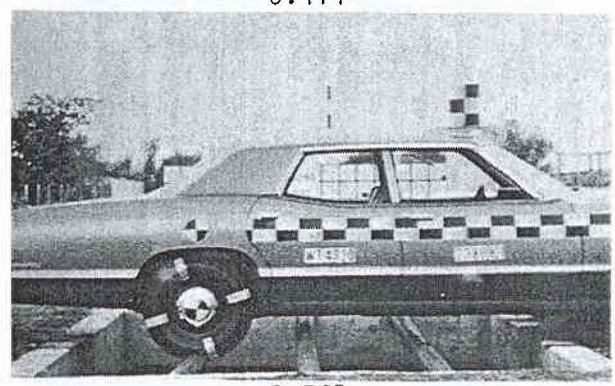

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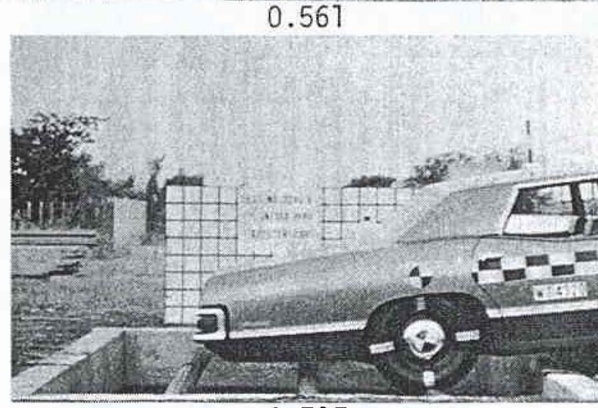

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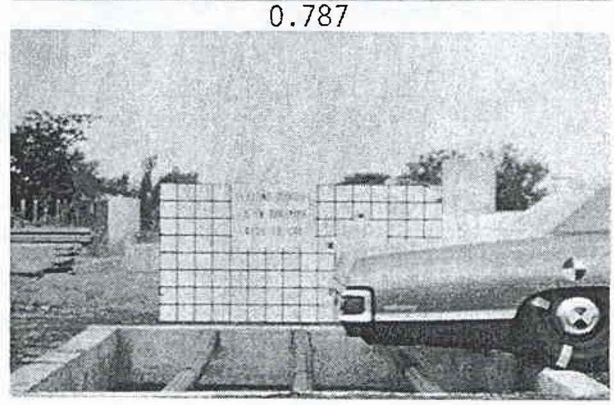

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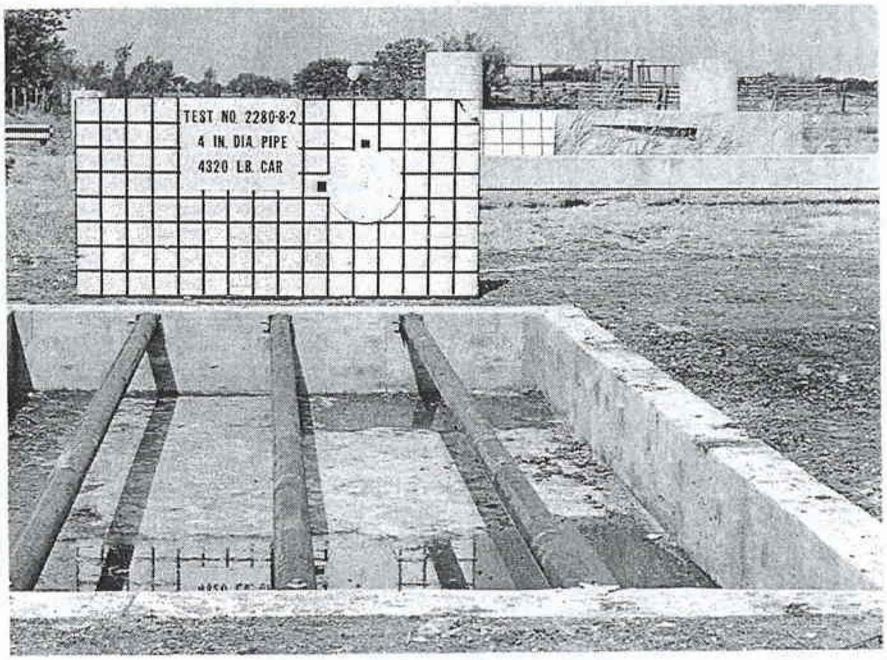
Figure 47. Sequential Photographs for Test 8-1.



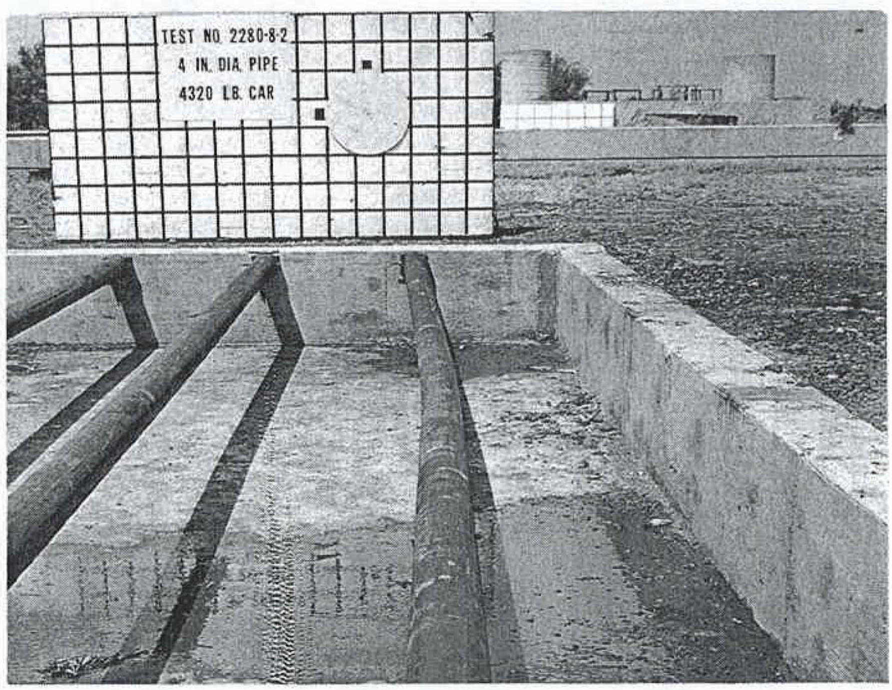
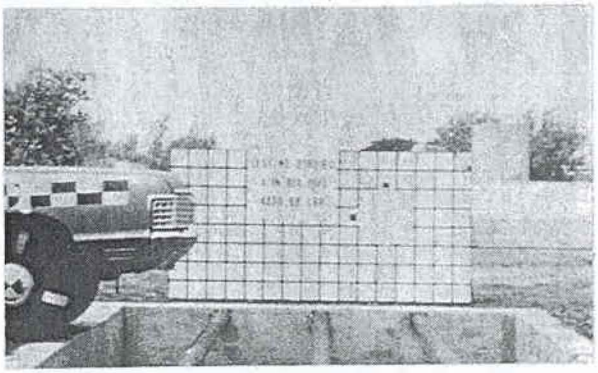


Figure 48. Test Installation Before and After Test 8-2.



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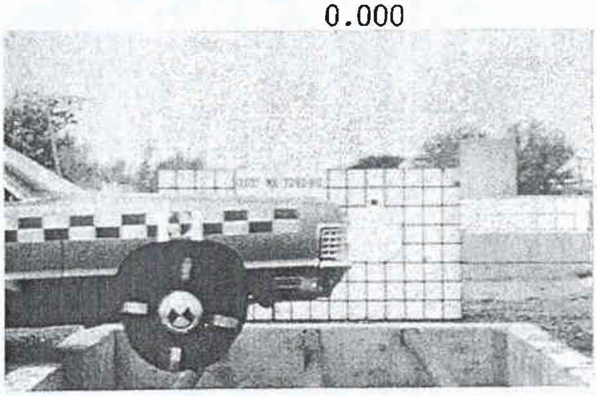

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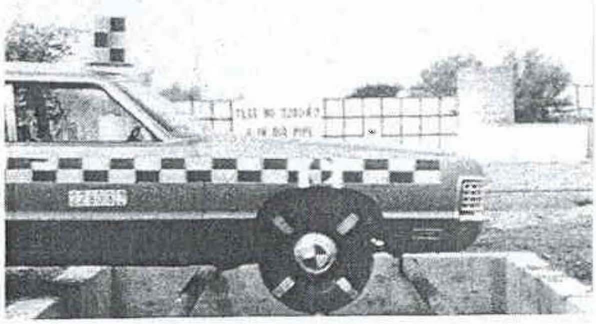

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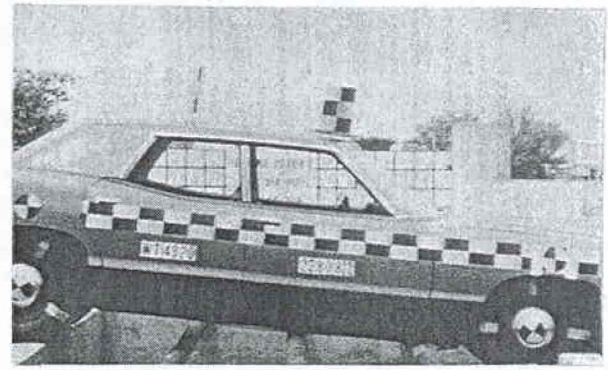
0.308



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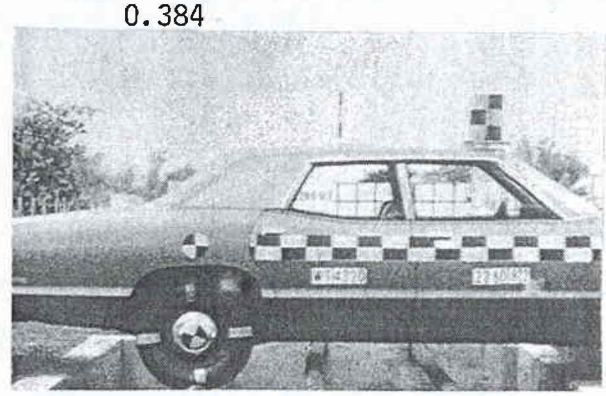

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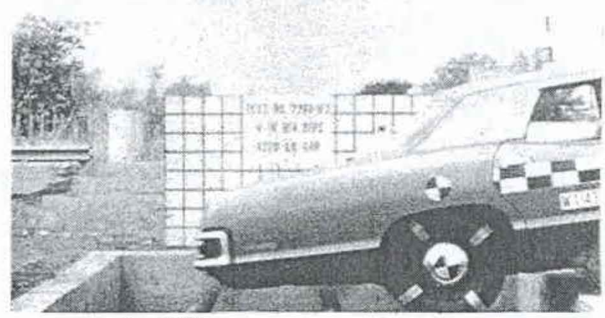

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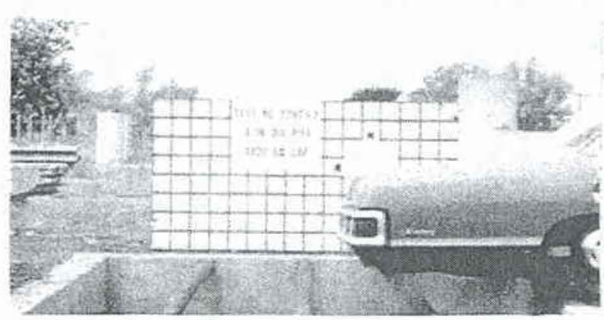

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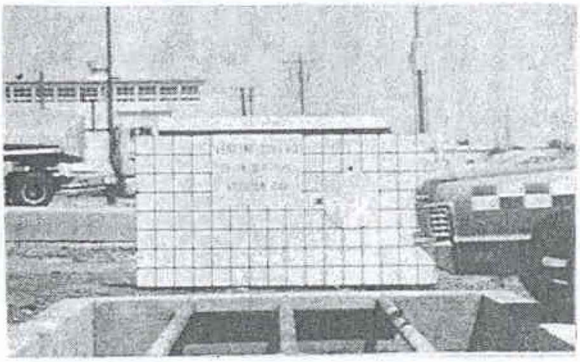
Figure 49. Sequential Photographs for Test 8-2.



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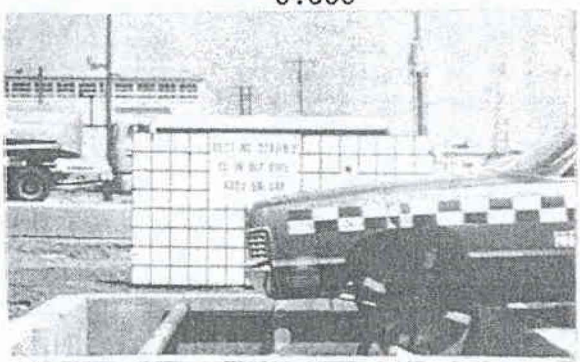

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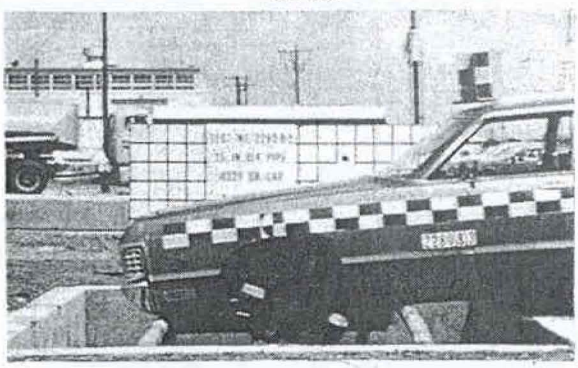

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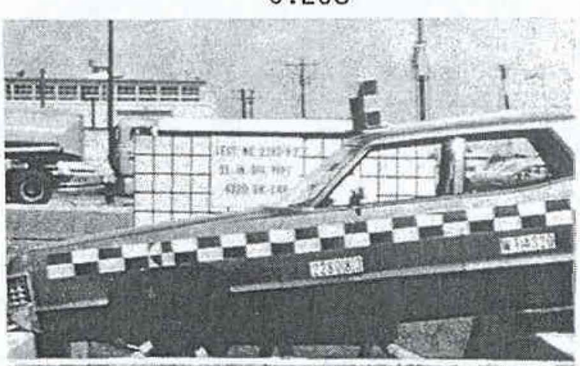

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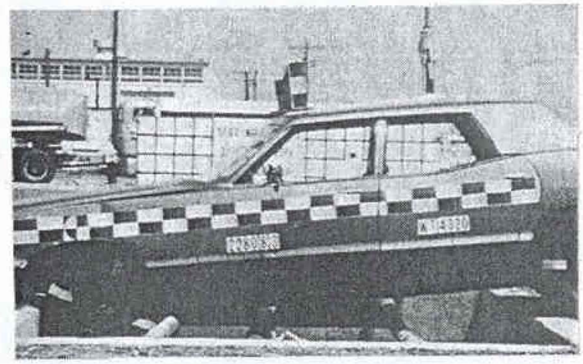

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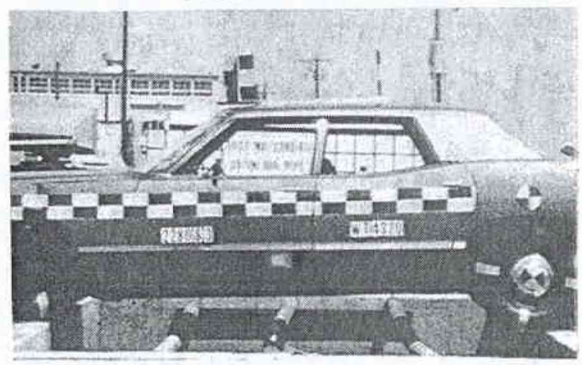
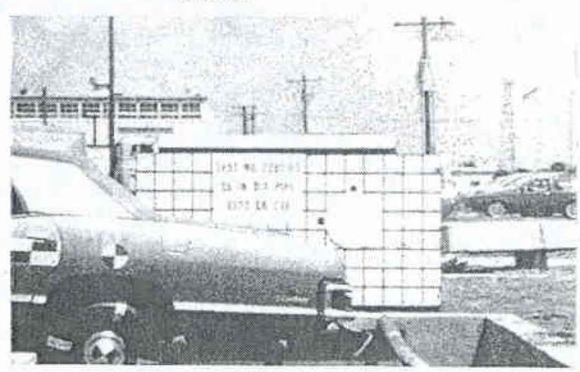


0.711

0.939



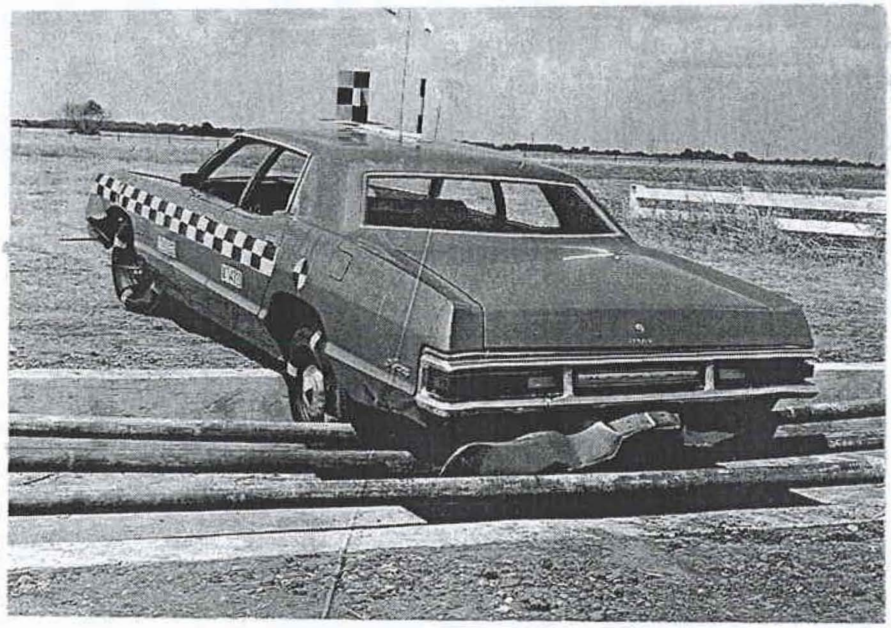
2.234

Figure 50. Sequential Photographs for Test 8-3.

Figures 51 and 52 show permanent deformations of the grates were larger and the test vehicle was damaged more than in the previous tests. Figure 53 shows that the grate-to-pit attachments were damaged as well. Therefore this test was only marginally acceptable. Since Test 3 was not completely successful, it was decided to utilize midspan vertical supports for the test of 3.0 in. (7.62 cm) I.D. standard schedule 40 steel pipe grates. Analysis of grate deformations from previous tests showed that wheel impact loads for design of midspan supports should be approximately 4000 lb (17,800 N) per wheel and oriented such that maximum stresses are developed in either grate member or midspan support. For design purposes the track width of a typical standard size automobile can be assumed to be 60 in. (152.4 cm). Figure 54 shows the modified test pit and the test vehicle before impact. Details of the grate and support structure are shown in Figure 55. Sequential photos from high-speed film of test 4, shown in Figure 56, show that the vehicle traversed the test pit quite easily. Figure 57 shows light damage to the test vehicle and relatively large horizontal deformations of the grate resulting from the test. Even though the horizontal deformations are large, this test can be considered successful since the vehicle damage was light and the vertical pipe deflections were small. Permanent deformations of the grates after each test are given in Table 6.

The final test examined the effect of a vehicle impacting an open box culvert at a speed of 20 mph (32 km/hr). Figure 58 shows sequential photos from high-speed film of this test. Figure 59 shows the damage to the vehicle which resulted from this test. It can also be seen in this figure that the wall of the concrete box culvert was cracked by the impacting vehicle.

From the observed deflections found in Table 6 and the previously mentioned test results, the following grate sizes or their equivalents are suggested.



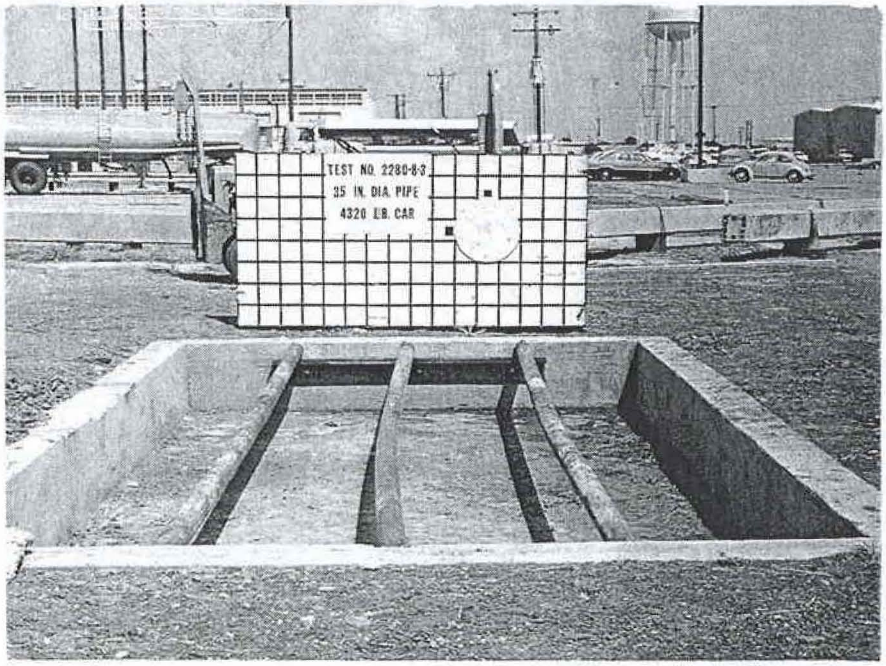


Figure 51. Test Installation After Test 8-3.

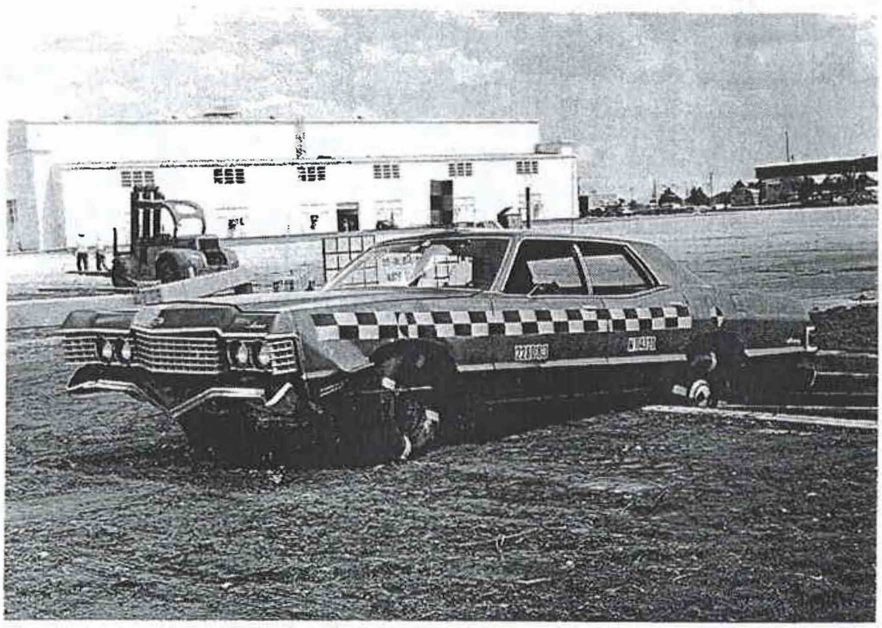
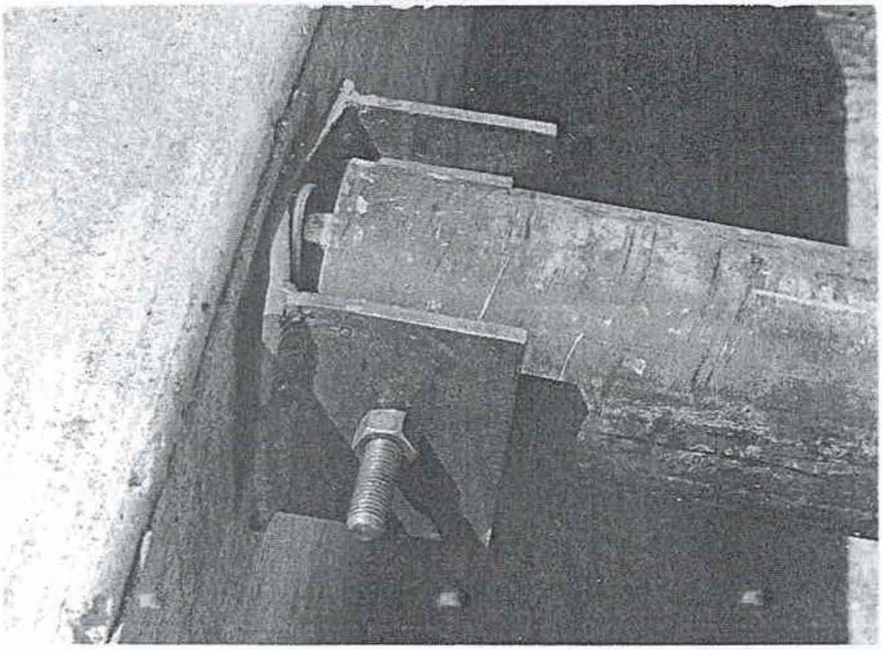


Figure 52. Test Vehicle After Test 8-3.



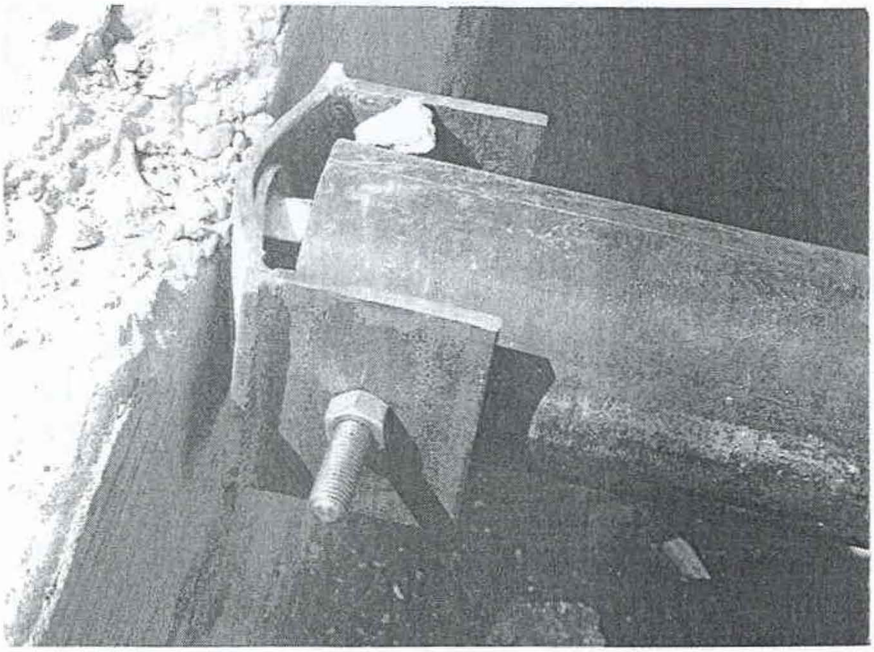


Figure 53. Damage to End Connections for Test 8-3.

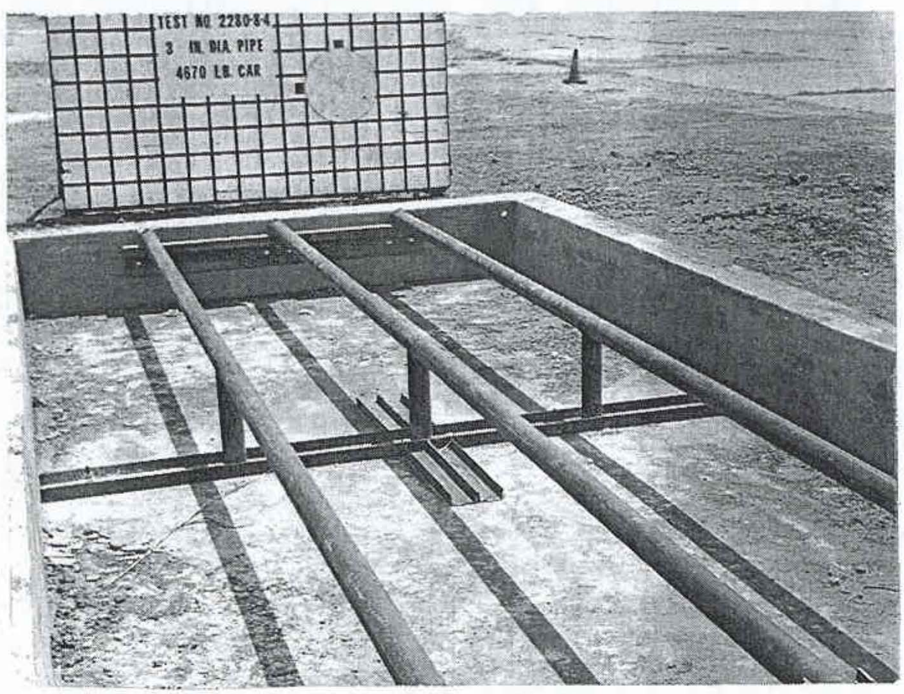
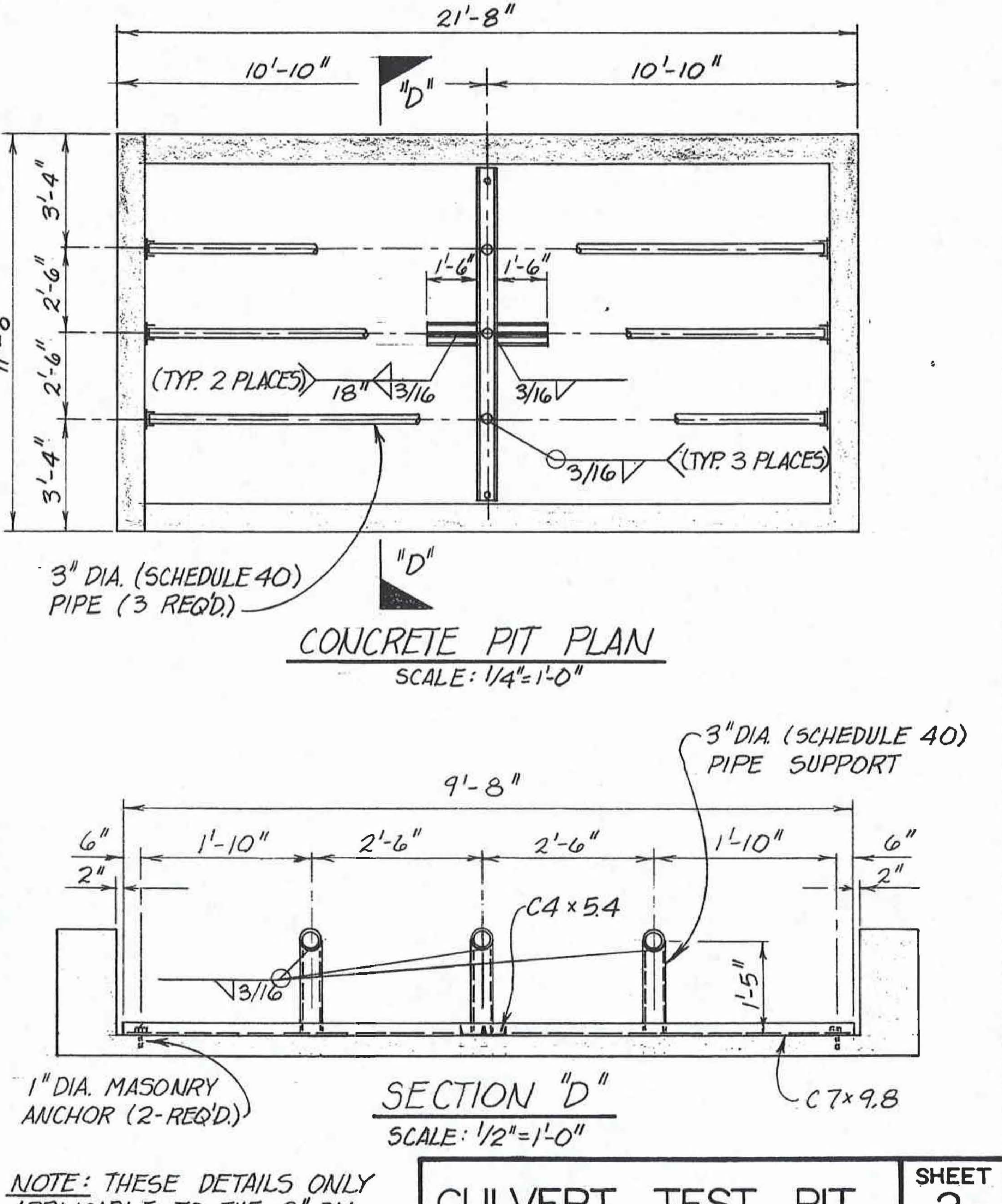


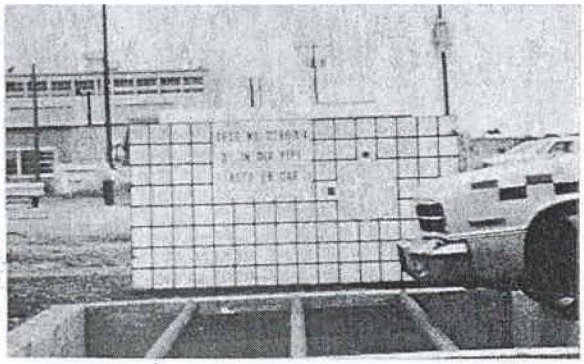
Figure 54. Test Vehicle and Installation before Test 8-4.

Figure 55. Culvert Test Pit, Test 8-4.



NOTE: THESE DETAILS ONLY APPLICABLE TO THE 3" DIA. PIPE.

CULVERT TEST PIT —STUDY 2280—	SHEET 2 OF 2



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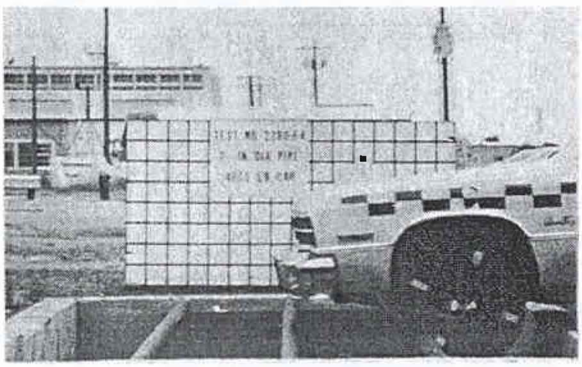

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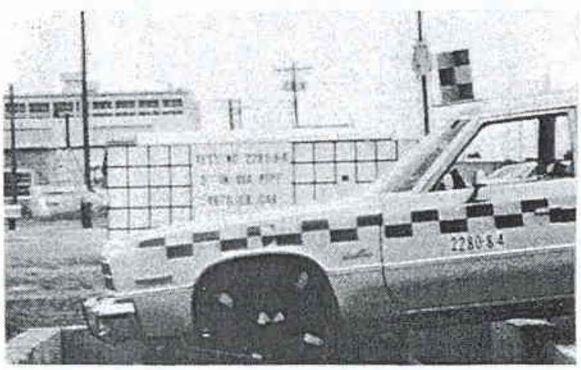
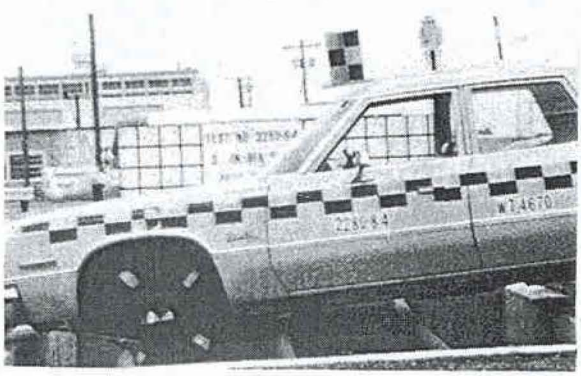


0.218



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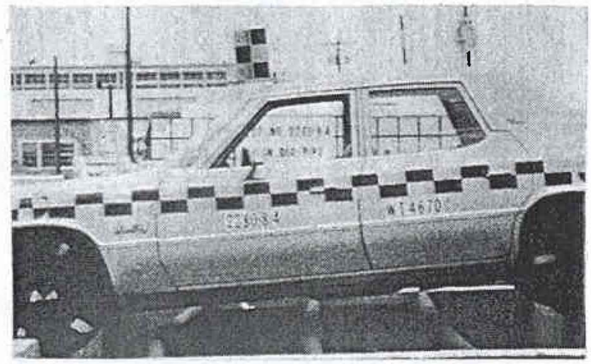
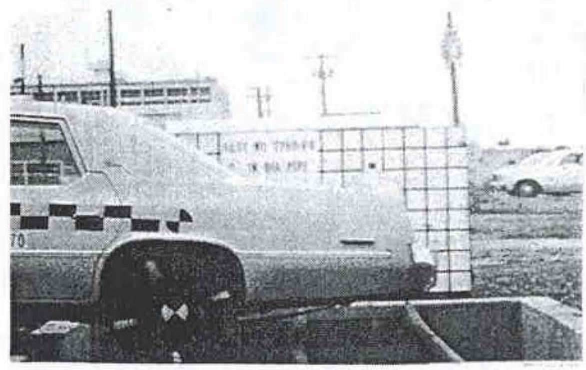


0.431

0.629



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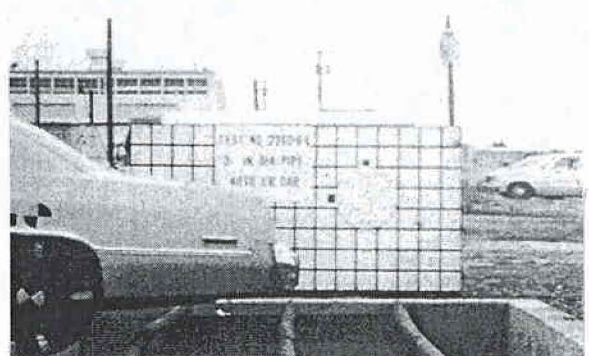


0.923

Figure 56. Sequential Photographs for Test 8-4.

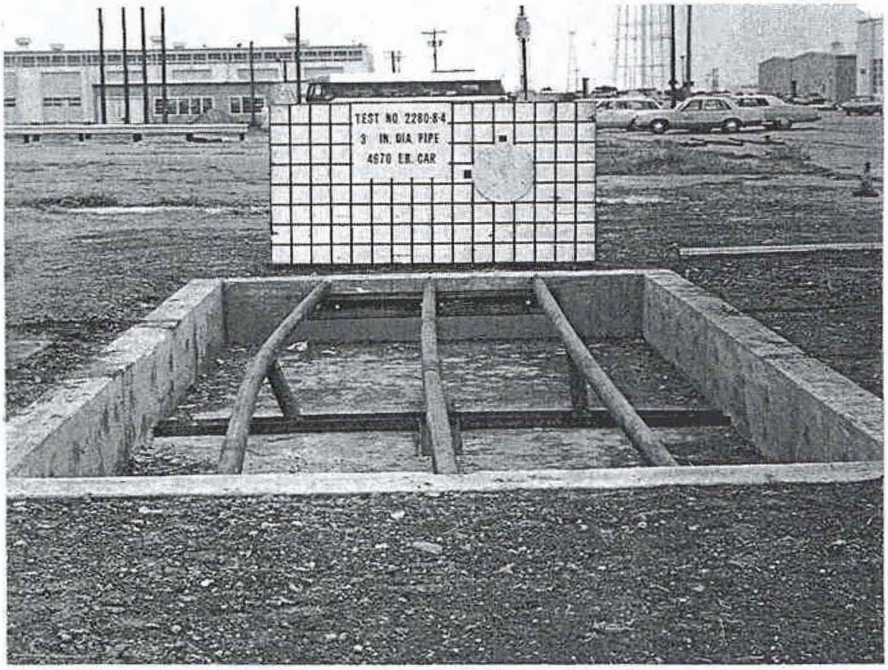
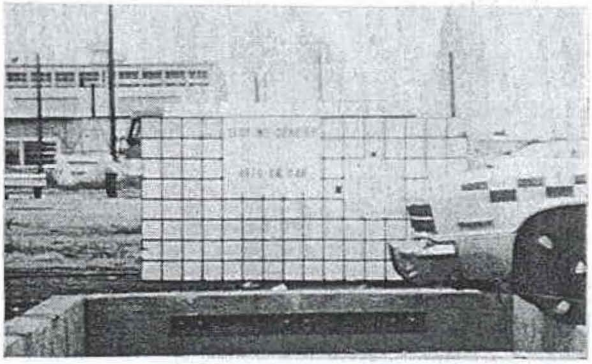


Figure 57. Test Vehicle and Installation after Test 8-4.



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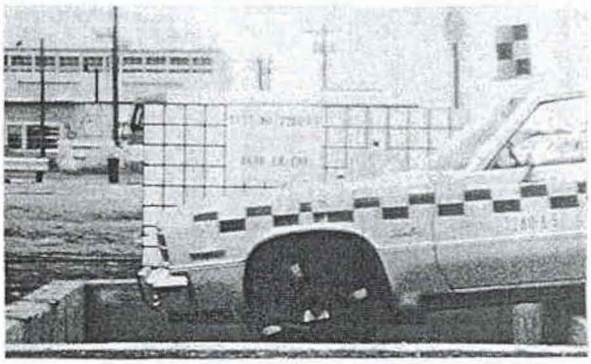

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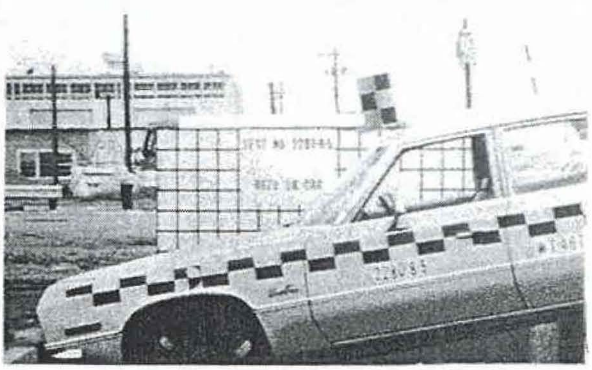
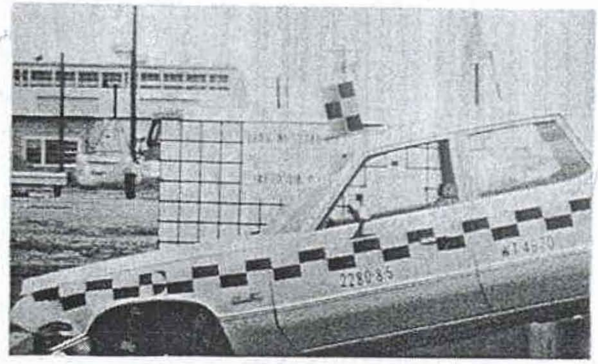
0.258



0.278



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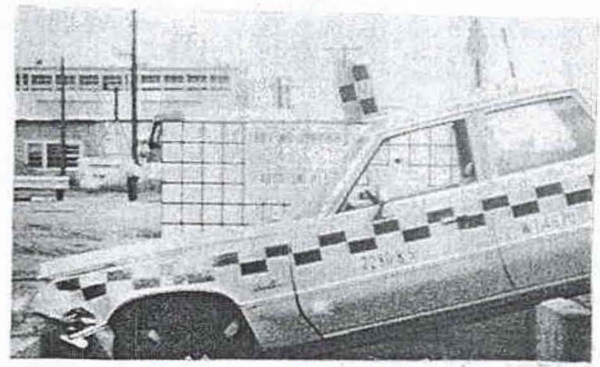
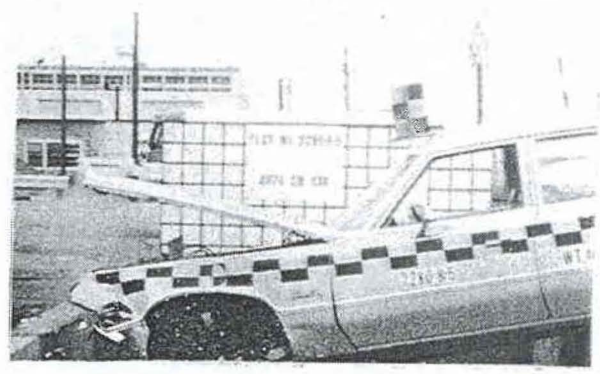
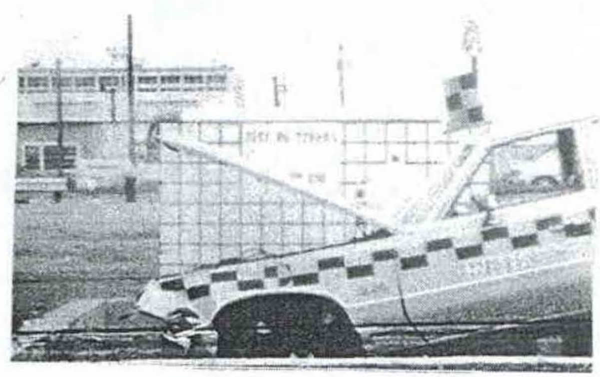


0.496



0.794



2.459

Figure 58. Sequential Photographs for Test 8-5.

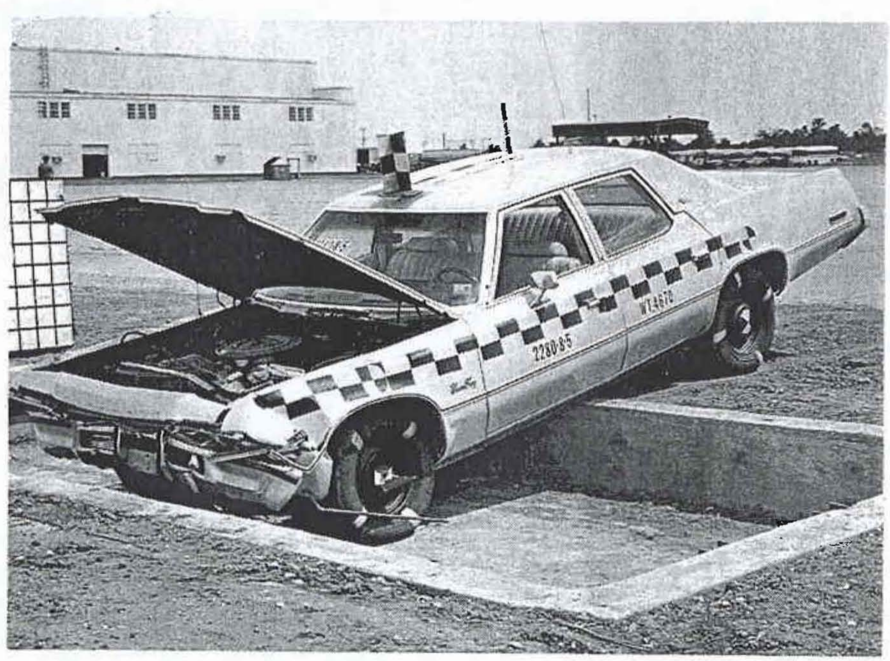


Figure 59. Test Vehicle Before and After Test 8-5.

Table 6. Cross Member Deflections
of Box Culvert Grating Strength Tests

TEST NO.	PIPE I.D.[a] (in.)	GRATE MEMBER[b]	VERTICAL DEFLECTION (in.)	EST. HORIZONTAL DEFLECTION (in.)
1	5	First	-0	0
		Second	-0	0
		Third	-15/16	3/8
2	4	First	-1/8	0
		Second	-1/2	1/4
		Third	-3	1 7/8
3	3.5	First	-1 3/4	2 7/8
		Second	-4 3/4	3 1/16
		Third	-4 1/8	1 7/16
4[c]	3	First	-0 3/4	1 1/2
		Second	+0 1/2	1 7/8
		Third	+0 1/8	4 3/4

[a]Schedule 40 steel pipe

[b]Grate members spaced on 30 in. centers

[c]Midspan vertical supports used on each grate

Span Length (ft)	Suggested Standard Schedule 40 Pipe Size I.D. (in.)
Up to 12	3.0
12 to 16	3.5
16 through 20	4.0

In addition, if adequate midspan vertical supports are incorporated for the larger span lengths, 3.0 in. (7.62 cm) I.D. standard schedule 40 pipe can be used for spans up to 20 ft (6.1 m).

WARRANTS FOR CROSS-DRAINAGE SAFETY TREATMENTS

A cost-effectiveness model was used to develop guidelines for safety treatment of cross-drainage structures in 1978 (5) by TTI for the SDHPT. Alternatives considered included (1) no treatment, (2) extend the culvert end to 30 ft (9.2 m) from the edge of the travelway, (3) install guardrail, or (4) place a safety grate over the culvert end. Since that study, a greater insight has been gained into the hazard of various culvert configurations, the required safety grate designs, and their costs through the study reported herein. It is noted that the recommendations contained herein will result in grates with fewer members than presently used by the SDHPT, and their net cost will be less. As a consequence of these findings it was concluded that the guidelines (5) should be updated. This chapter presents the results of the revised analysis.

Two methods of conducting the revised analysis were considered. The first involved a determination of current cost data for all options evaluated in reference 5. The other involved discounting current cost data for the recommended grate designs to 1978 values. The latter method was selected since it involved the least effort. It is noted that both methods would yield the same results if the relative costs of the alternatives remained constant from 1978 to the present since a comparative analysis is used in both methods. Current cost data for the recommended grates were obtained from the SDHPT for six different slope/culvert combinations, and the values are given in Table 7. Since the slope/culvert combinations provided in Table 7 did not match those used in reference 5 it was necessary to adjust the values. Assumptions made in discounting and adjusting these values were as follows:

- Discount rate equals 10%.

TABLE 7.
INITIAL COST OF CULVERT PIPE GRATES (1981)

EMBANKMENT SLOPE	CULVERT	GRATE COSTS ($)
3:1	42" dia pipe	600
6:1	42" dia pipe	6900
3:1	4' x 6' single box	1880
6:1	4' x 6' single box	7250
3:1	4' x 6' double box	3135
6:1	4' x 6' double box	16700

TABLE 8.
ADJUSTED COST OF CULVERT PIPE GRATES (1978)

EMBANKMENT SLOPE	CULVERT	GRATE COSTS ($)
2-1/2:1	36" dia pipe	380
6:1	36" dia pipe	4660
2-1/2:1	4' x 6' single box	1270
6:1	4' x 6' single box	5100
2-1/2:1	4' x 6' double box	2100
6:1	4' x 6' double box	11800

- Relative costs of alternatives in 1981 were the same as those in 1978.
- A grate on a 36-in. (91.4 cm) diameter pipe culvert is 5% less expensive than a grate on a 42-in. (106.7 cm) diameter pipe culvert.
- The initial cost of a grate on a 2-1/2:1 slope is 5% less than the initial cost of a grate on a 3:1 slope.

Adjusted cost figures based on these assumptions are given in Table 8.

With the cost data of Table 8 the analysis of reference 5 was repeated. The reader should refer to reference 5 for further information on costs of the other options and a description of the cost-effectiveness model used in the analysis. It is noted that in reference 5 a ranking factor, R, was used as the primary measure from which need was determined. Options having an R value less than one were not considered cost effective. Since publication of reference 5 it has been concluded that a more appropriate measure is the benefit/cost (B/C) ratio. B/C is related to R as follows:

$$B/C = R + 1$$

It can be seen that an R value of one is equivalent to a B/C of two. In consultation with SDHPT engineers it was agreed that the revised warrants should use the B/C as the measure of need, and options with a B/C less than one were not cost effective. Results presented herein are based on this premise.

Some additional changes were made in the analysis of reference 5. Based on crash tests reported herein, TTI researchers concluded that the severity of impact with a 36 in. (91.44 cm) open pipe culvert and drainage ditch was overstated in the previous analysis. The severity indices associated with each culvert/slope configuration investigated in this study are given in Table 9. Further changes included recalculation of fill costs for extension of a culvert and frequency of collision with a drainage ditch. The volume of fill material required for each extension option and the corresponding cost are shown in Table 10. The frequency of collision with a drainage ditch was overstated in the analysis of reference 5 because shielding of the ditch by the culvert had not been examined properly.

The revised cost-effectiveness analysis revealed that safety treatment of a 36 in. (91.4 cm) diameter pipe culvert is generally not warranted for the traffic volumes and roadside conditions investigated. Although for high traffic volumes extension of a 36 in. (91.4 cm) dia. pipe culvert was sometimes marginally cost effective, the safety treatment of these culverts cannot be recommended due to uncertainties concerning the severity of impact with complex side slope configurations resulting from culvert extension.

Shown in Figures 60 through 63 are warrants for the box culvert configurations considered, based on the revised analysis. These figures can be compared with Figures 5 through 8 of reference 5. Analysis of Figures 60 through 63 shows that safety treatment of cross-drainage box culverts in general is warranted when traffic volumes exceed approximately 750 vehicles per day. The particular treatment warranted depends on the type of culvert being treated and how far the culvert end is from the travelway. Note that guardrail treatment, while cost beneficial in some situations, was never as cost beneficial as grates or extension of the culvert end to the edge of the clear zone.

It is important to note that implicit in the "no safety treatment" option is the assumption that protrusions of the culvert structure above grade, including head walls and wing walls, will not exceed 4 in. (10.2 cm). It is preferable that there be no protrusion and that the culvert structure adhere to the adjoining side slope to minimize the potential for snagging of errant vehicles.

TABLE 9.
SEVERITY INDICES FOR UNPROTECTED CULVERTS

CULVERT TYPE	ROADWAY SIDE SLOPE	SEVERITY OF IMPACT WITH SIDE SLOPE	CULVERT	DITCH
36 in. pipe	2-1/2:1	3.3	3.5	3.5
36 in. pipe	6:1	1.3	3.5	3.4
4' x 6' single box	2-1/2:1	3.3	5.8	4.2
4' x 6' single box	6:1	1.3	5.8	3.5
4' x 6' double box	2-1/2:1	3.3	6.3	3.8
4' x 6' double box	6:1	1.3	6.3	3.0

TABLE 10.
VOLUME AND COST OF FILL
FOR EXTENSION OF CULVERTS
TO 30 FT FINAL OFFSET

CULVERT TYPE	ROADWAY SIDE SLOPE	ORIGINAL OFFSET 12 ft VOL. (yd^3)	12 ft COST ($)	18 ft VOL. (yd^3)	18 ft COST ($)	24 ft VOL. (yd^3)	24 ft COST ($)
36 in. dia. Pipe	2-1/2:1	232	2320	141	1410	115	1150
36 in. dia. Pipe	6:1	203	2030	106	1060	33	330
4' x 6' Single Box	2-1/2:1	295	2950	172	1720	58	580
4' x 6' Single Box	6:1	265	2650	133	1330	40	400
4' x 6' Double Box	2-1/2:1	302	3020	185	1850	68	680
4' x 6' Double Box	6:1	269	2690	139	1390	44	440

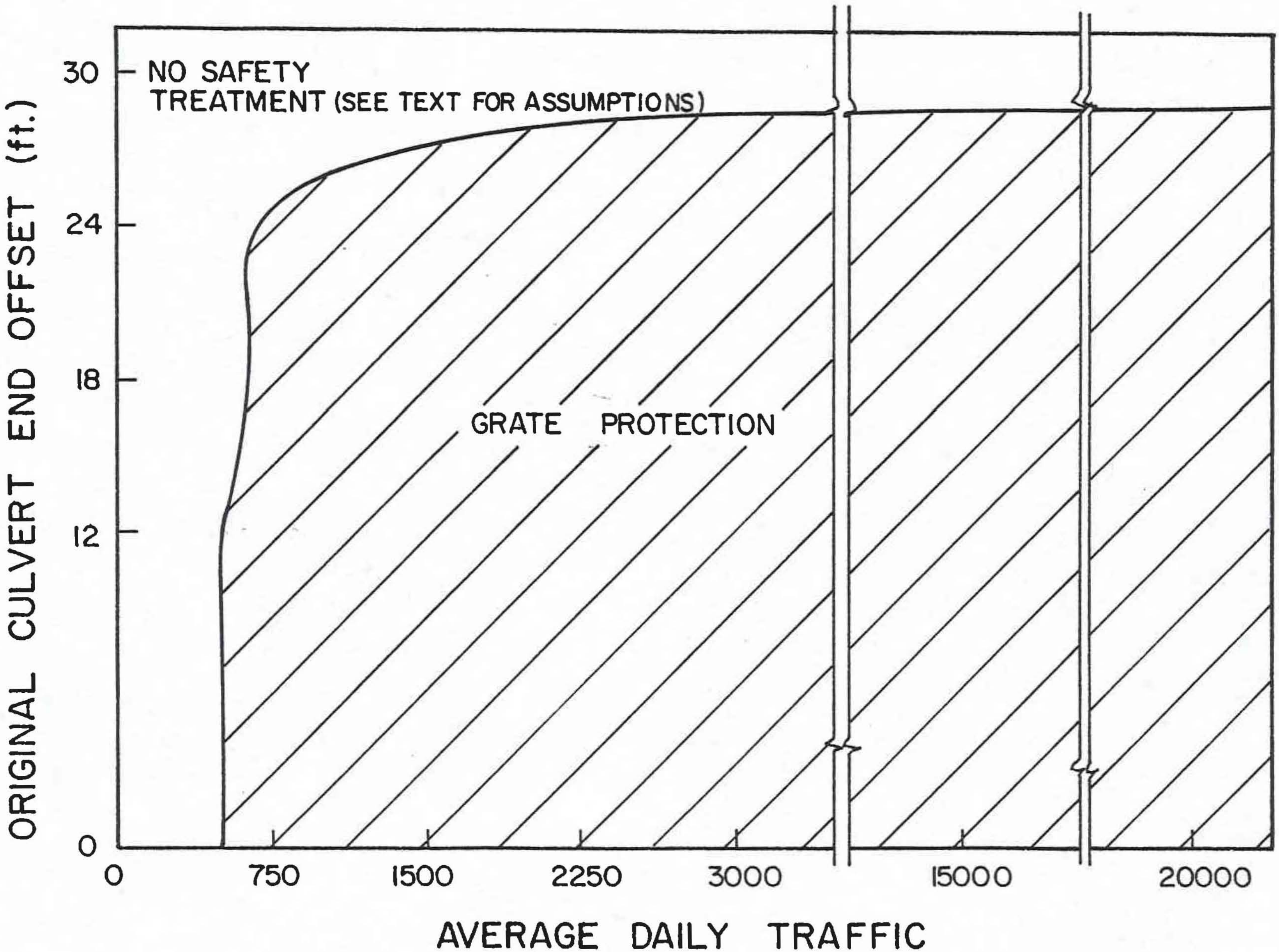


FIGURE 62. WARRANTS FOR SAFETY TREATMENT OF A 4' X 6' SINGLE BOX CULVERT ON A 2½:1 SLOPE.

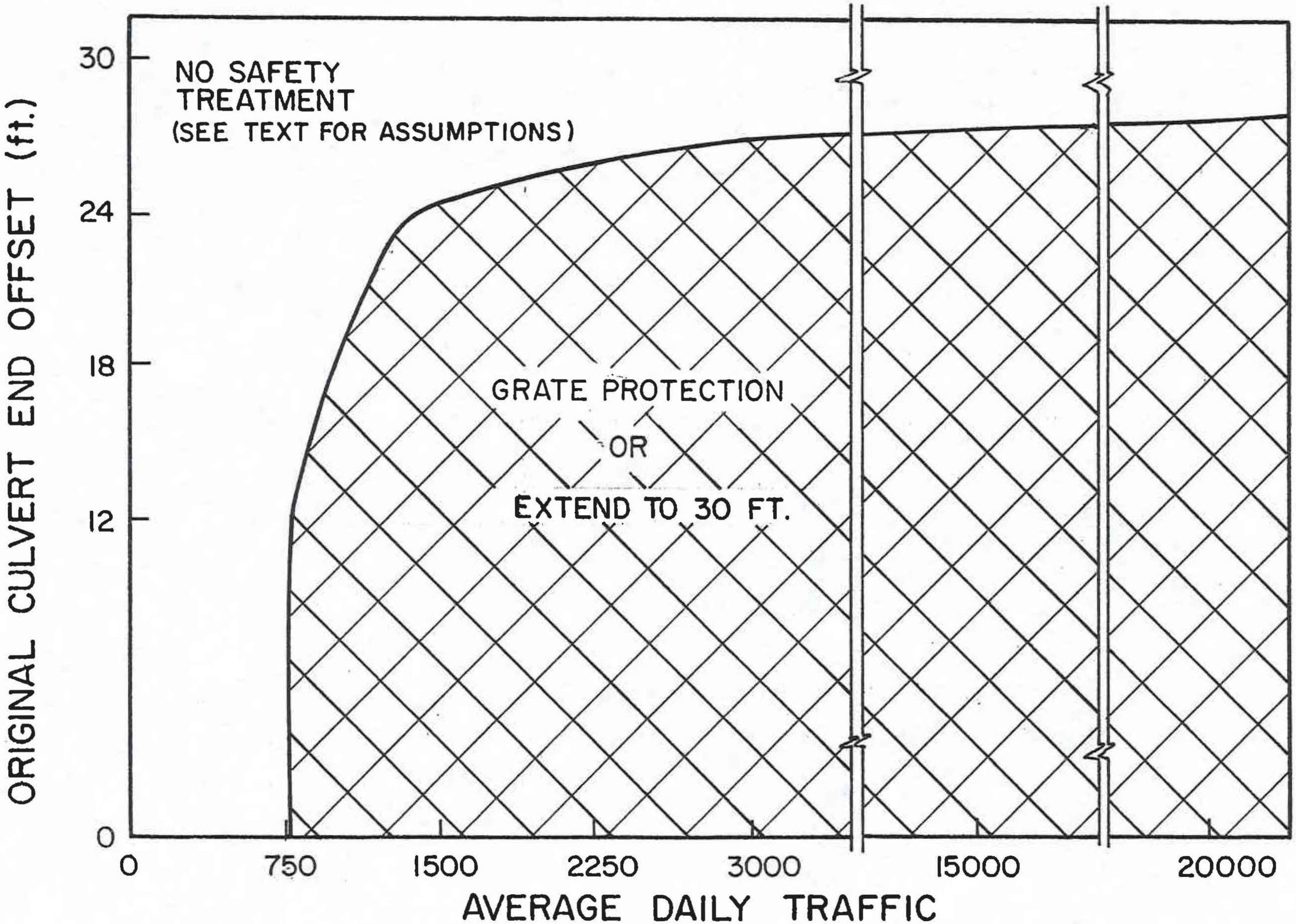


FIGURE 63. WARRANTS FOR SAFETY TREATMENT OF A 4' X 6' SINGLE BOX CULVERT ON A 6:1 SLOPE.

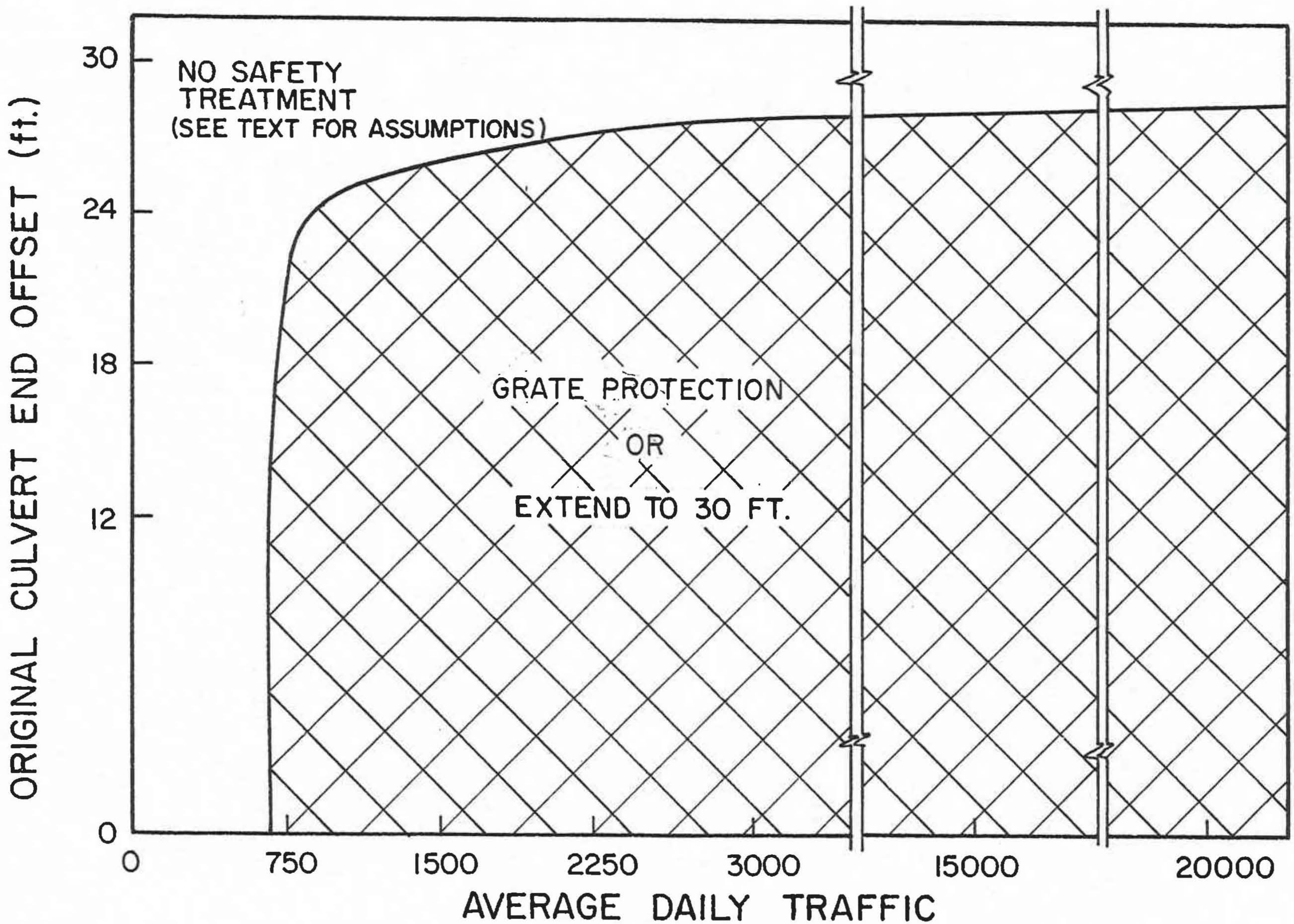


FIGURE 65. WARRANTS FOR SAFETY TREATMENT OF A 4' x 6' MULTI-BOX (2) CULVERT ON A 6:1 SLOPE.

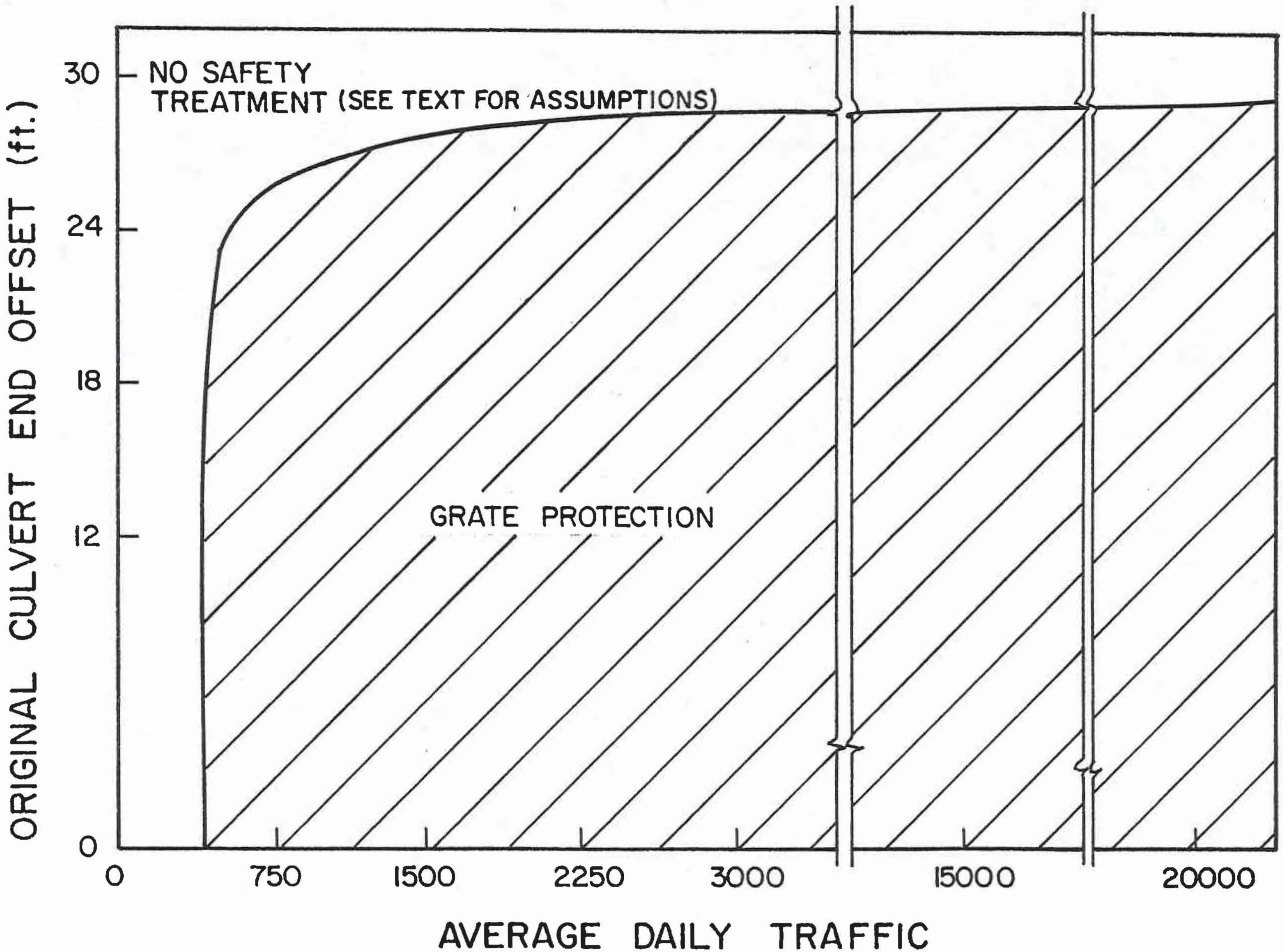


FIGURE 64. WARRANTS FOR SAFETY TREATMENT OF A 4' X 6' MULTI-BOX (2) CULVERT ON A 2½:1 SLOPE.

CONCLUSIONS

Conclusions drawn as a result of this research are:

1. Culvert ends should be made to match the existing side slope if they terminate within the clear zone. Protrusions of the culvert and adjoining wing walls and head wall above the terrain in excess of 3 to 4 in. should be avoided.
2. Round culverts with diameters of 30 in. or less need no end treatment other than as mentioned in 1 above. Elliptic or oval shaped culverts with major axes 30 in. or less need no end treatment other than as mentioned in 1 above. Rectangular shaped culverts with a horizontal clear distance 30 in. or less need no end treatment other than as mentioned in 1 above.
3. Culverts having dimensions greater than those given in 2 above can be safety treated with grate members, placed on 30-in. centers, that are oriented parallel to the water flow and in the plane of the surface of the side slope.
4. Grate member sizes depend on the span of the grates, the manner in which the grates are supported and the design vehicle weight. To support a full-size automobile, the following sizes are suggested (or their equivalent).

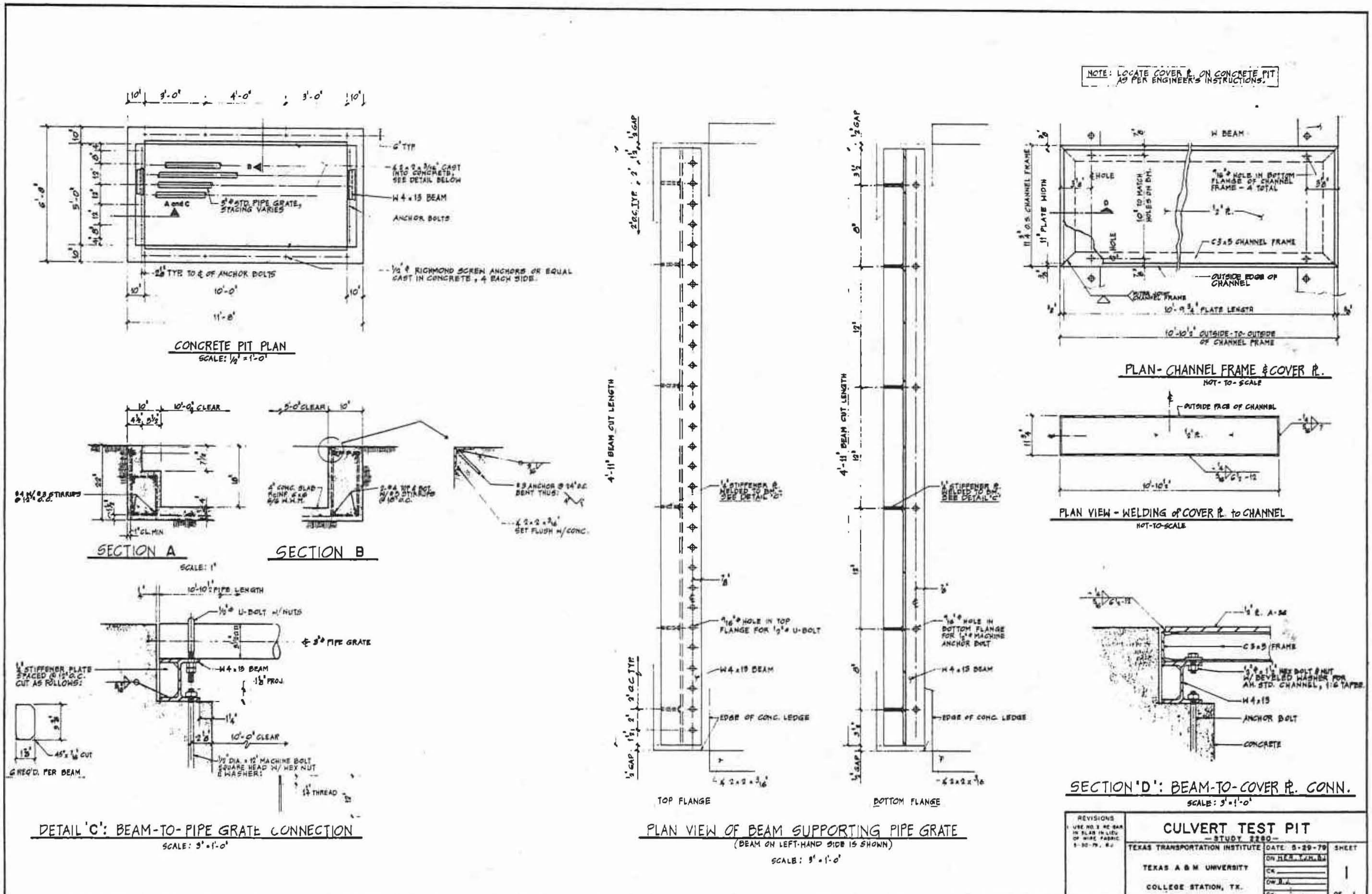
Span Length (ft)	Suggested Standard Schedule 40 Pipe Size I.D. (in.)
Up to 12	3.0
12 to 16	3.5
16 through 20	4.0

In addition, if midspan vertical supports are used for the larger span lengths, 3.0 in. (7.62 cm) I.D. standard schedule 40 pipe can be used for spans up to 20 ft (6.1 m).

5. Safety treatment of cross-drainage structures is warranted on roadways having traffic volumes of approximately 750 vehicles per day or more. Safety treatment of 36 in. (91.4 cm) dia. cross-drainage pipe culverts is generally not warranted for traffic volumes up to 20,000 vehicles per day. Safety treatment of larger cross-drainage structures is warranted on roadways having traffic volumes of approximately 750 vehicles per day or more.

APPENDIX A.

CULVERT TEST PIT DETAILS

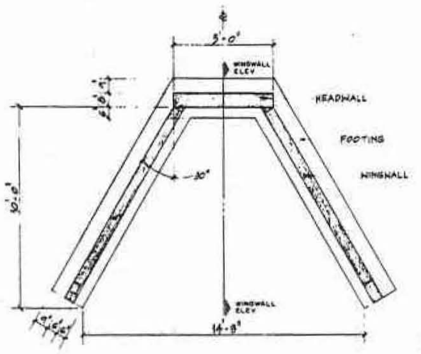

NOTE: LOCATE COVER ℞ ON CONCRETE PIT AS PER ENGINEER'S INSTRUCTIONS.
CONCRETE PIT PLAN
SCALE: 1/2" = 1'-0"
SECTION A
SECTION B
SCALE: 1"
DETAIL 'C': BEAM-TO-PIPE GRATE CONNECTION
SCALE: 3" = 1'-0"
PLAN VIEW OF BEAM SUPPORTING PIPE GRATE
(BEAM ON LEFT-HAND SIDE IS SHOWN)
SCALE: 3" = 1'-0"
TOP FLANGE
BOTTOM FLANGE
PLAN - CHANNEL FRAME & COVER ℞.
NOT-TO-SCALE
PLAN VIEW - WELDING of COVER ℞. to CHANNEL
NOT-TO-SCALE
SECTION 'D': BEAM-TO-COVER ℞. CONN.
SCALE: 3" = 1'-0"
W 4 x 13 BEAM
ANCHOR BOLTS
C 3 x 5 CHANNEL FRAME
ANCHOR BOLT
CONCRETE
CULVERT TEST PIT
— STUDY 2260 —
TEXAS TRANSPORTATION INSTITUTE
TEXAS A & M UNIVERSITY
COLLEGE STATION, TX.
DATE 5-29-79
SHEET 1 OF 1

APPENDIX B.

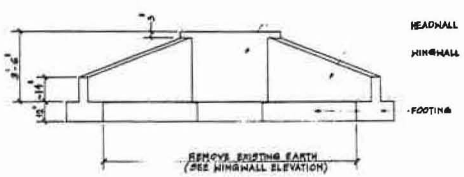
DETAILS OF AS-TESTED BOX CULVERT

WITH SAFETY GRATES,

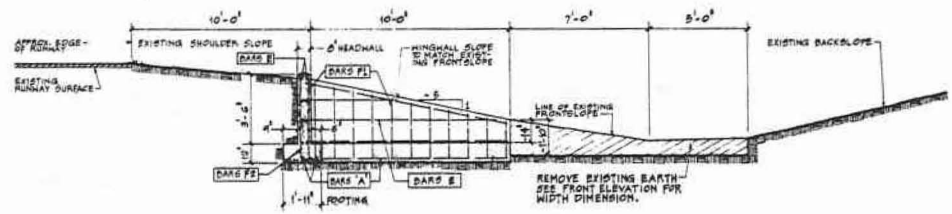
TESTS 4, 5, 6, and 7



PLAN VIEW



FRONT ELEVATION



WINGWALL ELEVATION

SCALE 3/8" = 1'-0"

REINFORCING BAR SCHEDULE

BARS E - No. 3

BARS F1 - No. 4

BARS F2 - No. 4, 90° BEND

BARS A - No. 4

NOTE: PROVIDE 1 1/2" MIN CLEAR COVER ON ALL REINFORCING STEEL

REVISIONS	CROSS-DRAINAGE STRUCTURE ROADSIDE CULVERT TEST STUDY 2-5-79-280		
	TEXAS TRANSPORTATION INSTITUTE	DATE 7-12-79	SHEET
	TEXAS A & M UNIVERSITY COLLEGE STATION, TX.	DN H.E.R., T.J.H., B.J. CK DW B.J. CK	1 OF 1.

REFERENCES

1. Linsley, R. K., and Franzini, J. B., Water Resources Engineering, 2nd Ed., McGraw-Hill Book Co., Inc., New York, N.Y., 1972, pp. 537-538.

2. "Improving Safety of Drainage Facilities", Administrative Circular No. 8-79, State Department of Highways and Public Transportation, January, 1979.

3. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", Transportation Research Circular No. 191, Transportation Research Board, February, 1978.

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

5. "Safety Treatment of Roadside Culverts on Low Volume Roads", Kohutek, T. L. and Ross, H. E., Jr., TTI Research Report 225-1, March 1978.