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16. Abstract

When multiple box culverts span over 20 ft, they are defined by AASHTO as bridge length and thus normally require the use of a full strength rigid bridge rail. The use of a rigid bridge rail creates a transition problem between the flexible metal beam guard fence which is commonly used upstream of the bridge rail. It would be safer and more economical to continue the flexible metal beam guard fence across the culvert even when the culvert length is over 20 ft and even when the soil fill depth over the culvert is less than the standard guardrail post embedment depth of 38 in. in Texas.

It was believed that more post could be used with a shallow embedment to achieve the desired guardrail strength. A metal beam guard fence design of this type was crash tested in this study and proved to be unsatisfactory.

Another concept investigated was to rigidly mount steel guard fence post (with blockout) to the top of the culvert deck when full soil embedment could not be achieved. A design of this type was also crash tested in this study and proved to be satisfactory.

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USE OF GUARDRAILS ON LOW FILL BRIDGE LENGTH CULVERTS

by

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and

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Research Report 405-2(F)
on
Research Study No. 2-5-85-405
Guardrail on Low Fill Bridge Length Culverts

Sponsored by

Texas State Department of Highways and Public Transportation
in cooperation with
the U.S. Department of Transportation
Federal Highway Administration

August 1987

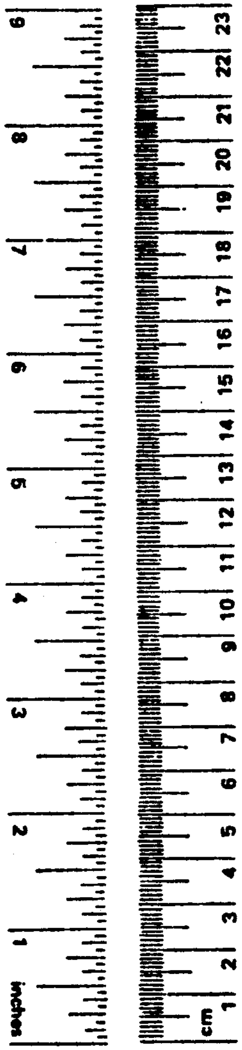
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

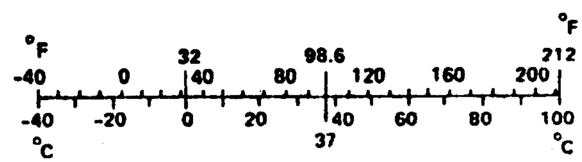
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Culverts, Bridge Rails, Guardrails, Longitudinal Barriers, Roadside Barriers

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the Texas State Department of Highways and Public Transportation (SDHPT), and the Federal Highway Administration (FHWA). Mr. John J. Panak (Bridge Design Engineer, SDHPT) and Mr. Harold Cooner (Engineer of Geometric Design, SDHPT) were closely involved in all phases of this study

IMPLEMENTATION STATEMENT

As of the writing of this report, the metal beam guard fence mounted on concrete culverts has been utilized in experimental installations on Texas highways.

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INTRODUCTION

When multiple box culverts span over 20 ft, they are defined by AASHTO (1)* as bridge length and thus normally require the use of a full strength rigid bridge rail (see the Glossary in Appendix A for definitions of barrier types). The use of a rigid bridge rail creates a transition problem between the flexible metal beam guard fence (see Appendix B for Texas standards) which is commonly used upstream of the bridge rail. It would be safer and more economical to continue the flexible metal beam guard fence across the culvert even when the culvert length is over 20 ft and even when the soil fill depth over the culvert is less than the standard guardrail post embedment depth of 38 in. Many of these culverts have soil fills of between 6 in. and 38 in.

The objective of this research study was to develop information to promote the concept of continuing the approach flexible metal beam guard fence across bridge length (over 20 ft) multiple box culverts. This concept is believed to be safer, more economical and more effective than using rigid bridge rails on such culverts.

Research Report 405-1 entitled "The Effects of Embedment Depth, Soil Properties, and Post Type on the Performance of Highway Guardrail Post" (5) presented data which could be used to modify the current metal beam guard fence for application when the full 38 in. post embedment depth could not be achieved. It was believed that more post could be used with a shallow embedment to achieve the desired guardrail strength. A metal beam guard fence design of this type was crash tested in this study and proved to be unsatisfactory.

Another concept investigated was to rigidly mount the guard fence post to the top of the culvert deck when full soil embedment could not be achieved. A design of this type was also crash tested in this study and proved to be satisfactory.

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*Numbers in parentheses, thus (1), refer to corresponding reference in list of references.

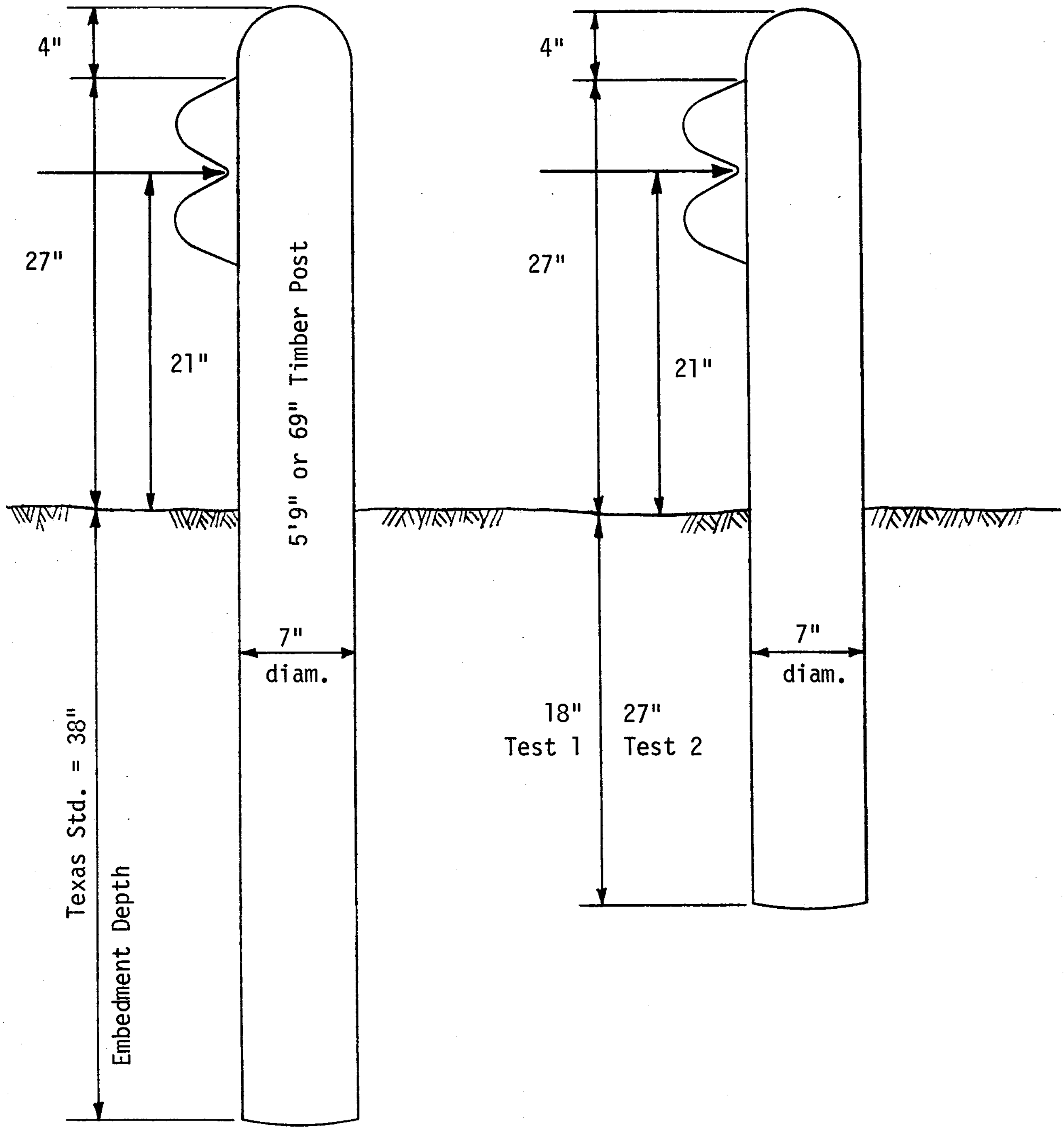


FIGURE 1. STANDARD TEXAS TIMBER GUARDRAIL POST AND MODIFIED VERSION USED IN TESTS 1 AND 2. (Prior to 1984)

METAL BEAM GUARD FENCE DESIGNS AND CRASH TESTS

At the beginning of this research it was believed that more guardrail posts could be used with a shallow embedment to achieve the necessary guard rail strength. Figure 1 shows the standard 38 in. embedment with the Texas standard 27 in. high W-beam mounting height. Figure 2 shows static load test results on these posts in a cohesionless soil (6) for various embedment depths. Figure 3 presents a summary of the maximum force and energy absorbed for various embedment depths. These data are from Figure 2 and reference 5 and have been modified slightly so the maximum force and energy could be presented on the same graph. The energy absorbed was computed out to 18 in. of deflection. Impact tests (3) with a pendulum traveling 17 mph will yield results four to five times these values. These data were used in selecting the modified guardrail designs presented.

The plan view of the typical modified guard fence designs to be tested is shown by Figure 4. As can be seen, a 50 ft long segment of the modified guard fence design was installed over a simulated concrete culvert. Standard guard fence with the standard turned down terminal (see Appendix B) were installed on both the upstream and downstream ends of the test section.

The single crash test conducted on each modified design was with a 4500 lb car impacting at 60 mph and a 25° angle (6).

MODIFIED GUARD FENCE NO. 1

The first modification is shown by Figure 5 using 7 in. diameter timber as shown on Figure 1. At first it was intended to use twice as many posts with one half the strength of a fully embedded post; for example, posts spaced at 3 ft 1-1/2 in. and embedded 24 or 27 in. (see Figures 2 and 3). However, another hypothesis prevailed. Since a strong guardrail and turned down end anchor was to be used upstream and downstream of the 50 ft long simulated culvert, the post only needed to hold the W-beam up to make initial contact with the car. The hypothesis was that the W-beam firmly anchored on each end could by itself redirect the car over this 50 ft length.

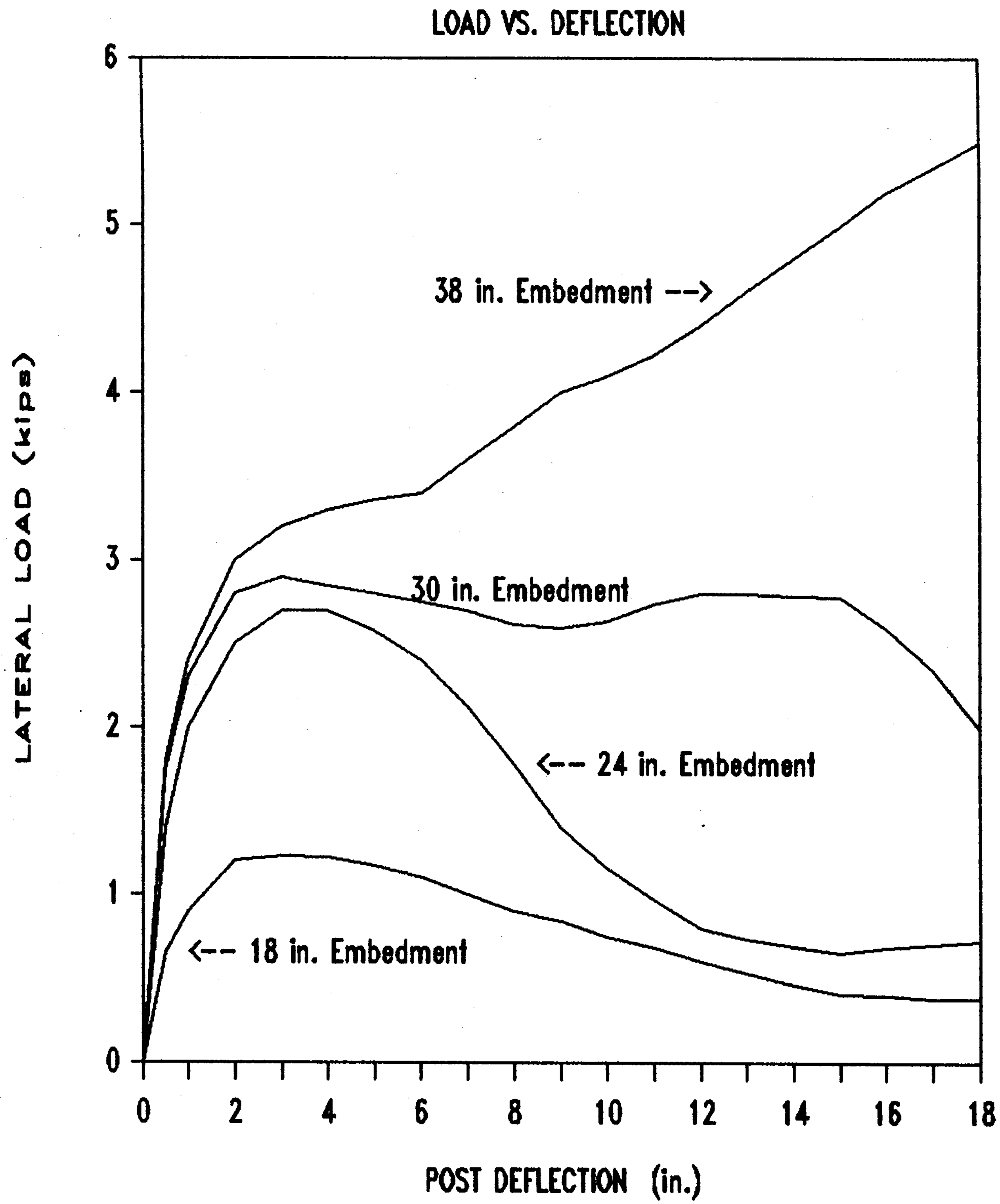


FIGURE 2. TYPICAL LOAD vs. DEFLECTION DATA FOR 7 IN. DIAMETER TIMBER POST EMBEDDED IN COHENSIONLESS SOIL. LOAD APPLIED AND DEFLECTION MEASURED AT CENTER OF W-BEAM (21 INCHES HIGH). DATA FROM REF. 5.

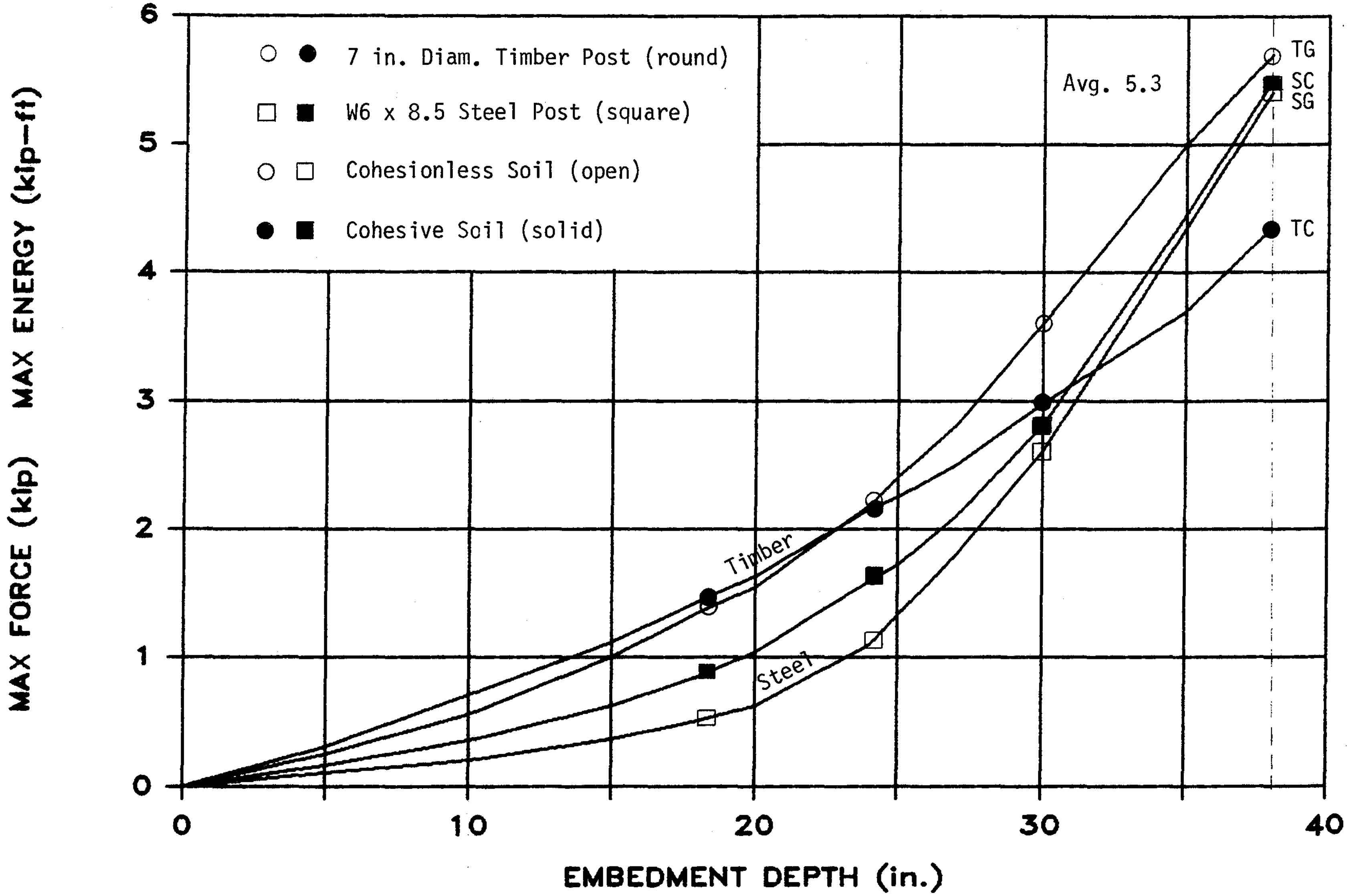


FIGURE 3. SUMMARY OF MAXIMUM FORCE AND ENERGY ABSORBED BY GUARDRAIL POST vs. EMBEDMENT DEPTH. (Data from Ref. 5)

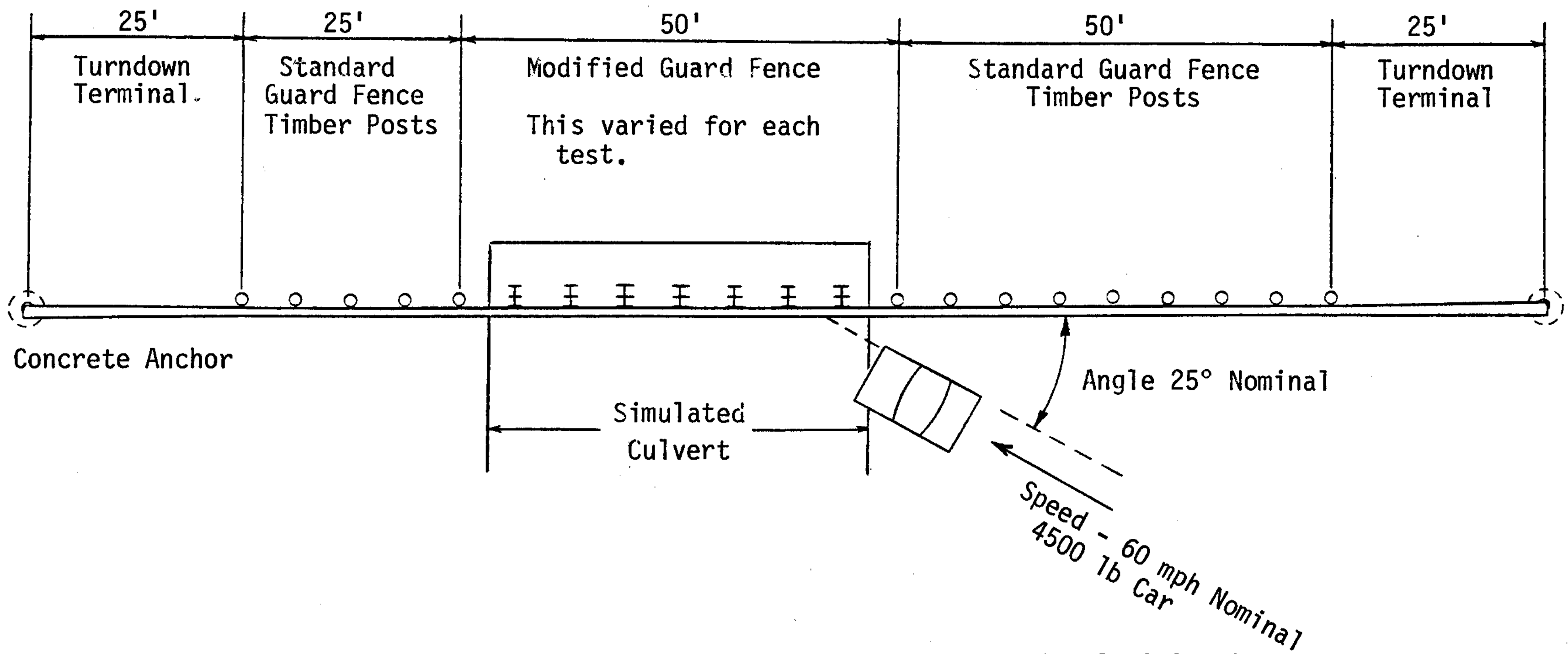


FIGURE 4. PLAN VIEW OF TYPICAL CRASH TEST SITE FOR TESTS 1, 2 AND 3.

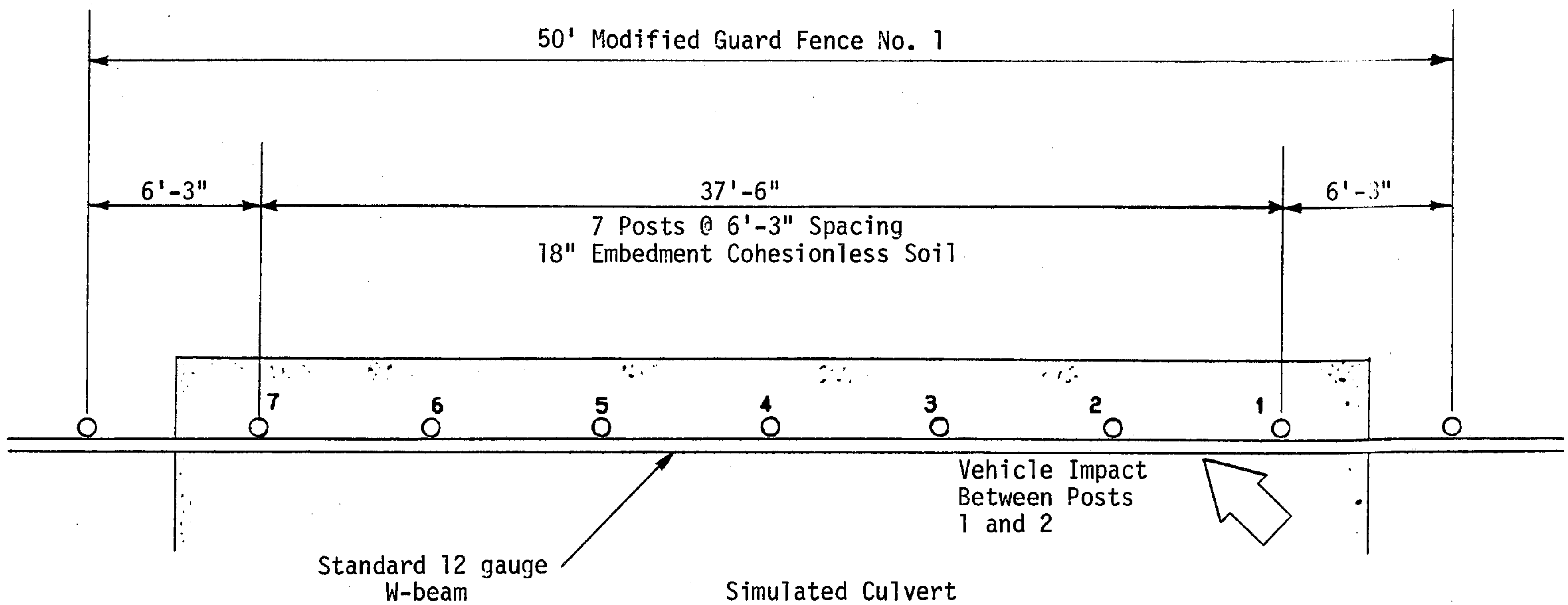


FIGURE 5. PLAN VIEW OF MODIFIED GUARD FENCE NO. 1 INSTALLATION FOR CRASH TEST 1.

This hypothesis was investigated using the BARRIER VII computer program, and a summary of the results is presented in Table 1. This table indicates the standard guard fence (6 ft-3 in. post spacing with 38 in. embedment) would deflect 20.8 in. when impacted with a 4500 lb car at 60 mph and 25° angle. The modified guard fence No. 1 shown on Figure 5 (6 ft-3 in. post spacing with 18 in. embedment) would deflect 34.4 in.

One problem with the analysis, which crash test 1 will demonstrate, is that BARRIER VII is a planar two-dimensional analysis. BARRIER VII cannot indicate that the W-beam will drop vertically and the car will vault vertically over the guardrail.

Crash Test 1. Figure 6 shows the modified guard fence installation and car before and after crash test 1. In this test a 4400 lb Chrysler Newport impacted the modified guard fence No. 1 at 61.9 mph and 26.2° angle. At 0.2 sec into the impact the car began to parallel the deflected (about 46.8 in.) W-beam rail, and the W-beam dropped and the car ramped over it. The car penetrated behind the rail and rolled over. The test was unsuccessful.

Figure 7 presents a summary of the crash test 1 data. Appendix C presents the sequence photographs of the test, and Appendix D presents the accelerometer, roll, pitch, and yaw data from the test vehicle.

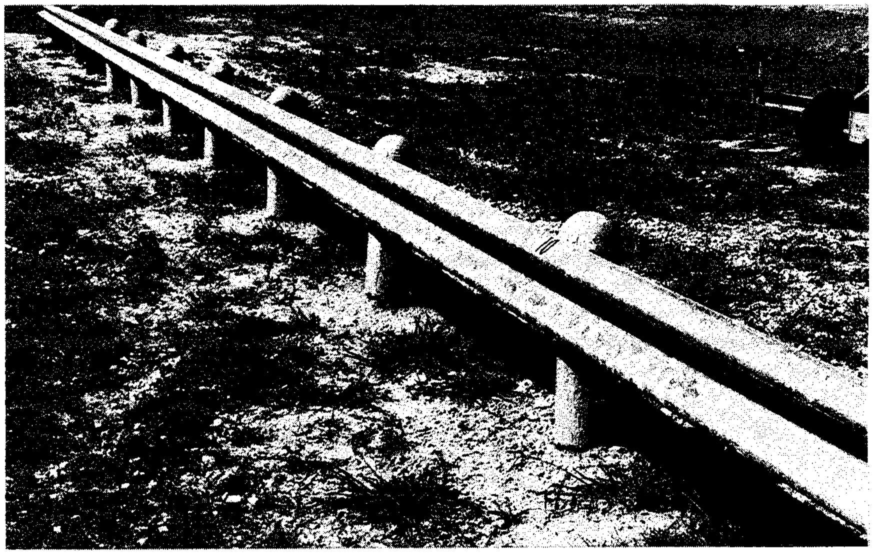
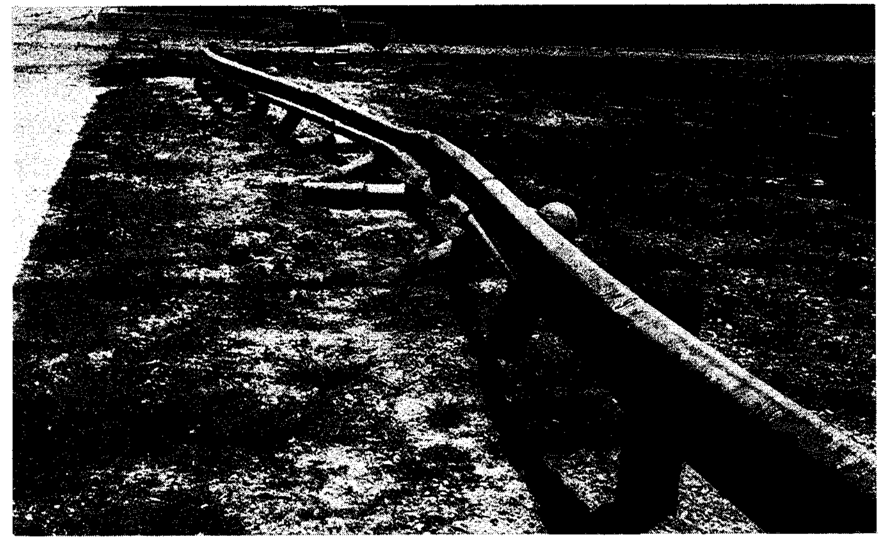
MODIFIED GUARD FENCE NO. 2

This guard fence design was in accordance with the original hypothesis that one could use twice as many posts with one half the strength to achieve the desired strength for vehicle redirection. Figure 3 was used to select the 7 in. diameter timber post embedded 27 in. in cohensionless soil to obtain one half the strength (both force and energy absorbed) of the standard 38 in. embedded post. This yields the design shown by Figure 8. Interpolating the data in Table 1 would indicate this guard fence design would deflect laterally about 20 in., which is about the same as the standard guard fence.

TABLE 1. SUMMARY OF BARRIER VII COMPUTER PROGRAM ANALYSIS OF MODIFIED METAL BEAM GUARD FENCE DESIGNS.

POST SPACING (ft-in.)	POST EMBEDMENT (in.)	POST STATIC LOAD CAPACITY (kips)	MAX. GUARD FENCE DEFLECTION (in.)
6'- 3"	38	3.0	20.8
6'-3"	24	1.5	31.0
6'-3"	18	1.0	34.4
3'-1 1/2"	24	1.5	22.0
3'-1 1/2"	18	1.0	25.6

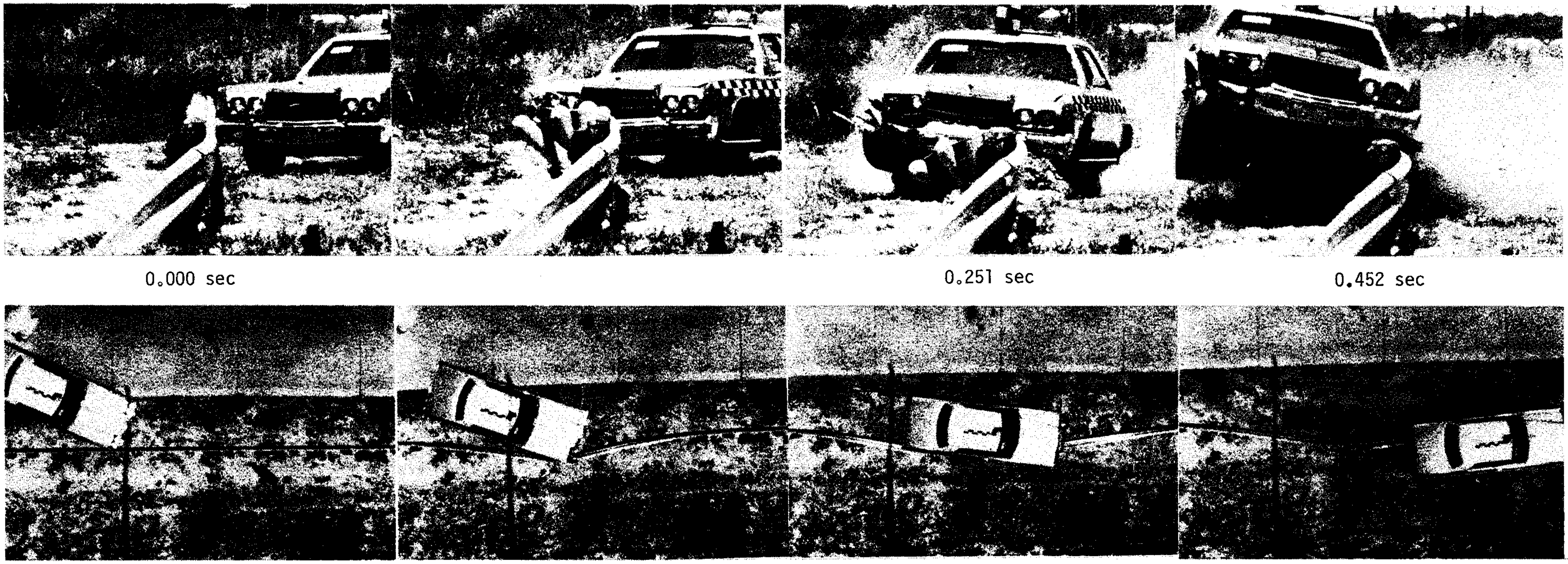
NOTE: 50 ft length of guardrail with 25 ft turn-down terminal on each end. Elastic-plastic post-soil model which yields at 2 in. deflection.
$F_{dyn} = F_{static} (1 + JV)$ where V is ft/sec and J = 0.14 sec/ft.
Impact by 4500 lb car at 60 mph and 25° angle.

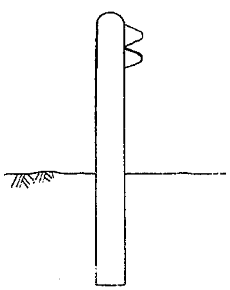



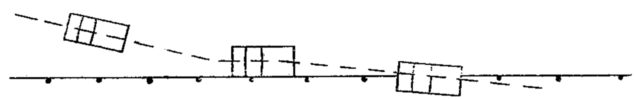
Before

After


FIGURE 6. MODIFIED GUARD FENCE NO. 1 AND CAR BEFORE AND AFTER CRASH TEST 1.







Test No.	2405-1
Date	7/22/85
Face Rail	12 ga. steel W-shape
Post	standard timber
Post Spacing	1.9 m (6 ft 3 in)
Length of Installation .	53.3 m (175 ft)
Beam Rail Deflection	
Max. Dynamic	1.19 m (3.9 ft)
Max. Permanent	1.12 m (3.7 ft)
Vehicle Damage	
TAE	01RFQ4
SAE	01RFEK5

Vehicle	1977 Chrysler Newport
Vehicle Weight . . . . . (w/instr.)	1996 kg (4400 lb)
Impact Speed	99.4 km/h (61.8 mph)
Impact Angle	26.2 degrees
Exit Speed	
Exit Angle	
Vehicle Acceleration (Max. 0.050 sec. avg.)	
Longitudinal	-3.1 g
Transverse	2.7 g
Vertical	3.5 g

FIGURE 7. SUMMARY OF CRASH TEST 1.

Crash Test 2. Figure 9 shows the modified guard fence No. 2 and car before and after the test. In this test a 4500 lb Cadillac Deville impacted the modified guard fence No. 2 at 61.8 mph and 23.2° angle. At about 0.15 sec the rail had deflected about 28 in. and the car was beginning to redirect (yaw about 10°), and W-beam broke in two. At 0.3 sec the car came parallel to the guardrail and rode down it about 50 ft before coming to a stop and rolling on its side beside and behind it.

Tensile tests of coupons from the broken W-beam indicated its yield strength as 80 ksi, ultimate strength as 106 ksi, and ductility of 17%. The steel in the W-beam easily satisfied the AASHTO requirements of yield strength of 50 ksi (minimum), ultimate strength of 70 ksi (minimum), and 12% minimum ductility.

Close examination of the timber posts indicated they bent over and pulled out of the soil simultaneously. The right front tire of the car literally rode up the inclined posts spaced so close together trying to push them down. While this was happening, the right front bumper of the car was firmly nestled in the groove of the W-beam and was exerting an upward force on the beam. This combination of forces -- downward force from post plus tire, upward force from bumper, and large tensile redirection force -- caused the W-beam to first split longitudinally down the center of the W (about 6.25 ft long split) and then break transversely.

Tests 1 and 2 have indicated that guardrail posts need sufficient embedment to develop enough friction to keep them from pulling out of the ground. They also need sufficient embedment to develop the required bending strength or lateral load capacity.

MODIFIED GUARD FENCE NO. 3

After the unsuccessful crash tests on modified guard fence designs Nos. 1 and 2, it was decided that the post would have to be attached to the culvert deck when the soil fill was less than the standard 38 in. The modified guard fence No. 3 design was as shown by Figures 11 and 12.

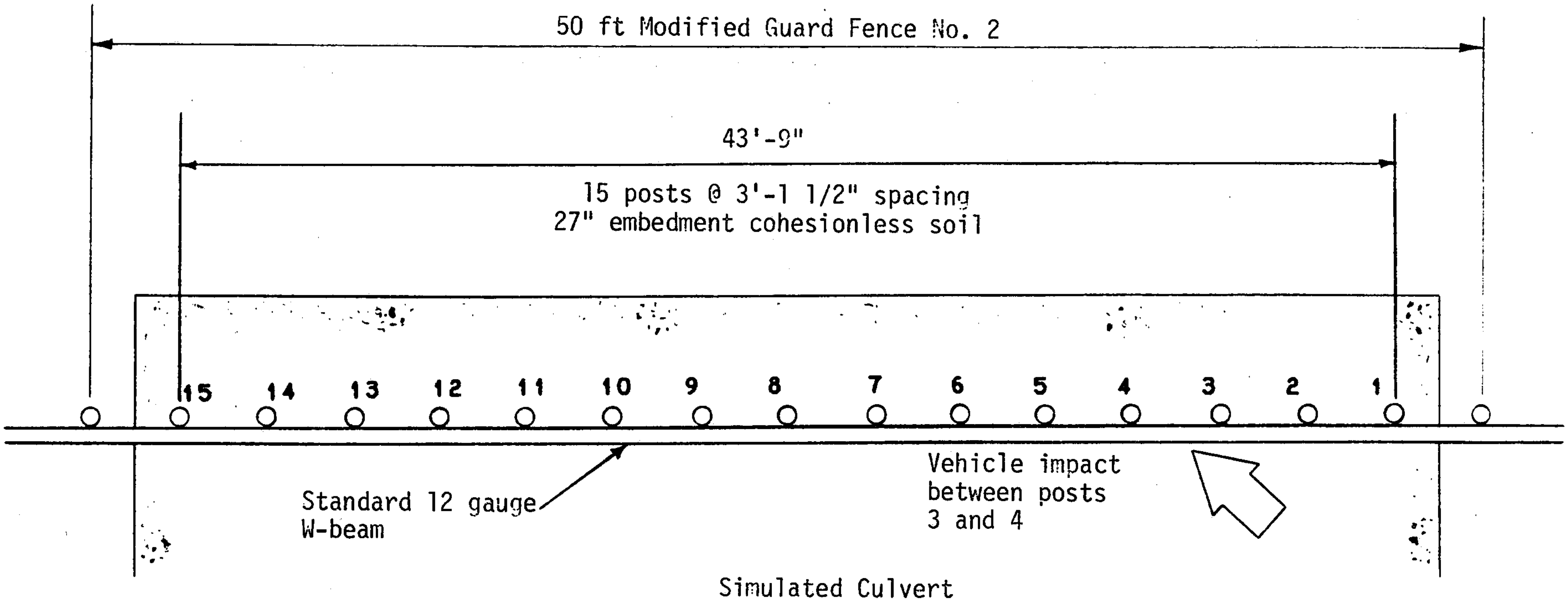
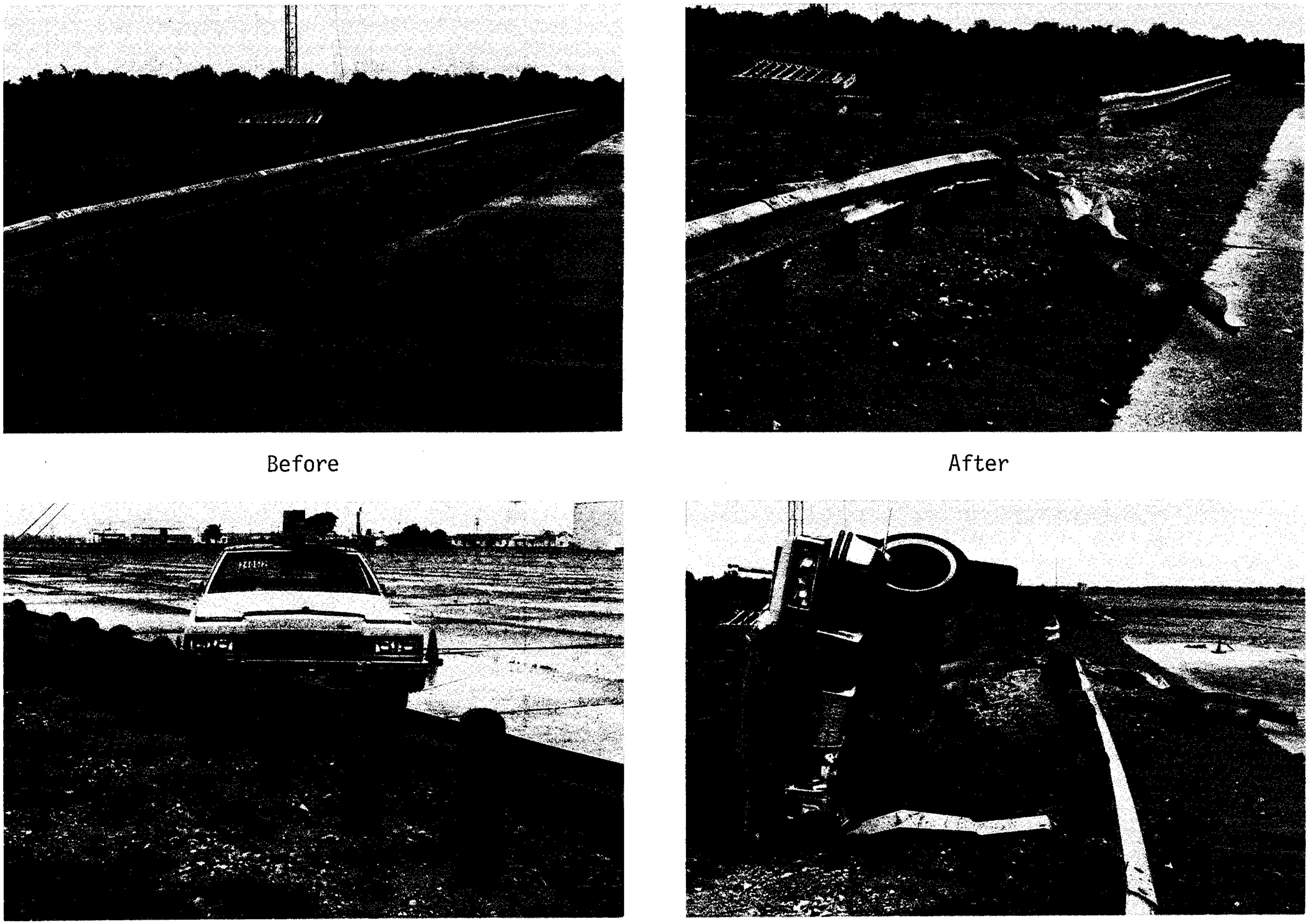


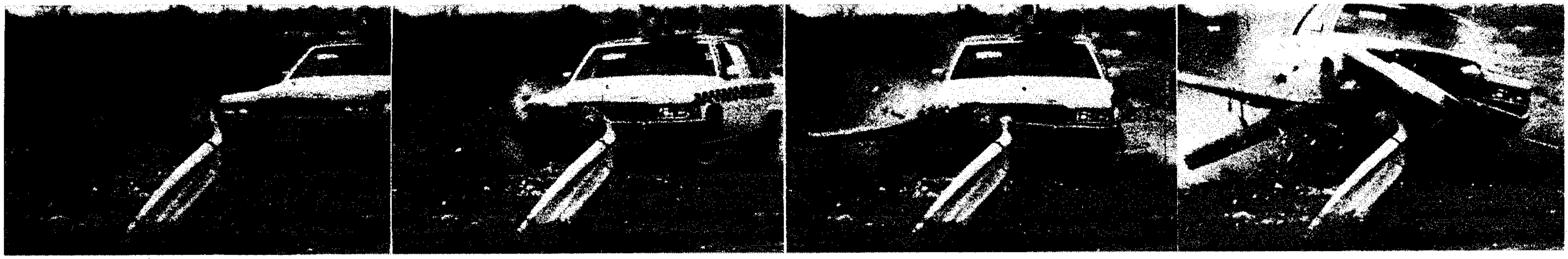
FIGURE 8. PLAN VIEW OF MODIFIED GUARD FENCE NO. 2 INSTALLATION FOR CRASH TEST 2.



Before

After

FIGURE 9. MODIFIED GUARD FENCE NO. 2 AND CAR BEFORE AND AFTER CRASH TEST 2.



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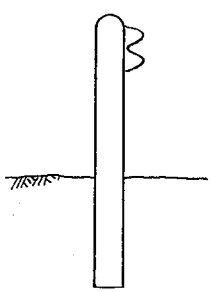
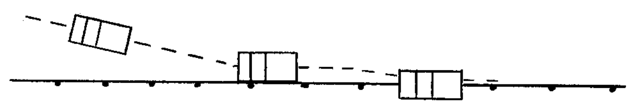




Test No. 2405-2	Vehicle . . . . 1979 Cadillac DeVille
Date 4/18/86	Vehicle Weight . . . . . . 2041 kg (4500 lb)
Face Rail . . . . 12 ga. steel W-shape	(w/instr.)
Post . . . . standard timber	Impact Speed . . . . 99.6 km/h (61.9 mph)
Post Spacing . . . . 0.95 m (3 ft 1.5 in)	Impact Angle . . . . 23.2 deg.
Length of Installation . 53.3 m (175 ft)	Exit Speed . . . .
Beam Rail Deflection	Exit Angle . . . .
Max. Dynamic . . . . . . 2.56 m (8.4 ft)	Vehicle Acceleration
Max. Permanent . . . . . fracture	(Max. 0.050 sec. avg.)
Vehicle Damage	Longitudinal . . . . . . -5.8 g
TAE 01RFQ4	Transverse . . . . 5.3 g
SAE 01RFEK4	Vertical . . . . 5.1 g

FIGURE 10. SUMMARY OF CRASH TEST 2.

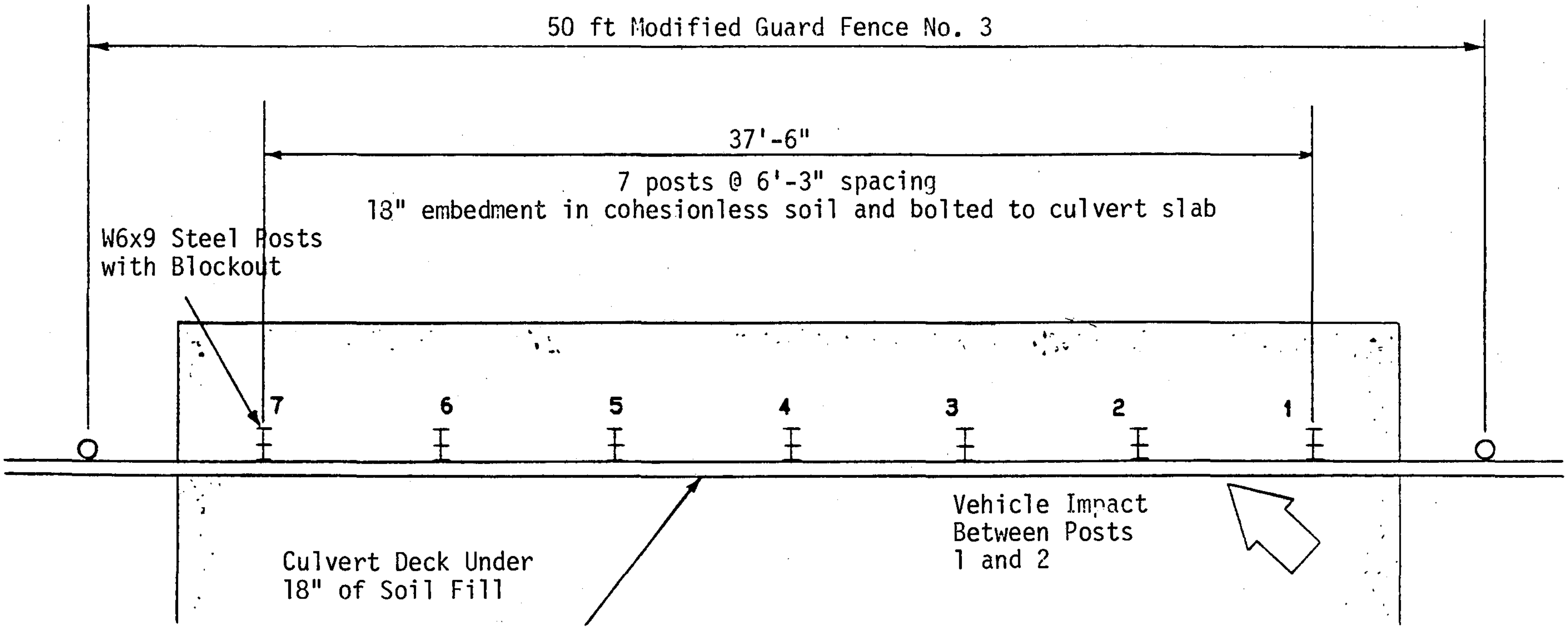


FIGURE 11. PLAN VIEW OF MODIFIED GUARD FENCE NO. 3 INSTALLATION FOR CRASH TEST 3.

The W6 x 9 standard steel guardrail post with blockout was fitted with a steel base plate and bolted to the simulated culvert slab as shown by Figure 12. The 6 in. thick culvert slab was reinforced as a typical Texas culvert slab (Appendix E). The centers of the posts were located 30 in. from the outer edge of the culvert. This design should not crack the culvert slab. Static load test results of this post (without soil fill) is shown by Figure 13. Failure was by yielding and then by local buckling of the compression flange. Damaged post could relatively easily be replaced by bolting on a new post. Additional load test results and simulated culvert slab details are presented in Appendix E.

Figure 14 presents the results of an analysis of how the guard fence post load capacity would change with different soil fill depths. The 18 in. soil fill depth was chosen for this test because the load capacity is low (about 8.5 kips) and the probability of the car tire snagging a post highest with low fill depths.

<u>Crash Test 3</u>. Figure 15 shows the modified guard fence No. 3 and car before and after crash test 3. The 4450 lb Cadillac Deville impacted the guard fence at 61.8 mph and 25.3° angle. The car was smoothly redirected as intended. The maximum rail deflection was 2.7 ft and four posts were severely damaged.

This test and modified guard fence No. 3 was very successful. With this design the guard fence can now be used over culverts even when full embedment depth of the guardrail post cannot be achieved.

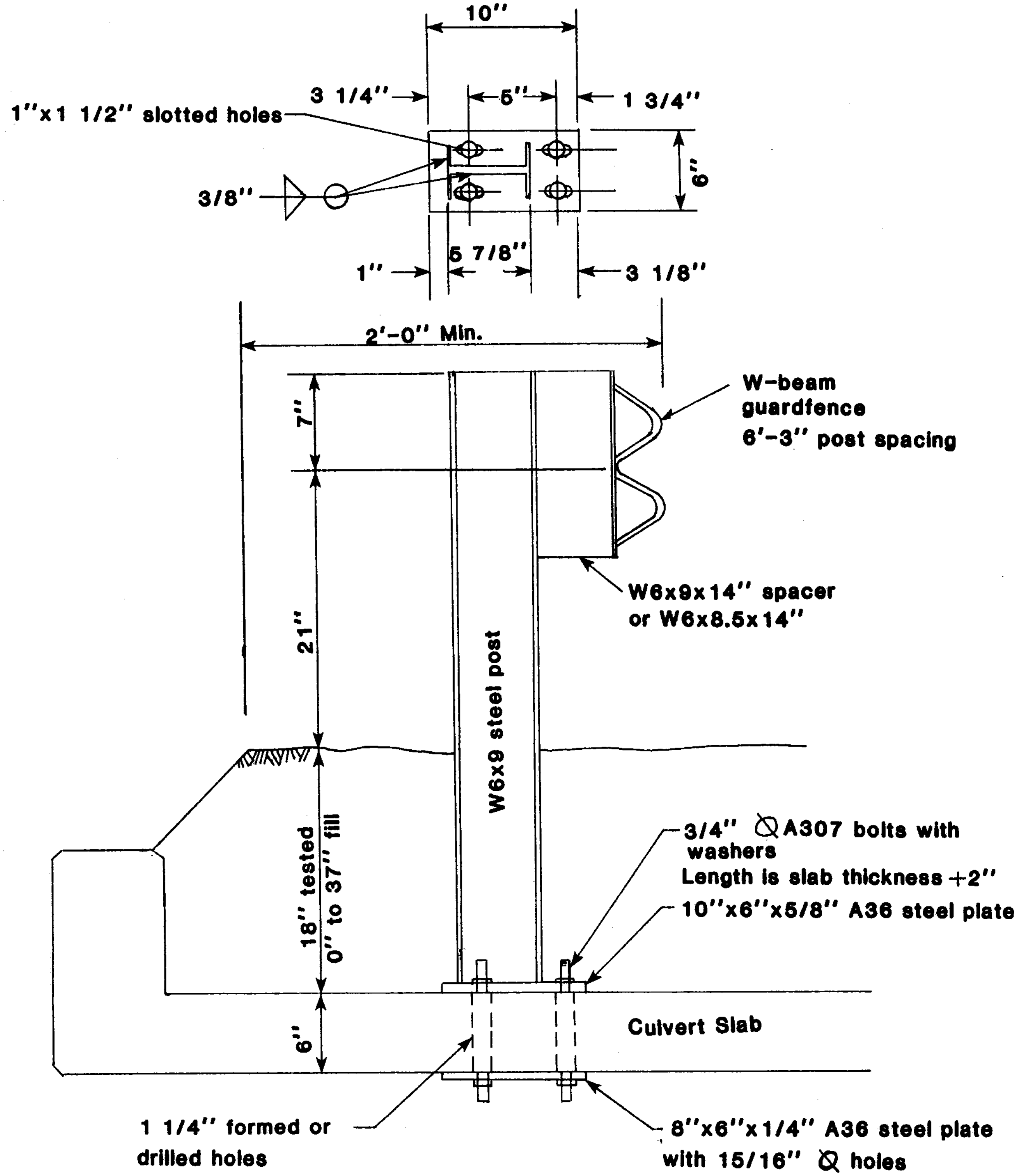
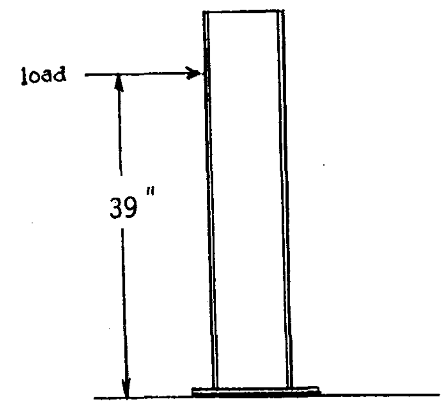


FIGURE 12. DETAIL OF STEEL GUARDFENCE POST
AND ATTACHMENT TO CULVERT SLAB.

STATIC TEST RESULTS

Test #1



Note: W6x9 steel post
No failure or bending of baseplates or bolts.
Failure due entirely to bending in post.

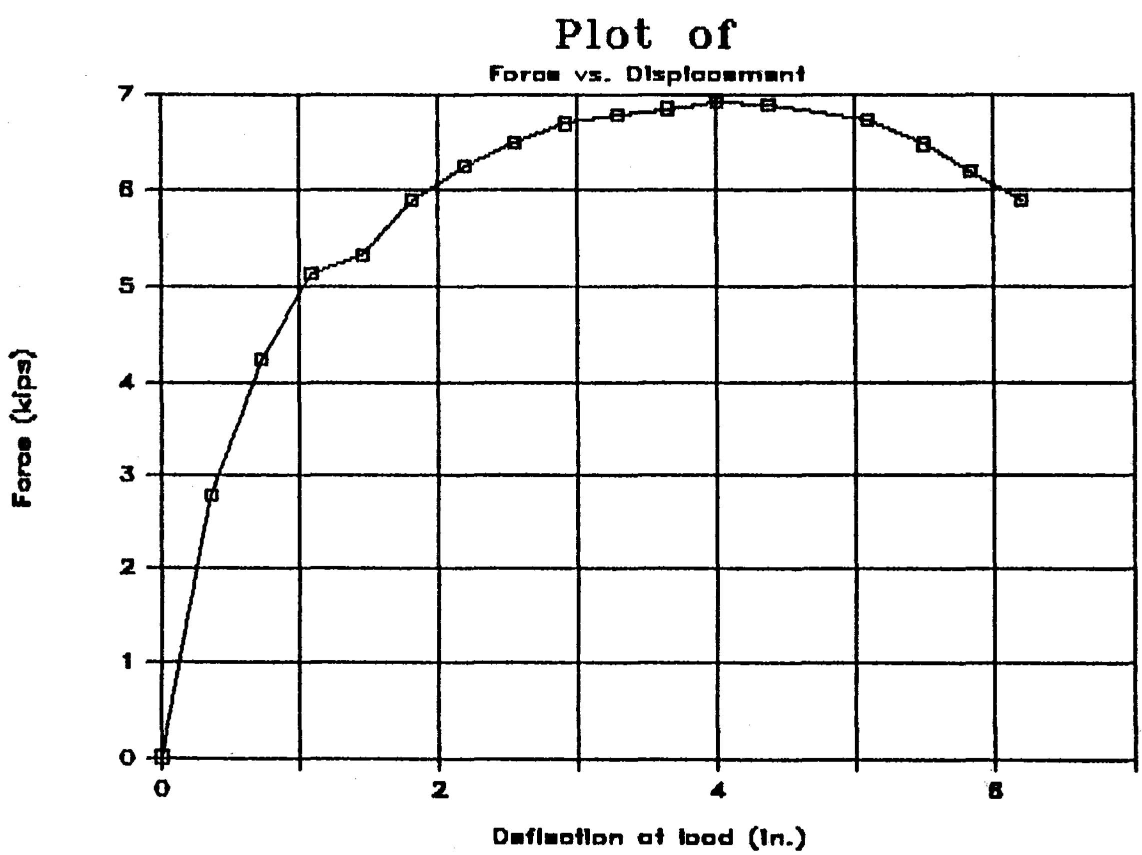


FIGURE 13. STATIC LOAD TEST RESULTS FOR GUARD FENCE POST USED IN CRASH TEST 3.

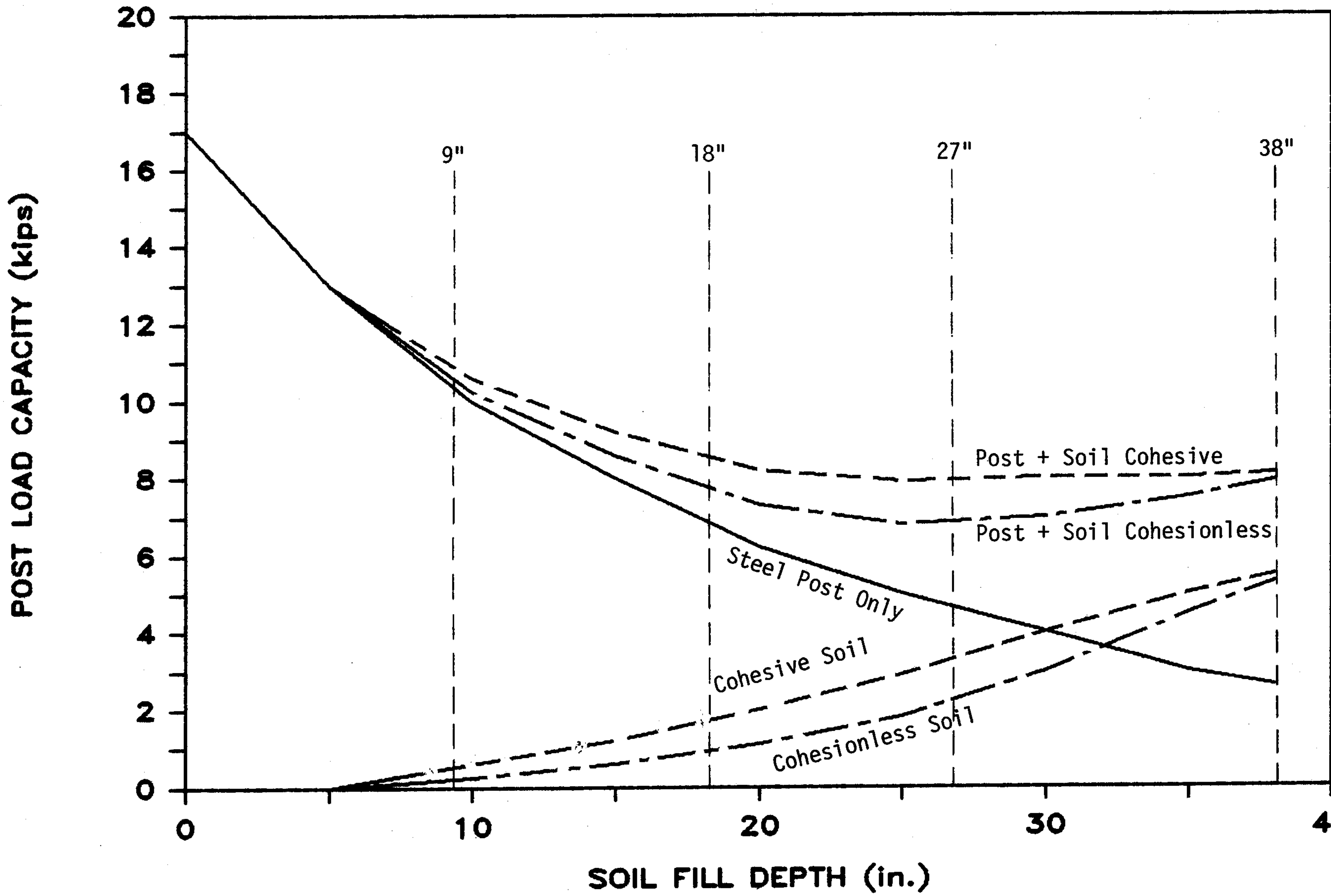


FIGURE 14. ANALYSIS OF GUARD FENCE POST LOAD CAPACITY FOR VARIOUS SOIL FILL DEPTHS.

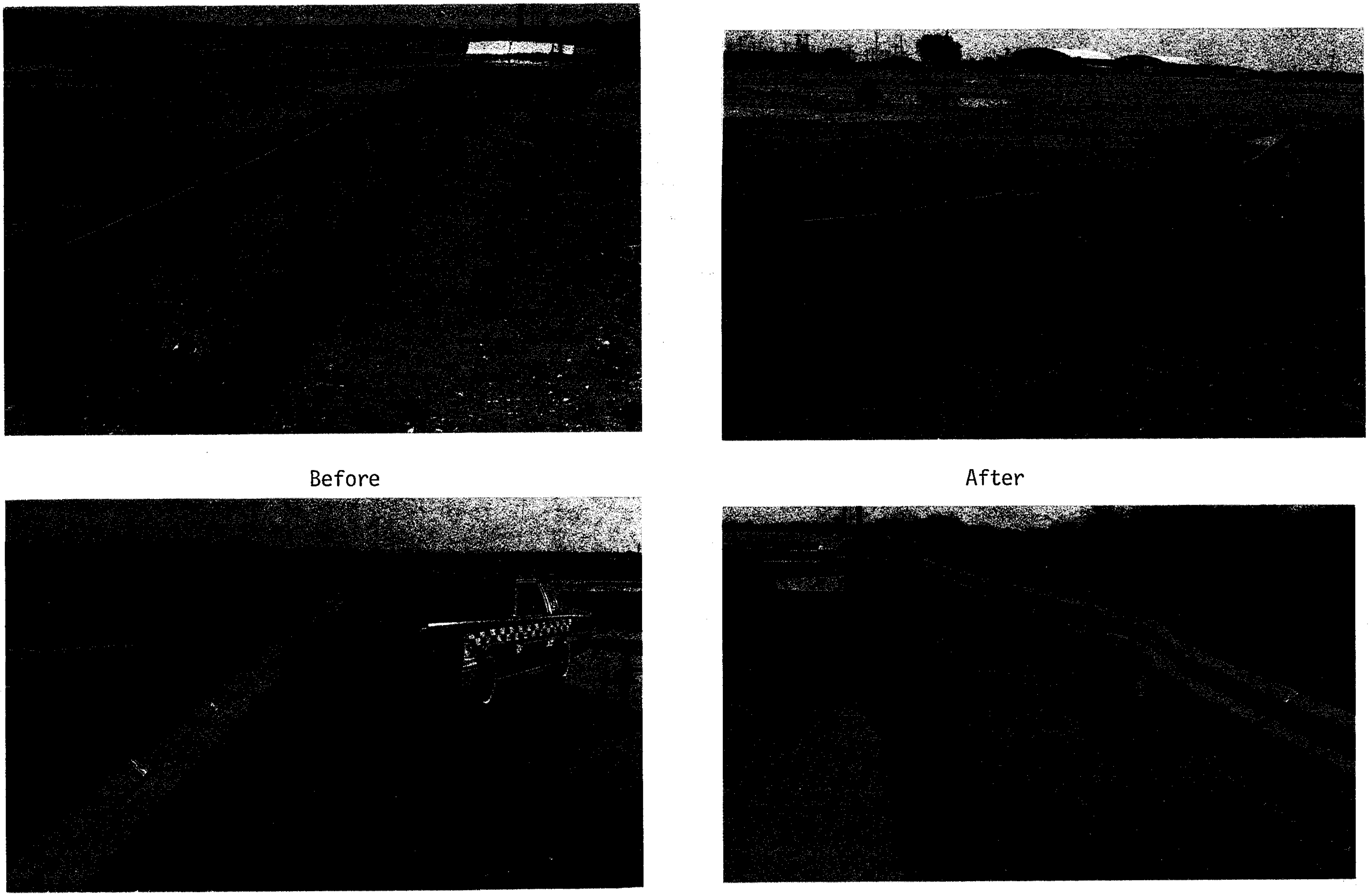
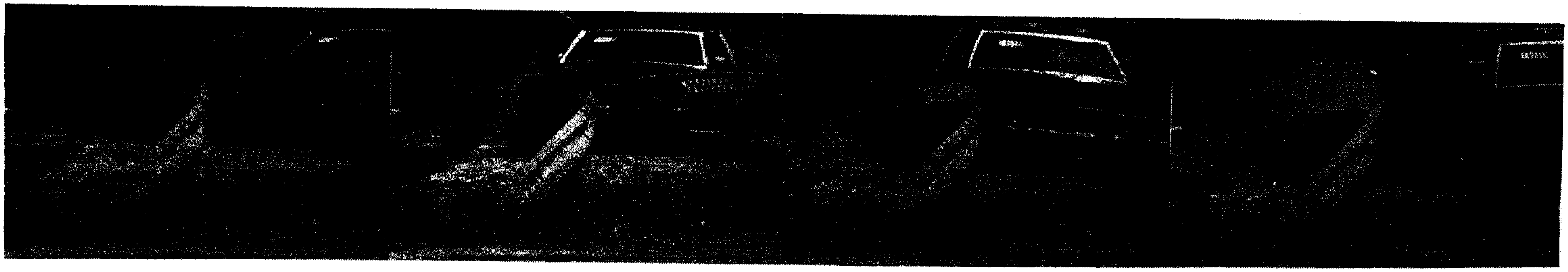


FIGURE 15. MODIFIED GUARD FENCE NO. 3 AND CAR BEFORE AND AFTER CRASH TEST 3.



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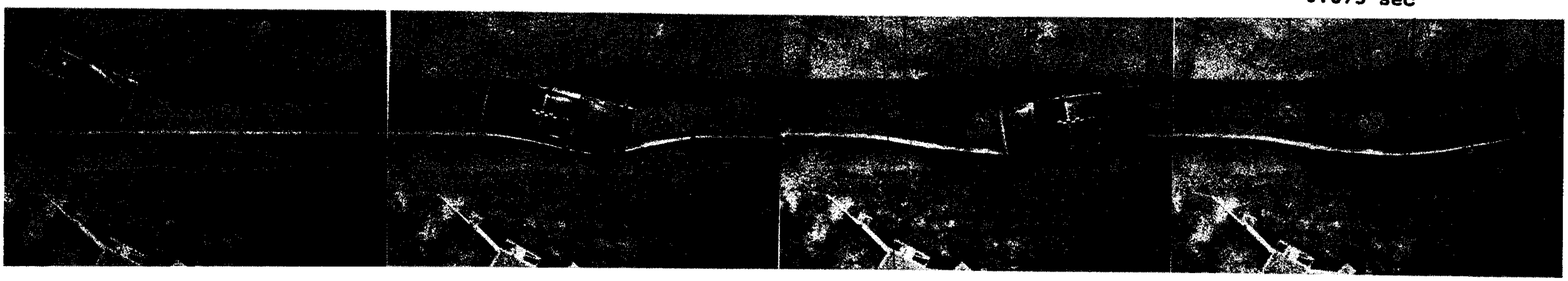

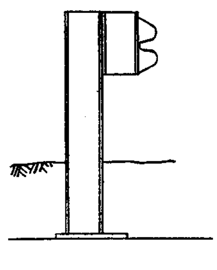

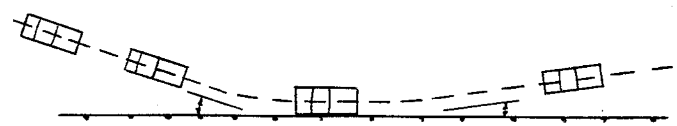

Test No.	2405-3	Vehicle	1978 Cadillae DeVille
Date	7/8/86	Vehicle Weight (w/instr.)	2019 kg (4450 lb)
Face Rail	12 ga. steel W-shape	Impact Speed	99.4 km/h (61.8 mph)
Post	W6x9	Impact Angle	25.3 deg.
Post Spacing	1.9 m (6 ft 3 in)	Exit Speed	59.9 km/h (37.2 mph)
Length of Installation	53.3 m (175ft)	Exit Angle	15.6 deg.
Beam Rail Deflection		Vehicle Acceleration (Max. 0.050 sec. avg.)	
Max. Dynamic	0.82 m (2.7 ft)	Longitudinal	-2.78 g
Max. Permanent	0.67 m (2.2 ft)	Transverse	4.59 g
Vehicle Damage		Vertical	-3.43 g
TAE	01RFQ4		
SAE	01RFES35		

FIGURE 16. SUMMARY OF CRASH TEST 3.

SUMMARY AND CONCLUSIONS

The culvert-mounted Modified Guard Fence No. 3 design meets all crash test performance requirements. The new guard fence smoothly redirected a 2019 kg (4450 lb) vehicle traveling 99.4 km/hr (61.8 mph) and impacting the rail at an angle of 25.3 degrees. This guard fence system does not have the transition problem that the presently required rigid system does because it is flexible along its entire length.

This new guard fence system is also cheaper than using more rigid bridge rails. The new system has an approximate installation cost of $17 per ft as opposed to the $35 per ft cost of typical T101 steel bridge rail.

REFERENCES

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2. Ross, H. E., Jr., Kohutek, T. L., and Pledger, J., "Guide for Selecting, Locating, and Designing Traffic Barriers," Report No. FHWA-RD-76-503, Federal Highway Administration, Washington, D.C., Feb. 1976.

3. Dewey, J. F., Jeyapalan, J. K., Hirsch, T. J., and Ross, H. E., "A Study of the Soil-Structure Interaction Behavior of Highway Guardrail Post," Research Report No. 343-1, Texas Transportation Institute, Texas A&M University, College Station, Texas, July 1983.

4. Eggers, D. W., Hirsch, T. J., and Ross, H. E., "Strength of Guardrail Post in Rock, Research Report No. 343-1 Supplement, Texas Transportation Institute, Texas A&M University, College Station, Texas, Sept. 1984.

5. Eggers, D. W. and Hirsch, T. J., "The Effects of Embedment Depth, Soil Properties, and Post Type on the Performance of Highway Guardrail Posts," Research Report 405-1, Texas Transportation Institute, Texas A&M University, College Station, Texas, Aug. 1986.

6. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, National Research Council, Washington, D.C., Mar. 1981.

7. Arnold, Althea and Hirsch, T. J., "Bridge Deck Designs for Railing Impacts," Research Report 295-1F, Texas Transportation Institute, Texas A&M University, College Station, Texas, Nov. 1983.

APPENDIX A

GLOSSARY

From Reference 2.

Area of Concern—An object or roadside condition that warrants shielding by a traffic barrier.

Barrier Warrant—A criterion that identifies an area of concern which should be shielded by a traffic barrier. The criterion may be a function of relative safety, economics, etc., or a combination of factors.

Bridge Rail—A longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.

Clear Zone—That roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. Establishment of a minimum width clear zone implies that rigid objects and certain other hazards with clearances less than the minimum width should be removed, relocated to an inaccessible position or outside the minimum clear zone, remodeled to make safely traversable or breakaway, or shielded.

Clearance—Lateral distance from edge of traveled way to a roadside object or feature.

Crash Cushion—A traffic barrier used to safely shield fixed objects or other hazards from approximately head-on impacts by errant vehicles. Examples are sand-filled plastic barrels, water-filled tubes, vermiculite concrete cartridges, and steel drums.

Crashworthy Barrier—One that can be impacted by a vehicle at or below the anticipated operating speed of the roadway with low probability of serious injury to the vehicle's occupants.

Experimental Barrier—One that has performed satisfactorily in full-scale crash tests and promises satisfactory in-service performance.

Impact Angle—For a longitudinal barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle's path at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle's path at impact.

Length of Need—Total length of a longitudinal barrier, measured with respect to centerline of roadway needed to shield an area of concern.

Longitudinal Barrier—A barrier whose primary functions are to prevent penetration and to safely redirect an errant vehicle away from a roadside or median hazard. The three types of longitudinal barriers are roadside barriers, median barriers, and bridge rails.

Median Barrier—A longitudinal barrier used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions.

Operating Speed—The highest speed at which reasonably prudent drivers can be expected to operate vehicles on a section of highway under low traffic densities and good weather conditions. This speed may be higher or lower than posted or legislated speed limits or nominal design speeds where alignment, surface, roadside development, or other features affect vehicle operation.

Operational Barrier—One that has performed satisfactorily in full-scale crash tests and has demonstrated satisfactory in-service performance.

Research and Development Barrier—One that is in the development stage and has had insufficient full-scale tests and in-service performance to be classified otherwise.

Roadside Barrier—A longitudinal barrier used to shield hazards located within an established minimum width clear zone. It may also be used to shield hazards in extensive areas between the roadways of a divided highway. It may occasionally be used to protect pedestrians or "bystanders" from vehicular traffic.

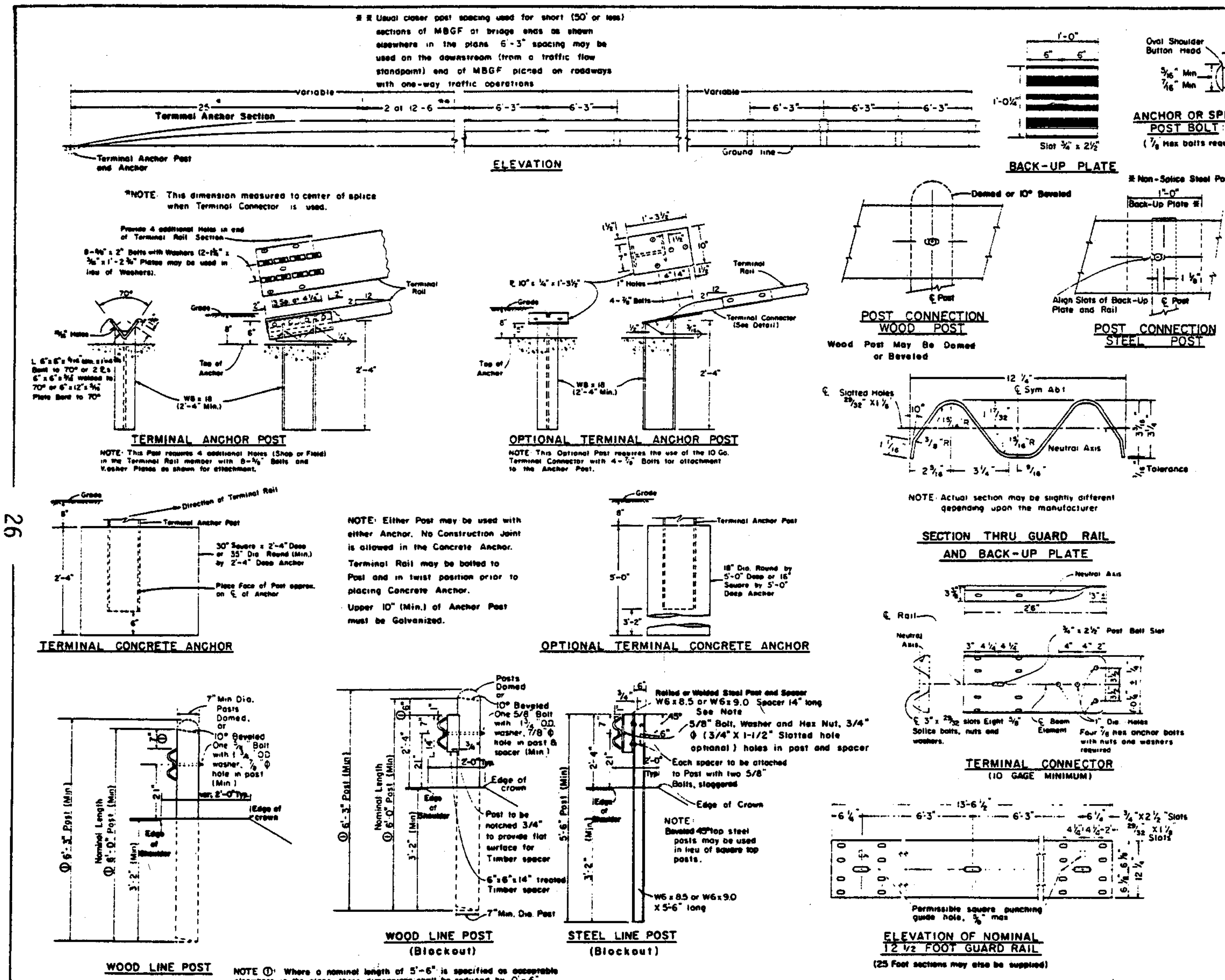
Roadway—The portion of a highway, including shoulders, for vehicular use.

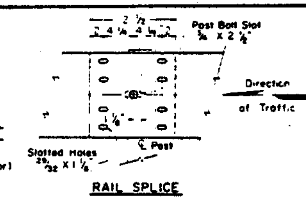
Shy Distance—Distance from the edge of the traveled way beyond which a roadside object will not be perceived as an immediate hazard by the typical driver, to the extent that he will change his vehicle's placement or speed.

Traffic Barrier—A device used to shield a hazard that is located on the roadside or in the median, or a device used to prevent crossover median accidents. As defined herein, there are four classes of traffic barriers, namely, roadside barriers, median barriers, bridge rails, and crash cushions.

Traveled Way—The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

APPENDIX B





GENERAL NOTES

1. THE EXACT POSITION OF GUARD FENCE SHALL BE AS SHOWN ELSEWHERE ON THE PLANS OR AS DIRECTED BY THE ENGINEER. GUARD FENCE SHALL BE TRANSITIONED TO A SMOOTH CONNECTION WITH OTHER GUARD FENCE OR STRUCTURE RAILING AS SHOWN ELSEWHERE ON PLANS.
2. AT THE OPTION OF THE CONTRACTOR THE RAIL ELEMENTS FOR THE GUARD FENCE MAY BE FURNISHED IN EITHER 12 1/2 OR 25 FOOT NOMINAL LENGTHS WITH POST BOLT SLOTS FOR CONNECTION TO POSTS.
3. BOLTS SHALL BE OF SUFFICIENT LENGTH TO EXTEND THROUGH THE FULL THICKNESS OF THE NUT AND NO MORE THAN 3/4" BEYOND IT.
4. THE TOP OF THE TERMINAL ANCHOR POST AND ALL STEEL FITTINGS THEREON SHALL BE GALVANIZED A MINIMUM OF 10" AS SHOWN.
5. WHERE SOLID ROCK IS ENCOUNTERED OR WHERE SHOWN ON THE PLANS, THE DIAMETER OF THE HOLES SHALL BE APPROXIMATELY 12 INCHES. THE BACKFILLING SHALL BE WITH A COHESIONLESS MATERIAL, AND EMBEDMENT DEPTH SHALL BE 1'-6" OR MORE AS DIRECTED BY THE ENGINEER. TIMBER POSTS SHALL NOT BE SET IN CONCRETE.
6. THE TERMINAL ANCHOR POST SHALL BE SET IN CLASS "A", "B" OR "C" CONCRETE IN ACCORDANCE WITH ITEM, "CONCRETE FOR STRUCTURES", OR SET IN CONCRETE IN ACCORDANCE WITH ITEM "CONCRETE PAVEMENT". CONCRETE SHALL BE SUBSIDIARY TO THE BID ITEM REQUIRING CONSTRUCTION OF THE TERMINAL RAIL SECTION AND ANCHORAGE SYSTEM.
7. TIMBER POSTS MAY BE BEVELED AT APPROXIMATELY 10 DEGREES ON THE TOP OR BOTH ENDS WITH HIGH SIDE OF TOP OF POST PLACED TOWARD THE ROADWAY OR THEY MAY BE DOMED. WHEN "BLOCKED OUT", THE UPPER PORTION OF THE POST SHALL BE NOTCHED 3/4" TO PROVIDE FLAT SURFACE FOR TIMBER SPACER. A TOLERANCE OF ± 1/8" WILL BE PERMITTED ON THE NOTCHED PORTION OF THE POST.
8. AN ANCHOR OTHER THAN TO A TERMINAL ANCHOR POST SHALL CONSIST OF A CONNECTION SIMILAR TO THE RAIL SPLICE OR SIMILAR TO THE TERMINAL CONNECTOR.
9. SPECIAL FABRICATION WILL BE REQUIRED IN INSTALLATIONS HAVING A CURVATURE OF LESS THAN 150' RADIUS.
10. POST SPACING WILL BE 6' - 3" EXCEPT THAT THE FIRST POST WILL BE 25' FROM THE TERMINAL ANCHOR POST AND THE NEXT TWO POSTS SPACED AT 12' - 6" WITH A MINIMUM OF 8 POSTS ADJACENT TO STRUCTURES SPACED AT 3' - 1 1/2".
11. THE 10 GAGE TERMINAL CONNECTORS MUST BE USED WITH THE OPTIONAL TERMINAL ANCHOR POST. EITHER ANCHOR POST MAY BE USED WITH EITHER CONCRETE ANCHOR.
12. CROWN WILL BE WIDENED TO ACCOMMODATE GUARD FENCE.
13. STEEL POSTS SHALL BE BLOCKED OUT. A W6x8.5 OR W6x9.0 STEEL SPACER SHALL BE USED WITH STEEL POSTS. BACK-UP PLATES SHALL BE PROVIDED AT INTERMEDIATE (NON-SPLICE) STEEL POSTS.
14. WHEN BLOCKOUT GUARD FENCE IS SPECIFIED ELSEWHERE IN THE PLANS, A 6" x 6" x 14" TREATED TIMBER SPACER OF YELLOW PINE SHALL BE USED WITH WOOD POSTS.
15. UNLESS OTHERWISE SHOWN IN THE PLANS, GUARD FENCE PLACED IN THE VICINITY OF CURBS SHALL BE BLOCKED OUT SO THAT THE FACE OF CURB IS LOCATED DIRECTLY BELOW OR BEHIND THE FACE OF RAIL. RAIL PLACED OVER CURBS SHALL BE INSTALLED SO THAT THE POST BOLT IS LOCATED APPROXIMATELY 21-INCHES ABOVE THE GUTTER PAN OR ROADWAY SURFACE.
16. WELDED STEEL POSTS AND SPACERS SHALL MEET THE REQUIREMENTS OF ASTM A-769. THE FLANGE WIDTH AND THICKNESS, WEB THICKNESS, AND DEPTH OF WELDED POSTS AND SPACERS SHALL EQUAL OR EXCEED THE DIMENSIONS OF A STANDARD ROLLED W6x8.5.
17. STEEL POSTS AND SPACERS SHALL MEET THE REQUIREMENTS OF ASTM A-36. BOLT HOLES SHALL BE APPROXIMATELY CENTERED BETWEEN WEB AND EDGE OF FLANGE OF SPACERS AND POSTS.
18. UNLESS OTHERWISE SHOWN IN THE PLANS, MBGF SHALL BE PLACED WITH THE FACE OF RAIL DIRECTLY ABOVE THE SHOULDER EDGE (OR CURBFACE) EXCEPT THE 25' TERMINAL ANCHOR SECTION AND ADJACENT 25' OF MBGF SHALL BE FLARED AT 25:1 (LONGITUDINAL:LATERAL) TO PROVIDE A 2' OFFSET BETWEEN BURIED ANCHOR AND SHOULDER EDGE (OR CURBFACE). FLARING THE 25' TERMINAL ANCHOR AND ADJACENT 25' MBGF IS OPTIONAL FOR ONE-WAY TRAFFIC CONDITIONS ON THE DOWNSTREAM END OF GUARD FENCE.
19. WASHERS USED WITH THE EIGHT 5/8" SPLICE BOLTS AND NUTS THAT ARE PROVIDED FOR TERMINAL CONNECTORS AND/OR TERMINAL ANCHOR POSTS SHALL BE 1 3/4" x 3" x 3/16", OR 1" I.D. AND 2" O.D. x 0.134" (ANSI B27.2) NARROW TYPE A PLAIN WASHERS.

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

METAL BEAM GUARD FENCE
GF (TD) - 84

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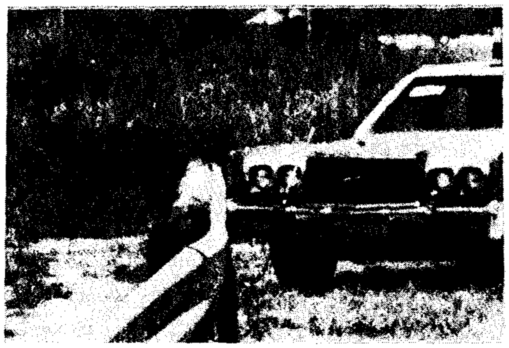
APPENDIX C.

SEQUENCE PHOTOGRAPHS OF CRASH TESTS 1, 2, AND 3



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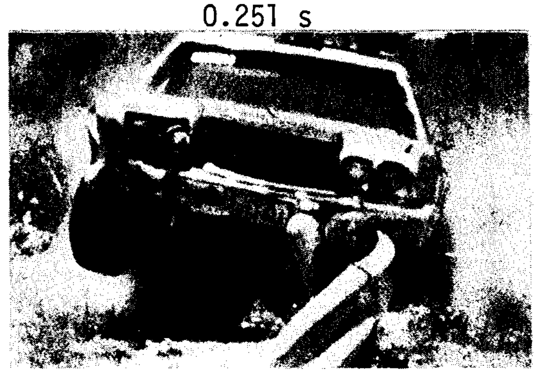

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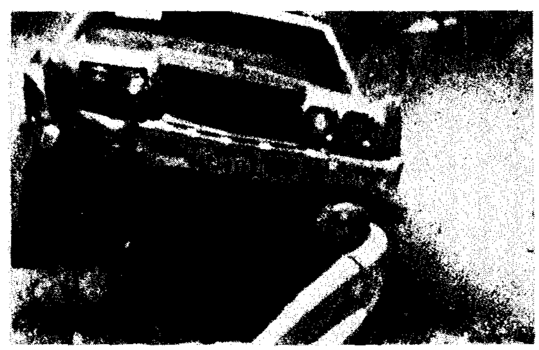

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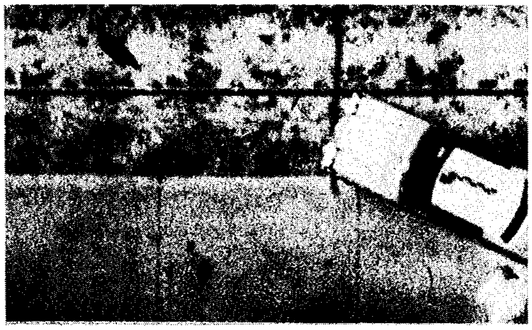

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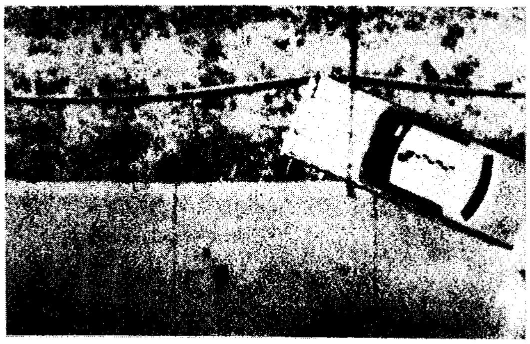

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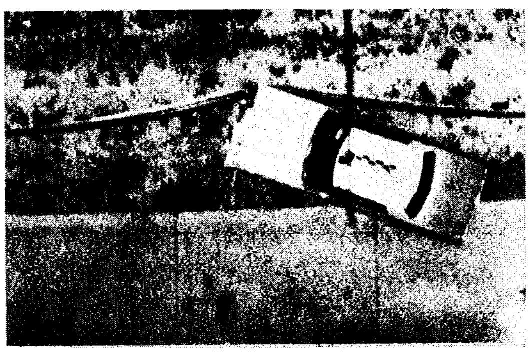

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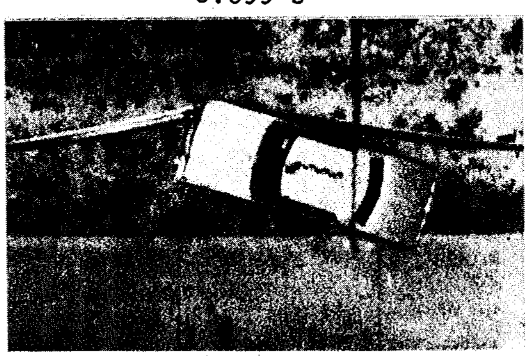

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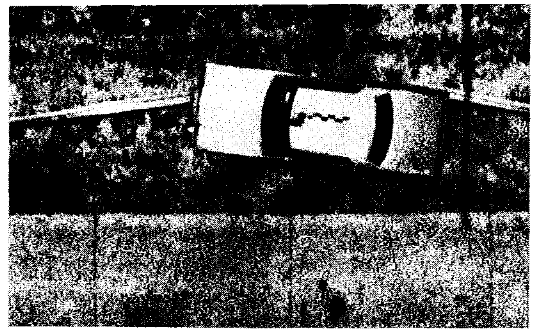

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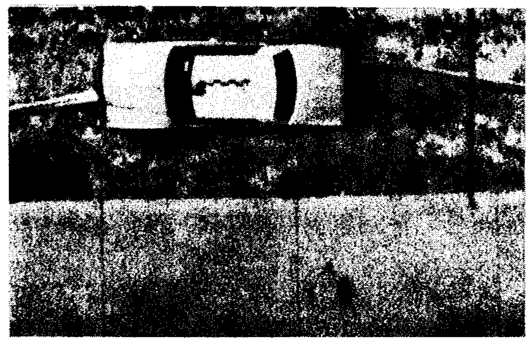

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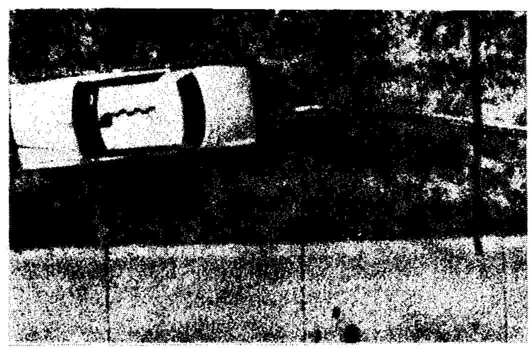

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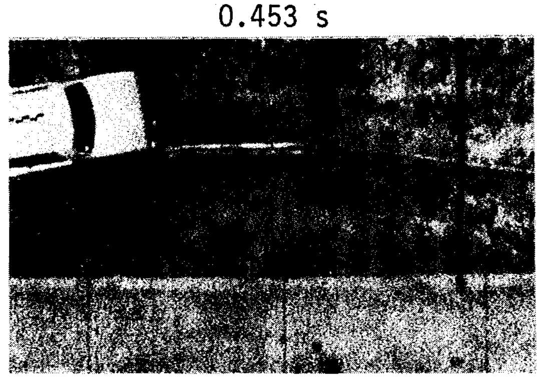

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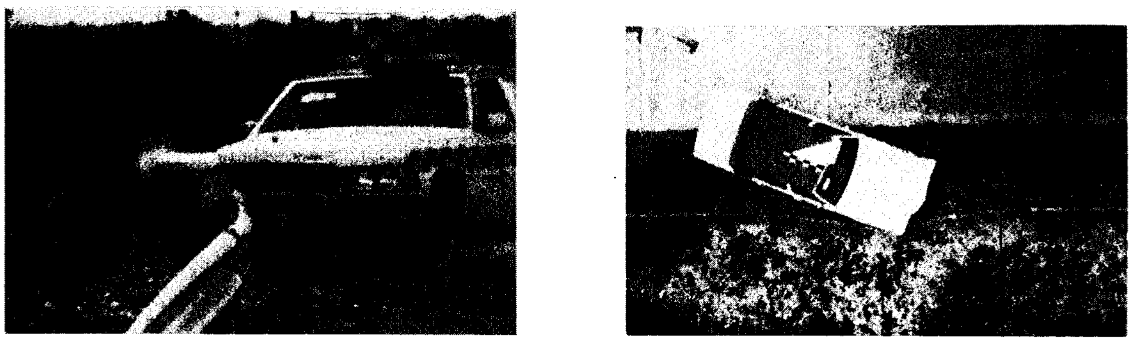

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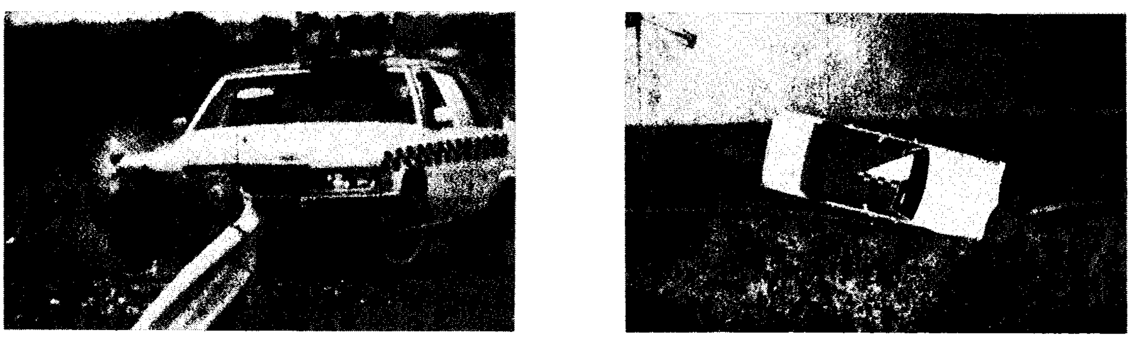

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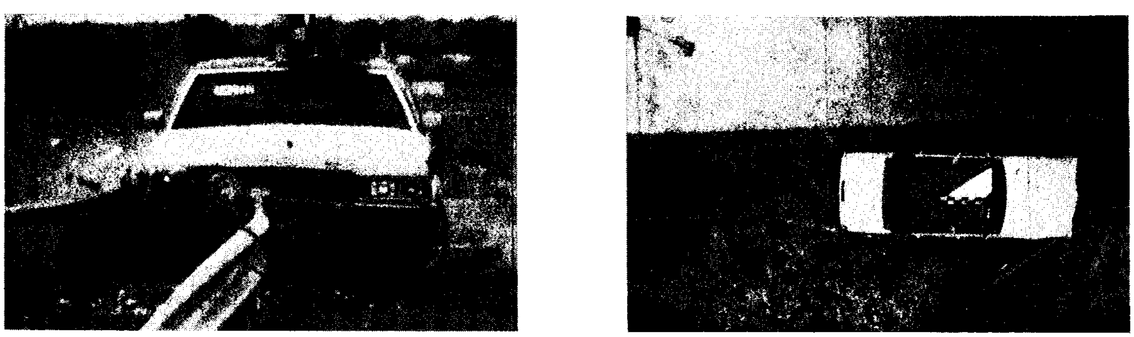

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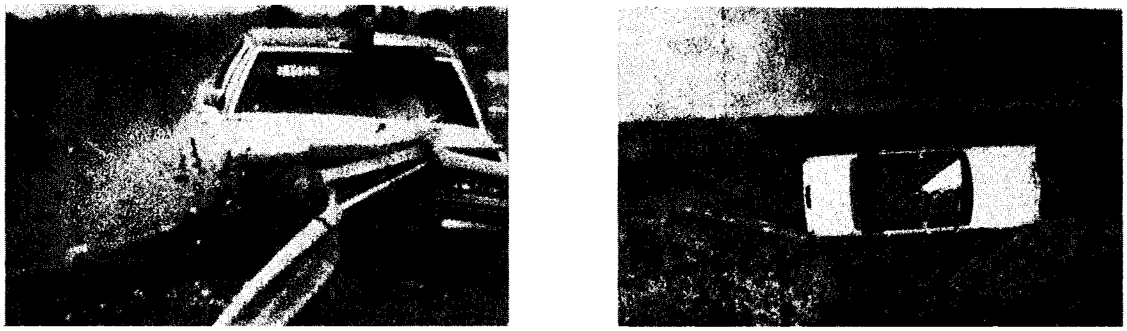

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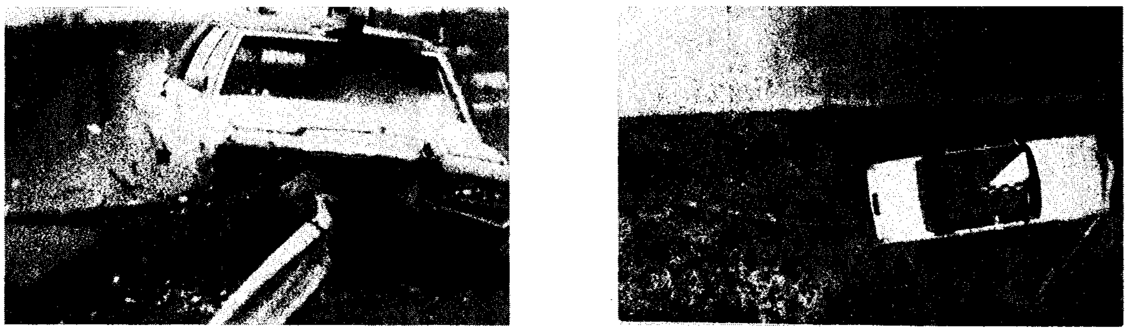

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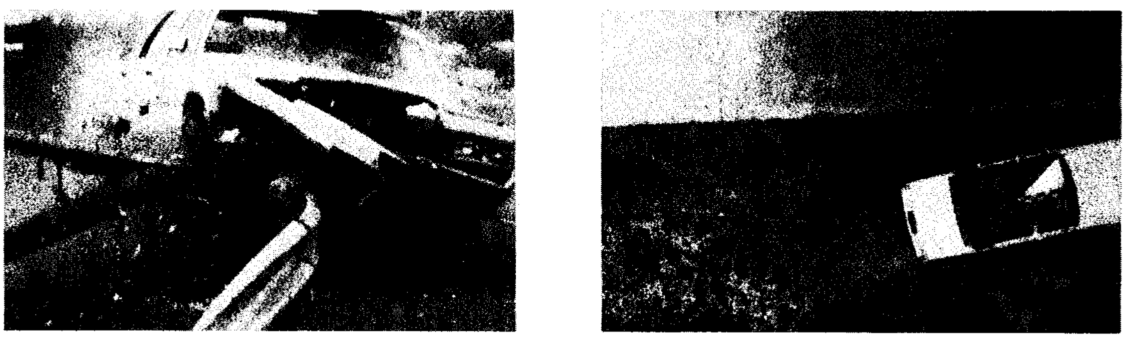

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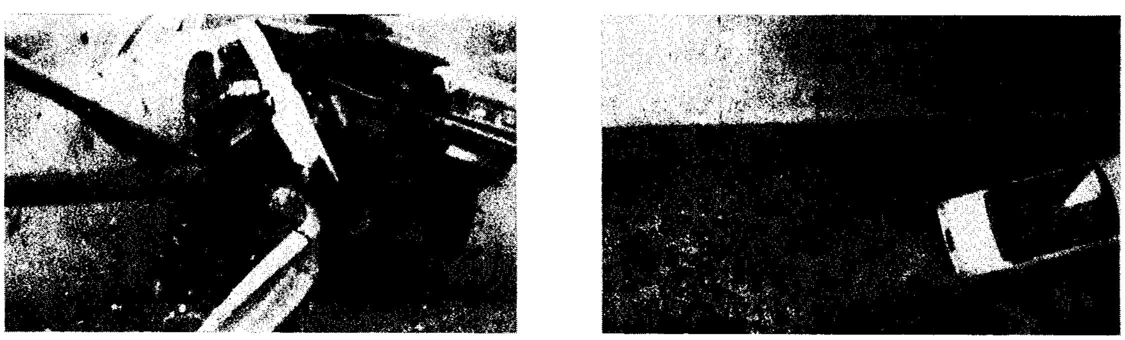

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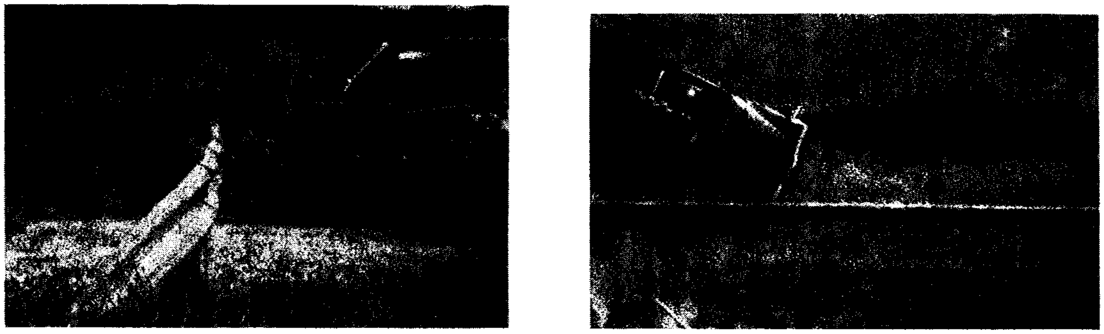

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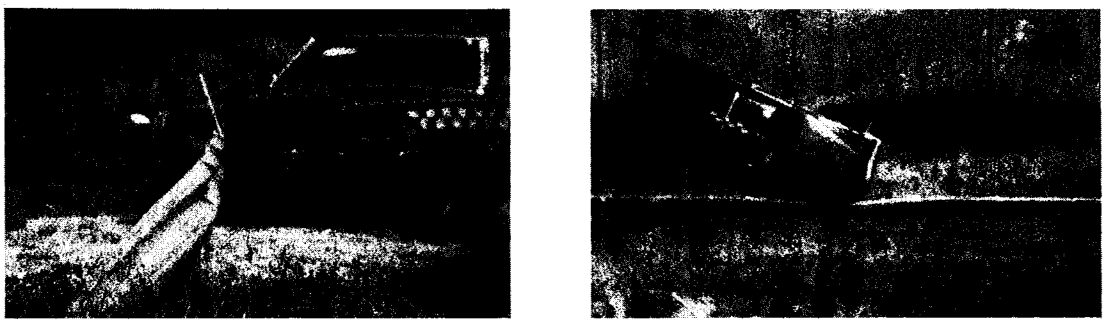

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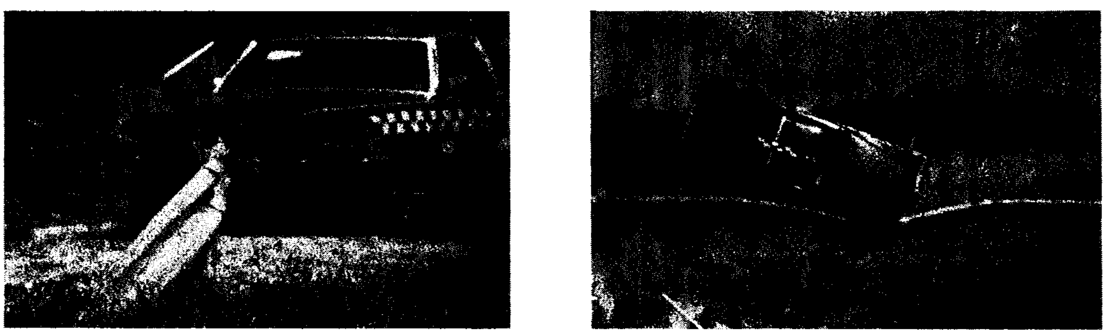

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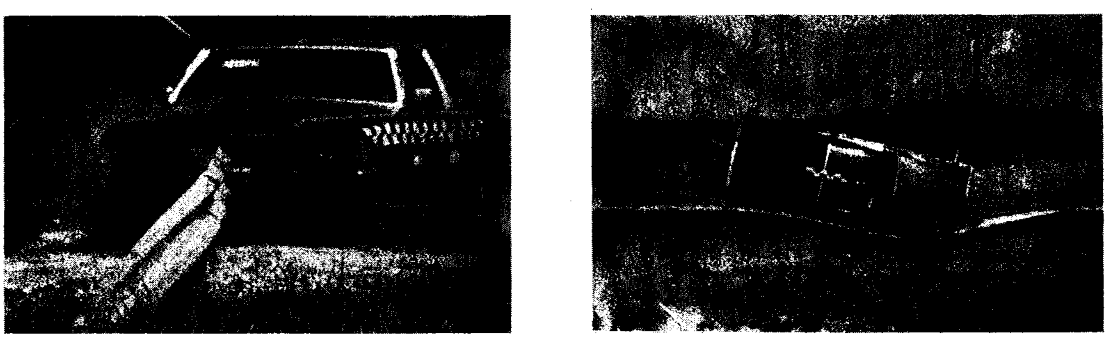

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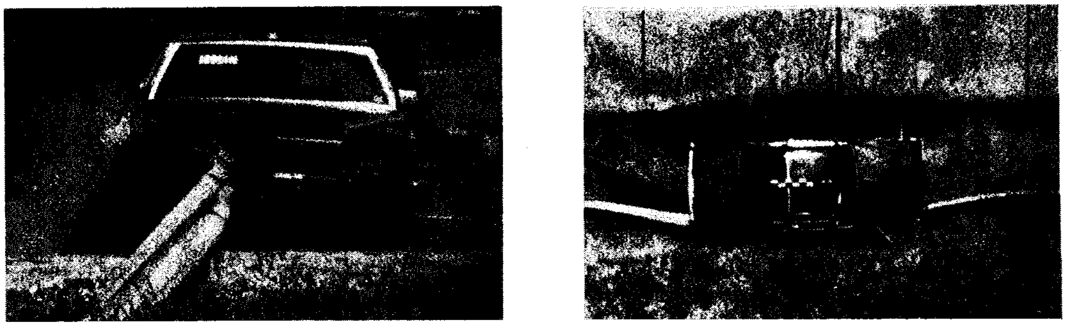

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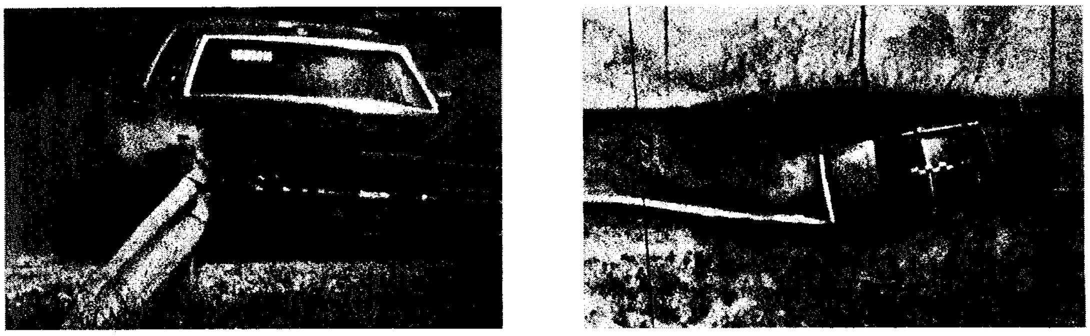

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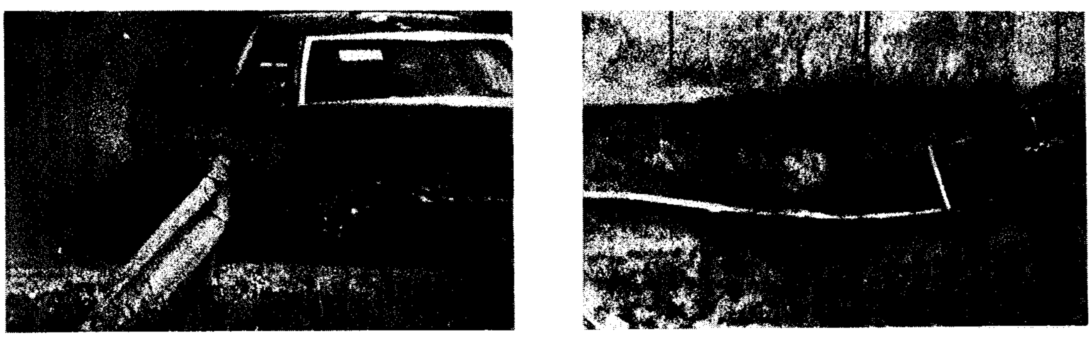

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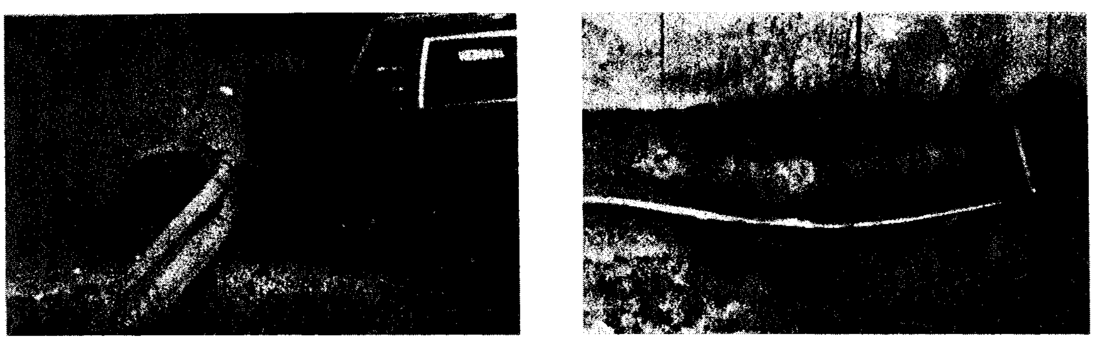

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Figure C4. Sequential photographs for test 2405-3 (continued).

APPENDIX D.

ACCELEROMETER, ROLL, PITCH, AND YAW DATA FOR CRASH TESTS 1, 2, AND 3

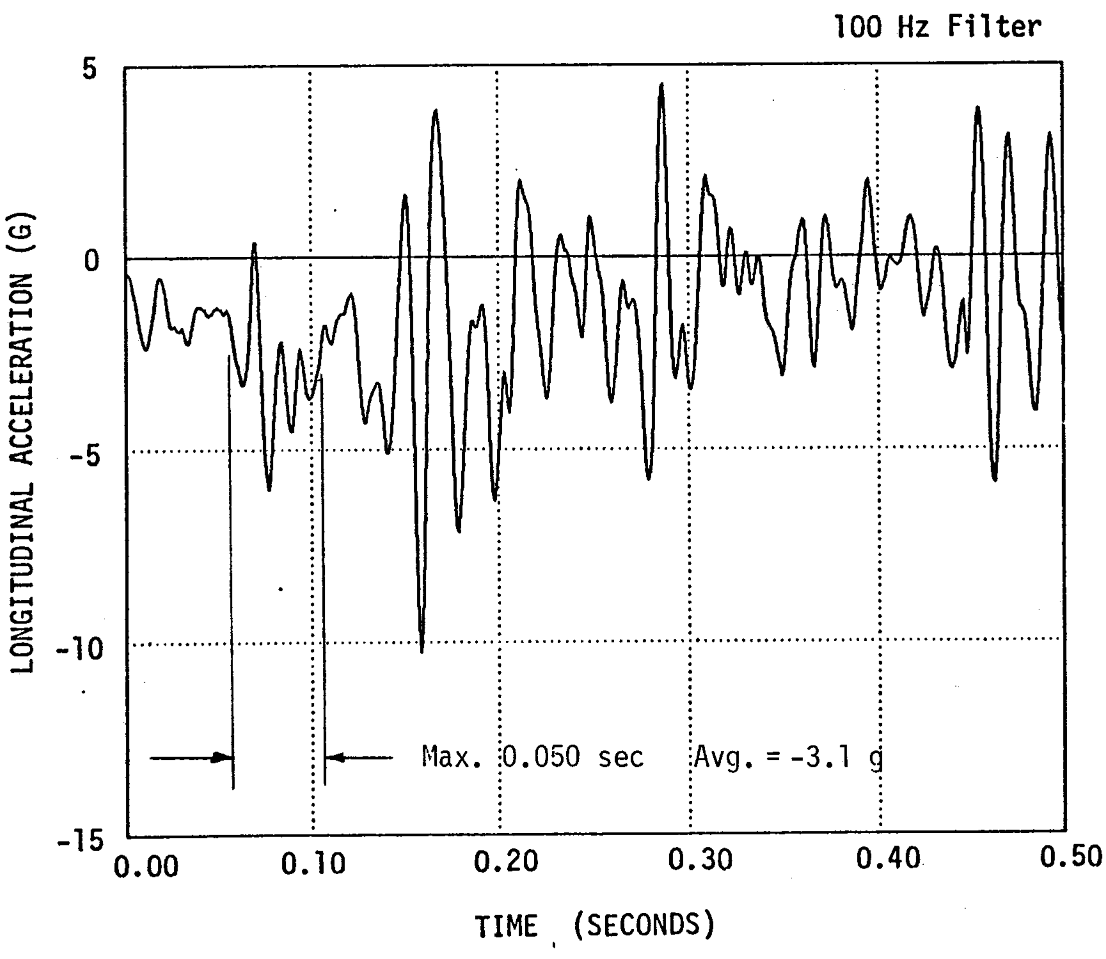


Figure D1. Vehicle longitudinal accelerometer trace for test 2405-1.

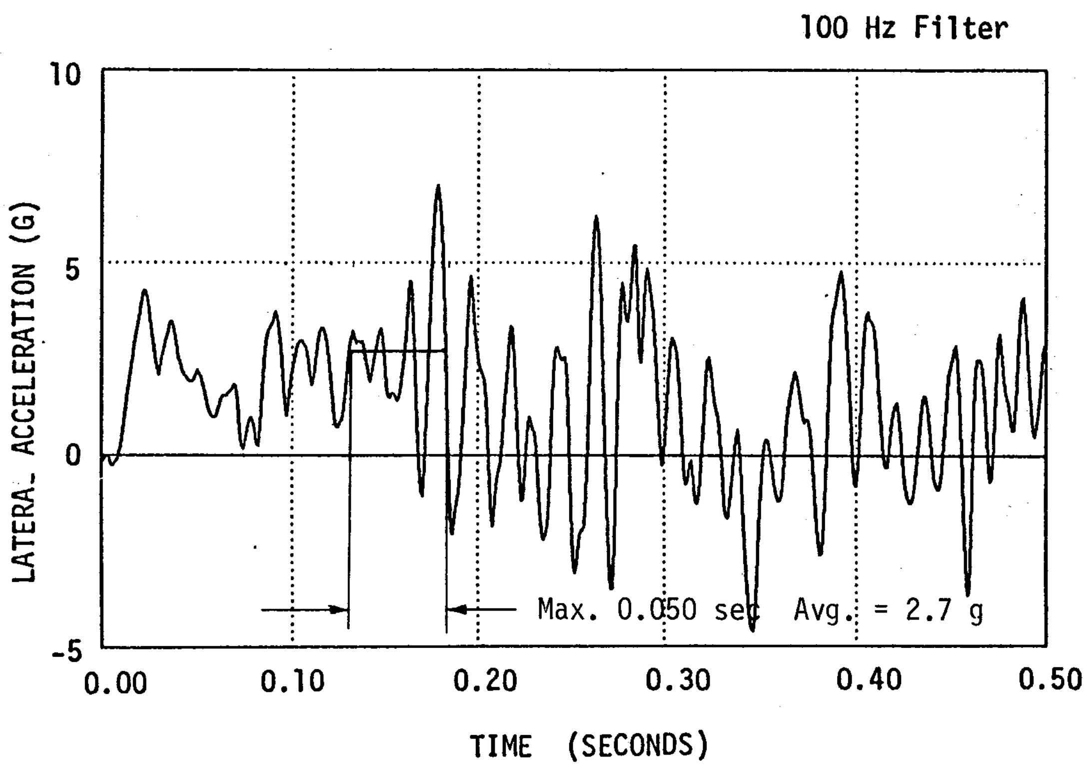


Figure D2. Vehicle lateral accelerometer trace for test 2405-1.

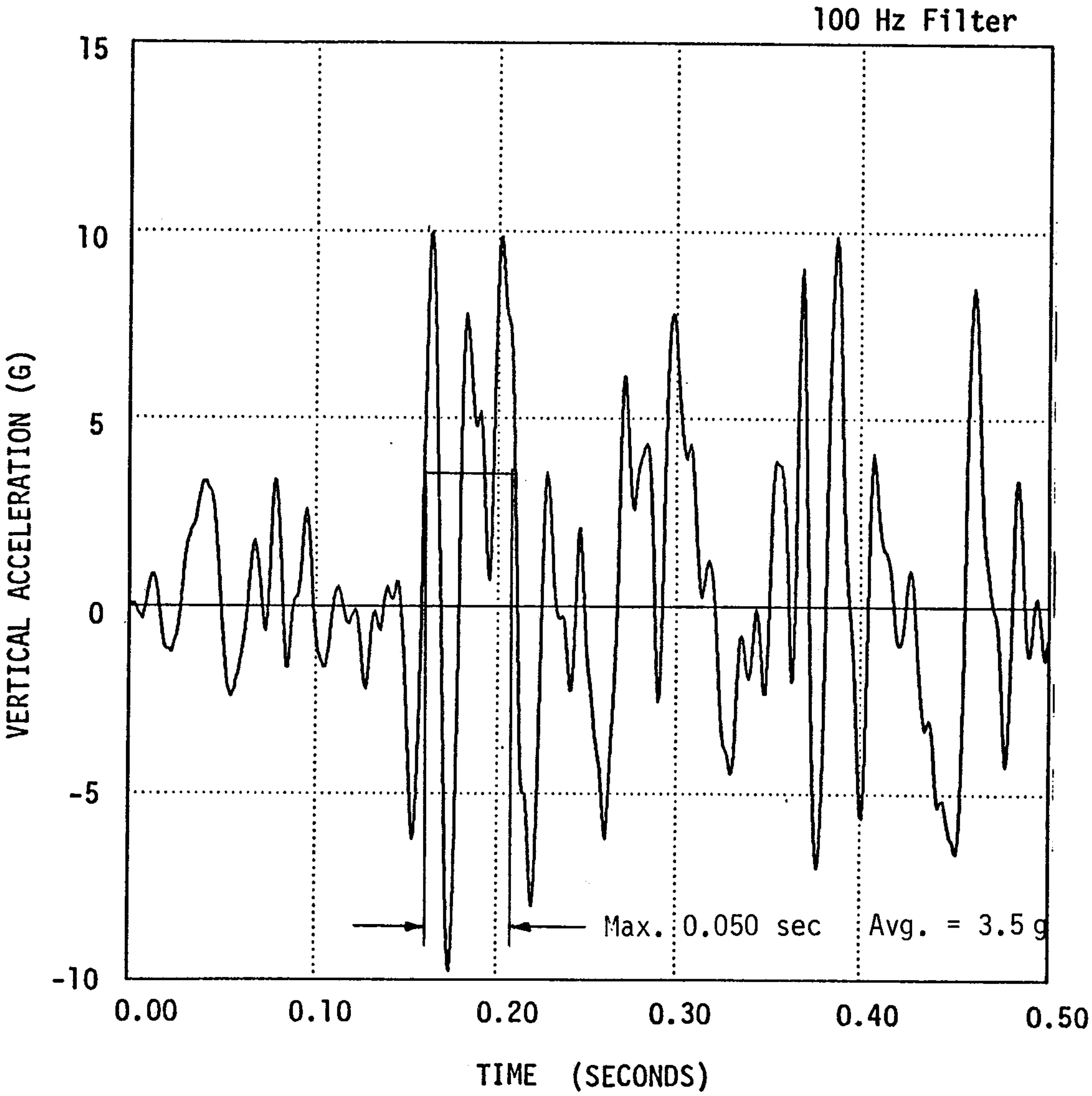
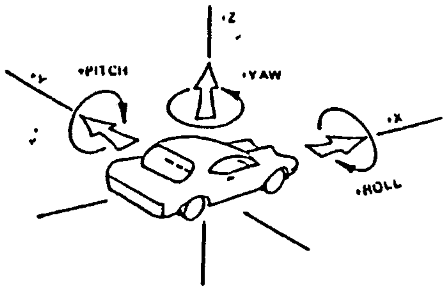


Figure D3. Vehicle vertical accelerometer trace for test 2405-1.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

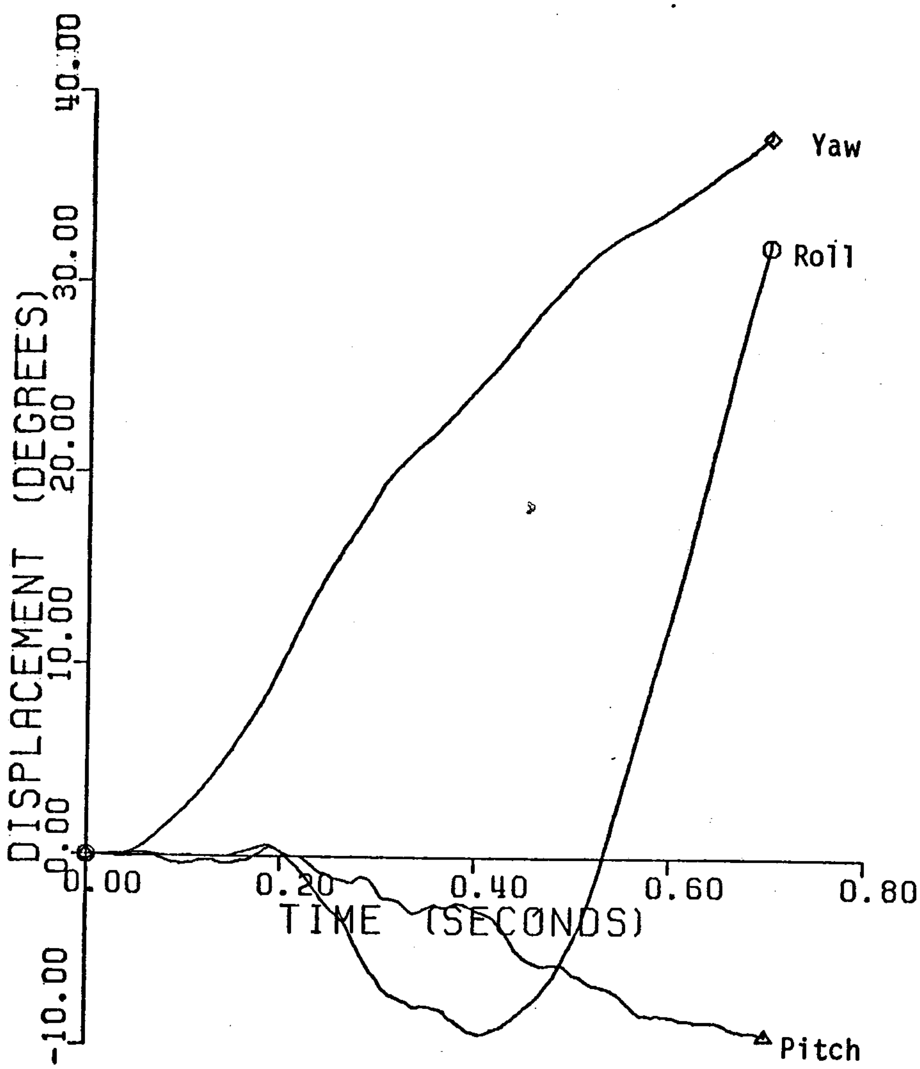


Figure D4. Vehicle angular displacements for test 2405-1.

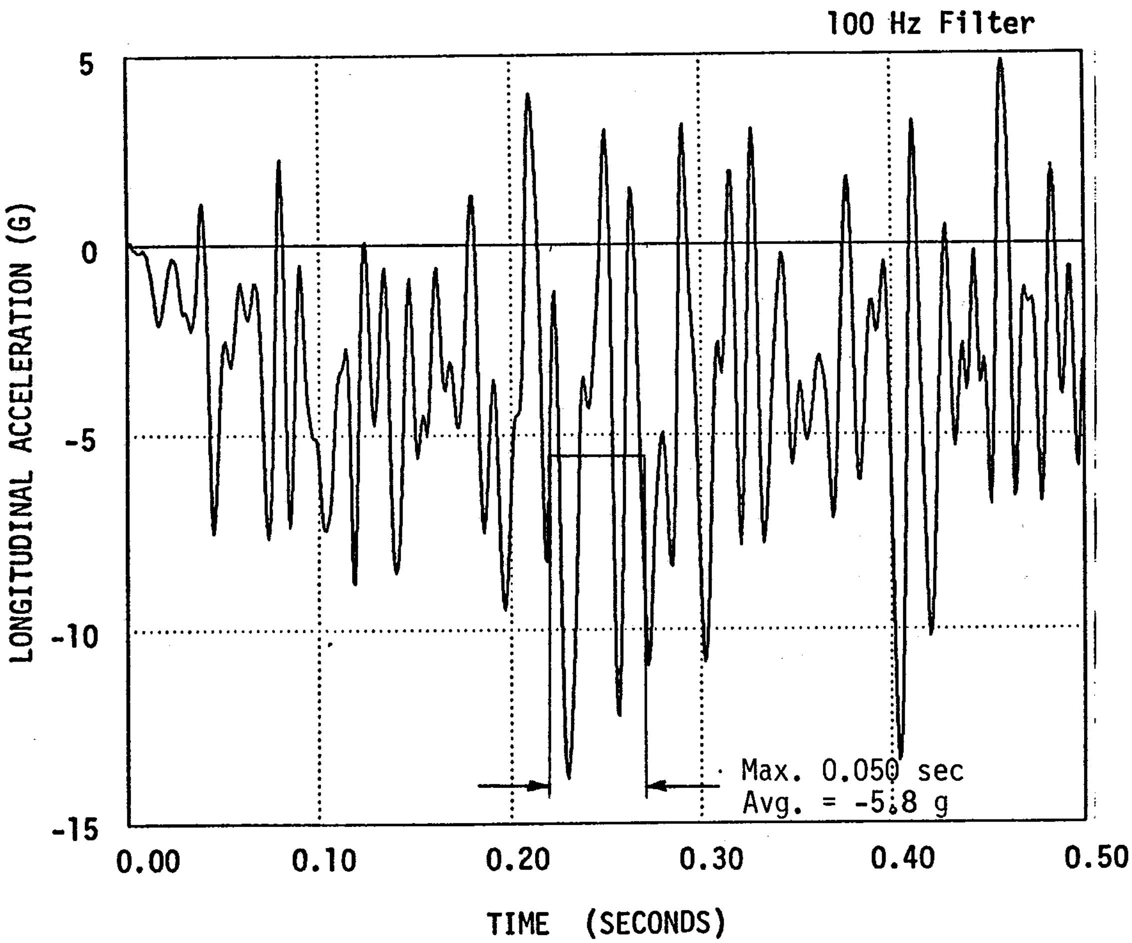


Figure D5. Vehicle longitudinal accelerometer trace for test 2405-2.

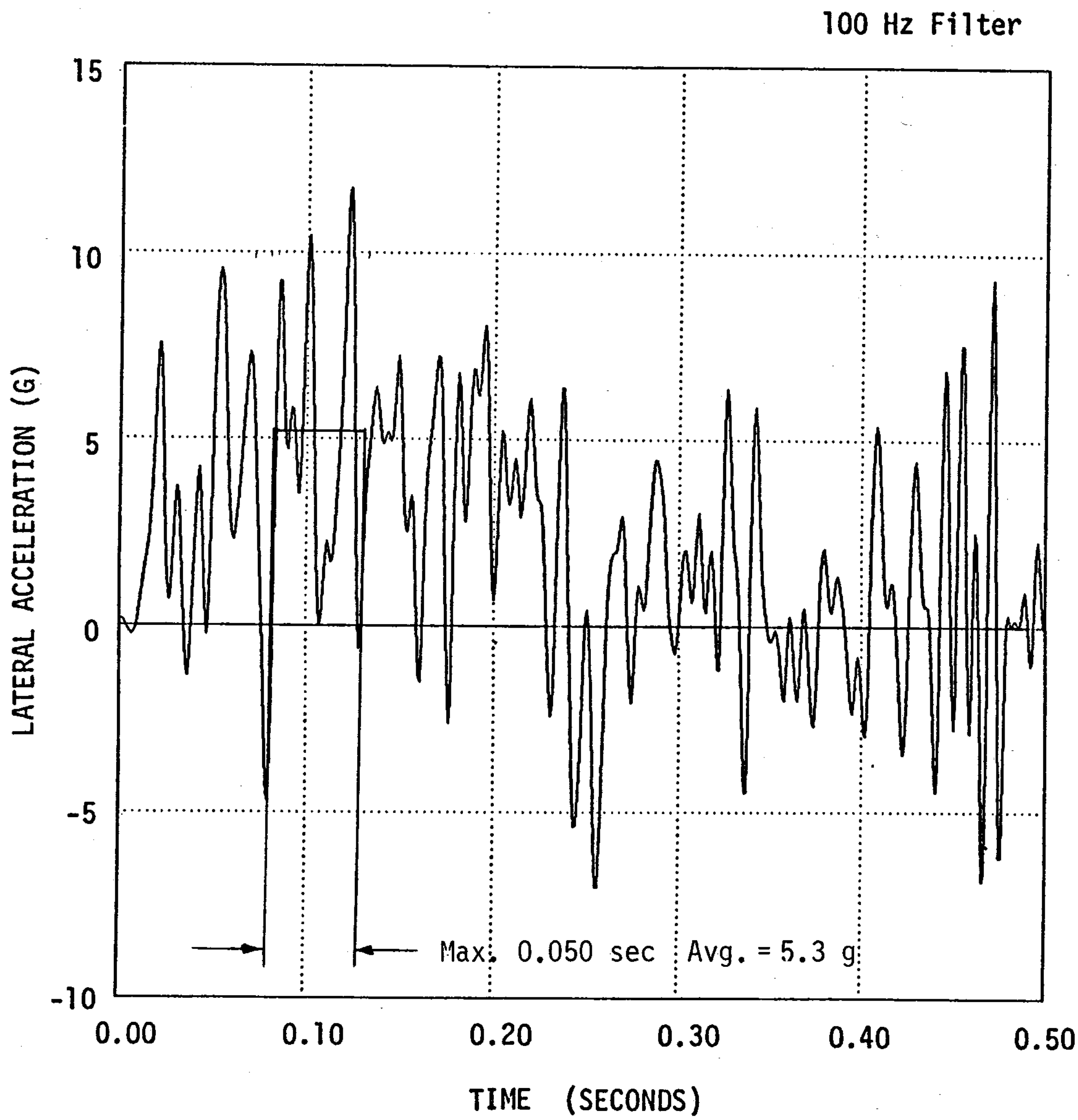


Figure D6. Vehicle lateral accelerometer trace for test 2405-2.

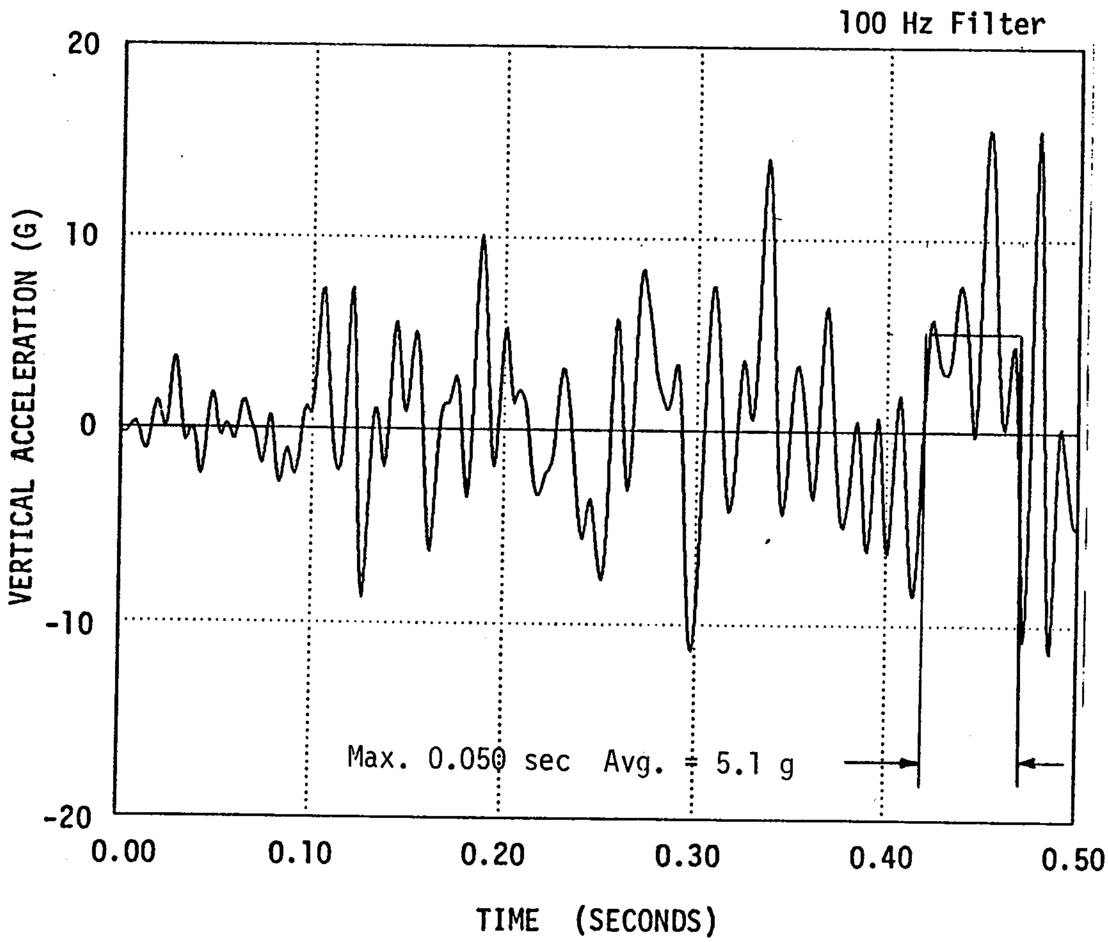
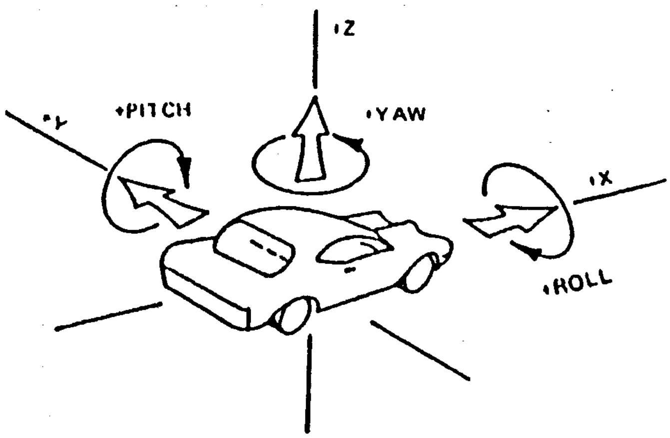


Figure D7. Vehicle vertical accelerometer trace for test 2405-2.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

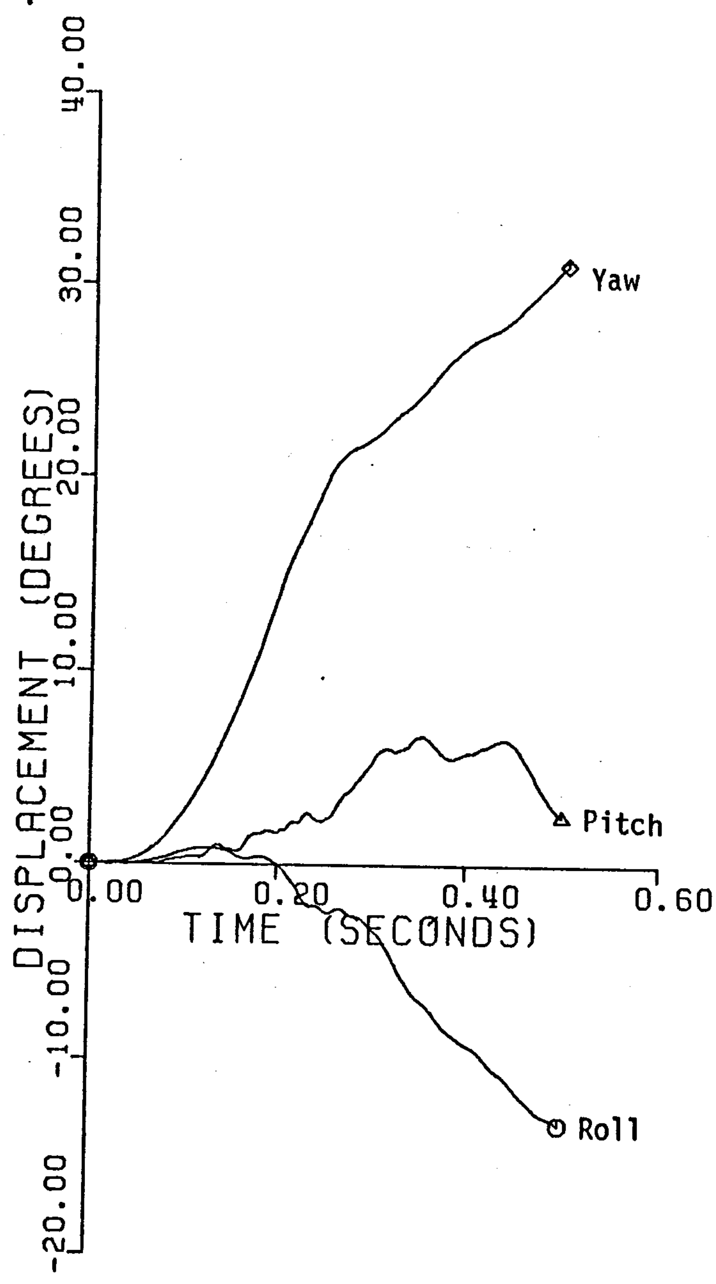


Figure D8. Vehicle angular displacements for test 2405-2.

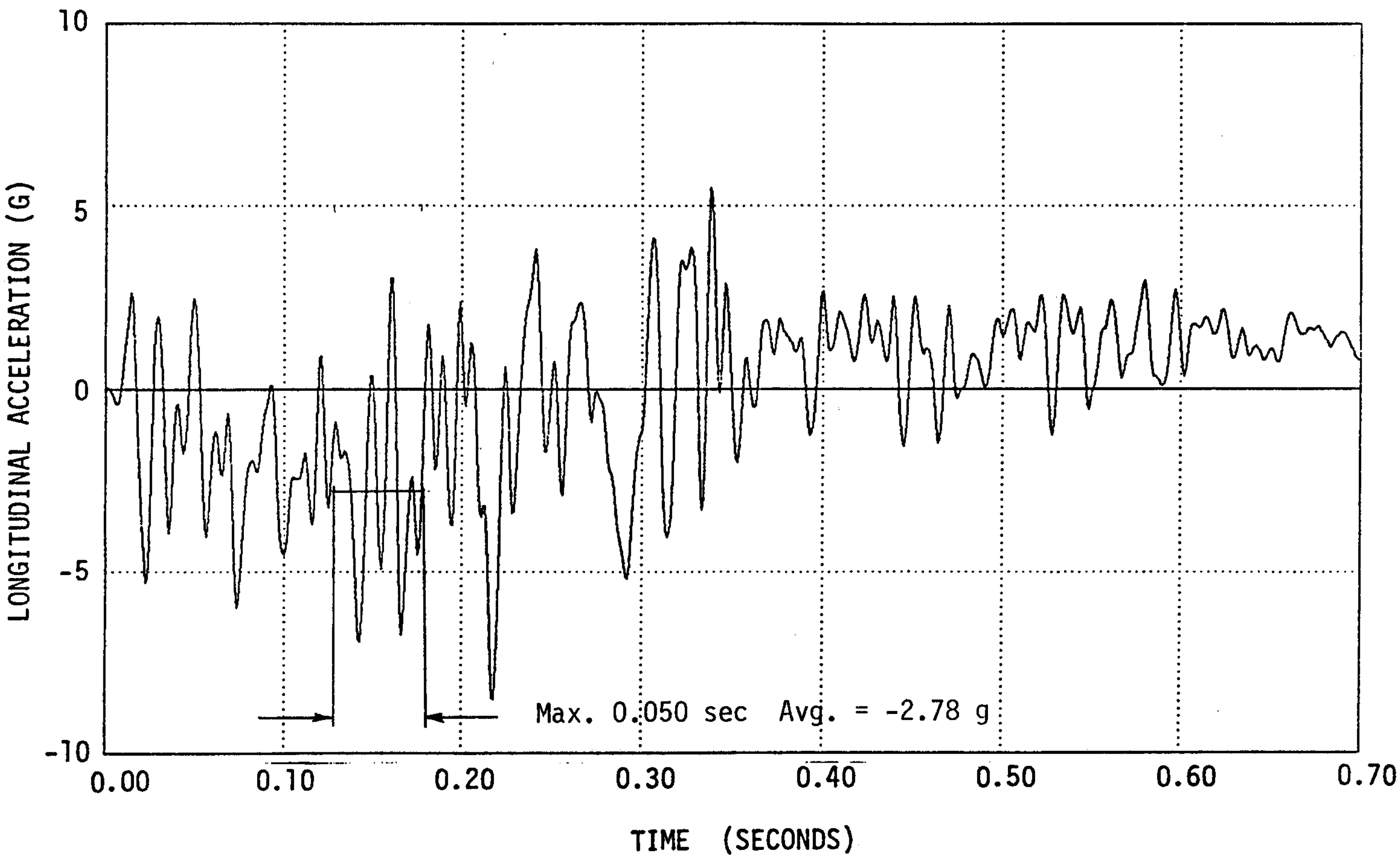


Figure D9. Vehicle longitudinal accelerometer trace for test 2405-3.

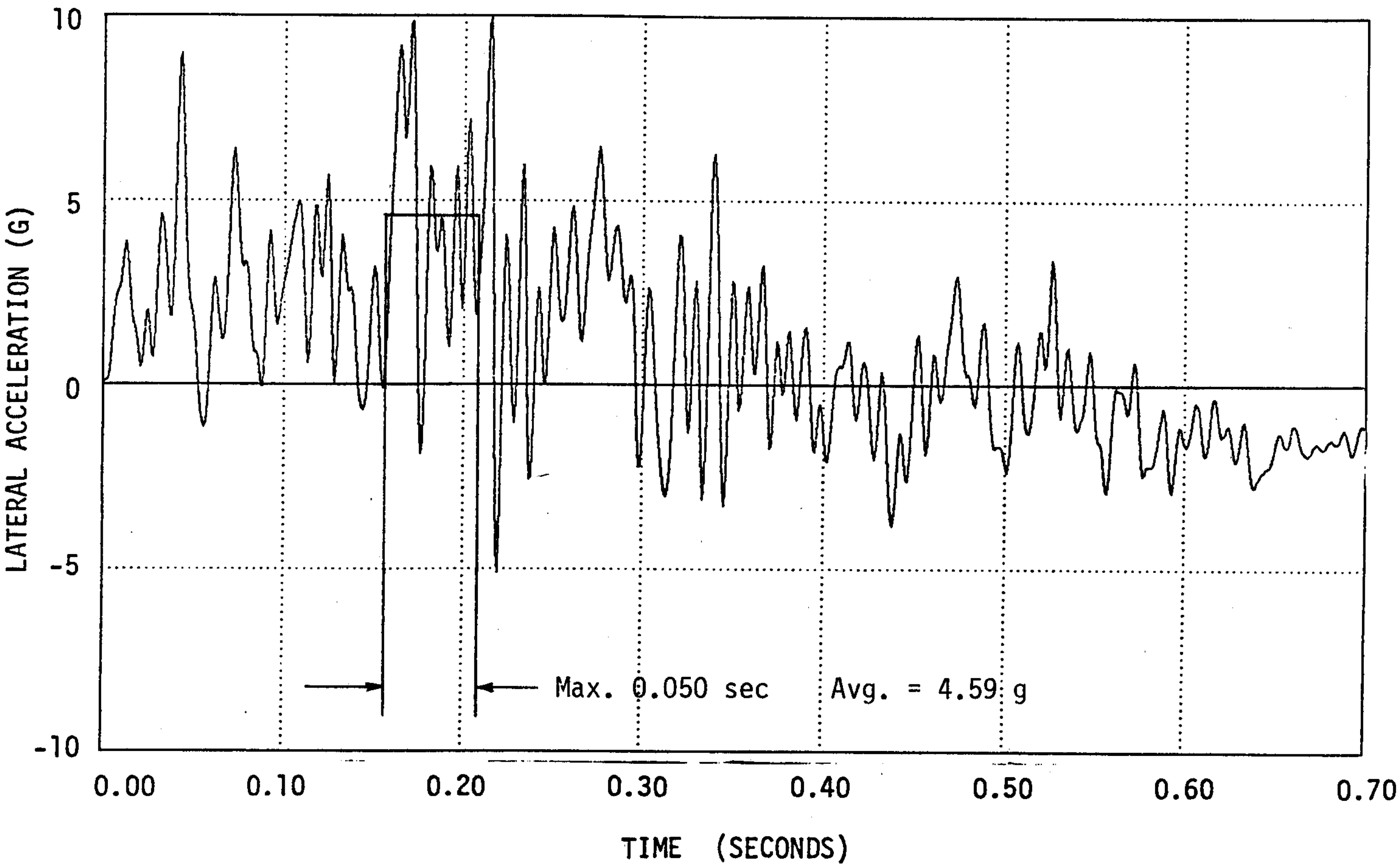


Figure D10. Vehicle lateral accelerometer trace for test 2405-3.

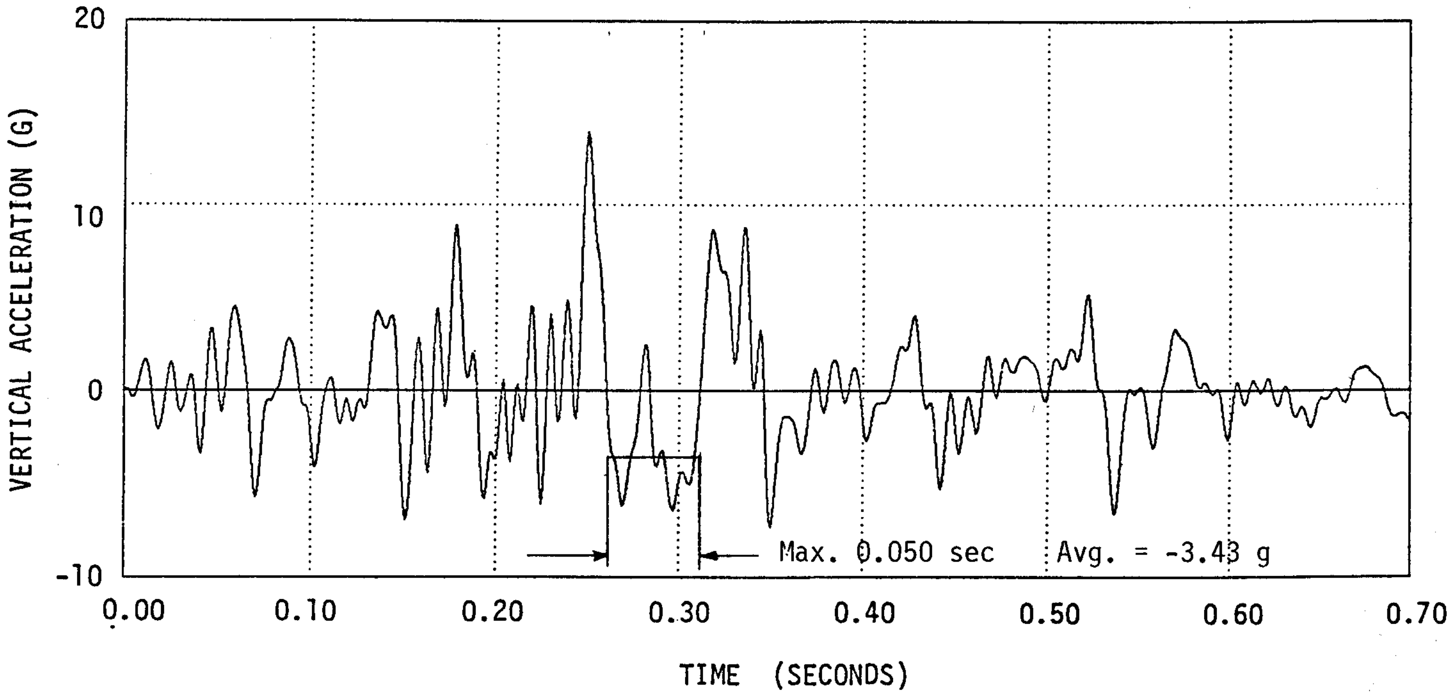
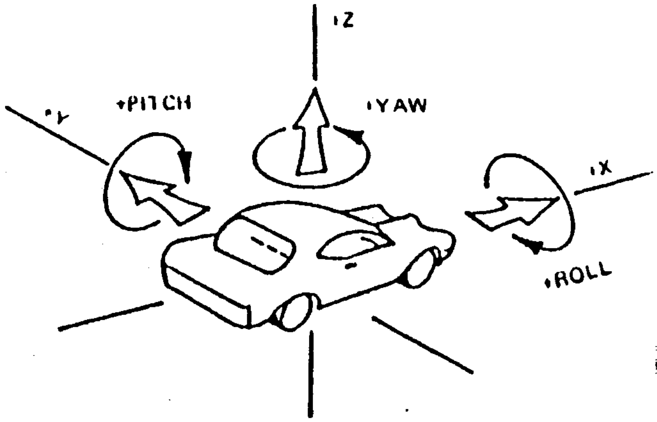


Figure D11. Vehicle vertical accelerometer trace for test 2405-3.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

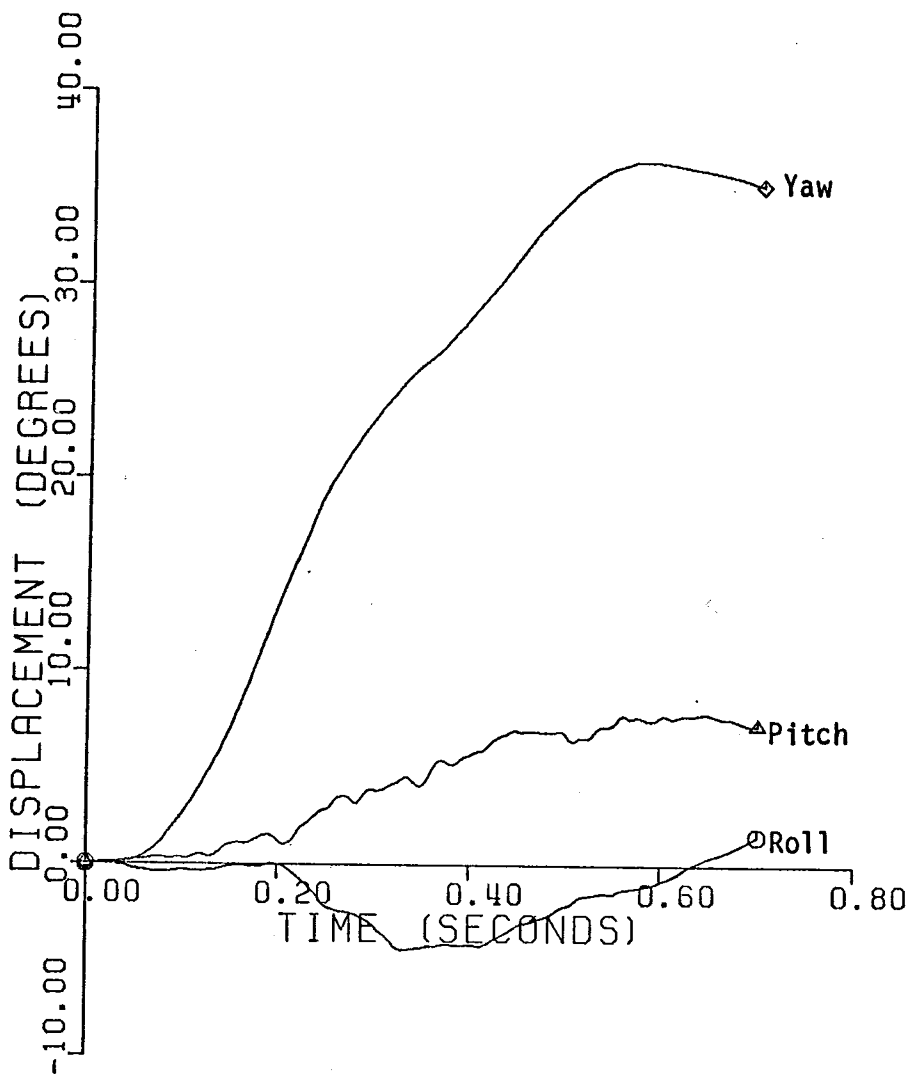


Figure D12. Vehicle angular displacements for test 2405-3.

APPENDIX E.

STATIC LOAD TEST DATA FOR GUARD FENCE POST
ATTACHED TO CONCRETE DECK

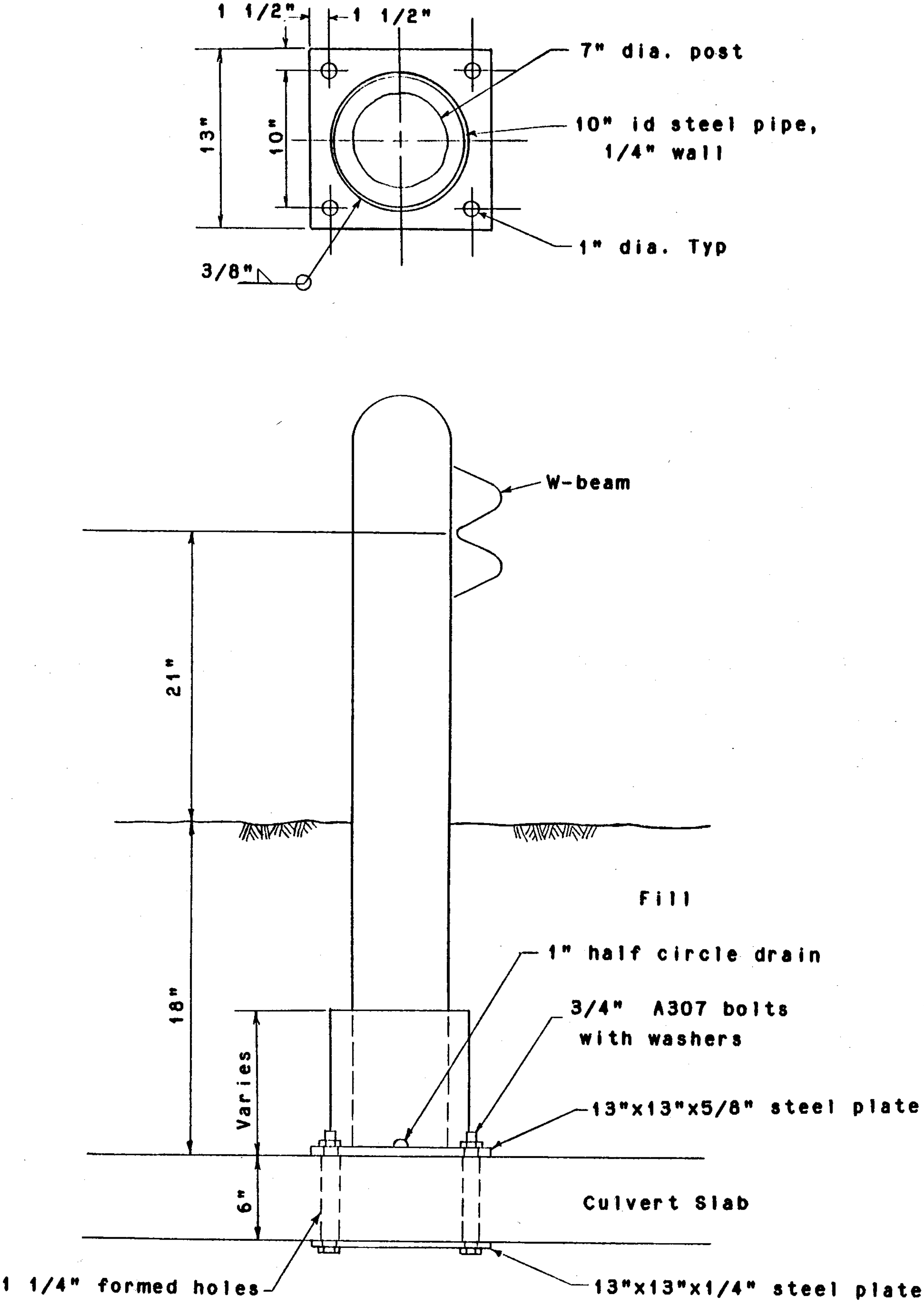
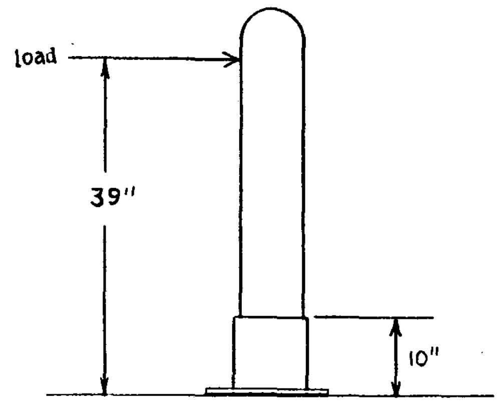


FIGURE E1. TIMBER POST IN 10 IN. DIAMETER STEEL PIPE SLEEVE

STATIC TEST DATA

Test #2

load (Kips)	Deflection at load (in)
0.00	0.00
0.44	0.50
0.53	1.00
0.74	1.50
0.86	2.00
1.30	3.00
1.56	3.50
1.80	4.00
2.12	4.50
2.34	5.00
2.80	6.00
2.90	6.50
3.20	7.00
3.40	7.50
3.64	8.00
4.08	9.00
4.34	9.50
4.66	10.00
5.00	10.50



Note: Timber Post with 10 inch soil filled pipe.
Deflection continued until equipment limitations required the test to be stopped.

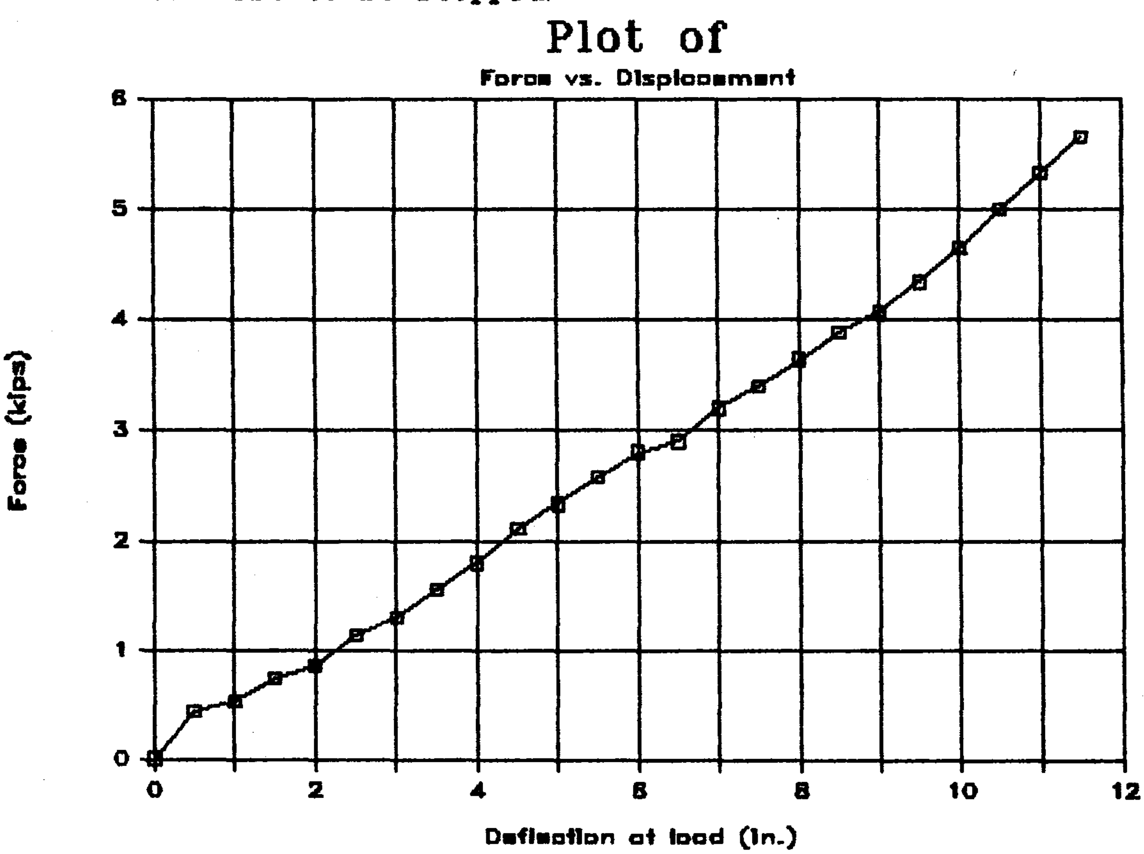
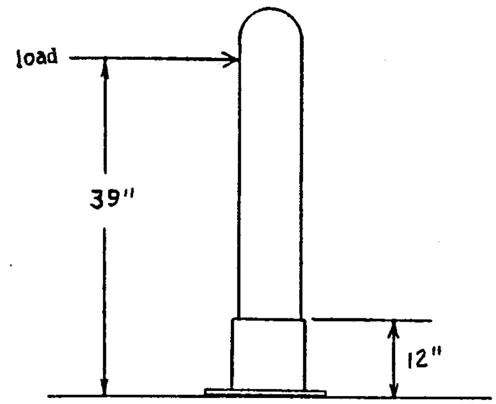


FIGURE E2. STATIC LOAD TEST RESULTS OF TIMBER POST IN 10 IN. HIGH PIPE SLEEVE.

STATIC TEST DATA

Test #3

load (kips)	Deflection at load (in)
0.00	0.00
1.76	0.50
2.00	1.00
3.00	1.50
3.60	2.00
4.14	2.50
4.62	3.00
5.00	3.50
5.40	4.00
5.72	4.50
6.00	5.00
5.60	5.50
5.84	6.50
5.90	7.00
5.22	7.50
4.80	8.50
4.50	9.00
4.45	9.50
4.40	10.00
4.00	10.50



Note: Timber post with 12 inch soil filled pipe.
Failure due to cracking at base of post

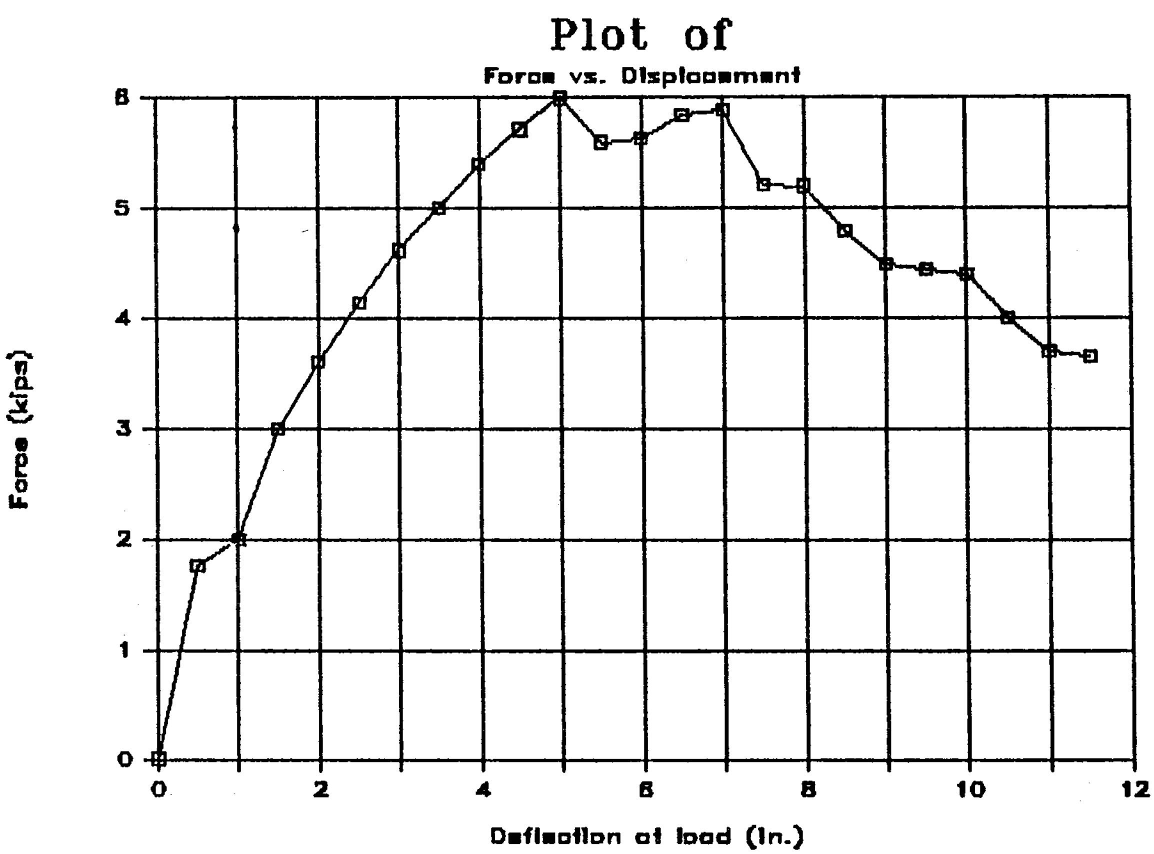
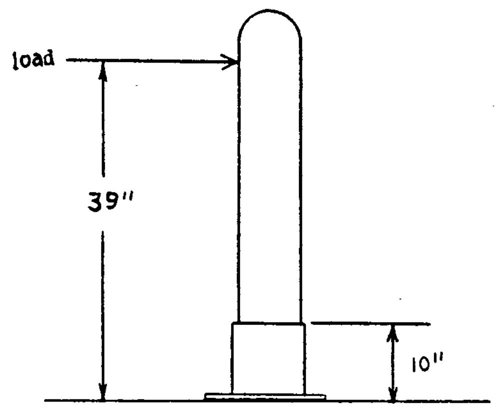


FIGURE E3. STATIC LOAD TEST RESULTS OF TIMBER POST IN 12 IN. HIGH PIPE SLEEVE.

STATIC TEST DATA

Test #4

load (Kips)	Deflection at load (in)
0.00	0.00
2.25	0.50
3.10	1.00
3.50	1.50
3.90	2.00
4.10	2.50
4.30	3.00
4.50	3.50
4.68	4.00
4.76	4.50
4.86	5.00
4.96	5.50
5.00	6.00
3.00	6.50
1.00	7.00



Note: Timber post with 10 in grouted in pipe.
Post failed at base with no movement of baseplate or bolts.

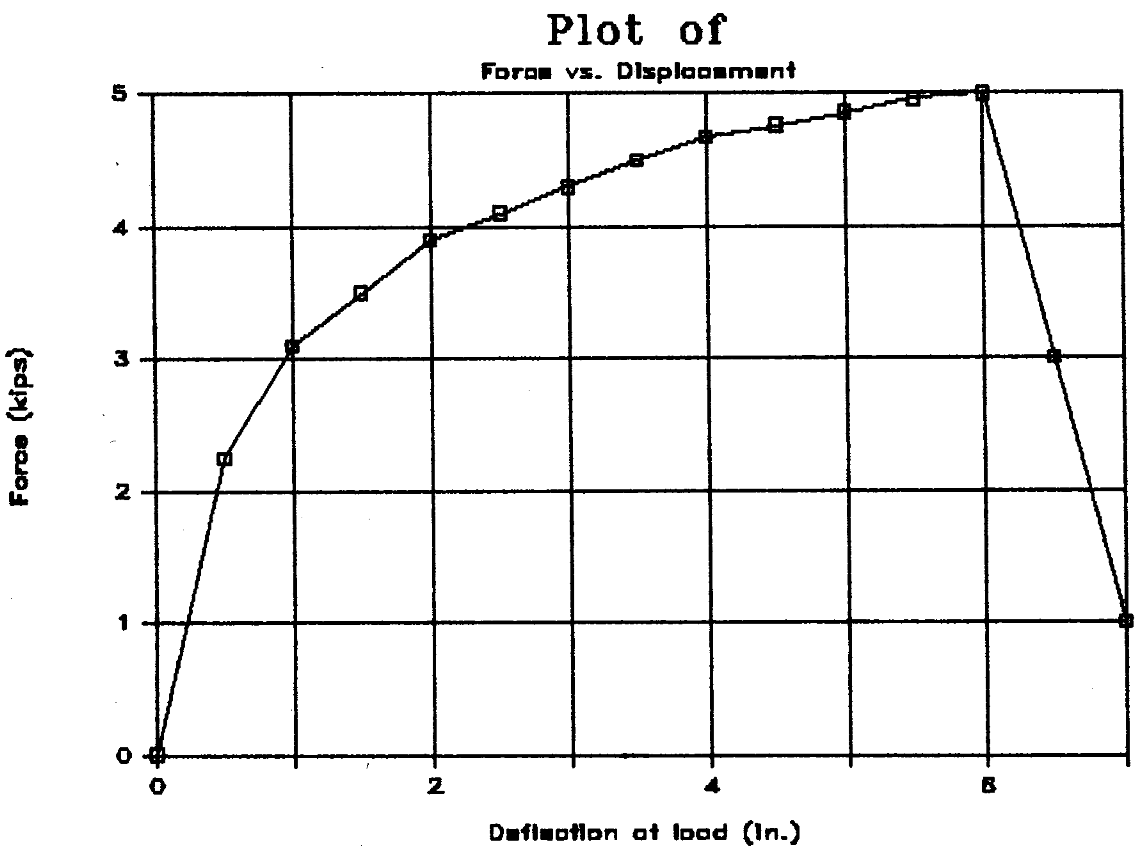


FIGURE E4. STATIC LOAD TEST RESULTS OF TIMBER POST GROUTED IN 10 IN. HIGH PIPE SLEEVE.

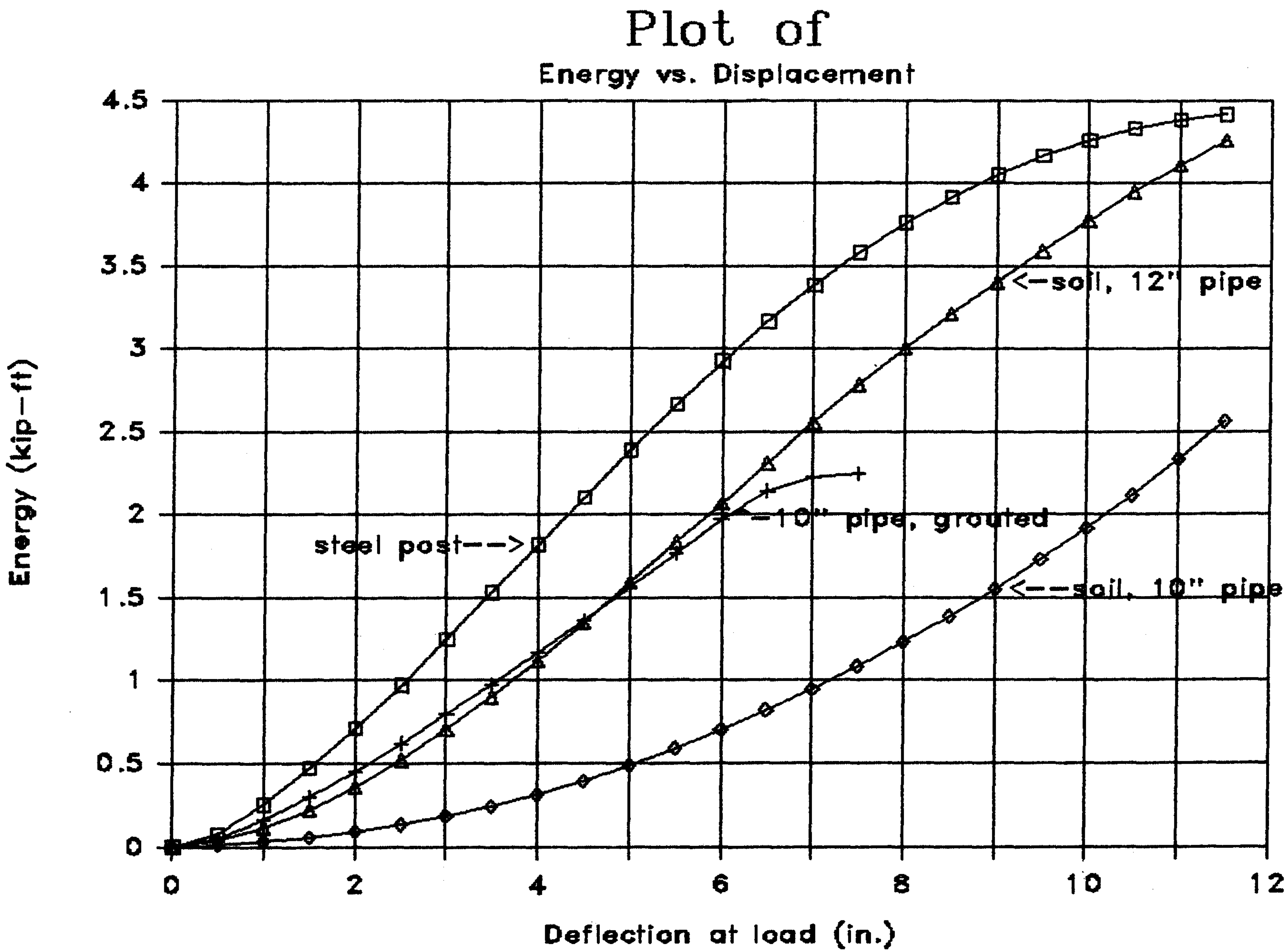


FIGURE E5. SUMMARY OF STEEL AND TIMBER POST STATIC TEST RESULTS.

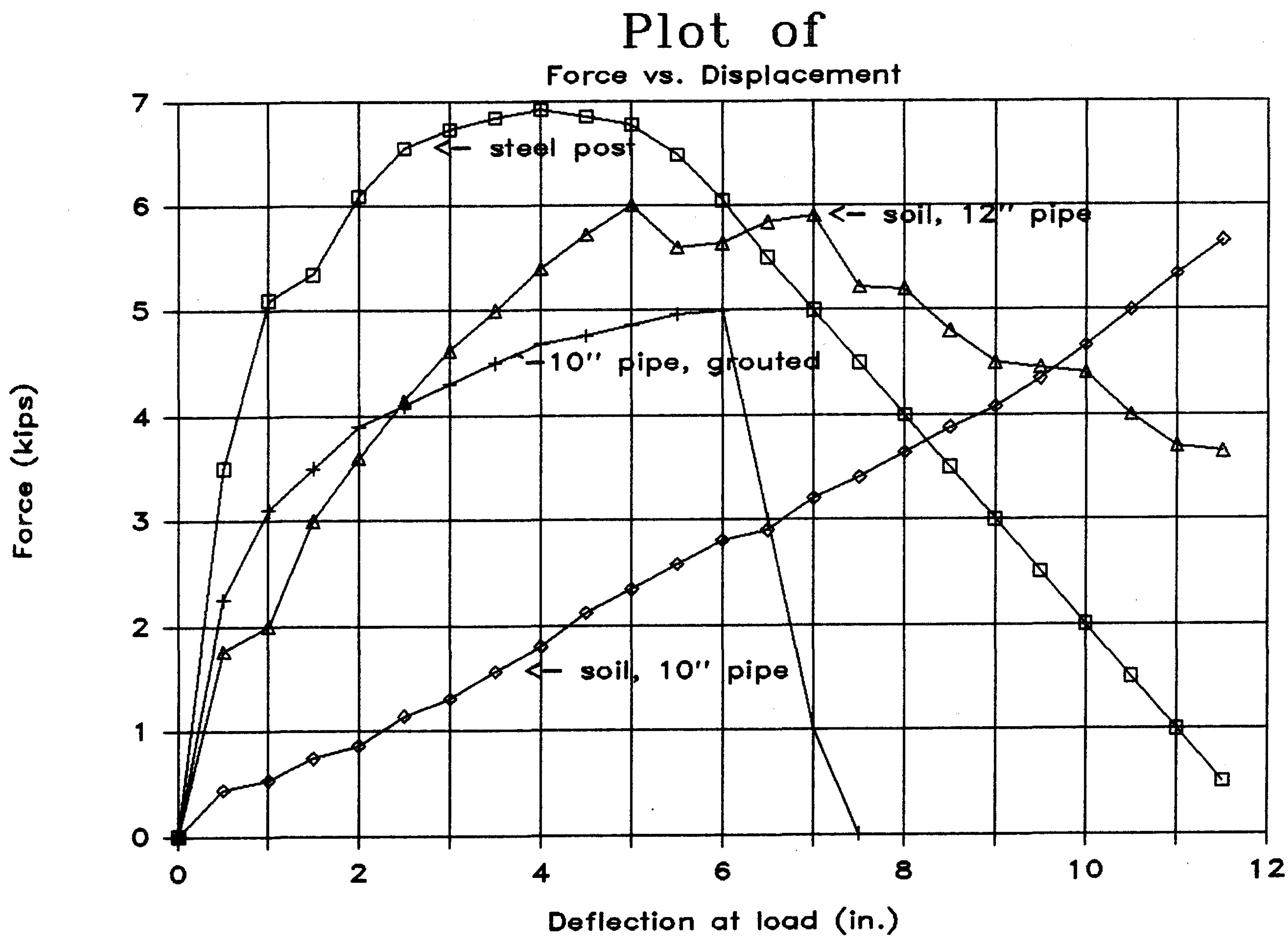
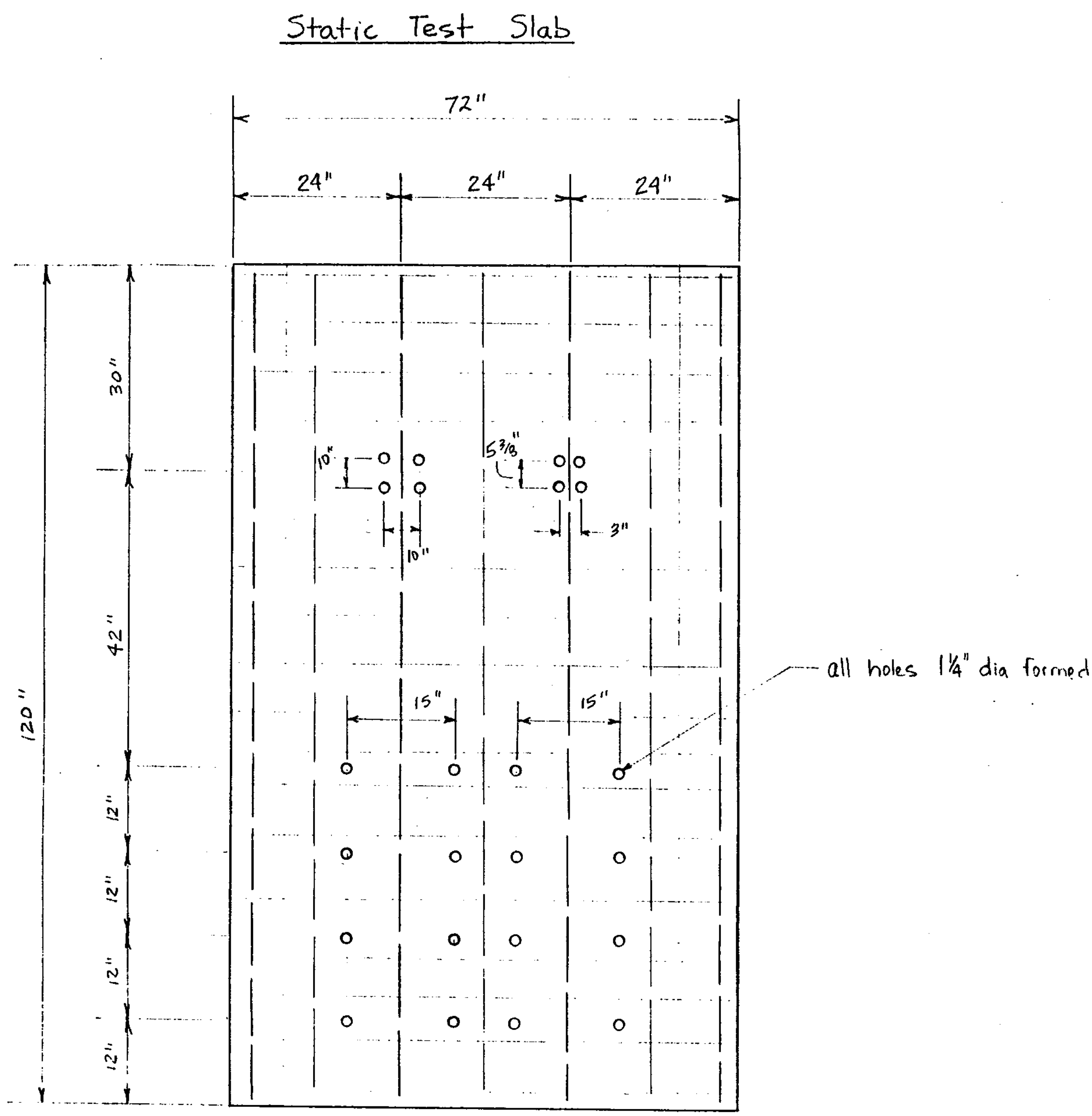


FIGURE E6. SUMMARY OF STEEL AND TIMBER POST STATIC TEST RESULTS



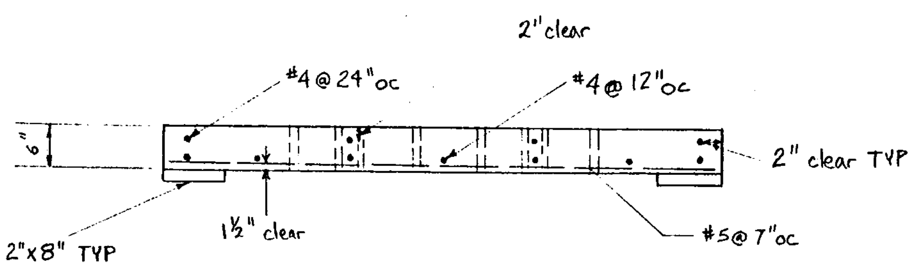


FIGURE E7. SUMMARY OF SIMULATED CULVERT SLAB REINFORCEMENT