No. FHWA/RD-80/502

CRASH TESTS OF SMALL HIGHWAY SIGN SUPPORTS

May 1980

Interim Report

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Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Implementation Division

Washington, D.C. 20590

FOREWORD

The results of the project entitled, "Cost Effectiveness of Small Highway Sign Supports," are presented in six reports and a 16 mm movie. The basic purpose of this study was to develop objective criteria and methodologies to assist engineers in the selection of a cost-effective sign support system.

The subject report discusses 22 fullscale crash tests conducted to evaluate the impact performance of widely used support systems for small roadside signs. Test results and test articles were evaluated in terms of current AASHTO performance specifications and FHWA guidelines.

The other reports developed as part of this study are:

State-of-the-Practice in Supports for Small Highway Signs	FHWA-TS-80-222
Cost Effectiveness of Small Highway Sign Supports - A Summary Report	FHWA-RD-80-501
Crash Test of Single Post Sign Installations Using Subcompact Automobiles	FHWA-RD-80-503
Crash Tests of Rural Mailbox Installations	FHWA-RD-80-504
Guidelines for Selecting a Cost-Effective Small Highway Sign Support System	FHWA-IP-79-7

A 16 mm movie entitled, "Small Sign Supports," was also developed.

These reports and movie were prepared by the Texas A&M Research Foundation, College Station, Texas. Copies of the reports are being distributed in accordance with the numbers agreed upon between each Regional Office and the Implementation Division for normal report distribution. Additional copies are available from the National Technical Information System, Springfield, Virginia 22161.

For additional information, please contact the Federal Highway Administration, Offices of Research and Development, Implementation Division, (HDV-21), Washington, D.C. 20590

E. M. Wood
Director
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NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-80/502		

4. Title and Subtitle	5. Report Date May 1980 6. Performing Organization Code
CRASH TESTS OF SMALL HIGHWAY SIGN SUPPORTS	8. Performing Organization Report No. 3254-3
7. Author(s) Ross, Hayes E. Jr., Walker, Kenneth C., and Effenberger, Michael J.	
9. Performing Organization Name and Address Texas A&M Research Foundation Texas Transportation Institute Texas A&M University College Station, Texas 77843	10. Work Unit No. (TRAIS) 31Z914 11. Contract or Grant No. DOT-FH-11-8821 13. Type of Report and Period Covered Interim July 1975 - January 1979
12. Sponsoring Agency Name and Address Office of Development Implementation Division Federal Highway Administration Washington, D.C. 20590	14. Sponsoring Agency Code

15. Supplementary Notes
Contract Technical Manager - W. J. Lindsay, FHWA Region 6
Contract Administrator - G. B. Trainer, FHWA, Washington, D.C.
Contract Liaison - J. R. Watson, Jr., and R. A. Richter, FHWA, Washington, D.C.

16. Abstract

This report describes 22 full-scale crash tests conducted to evaluate the impact performance of widely used support systems for small roadside signs. Promising new support systems were also evaluated. All systems were of the single post type, with one exception. One system had a vertical post and a back brace. Also summarized are the results of recent crash tests sponsored by industry on small sign support systems.

Test results and test articles were evaluated in terms of current AASHTO performance specifications and FHWA guidelines.

17. Key Words	18. Distribution Statement
Signs, Roadside, Sign Supports, Small Signs, Crash Tests, Impact Performance, Highway, Sign Posts, Single Post, Crashworthiness	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	310	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

W. J. Lindsay of the Federal Highway Administration (FHWA), Region 6, served as the technical contract manager. His guidance and cooperation throughout the study were very helpful. J. R. Watson, Jr., R. A. Richter, G. Trainer, H. L. Anderson, J. H. Hatton, and H. W. Taylor, all of FHWA, Washington, D.C., provided valuable assistance and timely suggestions. Other FHWA officials who provided input through an advisory committee to the project were W. H. Collins, N. Tuz, J. T. Brooks, D. B. Chisholm, and M. T. Browne.

Grateful acknowledgment is extended to all of the technical support personnel of the Texas Transportation Institute who assisted in the preparation, execution, and analysis of the 22 full-scale crash tests. Special thanks go to Don Cangelose, Jim Bradley, Bill Ray, Dick Zimmer, Gordon Samuelson, and Eddie Denk for their attention to details and sincere interest in quality research. Thanks are also extended to Dr. Gene Buth for his cooperation in scheduling the tests. The efficient and accurate typing of this report by Sylvia Velasco is acknowledged. John Mulvahill, with assistance from Benito Jackson, did the drafting work.

The assistance and cooperation of various suppliers of sign supports and signpost drivers are recognized. Space does not permit the listing of numerous other individuals and agencies who contributed to this study but whose help was nonetheless appreciated.

PREFACE

This report was prepared as a part of DOT Contract No. FH-11-8821, entitled "Cost Effectiveness of Small Highway Sign Supports". The contract began July 1975 and was completed January 1979.

The basic purpose of the contract was to develop objective criteria and methodologies to assist transportation agencies in the selection of a cost-effective sign support system. Four tasks were required: (1) survey existing practices; (2) evaluate the crashworthiness of widely used support systems and promising new systems; (3) develop methodologies whereby candidate systems can be evaluated on a cost-effective basis; and (4) to the extent possible, identify the relative cost effectiveness of current systems. Results of the initial phase of the contract are presented in the following reports:

1. "State of the Practice in Supports for Small Highway Signs", Ross, Hayes E., Jr.; Buffington, Jesse L.; Weaver, Graeme D.; and Shafer, Dale L.; Research Report 3254-1, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, June 1977.
2. "Survey of Current Practice in Supports for Small Signs -- Documentation of Data Reduction and Information File", Ross, Hayes E., Jr., and Shafer, Dale L., Research Report 3254-2, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, April 1977.
3. "Crash Tests of Small Highway Sign Supports", Ross, Hayes E., Jr.; Walker, Kenneth C.: and Effenberger, Michael J.; Research Report 3254-3, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, January, 1979.
4. "Guidelines for Selecting a Cost Effective Small Highway Sign Support System", Ross, Hayes E., Jr., and Griffin, Lindsay I., III, Research Report 3254-4, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, February, 1979.
5. "Cost Effectiveness of Small Highway Sign Supports -- A Summary Report", Ross, Hayes E., Jr., Research Report 3254-5F, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, February, 1979.

Subsequent to the initial contract, additional work was conducted under contract modifications. This included the crash test evaluation of rural mailboxes and the crash test evaluation of selected small sign supports using subcompact automobiles. Results of this work are published in two reports:

6. "Crash Tests of Rural Mailbox Installations", Ross, Hayes E., Jr., and Walker, Kenneth C., Research Report 3254-6, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, February, 1979.
7. "Crash Tests of Single Post Sign Installations Using Sub-Compact Automobiles", Ross, Hayes E., Jr., and Walker, Kenneth C., Research Report 3254-7, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, May, 1979.

A narrated, documentary 16 mm movie presenting a summary of the contract was also developed. Included in the movie are summaries of the crash tests described in this report. Copies of the movie, entitled "Small Sign Supports", can be obtained by contacting the

Office of Development
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Federal Highway Administration
Washington, D.C. 20590

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I. INTRODUCTION AND SCOPE

Varieties of systems are used to support small roadside signs. In a recent survey (1), conducted as a part of this study, the different types of support systems were identified. Design details of the widely used systems are summarized in Chapter II.

As a result of the above-mentioned survey, it became evident that the crashworthiness of most small sign supports was unknown. Although many sign support systems have been crash tested, practically all of the tests were with automobiles weighing 3200 lbs (1453 kg) or more. Appendix B of Reference 1 contains a summary of crash tests of sign supports conducted prior to this study. Current guidelines (2,3) recommend that the impact performance of a sign support be evaluated with a compact vehicle weighing approximately 2250 lbs (1022 kg). Use of smaller cars in crash test evaluation was precipitated by the current trend to smaller and more economical vehicles. Hence, it was concluded that a comprehensive test program should be undertaken to evaluate current systems in terms of current guidelines. A total of 22 full-scale crash tests was conducted. Also reported are the results of 13 crash tests supported by private industries for new support systems.

All tests were with installations having a single support. Single post installations represent approximately 75 percent of all roadside sign installations. A crash test program to evaluate multiple post installations is planned in the near future by FHWA.

Results of the tests presented herein are not limited to state highway or transportation agencies alone. Although operating speeds are generally less in city and county jurisdictions, a sign support can nonetheless be hazardous, especially to occupants of a small vehicle. It is important to note that many supports can be more hazardous at low speeds (15 to 25 mph) (24.1 to 40.2 km/h) than at high speeds (55 to 60 mph or greater) (88.5 to 96.5 km/h). Sign supports that fracture or break away on impact are generally more hazardous at low speeds. Systems that yield or bend are generally more hazardous at high speeds. That is not to say that yielding systems are necessarily safer at low speeds than systems that break. The point is that an agency should be aware of the impact performance of candidate systems for the expected operating speeds.

Although safety should be of primary importance, an agency should also investigate the economics of all candidate systems to insure that a cost-effective system is selected. Data presented herein are intended to be used in conjunction with a cost-effective selection procedure (4).

A summary of the tests and their results is given in Chapter III. Complete details are presented in the appendices.

II. SUMMARY OF CURRENT SYSTEMS

Table 1 shows the extent of use of the various types of sign supports as of 1977 (1). It can be seen that the steel U-post, or flanged channel post, is the most widely used support, followed by the wood post, steel pipe, and the steel tube. Together these four types comprise over 95 percent of all systems used. Rolled steel shapes with breakaway slip bases are used to some extent, primarily on controlled access interstate systems. Photographs and other design details of the systems are given in the appendix and in Reference 1.

Presented in Table 2 are typical design parameters of the prevalent support systems used for single-post installations. Systems 1 through 5 were evaluated through crash tests in this study. Systems 6 and 7 were deemed crashworthy based on previous testing (5,6,7), much of which involved supports much larger than those of Table 2.

Tests of promising new systems or those which evolved during the course of the study are also presented. These included a frangible coupling for use with the steel U-post, a bolted base design for the steel U-post utilizing a post-stub combination, and an aluminum post patterned after the back-to-back steel U-post.

Table 1. Extent of use of prevalent sign support systems[a] (1).

Type of Material/ Cross-Sectional Shape	Single Post: Type of Respondent					Multiple Posts: Type of Respondent				
	State Agencies	Cities	Counties	Other	Total	State Agencies	Cities	Counties	Other	Total
	Percent of Signs					Percent of Signs				
Steel										
"U" Single	29.8	48.6	48.3	36.6	34.0	32.4	1.8	97.8	4.5	29.7
"U" Back to Back	1.2	0.0	0.0	0.0	0.9	3.4	0.0	b	0.0	3.0
Square or Rectangular Tube	13.6	10.1	13.4	2.9	12.7	7.0	11.1	b	2.2	7.2
Round or Oval Pipe	25.3	31.6	3.3	12.0	24.8	4.9	81.3	b	b	12.4
Tapered Pipe	b	0.0	0.0	0.0	b	b	0.0	0.0	0.0	b
Beam (I, S, W, or H)	0.2	0.0	0.0	b	0.2	16.7	0.0	0.0	3.8	14.6
Angle (Z)	b	1.3	0.0	0.0	0.2	b	c	0.0	0.0	c
Aluminum										
"U" Single	c	c	0.0	0.0	c	c	b	0.0	0.0	c
Round or Oval Pipe	0.5	1.7	2.5	0.2	0.8	0.7	2.3	2.2	0.3	0.9
Beam (I, S, W, or H)	c	b	c	0.0	0.1	6.6	0.0	0.0	0.0	5.8
Angle (Z)	b	0.0	0.0	0.0	b	0.0	0.0	0.0	0.0	0.0
Wood										
Square or Rectangular	28.9	6.3	32.5	38.0	25.6	27.4	3.5	0.0	53.6	25.1
Round	0.5	0.0	0.0	4.2	0.5	0.9	0.0	0.0	15.5	1.0
Combination	0.0	0.0	0.0	6.1	0.1	b	0.0	0.0	20.1	0.3
Plastic										
Round Pipe	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Total (000)	(7,901)	(1,699)	(576)	(230)	(10,406)	(2,126)	(245)	(27)	(39)	(2,436)

[a]Based on the number of small signs in place, as reported by the respondents. This table does not represent all of the signs in place because a few respondents either did not estimate the percentage of usage of certain types of signs or did not report enough data to estimate the small sign population.

[b]Number of signs not reported.

[c]Negligible.

Table 2. Typical details of widely used small sign supports (1).

SYSTEM	SIZE	METHOD OF EMBEDMENT	DEPTH OF EMBEDMENT (ft)	BREAKAWAY MECHANISM
1. Steel U-Post	3 lb/ft	Driven	3.0 - 4.0	None[1]
1a. Steel U-Post Back-to-Back[2]	6 lb/ft	Driven	3.0 - 5.0	None[1]
2. Wood	4 in. x 4 in.	Drill and Backfill	3.0 - 5.0	None[1]
3. Steel Pipe	2.5 in. Dia. (Standard)	Concrete or Driven	2.0 - 5.0	None[1]
4. Square Steel Tube[3]	2.5 in. x 2.5 in. (12 gauge)	Driven	2.0 - 4.0	Post fracture at stub
5. Steel Pipe with Coupling[4]	2.5 in. Dia.	Concrete	2.0	Post fracture at coupling at base of post
6. Steel Pipe with Slip Base	3.0 in. Dia.	Concrete	2.0 - 3.0	Slip base
7. Steel Rolled Shapes with Slip Base	S3 x 5.7	Concrete	2.0 - 3.0	Slip base

[1]Post bends or breaks on impact.
[2]Two 3 lb/ft bolted together. Post used for larger single post signs.
[3]Most of these installations are perforated telescoping steel tubes, with each installation composed of a post, an anchor or stub, and a sleeve.
[4]Coupling and stub embedded in concrete footing. Post connected to top of coupling at groundline.

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb/ft = 1.489 kg/m

III. SUMMARY AND EVALUATION OF TEST RESULTS

Presented in this chapter is a summary of the crash test results and an evaluation of the results in terms of present criteria and guidelines. Complete details and photographs of each test are presented in the appendices.

III-A. Test Results

Presented in Table 3 is a summary of the 22 crash tests conducted in the study and the results obtained therefrom. Table 4 contains a summary of recent crash tests of single-post installations sponsored by other agencies and of relevance to this study. In all tests reported herein, close adherence to recommended test procedures (2,3) was maintained. With the exception of test M-13 of Table 4*, the test vehicles consisted of 1971-1973 Chevrolet Vegas weighing approximately 2250 lbs (1022 kg). In each test the lower edge of the sign panel was approximately 6 ft (1.83 m) above grade. Soil at the test site was in accordance with recommended guidelines (2,3). The types of posts evaluated are categorized as follows:

III-A-1. Wood posts

Tests 1, 2, 12, and M-13 involved wood posts. In tests 1, 2, and 12 the posts had no breakaway or weakening devices. In tests 1 and 2 the posts were "rough cut" and had full cross-sectional dimensions. In test 12 the post had standard dressed size dimensions of 5.5 in. by 3.5 in. (14.0 cm by 8.9 cm). In test M-13 holes were drilled in the post near groundline to affect breakaway on impact. Reference should also be made to Table B-3 of Reference 1 for results of other wood post tests.

III-A-2. Steel U-Posts

Tests 3, 4, 9, 13, 20, 20A, and 21 involved full-length steel U-posts. Of these there were two basic types of material and two basic designs. In tests 3, 4, 9, and 21 the posts were hot rolled

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*Test M-13 conducted with pendulum (21).

Table 3. Summary of test results.

TEST NO.	SYSTEM	IMPACT SPEED (mph)	POST SIZE	STUB SIZE	METHOD OF EMBEDMENT	DEPTH OF EMBEDMENT (ft)	WINDSHIELD BROKEN?	WINDSHIELD PENETRATED?	VEHICLE DAMAGE		RESTORATION REQUIRED FOR SIGN INSTALLATION	CHANGE IN VEHICLE MOMENTUM (lb-sec)
									TAD	SAE		
1	Wood (Southern Pine)	21.2	4 in. x 4 in.	None	Drill and Backfill	4.0	No	-	FL-1	12FLEN1	Replace post; Repair and reuse sign panel	484
2	Wood (Southern Pine)	64.6	4 in. x 4 in.	None	Drill and Backfill	4.0	Yes by Panel	No	FR-1	12FREN1	Replace post; repair and reuse sign panel	478
3	Steel U-Post (Billet Steel)	20.8	3 lb/ft	None	Driven	3.5	No	-	FL-0	12FLEN1	Replace post; Sign panel reusable	318
4	Steel U-Post (Billet Steel)	61.2	3 lb/ft	None	Driven	3.5	No	No	FR-4	12FREN3	Replace complete installation	950
5	Steel U-Post and Stub (Billet Steel) with Frangible Coupling	21.9	3 lb/ft	3 lb/ft	Driven	3.08	No	-	FL-0	12FLEN1	Replace post, frangible coupling, retaining straps and possibly the stub; Repair and reuse sign panel	267
6	Steel U-Post and Stub (Billet Steel) with Frangible Coupling	66.1	3 lb/ft	3 lb/ft	Driven	3.08	Yes by Panel	No	FR-1	12FREN1	Replace frangible coupling, retaining straps and stub; Sign post possibly reusable with straightening; Repair and reuse sign panel	287
7	Square Perforated Steel Tube -- Post and Stub	61.4	2.5 in. x 2.5 in. (10 ga.)	3 in. x 3 in. x 3/16 in.	Driven	2.92	Yes Due to hood hitting it	No	FL-4	12FLEN3	Stub possibly reusable; Replace post; Sign panel reusable	559
8	Aluminum Type X	63.7	3X	None	Drill and Backfill	3.5	No	-	FR-1	12FREN1	Replace post; Repair and reuse sign panel	414
9	Steel U-Post Back-to-Back (Billet Steel)	61.2	6 lb/ft	None	Drill and Backfill	4.0	Yes Due to hood hitting it	No	FL-5	12FLEN4	Replace complete installation	2249
10	Standard Steel Pipe	18.9	2.5 in. dia.	None	Drill and Backfill	4.0	No	-	FL-1	12FLEN1	Replace post; Repair and reuse sign panel	883
11	Standard Steel Pipe	61.4	2.5 in. dia.	None	Drill and Backfill	4.0	Yes Due to Car Rolling	No	L&T-5 R&T-5 FR-4	DOTBAD4 12FREN3	Replace post; Repair and reuse sign panel	1252
12	Wood (Southern Pine)	20.7	4 in. x 6 in. (Nominal Size)	None	Drill and Backfill	4.0	No	-	FL-2	12FLEN1	Replace post; Sign panel reusable	525
13	Steel U-Post (Rail Steel)	63.8	3 lb/ft	None	Driven	3.5	Yes by Panel	No	FR-2	12FREN1	Replace post; Repair and reuse sign panel	255
14	Standard Steel Pipe Post and Stub with Breakaway Collar	20.3	2.5 in. dia.	2.5 in. dia.	Concrete Footing	2.5 (footing) 2.0 (stub)	No	-	FL-1	12FLEN1	Replace post, sign, and footing; Sign panel reusable	802
15	Standard Steel Pipe Post and Stub with Breakaway Collar	63.3	2.5 in. dia.	2.5 in. dia.	Concrete Footing	2.5 (footing) 2.0 (stub)	No	-	FR-1	12FREN1	Replace post, stub, and footing; Repair and reuse sign panel	379
16	Standard Steel Pipe Post and Stub with Breakaway Collar	19.2	2.5 in. dia.	2.5 in. dia.	Concrete Footing	2.5 (footing) 2.0 (stub)	No	-	FL-1	12FLEN1	Replace post; stub reusable; Sign panel reusable	638
17	Steel U-Post Braced Leg Design (Billet Steel)	19.9	2 lb/ft post 2 lb/ft brace	None	Driven	2.5 Post 2.0 Brace	No	-	FR-0	12FREN1	Replace post and brace; Sign panel possibly reusable with straightening	783
18	Standard Steel Pipe	56.5	2.0 in. dia.	None	Drill and Backfill	4.0	No	-	FR-1	12FREN1	Replace post; Sign panel reusable	462
19	Steel U-Post Braced Leg Design (Billet Steel)	60.6	2 lb/ft post 2 lb/ft brace	None	Driven	2.5 Post 2.0 Brace	Yes	No	FL-2	12FLEN1	Replace post and brace; Sign panel reusable	529
20	Steel U-Post Back-to-Back (Rail Steel)	67.3	6 lb/ft	None	Drill and Backfill	4.0	Yes	No	FR-4	12FREN3	Replace post; Repair and reuse sign panel	701
20A	Steel U-Post Back-to-Back (Rail Steel)	62.9	6 lb/ft	None	Drill and Backfill	4.0	Yes	No	FL-2 L&T-3	12FLEN1 DOTPHD3	Replace complete installation	669
21	Steel U-Post Back-to-Back (Experimental Billet Steel)	57.9	6 lb/ft	None	Drill and Backfill	4.0	Yes	No	FR-2	12FREN1	Replace post; Repair and reuse sign panel	430

Metric Conversions:
1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m/ft = 1.489 kg/m
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

Table 4. Summary of test results from other sources.

TEST NO.	SYSTEM	IMPACT SPEED (mph)	PDST SIZE	STUB SIZE	METHDD DF EMBEDMENT	DEPTH DF EMBEDMENT	WINDSHIELD BRDKEN?	WINDSHIELD PENETRATED?	VEHICLE DAMAGE		RESTDRATION REQUIRED FDR SIGN INSTALLATIDN	CHANGE IN VEHICLE MDMENTUM (lb-sec)
									TAD	SAE		
3491-1 (B)	Steel U-Post and Stub (Rail Steel) with Bolted Connection	22.7	3 lb/ft	3 lb/ft	Driven	3.08	No	-	FL-1	12FLEN1	Replace stub and sign post; Sign panel reusable	19D
3491-2 (B)	Steel U-Post and Stub (Rail Steel) with Bolted Connection	S9.6	3 lb/ft	3 lb/ft	Driven	3.DB	No	-	FR-1	12FREN1	Replace complete installation	179
3491-3 (B)	Steel U-Post and Stub (Rail Steel) with Bolted Connection	17.2	3 lb/ft	3 lb/ft	Driven	3.08	No	-	FL-1	12FLEN1	Replace stub; Sign post possibly reusable with straightening; Repair and reuse sign panel	36B
3491-4 (B)	Steel U-Post and Stub (Rail Steel) with Bolted Connection	16.6	3 lb/ft	3 lb/ft	Driven	3.0B	No	-	FR-2	12FREN1	Replace complete installation	3SB
3636-1 (9)	Steel U-Post Back-to-Back (Rail Steel)	1B.8	6 lb/ft	None	Drill and Backfill	4.D	No	-	FL-2	12FLEN1	Replace complete installation	B10
3636-3 (9)	Steel U-Post Back-to-Back (Rail Steel)	63.D	6 lb/ft	None	Drill and Backfill	4.D	Yes	No	FL-3	12FLEN2	Replace sign posts; Repair and reuse sign panel	996
36B3-1 (1D)	Aluminum Type X Post	2D.S	6X	None	Drill and Backfill	4.D	No	-	FL-1	12FLEN1	Replace post and probably sign panel	B21
36B3-2 (1D)	Aluminum Type X Post	6D.1	6X	None	Drill and Backfill	4.D	Yes	No	FR-2	12FREN2	Replace post	4D2
3775-1 (2D)	Square Perfo-rated Steel Tube -- Post and Stub	19.3	2 in. x 2 in. (12 gauge)	2.2S in. x 2.2S in. (12 gauge)	Driven	2.B3	No	-	FR-D	12FREND	Replace panel and signpost. Stub reusable.	24S
3775-2 (2D)	Square Perfo-rated Steel Tube -- Post and Stub	6D.6	2 in. x 2 in. (12 gauge)	2.2S in. x 2.2S in. (12 gauge)	Driven	2.83	Yes	No	FL-1	12FLEN1	Replace signpost. Panel and stub reusable.	1D6
377S-3 (2D)	Square Perfo-rated Steel Tube -- Post and Stub	2D.4	2.S in. x 2.S in. (1D gauge)	3 in. x 3 in. x D.1B7S in.	Driven	2.B3	No	-	FR-2	12FREN1	Replace signpost. Panel and stub reusable.	632
377S-4 (2D)	Square Perfo-rated Steel Tube -- Post and Stub	62.9	2.S in. x 2.S in. (1D gauge)	3 in. x 3 in. x D.1B7S in.	Driven	2.B3	No	-	FL-1	12FLEN1	Replace signpost. Straighten panel. Stub reusable.	16S
M-13[a] (21)	Wood Post with Weakened Section (Drilled Holes)	2D.D	6 in. x B in. (Nominal Size)	None	Concrete Footing	4.S	N/A	N/A	N/A	N/A	Unknown	2B1

[a]Test conducted with soft-nose pendulum. See Reference 21 for other wood post tests with pendulum.

Metric Conversions:

1 in. = 2.S4 cm
1 ft = D.30S m
1 lb_m/ft = 1.4B9 kg/m
1 lb -sec = 4.4S N-s
1 mph = 1.6D9 km/h

from billet steel. Of these, the material in tests 3, 4, and 9, taken from commercially available stock (14), was considerably more impact resistant than that of test 21. Post material in test 21 was actually of an experimental nature and was provided by a producer of billet steel U-posts (14). Use of the "experimental posts" in test 21 was precipitated by adverse results in tests 4 and 9. Further discussions of material properties of yielding or base bending metal posts are presented in subsequent sections of this report and in Appendix B.

Posts in tests 13, 20, 20A, 3636-1, and 3636-2, taken from commercially available stock (15), were hot rolled from rail steel. In test 20, the intended impact speed was 60 mph (96.5 km/h), and the actual speed was approximately 67 mph (107.8 km/h). Test 20A was a repeat of test 20 at a lower speed.

With regard to designs, the supports in tests 3, 4, and 13 consisted of a single 3 lb/ft (4.5 kg/m) post. In tests 9, 20, 20A, 21, 3636-1, and 3636-3, the supports consisted of two 3 lb/ft (4.5 kg/m) posts bolted together to form a single back-to-back design weighing 6 lb/ft (9.0 kg/m). Reference should also be made to Table B-1 of Reference 1 for other tests of the steel U-post.

III-A-3. Steel U-Posts with Special Features

Three designs utilizing the steel U-post as a basic component have been evaluated. In the first of these, a frangible breakaway coupling was evaluated in tests 5 and 6. The coupling is used as a connection between a steel U-post stub and a steel U-post signpost.

In tests 17 and 19, an installation using a vertical U-post with a U-post back or knee brace was evaluated. This design is widely used in the state of Arkansas.

In tests 3491-1 through 3491-4 a stub-signpost design was evaluated. The main feature of this system is a bolted connection at the stub-signpost interface and retainer-spacer strap. Tests of this concept have also been conducted on multiple-post sign installations (9).

III-A-4. Standard Steel Pipe

Tests 10, 11, and 18 involved full-length standard steel pipe. An anti-twist plate was welded to the base of the post in each case. Reference should also be made to Table B-4 of Reference 1 for other tests of pipe post.

III-A-5. Standard Steel Pipe with Breakaway Coupling

Tests 14, 15, and 16 involved standard steel pipe with a standard threaded pipe collar at the base. The collar and a short pipe stub were embedded in a concrete footing. This support system is used primarily in Texas. In test 16, a slight change in the embedment depth of the collar was made which reduced the damage to the installation from impact. Further discussions of this change are given in the appendix. Reference should be made to Table B-4 of Reference 1 for other tests of this system.

III-A-6. Square Steel Tubing

Tests 7 and 3775-1 through 3775-4 involved a square perforated steel tube stub-signpost design. Reference should also be made to Table B-4 of Reference 1 for results of other tests of this system.

III-A-7. Aluminum Post

Tests 8, 3683-1, and 3683-2 involved aluminum posts with a cross section similar to that in a back-to-back steel U-post design. The post in test 8 was a type 3X and in tests 3683-1 and -2 the post was a type 6X. These are the manufacturer's designations (11).

III-B. Acceptance Criteria

Three sources are widely used in evaluating the hazard potential of a roadside sign installation. A rather detailed summary of the guidelines contained in these three sources is given in Chapter IV of Reference 1. The essence of these criteria is presented in the following three sub-sections. Section III-C contains an evaluation of the test results in terms of these criteria.

III-B-1. AASHTO Specification (12)

According to AASHTO, "Satisfactory dynamic performance is indicated when the maximum change in momentum for a standard 2250 lb (1020 kg) vehicle, or its equivalent, striking a breakaway support at speeds from 20 mph to 60 mph (32 km/h to 97 km/h) does not exceed 1100 pound-seconds (4893 N-sec), but desirably does not exceed 750 pound/seconds (3336 N-sec)."

As used in the Specification, "breakaway supports" is a generic term meant to include all types of sign supports whether the release mechanism is a slip plane, plastic hinges, fracture elements, or a combination of these. The Specification states that "Breakaway structures should also be designed to prevent the structure or its parts from penetrating the vehicle occupant compartment." The Specification also alludes to the unacceptability of vehicle rollover following impact with the test article.

III-B-2. Transportation Research Circular No. 191 (3)

The referenced document, which has just recently been published, supersedes NCHRP Report No. 153 (2). Its basic purpose is to provide recommended guidelines for crash test evaluation of a given highway appurtenance. With regard to sign supports, it contains recommended test site soil conditions, vehicle size and impact conditions, data acquisition and data reduction procedures, and performance criteria. The performance criteria of Circular No. 191 with regard to sign supports are essentially the same as that of AASHTO (12). Close adherence to the recommended procedures in Circular No. 191 (3) was maintained in the crash tests reported herein.

III-B-3. FHWA Notice N5040.20 (13)

The subject of the referenced Notice was the AASHTO Specifications (12). Its stated purpose was as follows:

"a. To institute application of the subject specifications

"b. To transmit suggested guidelines for application of the breakaway requirements of the subject specifications."

Two items contained in this Notice were of special interest to the tests reported herein. First, limiting plastic section moduli for metal base bending (yielding) posts were given for single, double, or triple post installations. Second, limiting elastic section moduli for wood posts were given for single, double, or triple post installations. Shown in Tables 5 and 6 are limiting values for widely used metal and wood posts and the number of posts permitted in an 8 ft (2.44 m) path.

III-C. Analysis of Tests

Given in Table 7 is an evaluation of the test results and test articles in terms of current acceptance criteria. A graphical presentation of the change in momentum is given in Figure 1. Included in the data are results of recent tests by industry on small sign supports.

III-C-1. Adherence to AASHTO Specifications (12)

Analyses of these results show that two systems clearly do not meet AASHTO performance specifications, namely the 2½ in. (6.35 cm) diameter standard steel pipe and the 6 lb/ft (8.93 kg/m) back-to-back billet steel U-post. Both are base bending or yielding type posts with no breakaway mechanism. In the past, when large automobiles were more predominant, these type signs could be easily ridden down. Now that the small car population has become significant, the base bending type post is of much more concern, especially at the higher impact speeds.

To improve the impact behavior of the billet steel U-post, a manufacturer (14) developed a steel alloy which exhibited brittle fracture during laboratory impact load tests. Mechanical and chemical properties of the material, and all other metal posts tested, are given in Appendix B. Test 21 was therefore scheduled to evaluate the impact behavior of this material under full-scale conditions. The post in test 21 was identical to that in test 9 except for the alloy. Comparison of tests 9 and 21 shows that severity of impact was significantly reduced with the new material. In test 21 the post fractured while in test 9 it did not, and

Table 5. Plastic section moduli of typical base bending supports for small signs.

POST TYPE	SIZE	PLASTIC SECTION MODULUS (IN^3)	LIMITING PLASTIC SECTION MODULUS (IN^3)[i]			NUMBER OF POSTS PERMITTED IN 8-FOOT PATH[i]
			1-POST	2-POST	3-POST	
Steel U-Post	2 lb/ft	0.35[a,b] 0.25[d]	1.3	0.7	0.4	3[a,b] 3[d]
	3 lb/ft	0.63[a,b] 0.53[d]	1.3	0.7	0.4	2[a,b] 2[d]
	4 lb/ft	0.98[a,b] (e)	1.3	0.7	0.4	1[a,b] -
	6 lb/ft[f]	1.6[a,c] 1.9[d]	1.3	0.7	0.4	0[a,c] 0[d]
	8 lb/ft[g]	2.1[a,c] (e)	1.3	0.7	0.4	0[a,c] -
Aluminum U-Post[h]	2X	0.45	3.41	1.83	1.05	3
	3X	1.06	3.41	1.83	1.05	3
	4X	1.27	3.41	1.83	1.05	2
	6	3.03	3.41	1.83	1.05	1
	8	4.20	3.41	1.83	1.05	0
Standard Steel Pipe	2 in.ϕ	0.76	2.38[j]	1.28[j]	0.73[j]	3
	2½ in.ϕ	1.45	2.38[j]	1.28[j]	0.73[j]	1
	3 in.ϕ	2.33	2.38[j]	1.28[j]	0.73[j]	1
	3½ in.ϕ	3.22	2.38[j]	1.28[j]	0.73[j]	0
	4 in.ϕ	4.31	2.38[j]	1.28[j]	0.73[j]	0
Standard Aluminum Pipe	2 in.ϕ	0.76	3.41[k]	1.83[k]	1.05[k]	3
	2½ in.ϕ	1.45	3.41[k]	1.83[k]	1.05[k]	2
	3 in.ϕ	2.33	3.41[k]	1.83[k]	1.05[k]	1
	3½ in.ϕ	3.22	3.41[k]	1.83[k]	1.05[k]	1
	4 in.ϕ	4.31	3.41[k]	1.83[k]	1.05[k]	0
Square Steel Tubing (No Perforations)	2½ in x 2½ in[l]	1.11	2.38[n]	1.28[n]	0.73[n]	2
	2 in x 2 in[m]	0.55	2.38[n]	1.28[n]	0.73[n]	3
	1½ in x 1½ in[m]	0.30	2.38[n]	1.28[n]	0.73[n]	3
	1 in x 1 in[m]	0.12	2.38[n]	1.28[n]	0.73[n]	3
Square Steel Tubing (Perforated by 7/16 in.ϕ holes on four sides 1 in. o.c.)	2½ in x 2½ in[l]	0.95[l]	2.38[n]	1.28[n]	0.73[n]	2
	2 in x 2 in[m]	0.45[l]	2.38[n]	1.28[n]	0.73[n]	3
	1½ in x 1½ in[m]	0.22[l]	2.38[n]	1.28[n]	0.73[n]	3
	1 in x 1 in[p]	--	2.38[n]	1.28[n]	0.73[n]	3

[a] Data for Franklin Steel Company U-Post (15).

[b] Data furnished by Franklin Steel Company.

[c] Figures are approximate.

[d] Data for Armco Steel Corporation U-Post (14).

[e] Not produced by Armco Steel Corporation.

[f] Two 3 lb/ft sections back-to-back.

[g] Two 4 lb/ft sections back-to-back.

[h] Size designations and moduli furnished by Magnode Products Inc. (11). Posts are designed to provide bending strength about axis parallel to sign face equivalent to corresponding steel U-posts. Designating numbers represent weight per foot of corresponding steel U-posts. Limiting moduli based on 6061-T6 aluminum with ultimate strength of 42 ksi.

[i] As per criteria in FHWA Notice N5040.20 (13).

[j] Based on A53-69a steel with ultimate strength of 60 ksi.

[k] Based on 6061-T6 aluminum with ultimate strength of 42 ksi.

[l] Wall thickness of 0.135 in.

[m] Wall thickness of 0.105 in.

[n] Based on ultimate strength of 60 ksi.

[p] Not produced.

Metric Conversions:

1 in. = 2.54 cm
1 $in.^3$ = 16.4 cm^3
1 ft = 0.305 m
1 lb/ft = 1.489 kg/m
1 ksi = 6.895 x 10^6Pa

Table 6. Elastic section moduli of typical wood supports for small signs[a].

NOMINAL DIMENSION[c]	ELASTIC SECTION MODULUS (IN^3)		LIMITING ELASTIC SECTION MODULUS (IN^3)[b]			NUMBER OF POSTS PERMITTED IN 8-FOOT PATH[b]
	NOMINAL DIMENSION	DRESSED	1-POST	2-POST	3-POST	
4 in x 4 in	10.7	7.1	24.0	18.0	14.0	3[e]
4 in x 6 in	24.0	17.6	24.0	18.0	14.0	2[e]
6 in x 6 in	36.0	27.7	24.0	18.0	14.0	0[e]
6 in x 8 in	64.0	51.6	24.0	18.0	14.0	0[e]
4 in.ϕ[d]	6.3	--	24.0	18.0	14.0	3
5 in.ϕ[d]	12.3	--	24.0	18.0	14.0	3
6 in.ϕ[d]	21.2	--	24.0	18.0	14.0	1
7 in.ϕ[d]	33.7	--	24.0	18.0	14.0	0

[a]Data shown assumes posts have no weakened sections.

[b]As per criteria in FHWA Notice N5040.20 (13).

[c]Subtract ½ inch for dressed dimensions. For example, a 4 in. x 4 in. has a dressed size of 3½ in. x 3½ in.

[d]Dimensions assumed at groundline.

[e]Values are for dressed sizes.

METRIC CONVERSIONS: 1 in. = 2.54 cm
1 ft = 0.305 m

Table 7. Evaluation of test data and posts.

POST TYPE	TEST NO.[a]	POST SIZE	IMPACT SPEEO (mph)	SATISFY FOLLOWING CRITERIA:			
				VEHICLE MOMENTUM CHANGE[b]?	TRAJECTORY OF SIGN ANO SUPPORT[b]?	VEHICLE REMAIN UPRIGHT[b]?	POST SECTION MODULUS[c]?
Wood	1	4 in. x 4 in.	21.2	Yes	Yes	Yes	Yes
	2	4 in. x 4 in.	64.6	Yes	Yes[d]	Yes	Yes
	12	4 in. x 6 in.	20.7	Yes	Yes	Yes	Yes
	M-13 (21)	6 in. x B in. (weakened)	20.0	Yes	Unav.	Unav.	Not Applicable
Steel U-Post (Billet Steel)	3	3 lb/ft	20.8	Yes	Yes	Yes	Yes
	4	3 lb/ft	61.2	Yes[e]	Yes	Yes	Yes
	9	6 lb/ft	61.2	No	Yes[d]	Yes	No
Steel U-Post (Experimental Billet Steel)[f]	21	6 lb/ft	S7.9	Yes	Yes[d]	Yes	No
Steel U-Post (Rail Steel)	13	3 lb/ft	63.B	Yes	Yes[d]	Yes	Yes
	20	6 lb/ft	67.3	Yes	Yes[d]	Yes	No
	20A	6 lb/ft	62.9	Yes	Yes[d]	No[h]	No
	3636-1 (9)	6 lb/ft	1B.B	Yes[e]	Yes	Yes	No
	3636-3 (9)	6 lb/ft	63.0	Yes[e]	Yes[d]	Yes	No
Steel U-Post with Frangible Coupling	S	3 lb/ft	21.9	Yes	Yes	Yes	Not Applicable
	6	3 lb/ft	66.1	Yes	Yes[d]	Yes	Not Applicable
Steel U-Post with Back Brace	17	2 lb/ft	19.9	Yes[e]	Yes	Yes	Yes
	19	2 lb/ft	60.6	Yes	Yes[d]	Yes	Yes
Steel U-Post with Bolted Base	3491-1 (8)	3 lb/ft	22.7	Yes	Yes	Yes	Yes
	3491-2 (B)	3 lb/ft	S9.6	Yes	Yes	Yes	Yes
	3491-3 (B)	3 lb/ft	17.2	Yes	Yes	Yes	Yes
	3491-4 (B)	3 lb/ft	16.6	Yes	Yes	Yes	Yes
Standard Steel Pipe	10	2½ in. Dia.	18.9	Yes[e]	Yes	Yes	Yes
	11	2½ in. Oia.	61.4	No	Yes	No	Yes
	18	2 in. Oia.	S6.S	Yes	Yes	Yes	Yes
Standard Steel Pipe with Breakaway Coupling	14	2½ in. Oia.	20.3	Yes[e]	Yes	Yes	Not Applicable
	1S	2½ in. Oia.	63.3	Yes	Yes	Yes	Not Applicable
	16	2½ in. Dia.	19.2	Yes	Yes	Yes	Not Applicable
Square Steel Perforated Tubing	7	2½ in. x 2½ in.	61.4	Yes	Yes[d]	Yes	Yes
	377S-1 (20)	2 in. x 2 in.	19.3	Yes	Yes	Yes	Yes
	377S-2 (20)	2 in. x 2 in.	60.6	Yes	Yes[d]	Yes	Yes
	377S-3 (20)	2½ in. x 2½ in.	20.4	Yes	Yes	Yes	Yes
	377S-4 (20)	2½ in. x 2½ in.	62.9	Yes	Yes	Yes	Yes
Aluminum Type X	8	3X[g]	63.7	Yes	Yes	Yes	Yes
	3683-1	6X9	20.S	Yes[e]	Yes	Yes	Yes
	3683-2	6X9	60.1	Yes	Yes[d]	Yes	Yes

[a]See Table III-1, Table III-2, and appendix for more details.

[b]See Sections III-B-1 and III-B-2.

[c]See Section III-B-3.

[d]Sign panel and/or hood hit and broke windshield but did not penetrate windshield.

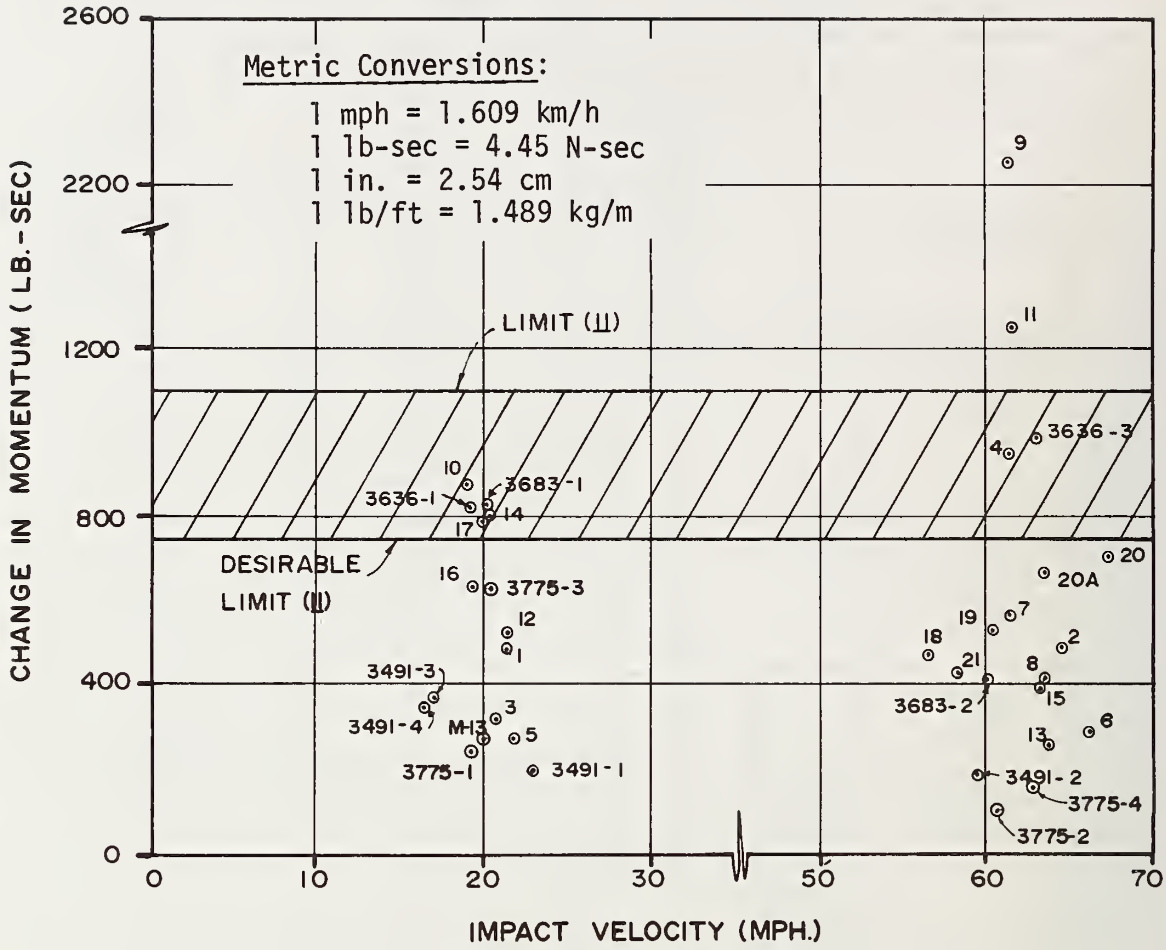
[e]Above "desirable" limit but below upper limit.

[f]Experimental material - see Section III-A-2.

[g]Manufacturer's designation (11).

[h]See text for discussion.

Metric Conversion: 1 in. = 2.S4 cm
1 lb_m/ft = 1.489 kg/m
1 mph = 0.447 m/s



TEST ARTICLE DESCRIPTION

TEST NO.	
1,2	4 in. x 4 in. Wood
12	4 in. x 6 in. Wood
8	3X Aluminum Type X
3683-1,2	6X Aluminum Type X
7, 3775-3,4	2.5 in. x 2.5 in. (10 ga.) Square Perforated Steel Tube Post and Stub
3775-1,2	2 in. x 2 in. (12 ga.) Square Perforated Steel Tube Post and Stub
3,4	3 lb/ft Billet Steel U-Post
5,6	3 lb/ft Billet Steel U-Post and Stub (Frangible Coupling)
9	6 lb/ft Billet Steel U-Post Back-to-Back
21	6 lb/ft Experimental Billet Steel U-Post Back-to-Back
17,19	2 lb/ft Billet Steel U-Post Braced Leg Design
13	3 lb/ft Rail Steel U-Post
3491-1,2,3,4	3 lb/ft Rail Steel U-Post and Stub (Bolted Connection)
20,20A, 3636-1,3	6 lb/ft Rail Steel U-Post Back-to-Back
18	2.0 in. Dia. Standard Steel Pipe
10,11	2.5 in. Dia. Standard Steel Pipe
14,15,16	2.5 in. Dia. Standard Steel Pipe Post and Stub with Breakaway Collar
M-13	6 in. x 8 in. Wood (Weakened Section)

Figure 1. Change in momentum versus impact velocity.

therein is the major reason for the different impact behavior. Research is still underway by the manufacturer (14) to determine an alloy which not only meets safety performance specifications but is also cost effective in terms of production and field application.

Four supports had a change in momentum above the desirable limit but below the upper limit. These were the 2½ in. (6.35 cm) standard steel pipe with a breakaway coupling (test 14), a 2 lb/ft (2.98 kg/m) steel U-post system composed of a vertical post and a back brace (test 17), a 3 lb/ft (4.47 kg/m) full-length steel U-post (test 4), and an aluminum type 6X (11) (test 3693-1).

With regard to test 14, a second test (test 16) of the same design, with a minor change (see Section III-A-5 and Appendix A, Section A-2-5), was conducted. Change in momentum in test 16 was well below the desirable limit. Change in momentum for this system at a high-speed impact (test 15) was also well below the desirable limit.

With regard to the steel U-post system having a vertical back brace, the change in momentum was only slightly greater than the desirable limit. Change in momentum of this system for a 60 mph (96.5 km/h) impact was considerably below the desirable limit. It is noted that the posts in this system were from the same type billet steel used in posts evaluated in tests 3, 4, and 9.

Steel in the U-post evaluated in test 4 was identical to that in test 9. The comments made regarding test 9 would therefore be applicable to test 4.

The other system which fell in the "grey" area was the aluminum type 6X post. In this case the change in momentum was above the desirable limit for the low-speed impact. Change in momentum was well below the desirable limit for the high-speed impact. Acceptance of this system from a safety performance standpoint would seem appropriate since the difference between the actual change in momentum and desirable limit in the low-speed test is not believed to be excessive.

With regard to the trajectory hazard, there were no penetrations into the passenger compartment as such by the panel and/or post in any test. There were, however, several tests in which the windshield was broken. In most cases breakage resulted from the panel and post rotating into the windshield. In some cases the hood was pushed back into the windshield. In some tests the windshield was only cracked while in others it was shattered and dished. Reference should be made to Appendix A for photos of vehicle damage. In test 20 the panel and post impacted the roof causing a considerable dent on the passenger side of the vehicle. However, the impact speed in test 20 was higher than called for in current test procedures (3).

Numerous factors influence the trajectory a given system will undergo. These include the vehicle type and size, impact speed, soil conditions, type of support, mounting height of panel, type of panel, and type of post-to-panel attachment. By studying the sequential photos of the tests (see Section A-3 of Appendix A), it can be seen that if a full-size automobile had been used in the tests, windshield contact would have occurred in some tests where none occurred with the compact test automobile. The converse of that is true in other tests. Likewise, if the panel had been mounted higher the windshield of the compact car would not have been contacted in certain tests but would have been with a full-size automobile.

After careful analysis of each test, the above factors notwithstanding, it is concluded that the penetration problem can be minimized by adequately attaching the panel to the post. In general, impact will accelerate the post and panel causing the post to bend and the panel to rotate downward toward the hood. If the post fractures, or a breakaway device releases, the post and panel are also accelerated in the direction of vehicle travel. To reduce the chance of penetration, it is important that the panel remain with the post during this initial contact so that its velocity relative to the vehicle's is minimized. It should be noted that keeping the panel on the post will not necessarily prevent windshield breakage. For some designs the tradeoff for a low change in momentum may be a broken windshield. An illustration of this can be seen by comparing the results of tests 4 and 13. Test conditions and post designs and sizes were very similar. The windshield was shattered and dished in test 13 and unbroken in test 4. Change in momentum was 255 lb-sec (1134 N-s) in test 13 and 950 lb-sec (4228 N-s) in test 4. In test 13 the post fractured and the post and panel rotated down into the windshield. In test 4 the post wrapped around the hood of the vehicle before being ridden down, without fracturing.

Sign panel accelerations were approximated by analysis of high-speed film. Combined accelerations up to 40 g's acting both perpendicular and parallel to the face of the sign were calculated. Highest acceleration occurred in the base bending posts that did not fracture. Even with a factor of safety of two, design of an adequate attachment should not be difficult, especially with aluminum panels. Determination of attachment loads is found by simply multiplying the weight of the panel by 40 and that by the desired factor of safety. For example, a 3 ft (0.92 m) by 4 ft (1.22 m) by 0.1 in. (0.25 cm) flat sheet aluminum panel weighs about 17.3 lb (7.85 kg). With a factor of safety of two, the fasteners would have to resist a total force of approximately 1385 lb (3847 N) in tension and shear. The tensile and shear load per fastener would equal the total force divided by the number of fasteners. Washers should be used as needed to prevent pullout of the nut and bolted head through the panel and post.

Vehicle rollover occurred in tests 11 and 20A. Prior to discussing these two tests, it should be noted that in each test the initial contact point on the vehicle was approximately 15 in.

(38.1 cm) either to the left or right of the center of the bumper. In addition to a longitudinal force, this produced a moment on the vehicle about the yaw axis. In test 11 impact caused the vehicle to pitch down, yaw, and roll. After loss of post contact, the vehicle attained a significant yaw and roll motion which resulted in complete loss of stability. The vehicle rolled three times before coming to a stop and was a total loss. In test 20A, the post fractured and was carried along with the vehicle for about 50 ft (15.2 m). At that point the brakes were applied to the vehicle causing the panel to slide off the hood onto the ground in front of the vehicle. Application of the brakes also caused the vehicle to begin a yawing motion. When the panel and post were hit by the front of the vehicle the panel dug into the soil, resisting vehicle motion. This tripped the vehicle, and it rolled two times.

Analysis shows that the rollover in test 11 was initiated during impact with the post and was therefore what may be termed repeatable. On the other hand, rollover in test 20A was caused by events which occurred after impact, i.e., the panel tripped the vehicle after hitting the ground. One can only speculate as to the probability of such an occurrence; however, it is believed to be very low. It is noted that tests 20 and 20A were very similar except the impact speed was higher in test 20. The vehicle did not roll in test 20.

Although it did not occur, the vehicle appeared to be near rollover in test 4. After impact the vehicle began to yaw and roll. Then the cable guidance applied a steer correction which stabilized the yaw and roll motions and apparently prevented rollover.

Careful consideration should be given to off-center impacts in future sign and luminaire support tests. It is likely that there are vehicle-test article combinations for which rollover would be a possibility, especially for high-speed impacts. A small vehicle with a short wheel base and relatively small mass moments of inertia is especially suspect when impacting a system which produces a change in momentum between 750 lb-sec (3336 N-s) and 1100 lb-sec (4893 N-s).

III-C-2. Adherence to FHWA Notice N5040.20 (13)

From Table III-5 it can be seen that, in general, the crash test results validated the guidelines presented in the subject Notice with regard to small sign supports. Disagreement was found in three instances. First, the 6 lb/ft (8.9 kg/m) experimental billet steel U-post met AASHTO performance criteria (test 21) but was not acceptable by the Notice. Second, the 6 lb/ft (8.9 kg/m) rail steel U-post also met AASHTO criteria (tests 20, 20A, 3636-1, and 3636-3) but was not acceptable by the Notice. Third, the 2½ in. (6.35 cm) diameter standard steel pipe did not meet AASHTO criteria (test 11) but was acceptable by the Notice.

These differences are due primarily to an assumption made by FHWA in arriving at limiting plastic section moduli. It was assumed that the impact resistance, and hence the impact severity, of a base bending post was directly related to the static strength of the post material. This meant that the limiting modulus for a given post was inversely proportional to the strength of the post. Analysis of the crash tests and laboratory tests of the metal posts showed this to be an invalid assumption.

Toughness or ductility during impact was found to be the key factor in impact severity of base bending posts. Posts which exhibited brittle fracture during impact offered considerably less resistance than those that underwent large deformations and yielding without fracturing. Good correlation was found between impact behavior as measured by Charpy impact tests and as observed in the full-scale crash test results. It was found that posts that fractured during full-scale tests had Charpy fracture energy values below 1600 in.-lb/in.^{2} (2832 cm-N/cm^2), and posts that did not fracture had energy values above 2500 in.-lb/in.^{2} (4425 cm-N/cm^2).

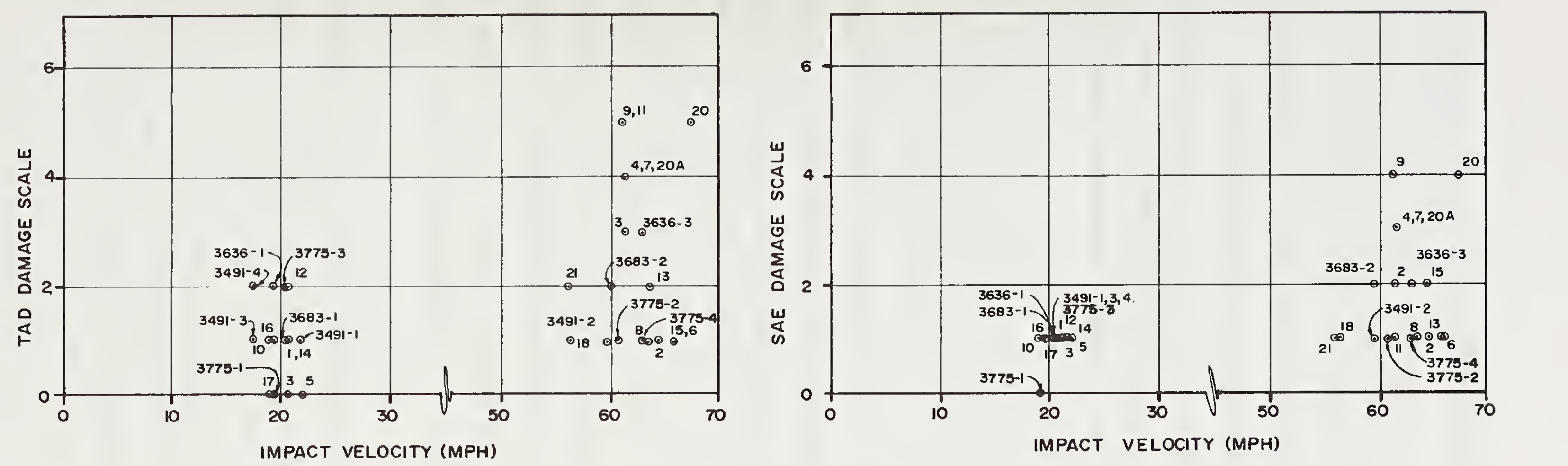
Reference should be made to Appendix B for more details of post material properties and Charpy test results, and to the commentary and recommendations in Section V-B. Surprisingly, it was found that "percent elongation", which is a measure of ductility or the ability to absorb energy under static loading, is not necessarily a measure of a material's ability to absorb energy under impact loading.

III-C-3. Damage to Installation and Vehicle

There are no performance specifications per se regarding damage to either the vehicle or the sign installation for vehicle impact tests. Nonetheless, before selecting a support system, consideration should be given to "typical" damages resulting from "typical" automobile collisions.

Damage to the sign installation after each crash test was noted, and listed in Tables 3 and 4 is what would have been required to restore each installation to its original undamaged configuration. Photos of sign damage are given in Appendix A, Section A-3.

Vehicle damage after each test was assessed according to two nationally recognized rating scales. These were the Vehicle Damage Scale published by the Traffic Accident Data Project (TAD) (18) and the Collision Deformation Classification recommended by the Society of Automotive Engineers (SAE) (19). Both ratings for each test are given in Tables 3 and 4, and a graphical presentation of the relative damage is given in Figure 2. The ordinates of Figure 2 are the last number in the coded scales. In both the TAD and the SAE ratings, the last number represents a measure of vehicle damage. Numbers and letters preceding the last number are codes used to identify the area of the vehicle where the damage occurred. Photos of vehicle damage are given in Appendix A, Section A-3.



Metric Conversions:

1 in. = 2.54 cm
1 lb/ft = 1.489 kg/m
1 mph = 1.609 km/h

TEST ARTICLE DESCRIPTION

TEST NO.	
1,2	4 in. x 4 in. Wood
12	4 in. x 6 in. Wood
8	3X Aluminum Type X
3683-1,2	6X Aluminum Type X
7, 3775-3,4	2.5 in. x 2.5 in. (10 ga.) Square Perforated Steel Tube Post and Stub
3775-1,2	2 in. x 2 in. (12 ga) Square Perforated Steel Tube Post and Stub
3,4	3 lb/ft Billet Steel U-Post
5,6	3 lb/ft Billet Steel U-Post and Stub (Frangible Coupling)
9	6 lb/ft Billet Steel U-Post Back-to-Back
21	6 lb/ft Experimental Billet Steel U-Post Back-to-Back
17,19	2 lb/ft Billet Steel U-Post Braced Leg Design
13	3 lb/ft Rail Steel U-Post
3491-1,2,3,4	3 lb/ft Rail Steel U-Post and Stub (Bolted Connection)
20,20A, 3636-1,3	6 lb/ft Rail Steel U-Post Back-to-Back
18	2.0 in. Dia. Standard Steel Pipe
10,11	2.5 in. Dia. Standard Steel Pipe
14,15,16	2.5 in. Dia. Standard Steel Pipe Post and Stub with Breakaway Collar

Figure 2. Vehicle damage versus impact velocity.

IV. CONCLUSIONS

With the advent of smaller vehicles, the small single post roadside sign installation can no longer be considered an insignificant hazard. While many presently used support systems were proved acceptable by current "change in momentum" performance specifications (3,12), others were shown to be totally unacceptable. Others were what may be termed marginally acceptable. Support systems with breakaway or fracture mechanisms performed much better from a change in momentum standpoint than the base bending or yielding supports.

Of the 22 full-scale tests conducted in this study, and 13 tests by other agencies summarized herein, there were no clear violations of the post-impact trajectory requirements of the specifications (3,12). In essence, intrusion by the test article or intrusion by the vehicle structure into the passenger compartment is not acceptable. Although there were no instances of test article penetration into the passenger compartment per se, the windshield was impacted either by the panel or the hood (as it was pushed back) in several tests. Damage ranged from only cracks to a large dish in the windshield. Breakage occurred in high-speed tests only. It is concluded that the trajectory hazard can be minimized by designing the panel-to-support attachment so that the panel remains with the support after impact. However, for some support systems, the tradeoff for a low change in momentum may be a broken windshield.

Vehicle rollover occurred in two tests, and the test vehicle appeared near rollover in another test. In two of these three cases, this behavior was a consequence of the initial post-vehicle contact point. In all tests, the contact point was either 15 in. (38.1 cm) to the left or the right of the center of the front bumper. In addition to a longitudinal force, this eccentricity of loading produced a twisting moment on the vehicle. Since off-center hits undoubtedly occur in practice, careful consideration should be given to off-center impacts in future sign and luminaire support tests. For a given size post, the potential for rollover increases as vehicle size decreases.

In general, the test results validated the post size limitations of FHWA Notice N5040.20 (13). However, disagreement was found in the case of base bending steel pipe posts and steel U-posts. Limits on pipe sizes were found to be too high, and limits on certain types of steel U-posts were found to be too low. Charpy impact tests were conducted on specimens from the base bending posts to determine why some posts fractured during full-scale tests and others did not. Posts that did not fracture caused considerably higher changes in momentum than comparable size posts that fractured. Based on the Charpy tests, post fracture can be anticipated for a high-speed impact if the fracture energy is less than 2000 in.-lb/in.^{2} (3540 cm-N/cm^2) at 150°F (65.6°C), provided, of course, the post is not larger than the limits determined herein. It was also observed that ductility, as measured by percent elongation in a static load test, is not necessarily indicative of the ability of a material to absorb energy under dynamic loads. It is also noted that wood posts larger in size than permitted by the subject Notice (13) have been shown to meet AASHTO impact specifications (12), i.e., test M-13 of Table 4. However, holes were drilled at the base of these larger posts to influence breakaway (21).

Adequate panel-to-post attachment can be achieved if the fasteners can carry a total tensile and shear working load equal to 40 times the weight of the panel. Tensile and shear load per fastener would equal the total force divided by the number of fasteners.

The following is a breakdown of the crash test performance of widely used single support systems, as well as promising new systems, in terms of AASHTO change in momentum limits (12). *Note that the limiting sizes within the "acceptable" category are not necessarily the maximum sizes that will satisfy the AASHTO specification.* These limits are based on current test results. Future tests, if and when conducted, may show that larger sizes of some designs are acceptable.

ACCEPTABLE (change in momentum less than 750 lb-sec (3336 N-s)):

Steel U-Posts:

- Rail steel U-post with bolted base assembly (15). Post sizes up through 4 lb/ft (6 kg/m) have been crash tested. (Tests 3491-1, -2, -3, and -4)
- Steel U-post with frangible coupling at base (16). Couplings for post sizes of 3 lb/ft (4.5 kg/m) have been crash tested. (Tests 5 and 6)
- Up to 3 lb/ft (4.5 kg/m) full-length rail steel U-post. (Test 13)
- Up to 6 lb/ft (8.9 kg/m) full-length "experimental" billet steel U-posts (two 3 lb/ft (4.5 kg/m) posts back-to-back). (Test 21)

Wood Posts:

- Up to 4 in. x 6 in. (10.2 cm x 15.2 cm) (nominal dimensions), grade 2, southern pine (or equivalent) posts with no breakaway or weakening device. (Tests 1, 2, and 12)
- Up to 6 in. x 8 in. (15.2 cm x 20.3 cm) (nominal dimensions), grade 2, southern pine posts (or equivalent) with holes at base for breakaway mechanism (21). (Test M-13)

Pipe Posts:

- Up to 2 in. (5.1 cm) inside diameter full-length standard steel pipe with no breakaway or weakening device. (Test 18)
- Up to 2½ in. (6.35 cm) inside diameter standard steel pipe with breakaway coupling. (Tests 14, 15, and 16)

Square Steel Tube Posts:

- Up to 2½ in. x 2½ in. (6.35 cm x 6.35 cm), 10 gauge (0.34 cm) square steel tube (17). (Tests 7, 3775-1, -2, -3, and -4)

Aluminum Posts:

- Up to type 3X aluminum full-length post (11). (Test 8)

NOTE: Crash tests of the slip base breakaway design (5,6,7) and the load concentration coupler design (22,23) have shown that these systems can easily meet current performance specifications for single post installations. Most of the referenced tests involved installations with multiple supports much larger than would be typically used in a single post installation. Slip bases are commonly used with standard steel pipe and rolled steel shapes. The load concentration coupler is typically used with rolled steel shapes.

MARGINALLY ACCEPTABLE (change in momentum greater than 750 lb-sec (3336 N-s) but less than 1100 lb-sec (4893 N-s)):

Steel U-Posts

- 6 lb/ft (8.0 kg/m) full-length rail steel U-posts (two 3 lb/ft (4.5 kg/m) posts back-to-back). (Tests 20, 20A, 3636-1, and -2)
- 2 lb/ft billet steel (3 kg/m) vertical post and 2 lb/ft billet steel (3 kg/m) back brace. (Tests 17 and 19)
- 3 lb/ft (4.5 kg/m) full-length billet steel U-post. (Tests 3 and 4)

Aluminum Posts:

- Aluminum type 6X full-length post (11). (Tests 3683-1 and -3)

UNACCEPTABLE (change in momentum above 1100 lb-sec (4893 N-s)):

Steel U-post:

- 6 lb/ft (8.9 kg/m) full-length billet steel U-posts (two 3 lb/ft (4.5 kg/m) posts back-to-back). (Test 9)

Pipe:

- 2½ in. (6.35 cm) inside diameter full-length standard steel pipe. (Test 11)

V. COMMENTARY AND RECOMMENDATIONS

V-A. AASHTO Impact Performance Specifications (12)

Questions often arise as to the adequacy of the AASHTO impact performance specifications for sign and luminaire supports, specifically the change in momentum limits (see Section III-B-1). Many feel that limits are too restrictive, i.e., they are too low.

To properly discuss the Specifications, implications of the momentum limits need to be amplified. Stated another way the limits imply that the change in velocity of a 2250 lb (1020 kg) vehicle striking a sign post(s) should not exceed 10.7 mph (17.3 km/h), but desirably does not exceed 7.3 mph (11.8 km/h). The 10.7 mph (17.3 km/h) value was based on data which showed that an unrestrained occupant that impacted the instrument panel or dashboard of an automobile at more than approximately 10 mph (16.9 km/h) could be expected to sustain disabling injuries. These data were developed for vehicles having little or no interior occupant cushioning or restraint devices. Recent advancements in restraint systems, interior "packaging" of the occupant, and general crashworthiness of vehicles have undoubtedly raised the critical occupant impact velocity, or the critical vehicle velocity change. On the other hand, the trend toward smaller vehicles continues, and predictions are that a significant portion of the future vehicle population will weigh 2000 lb (908 kg) or less. For a given size post and impact speed, momentum change can be expected to increase as the vehicle size decreases. Increased bumper stiffness and new structural designs may offset this problem somewhat. However, even if the momentum change remained constant, the velocity change would increase. For example, an 1100 lb-sec (4893 N-sec) momentum change for an 1800 lb (817 kg) vehicle means the change in velocity would be 13.4 mph (21.6 km/h), as opposed to a 10.7 mph (17.3 km/h) change for the 2250 lb vehicle (1020 kg). One must also consider the stability factor of the smaller vehicle. For a given size post and impact speed, the potential for spinout and rollover will probably increase as the wheel base and inertia properties decrease. The problem should also be viewed from an energy management standpoint.

For impact speeds of 20 mph (32.2 km/h) and 60 mph (96.5 km/h) and a 10 mph (16.1 km/h) velocity change, the change in kinetic energy of the vehicle at the higher speed is approximately 3.7 times that at the lower speed. Most of the kinetic energy loss is absorbed through crush of the vehicle, which means that for equal changes in velocity (or momentum) the vehicle will be damaged considerably more at the higher speed. Systems which cause minimal velocity change at the higher speeds are desirable.

Another factor which must be considered is the economic impact of the Specifications. At present there are a number of different economical support systems, at least for signs up to about 30 ft^2 (4.7 m^2) in area, that satisfy the Specifications. If the change in momentum limits were lowered some of these systems might be unacceptable, in which case it would be necessary to use more expensive designs. The benefits derived from increased safety would have to be weighed against any increased costs.

In view of the aforementioned pros and cons, the present Specifications appear to be a reasonable compromise and reflect an acceptable balance between benefits (safety) and costs, at least for the immediate future. They should be reviewed periodically as the state of knowledge advances, and revised as warranted.

It is recommended that the current "change in momentum" limits be restated in terms of "change in vehicle velocity" limits, viz., "Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 2250 lb (1020 kg) vehicle, or its equivalent, striking a sign support(s) at velocities from 20 mph to 60 mph (32 km/h to 97 km/h) does not exceed 10.7 mph (17.3 km/h), but desirably does not exceed 7.3 mph (11.8 km/h)." By so doing it is believed that more people would understand what is actually required.

V-B. Base Bending Metal Posts

Base bending metal signposts have been used for many years to provide effective, economical supports for roadside signs. Their continued use is anticipated. However, analysis of the tests presented herein clearly shows that more attention must now be given to the properties of these posts and the limiting sizes which should be permitted.

A base bending metal post is defined as one having no built-in breakaway or weakened design. Systems in this category include full length steel U-posts (tests 3, 4, 9, 13, 17, 19, 20, 20A, 21), aluminum X-posts (tests 8, 3683-1, 3683-2), and standard steel pipe posts (tests 10, 11, 18). For successful impact performance the post must bend and lay down and/or fracture without causing an excessive change in vehicle velocity. Tests have shown that posts that fracture offer much less impact resistance than posts of equal size that bend and lay down, especially for high-speed impacts.

Impact behavior of several widely used base bending metal posts has been determined in the study reported herein. Two questions arise, however. First, what material specifications are needed to insure that a post will exhibit a brittle failure or fracture? Secondly, what is the limiting size of a given shaped post to avoid excessive changes in vehicle velocity?

Initial attempts were made to relate the likelihood of post fracture with the ductility of the post material as measured by percent elongation in a static test. This proved unsuccessful. Standard Charpy impact tests (ASTM E23-72) were then conducted on specimens taken from the base bending posts. The results are presented in Appendix B. These data indicate that a post will fracture in high-speed impacts if the fracture energy is less than 2000 in.-lb/in.^{2} (3540 cm-N/cm^2) at 150^{o}F (65.6^{o}C), provided, of course, the post is not excessively large in size. It is therefore recommended that this be the limiting fracture energy value for those base bending systems which depend on material fracture to satisfy AASHTO impact performance criteria.

FHWA Notice N5040.20 (13) set forth criteria whereby size limits could be determined for a given type base bending post. The criteria were based on a limiting plastic section modulus. As discussed in Section III-C-2, the crash tests showed the criteria were conservative in some cases (a larger post acceptable) and unconservative in others (post size permitted too large). Attempts to amend these criteria have not been successful, i.e., no specific measure or criterion has been found whereby safe size limits can be determined with confidence without crash test data. This was not totally unexpected since the impact behavior of a base bending post depends on a number of complex variables, such as its cross-sectional shape, mechanical properties, chemical properties, and its energy absorption capabilities under dynamic loading. An effort to develop a finite element computer model to simulate the base bending post during impact, utilizing nonlinear geometric and material properties, was only partially successful. Until a more reliable methodology or criterion is developed, full-scale crash testing appears to be the only means available to accurately evaluate the impact behavior of a base bending sign.

V-C. Embedment Conditions

For the tests reported herein, the posts were embedded either directly or through a concrete footing in a relatively dry soil that closely approximated the properties of the soil recommended in TRB Circular 191 (3). It is a low-cohesive base material with a strength probably higher than most roadside soils. What then, if anything, can be inferred from these tests about probable impact behavior of the posts in other soils?

Base bending posts (see Section V-B for systems in this category) - It is conjectured that base bending posts that satisfied AASHTO performance specifications in the test soil will perform satisfactorily when embedded in most roadside soils. Impact resistance of these posts should decrease with decreasing soil strength since the posts are more likely to be pulled out of the soil. It can also be inferred that impact behavior of a base bending post will not, in general, be adversely affected by depth of embedment, provided (1) the post did not pull out in the test, and (2) the post met the AASHTO performance specifications. On the other hand, a base bending post should be embedded no deeper than necessary for environmental loads.

Special metal post designs - Three systems have unique design features, namely, the bolted base U-post system (tests 3491-1, -2, -3, and -4), the perforated, square steel tube system (tests 7, 3775-1, -2, -3, and -4), and the steel U-post with a frangible coupling (tests 3 and 4). All three systems employ a signpost-stub combination, and each has a built-in fracture mechanism. Although these systems will likely perform better in a stiffer soil, their impact behavior is not believed to be overly sensitive to soil conditions. The square steel tube system has been in use for several years throughout the country, and there is no evidence of adverse behavior due to soil conditions.

Wood posts - A relatively stiff soil or concrete base is desirable for embedment of a wood post since the post must fracture to minimize impact resistance. However, a number of states use wood posts embedded in varying soil types, and there is no evidence to indicate that their impact behavior is adversely affected by soil conditions.

Breakaway designs - Included in the breakaway category are slip-base designs (6,7), breakaway pipe-collar design (see tests 14, 15, and 16), and the load concentration coupler (22,23). With few exceptions, all such designs have been tested and are installed in the field with concrete footings. Actuation of these breakaway mechanisms is believed to be sensitive to base movement. Unless and until future developments prove otherwise, continued use of a concrete footing seems warranted.

APPENDIX A. TEST DETAILS

A. TEST DETAILS

This appendix contains a description of the test vehicle, design details of the test article, and installation details for each of the 22 tests. Also presented are results from the accelerometer measurements and photographic coverage of before, during, and after scenes of each test. Appendix B contains physical and chemical properties of the sign supports. Appendix C contains a description of the properties of the soil at the test site. Appendix D contains a description of the data acquisition systems.

As specified by AASHTO (12), satisfactory impact performance of a sign installation must be demonstrated at speeds from 20 mph to 60 mph (32 km/h to 97 km/h). As a consequence, most of the support systems evaluated in the test program were impacted at both 20 mph (32 km/h) and 60 mph (97 km/h). In some cases, however, it was evident as a result of completed tests that low-speed impacts were more critical for some systems while the opposite was true for others. For example, after low- and high-speed impacts with steel U-posts, it was clear that the change in momentum was higher at the higher speeds. Only a high-speed test was conducted on the square steel tube design since tests by others indicated satisfactory performance at low speeds (see Table B-6 of Reference 1).

A-1. Test Vehicles

The test vehicles consisted of 1971-1973 Chevrolet Vegas weighing approximately 2,250 lb (1022 kg). Figure 3 contains photographs of a 1972 Vega. Design differences between the 1971-1973 models were very minor. Figure 4 contains typical dimensions of the 1971-1973 Vegas used in the crash tests.

Damage to the vehicle after each test is given in subsequent sections of this appendix. In some cases the same vehicle was used in two tests. This was done only when the initial test caused minor damage to the vehicle.

(a) TOP VIEW

(b) SIDE VIEW

Figure 3. 1972 Chevrolet Vega.

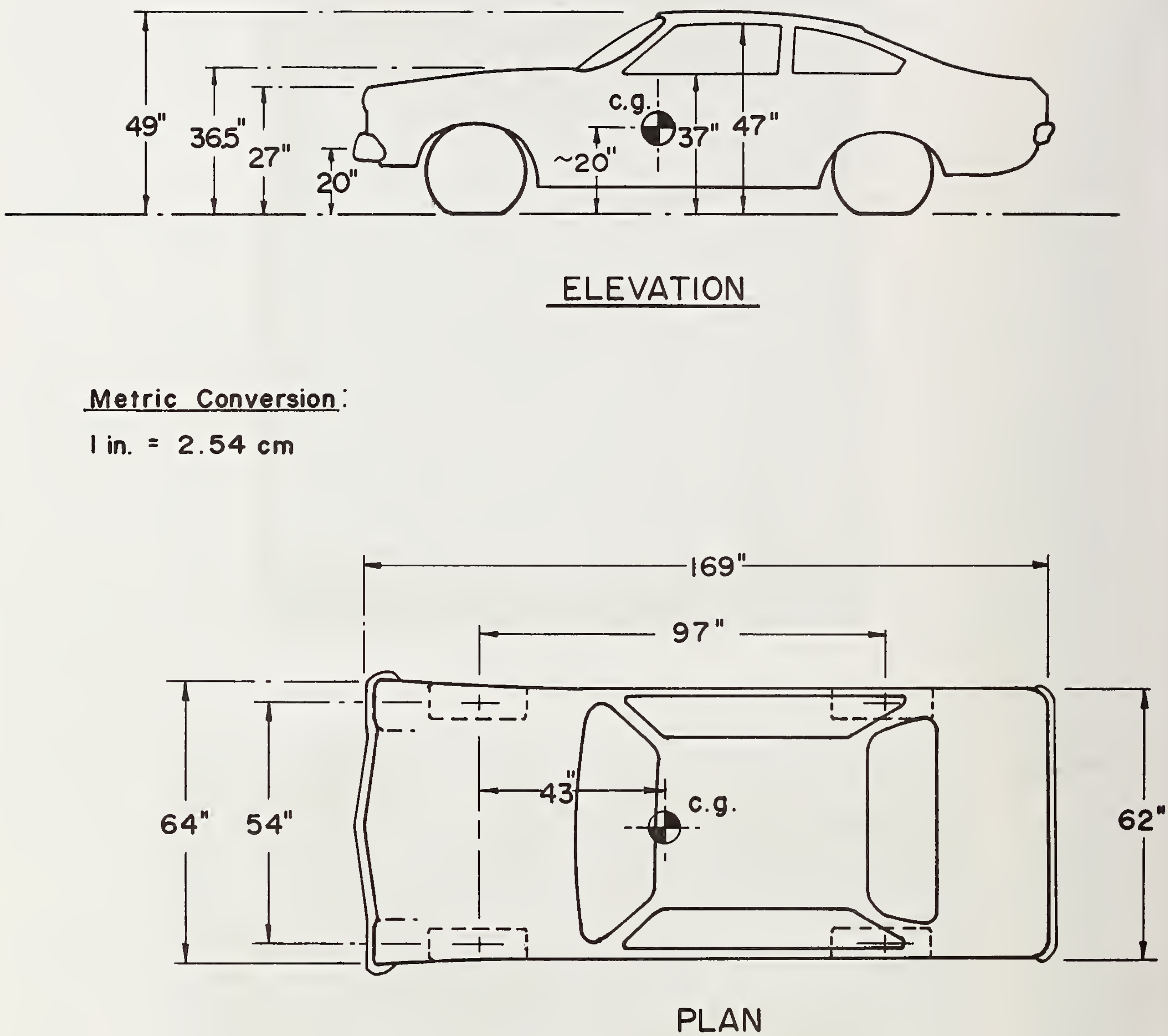


Figure 4. Typical dimensions of 1971-1973 Chevrolet Vega.

A-2. Design and Installation Details of Test Articles

This section contains a comprehensive description of test article details and methods of installation. An effort has been made to show what is typically required to install a given support system in terms of manpower and equipment.

Table 8 contains a summary of the design and installation details of the 22 test articles. Physical and chemical properties of the sign supports are given in Appendix C.

As noted in Table 8, some posts were embedded by a "drill and backfill" method. In those cases a powered auger with a 16 in. (40.6 cm) diameter bit was used to drill the hole. Sign panel dimensions and fastener details are given in Figure 5. Aluminum sign panels, approximately 0.1 in. (0.25 cm) thick, were used in the tests. Note that two panel sizes were used, 24 in. (61 cm) by 30 in. (76.2 cm) and 36 in. (91.4 cm) by 48 in. (121.1 cm). The number of panel sizes was limited to two to keep the number of test variables as small as possible. Consequently, the post used in a given test may be overdesigned or too large for the panel selected. However, it is believed that the panel size is typical in most cases. As a matter of interest, most states do not stock a wide variety of post sizes. To do so results in added inventories and more attention to detail on the part of maintenance forces. As a consequence, many signposts are overdesigned for the panel sizes they are supporting.

Specific comments and details relevant to the various design types follow.

A-2-1. <u>Wood Post</u>

Shown in Figure 6 is the installation of a 4 in. by 4 in. (10.2 cm by 10.2 cm) wood post. The post was placed in a 16 in. (40.6 cm) diameter hole and backfilled. As shown, a pneumatic tamper was used to tamp the soil around the post. This same procedure was followed in other cases where "drill and backfill" was the method of embedment. Figure 7 shows how the installation

Table 8. Test article details.

TEST NO.	POST TYPE AND SIZE	STUB TYPE AND SIZE	METHOD OF EMBEDMENT	DEPTH OF EMBEDMENT (ft)	PANEL AND FASTENER CONFIGURATION (See Figure A-3)	PANEL-TO-POST HARDWARE	SPECIAL DETAILS
1,2	Wood - Southern Pine 4 in. x 4 in. (Actual Size)	None	Drill and Backfill	4.0	I	Three 3/8 in. Grade 5 Steel Bolts and Nuts; Six Flat Washers	None
3,4	Steel (Billet) U-Post 3 lb/ft	None	Driven	3.5	II	Two 3/8 in. Grade 5 Steel Bolts and Nuts; Four Flat Washers; Two 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	None
5,6	Steel (Billet) U-Post with Frangible Coupling 3 lb/ft	Steel (Billet) U-Post 3 lb/ft	Driven	3.08	II	See Figure A-12. Two 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	See Figures A-10 through A-13.
7	Square Steel Perforated Tubing 2.5 in. x 2.5 in. (10 ga)	Square Steel Tubing 3.0 in. x 3.0 in. x 0.1875 in.	Driven	2.92	II	Two 3/B in. Grade 5 Steel Bolts and Nuts; Four Flat Washers	None
B	Aluminum Type X 3X	None	Drill and Backfill	3.5	II	Two 3/8 in. Grade 5 Steel Bolts and Nuts; Four Flat Washers; Two 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	None
9,21	Steel (Billet) U-Post Back-to-Back 6 lb/ft (Two 3 lb/ft Posts)	None	Drill and Backfill	4.0	III	Three 3/8 in. Grade 5 Steel Bolts and Nuts; Six Flat Washers; Three 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	See Figures A-8 and A-9 and Text for Post-to-Post Bolt Pattern.
10,11	Standard Steel Pipe 2.5 in. Dia	None	Drill and Backfill	4.0	III	See Figures A-19 and A-20.	See Figure A-18 and Text for Anti-Twist Plate.
12	Wood - Southern Pine 3.5 in. x 5.5 in. (Actual Size)	None	Drill and Backfill	4.0	III	Three 3/B in. Grade 5 Steel Bolts and Nuts; Six Flat Washers	None
13	Steel (Rail) U-Post 3 lb/ft	None	Driven	3.5	II	Two 3/8 in. Grade 5 Steel Bolts and Nuts; Four Flat Washers	None
14,15, 16	Standard Steel Pipe with Breakaway Collar 2½ in. Dia	Standard Steel Pipe 2½ in. Dia	Concrete Footing	See Figure A-22	IV	See Figures A-19 and A-20.	See Figures A-22, A-23, and A-24 and Text.
17,19	Steel (Billet) U-Post and Back Brace 2 lb/ft Post 2 lb/ft Brace	None	Driven	See Figure A-15	II	Two 5/16 in. Grade 5 Steel Bolts and Nuts; Four Flat Washers; Two 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	See Figures A-15, A-16, and A-17.
1B	Standard Steel Pipe 2.0 in. Dia	None	Drill and Backfill	4.0	II	See Figures A-19 and A-20.	See Figure A-18 and Text for Anti-Twist Plate.
20,20A	Steel (Rail) U-Post Back-to-Back 6 lb.ft (Two 3 lb/ft Posts)	None	Drill and Backfill	4.0	III	Three 3/8 in. Grade 5 Steel Bolts and Nuts; Six Flat Washers; Three 2 in. x 4.5 in. x 0.125 in. Aluminum Backup Plates	See Figures A-8 and A-9 and Text for Post-to-Post Bolt Pattern.

Metric Conversions: 1 in. = 2.54 cm
1 ft = 0.305 m
1 lb/ft = 1.489 kg/m

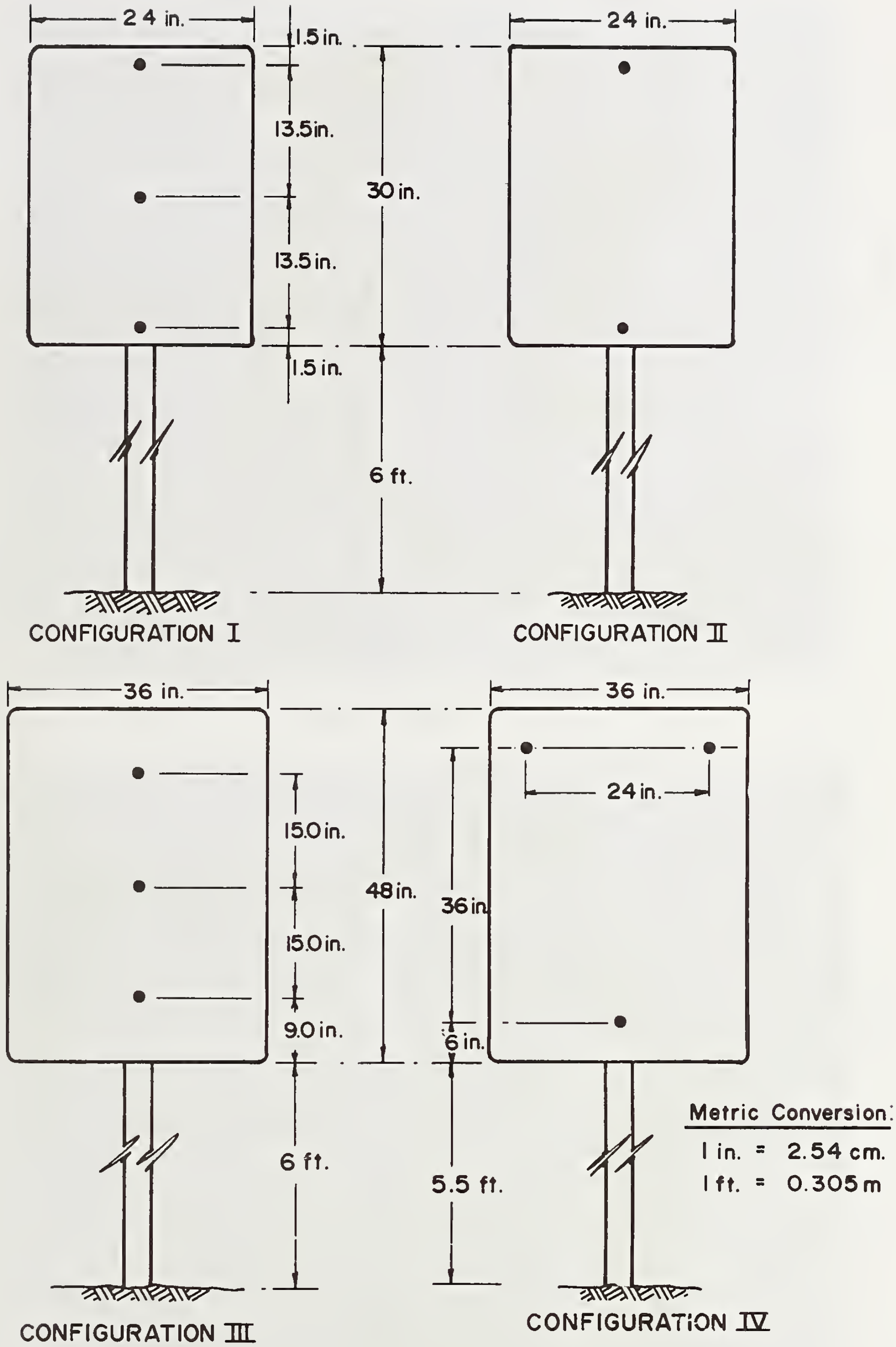


FIGURE 5 . PANEL SIZE AND FASTENER DETAILS.

(a) BACKFILLING

(b) TAMPING

Figure 6. Wood post installation procedure.

(a) TESTS 1 AND 2

(b) TEST 12

Figure 7. Sign system, tests 1, 2, and 12.

looked before tests 1, 2, and 12. In test 12 the post was oriented so that bending took place about the strong axis of the cross section. No breakaway or weakening devices were used in either of the three tests.

A-2-2. Steel U-Posts

Tests 3, 4, 9, 13, 20, 20A, and 21 involved full-length steel U-posts. Of these, there were two basic types of material and two basic designs. In tests 3, 4, 9, and 21, the posts were hot rolled from billet steel. Of these, the material in tests 3, 4, and 9, taken from commercially available stock (14), was considerably more impact resistant than that of test 21. Post material in test 21 was of an experimental nature and was provided by a producer of billet steel U-post (14). Use of the "experimental" posts in test 21 was precipitated by adverse results in test 9.

Posts in tests 13, 20, and 20A, taken from commercially available stock (15), was hot rolled from rail steel. Further discussions of material properties of the steel U-posts are presented in Appendix B.

With regard to designs, the support in tests 3, 4, and 13 consisted of a single 3 lb/ft (4.5 kg/m) post. In tests 3 and 4 the post was driven by hand, and in test 13 it was driven by a gasoline powered unit, as shown in Figure 8. Both methods are commonly used to install these type posts.

As noted in Table 8, aluminum backup plates were used in all of the U-post tests. The plates stiffen the panel-to-post attachment and reduce the tendency of the panel to dish in if the bolts are overtightened. Photos of the installation for tests 3, 4, and 13 are shown in Figure 9. Note the backup plates in part (b) of Figure 9.

Tests 9, 20, 20A, and 21 involved two 3 lb/ft (4.5 kg/m) posts bolted together to form a single back-to-back design weighing 6 lb/ft (9.0 kg/m). Cross-sectional views of the two types of back-to-back posts are shown in Figure 10. Cross-sectional properties and

(a) TESTS 3 AND 4

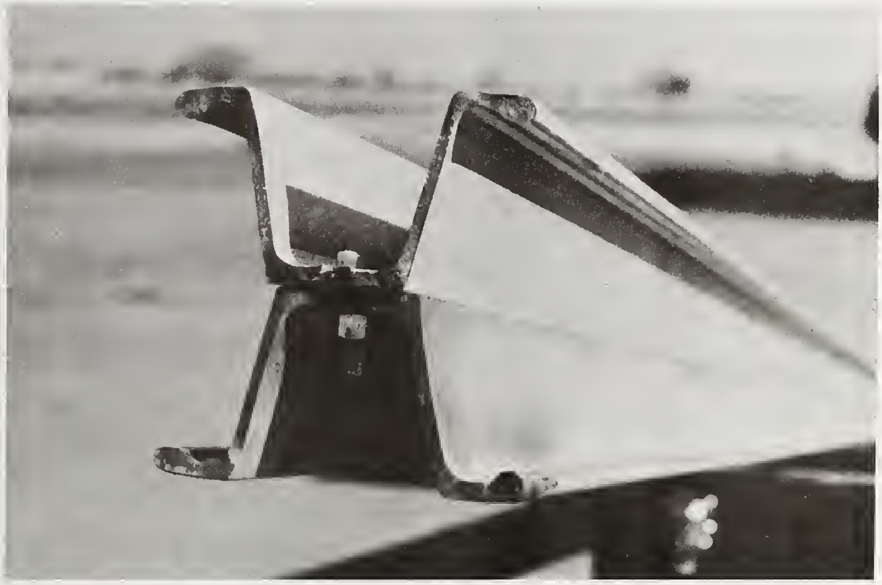
(b) TEST 13

Figure 8. Installation procedure for 3 lb/ft U-post.

(a) REAR VIEW

(b) FRONT VIEW

Figure 9. Sign system, tests 3, 4, and 13.



(a) CROSS SECTION FOR TESTS 9 AND 21 (14)

(b) CROSS SECTION FOR TESTS 20 AND 20A

Figure 10. U-posts back-to-back cross section.

dimensions of these and other size U-posts are given in Appendix D of Reference 1. Shown in Figure 11 are photos of the post-to-post bolt pattern and the completed installation for tests 9, 20, 20A, and 21. Post-to-post bolts were 5/16 in. (0.79 cm) diameter, grade 5, and were spaced on 4 in. (10.2 cm) centers below groundline and on 16 in. (40.6 cm) centers above ground. A lock washer was placed between the nut and the post.

A-2-3. Steel U-Posts with Special Features

Two designs utilizing the steel U-post as a basic concept were crash tested. In the first of these, a frangible cast iron breakaway coupling was evaluated. The coupling is a commercially available patented device (16). Figures 12 and 13 illustrate how the coupling was assembled. First a 3 lb/ft (4.5 kg/m) U-post stub 3.5 ft (1.07 m) in length was driven into the ground approximately 3.08 ft (0.94 m). Then a K-3300 coupling (manufacturer's designation) and two retainer straps are attached to the stub with two 3/8 in. (0.95 cm) grade 5 steel bolts and washers. Finally, the signpost, with panel attached, is bolted to the coupling assembly with two 3/8 in. (0.95 cm) grade 5 stud bolts and washers. In accordance with the manufacturer's recommendations (16), a 4 ft (1.22 m) length of 2 lb/ft (3.0 kg/m) U-post was nested inside the signpost to stiffen the post in the area of impact. It is attached to the signpost with two 3/8 in. (0.95 cm) grade 5 steel bolts and washers. This is shown in Figure 14. Also shown in Figure 14 is a "security fastener" used to attach the panel to the post. Further details of the fastener and assembly details are given in Figure 15. Its intended purpose is to minimize instances of vandalism or theft of sign panels. The security fasteners were used in tests 5 and 6 to evaluate their performance under impact conditions. Shown in Figure 16 is the completed installation. Note the security nut on the back side of the sign.

Tests 17 and 19 involved an installation with a vertical 2 lb/ft (3.0 kg/m) U-post and a 2 lb/ft (3.0 kg/m) U-post back brace.

(a) POST-TO-POST BOLT PATTERN

(b) COMPLETED INSTALLATION

Figure 11. Sign system, tests 9, 20, 20A, and 21.

(a) DRIVING STUB

(b) COUPLING-TO-STUB CONNECTION

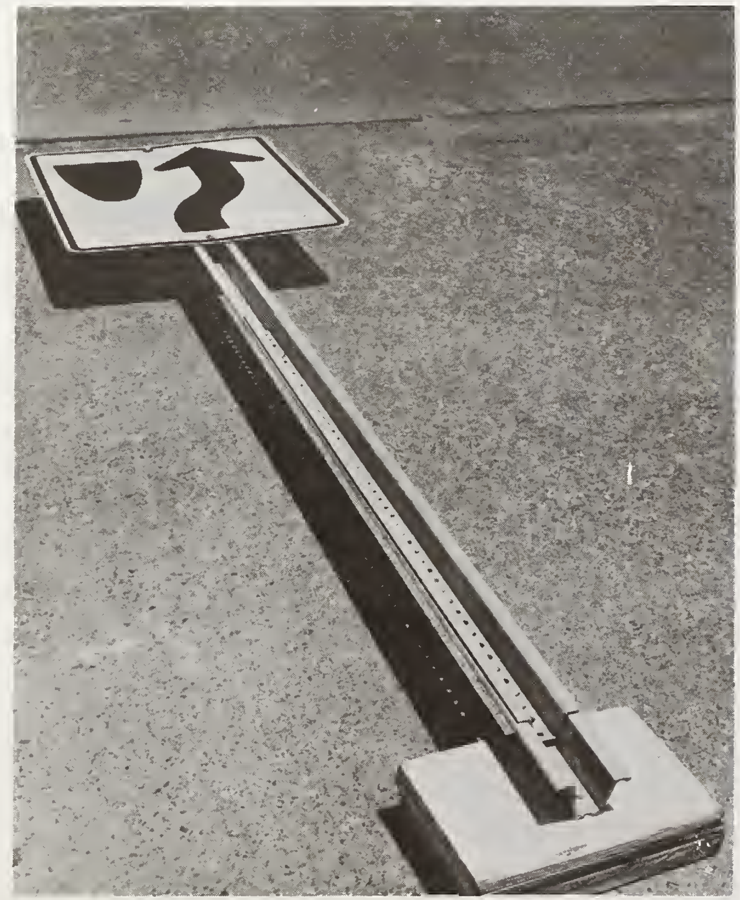
Figure 12. Stub and coupling installation, tests 5 and 6.

(a) POST INSTALLATION

(b) COMPLETED COUPLING

Figure 13. Post installation, tests 5 and 6.

(a) TIGHTENING SECURITY FASTENER



(b) U-POST STIFFENER

Figure 14. Special features, tests 5 and 6.

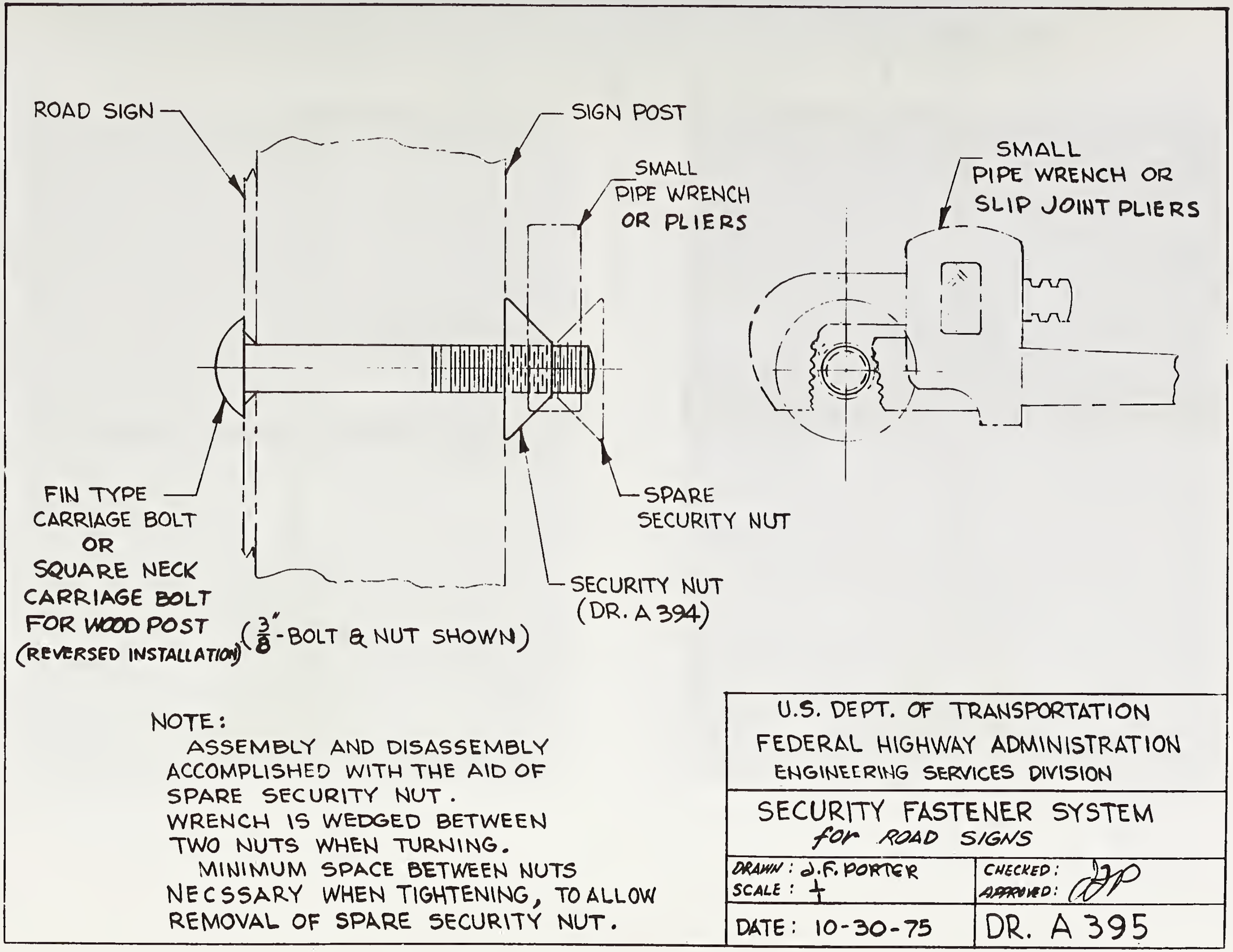


Figure 15. Security fastener details.

(a) REAR VIEW

(b) FRONT VIEW

Figure 16. Sign system, tests 5 and 6.

Details of the system are shown in Figures 17 and 18, and the completed installation is shown in Figure 19. Both the vertical post and the back brace were driven into the ground with a sledge hammer. This system is widely used in Arkansas.

A-2-4. Standard Steel Pipe

Tests 10, 11, and 18 involved full-length standard steel pipe. Tests 10 and 11 involved a 2½ in. (6.4 cm) diameter pipe, and test 18 involved a 2 in. (5.1 cm) diameter pipe. In each test the pipe was embedded in a drilled hole.

A steel anti-twist plate, 4 in. by 4 in. by 0.125 in. (10.2 cm by 30.5 cm by 0.32 cm), was welded to the post 12 in. (30.5 cm) above the bottom of the post. The anti-twist plate can be seen in Figure 20. A pipe clamp casting was used to attach the panel to the post. Details of the clamp are given in Figure 21. Photos of the clamp are presented in Figure 22. Figure 23 shows the completed installations.

A-2-5. Standard Steel Pipe with Breakaway Coupling

Tests 14, 15, and 16 involved standard steel pipe with a "breakaway pipe collar". Details of this system are given in Figure 24. This system is used primarily in Texas.

Installation is accomplished by first pouring a concrete footing with the stub and collar embedded in the concrete. Then, after the concrete has cured, the threaded post with panel attached is inserted and screwed into the collar. Photos of the installation are shown in Figure 25.

As noted in Figure 24, the collar was embedded to within approximately 1.0 in. (2.54 cm) of the top of the footing in tests 14 and 15 and to within approximately 0.25 in. (0.64 cm) in test 16. Also, in tests 14 and 15, the collar was greased prior to embedment so that the concrete would not bond to the collar. It was anticipated that upon impact either the signpost would fracture in the threaded portion at or just above the top of the collar, or, the

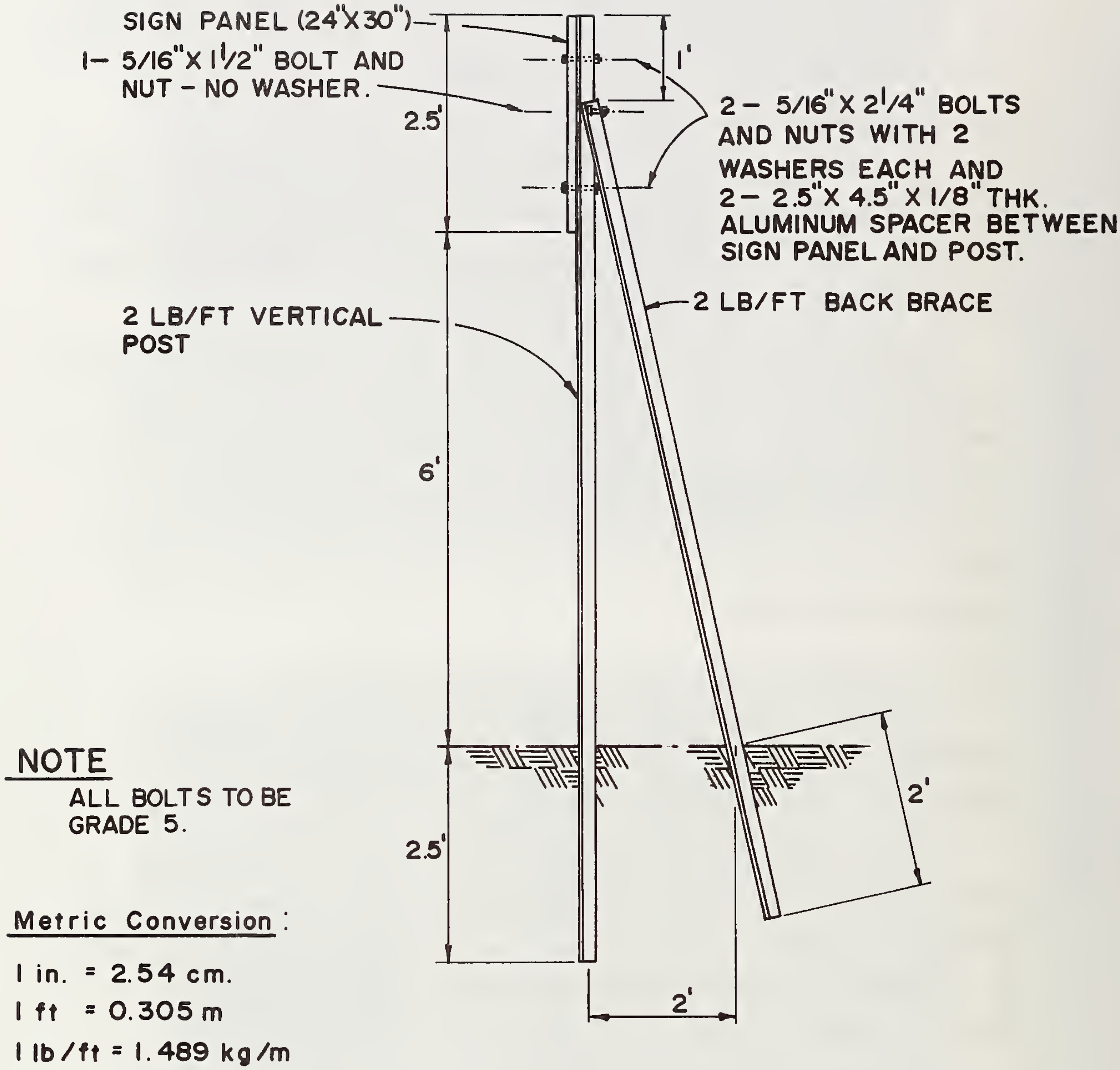
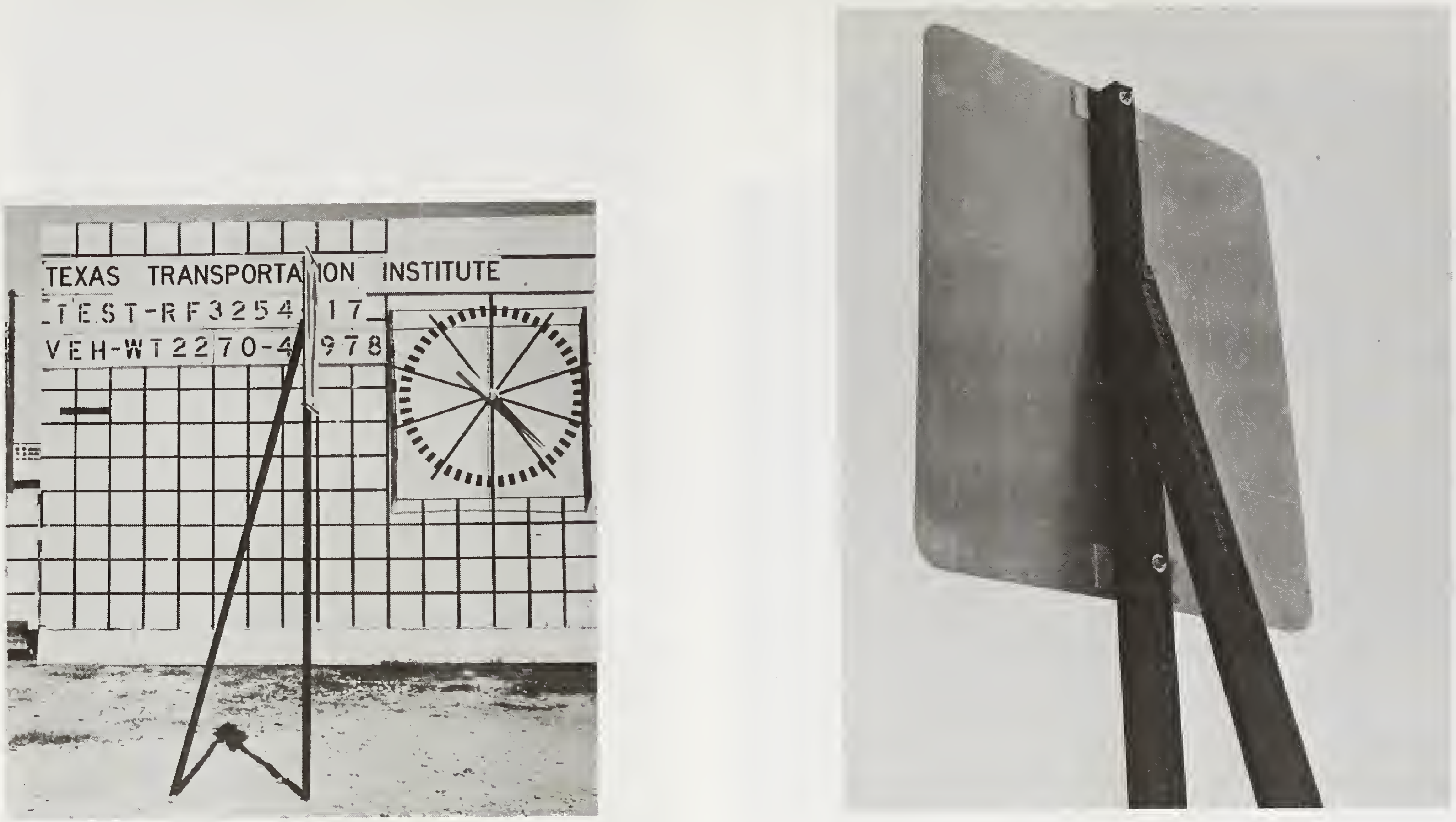


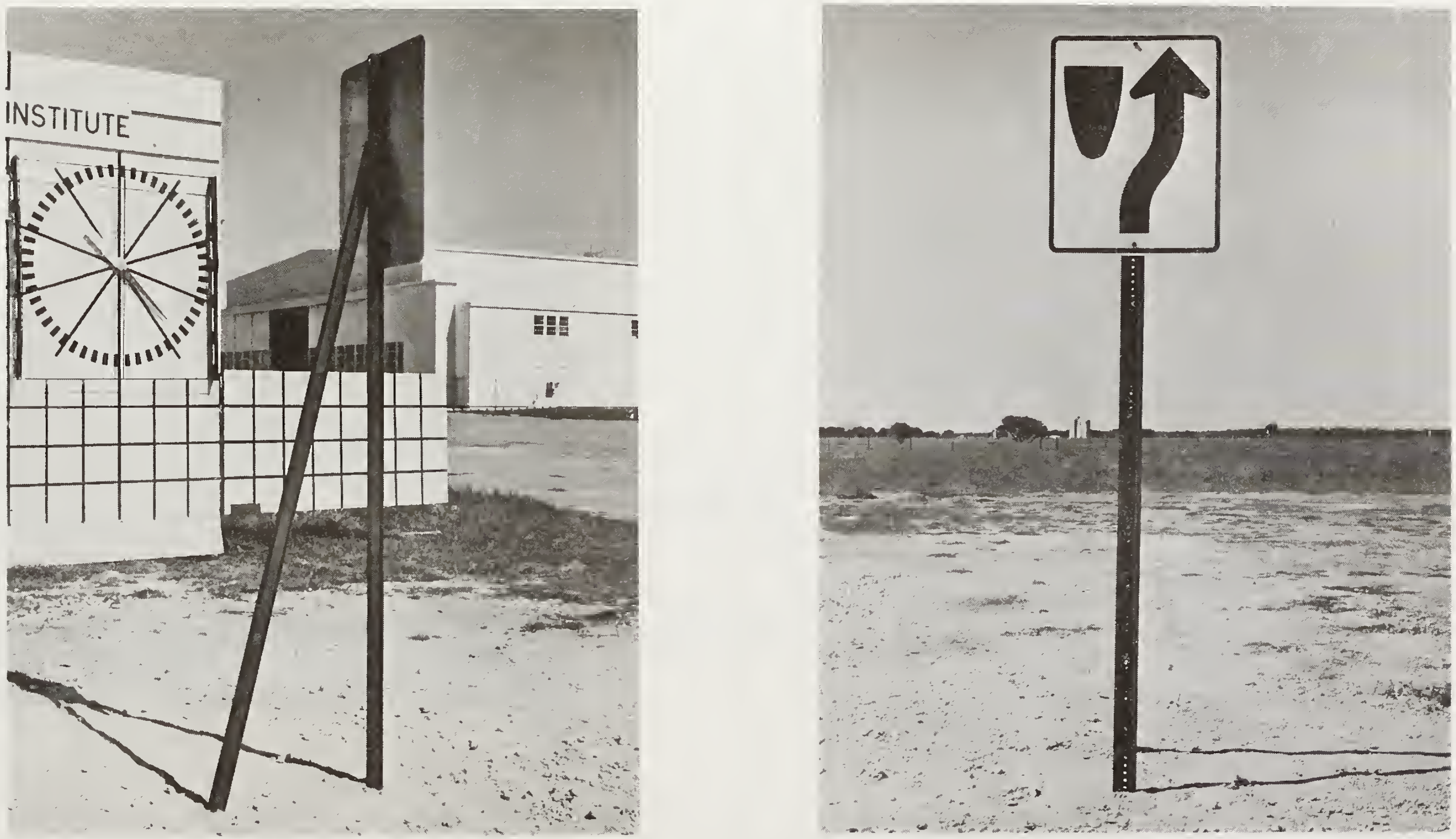
Figure 17. Arkansas braced-leg support system.



(a) SIDE VIEW

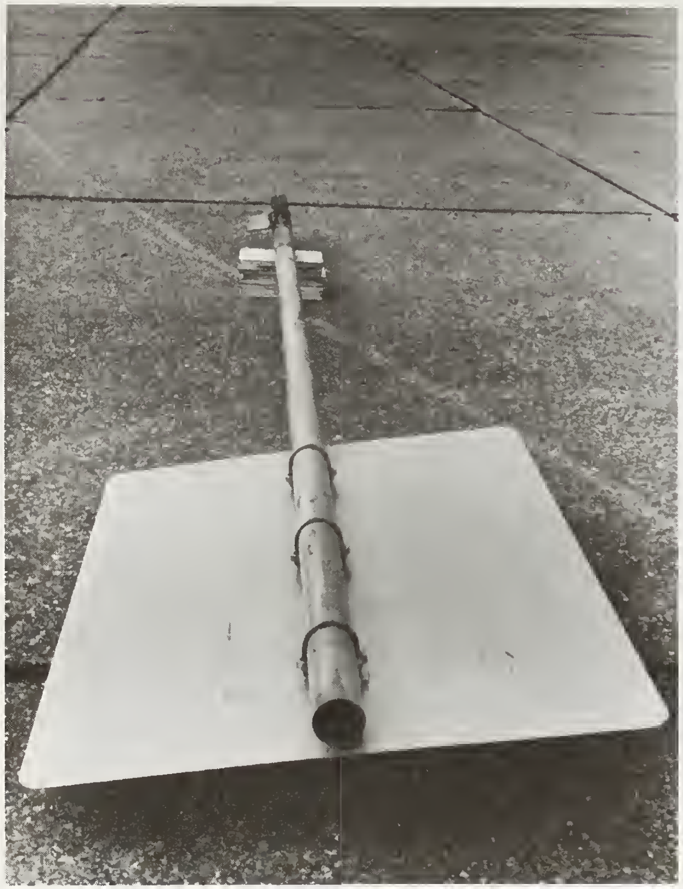
(b) REAR OF PANEL

Figure 18. Installation details, tests 17 and 19.



(a) REAR VIEW (b) FRONT VIEW

Figure 19. Sign system, tests 17 and 19.

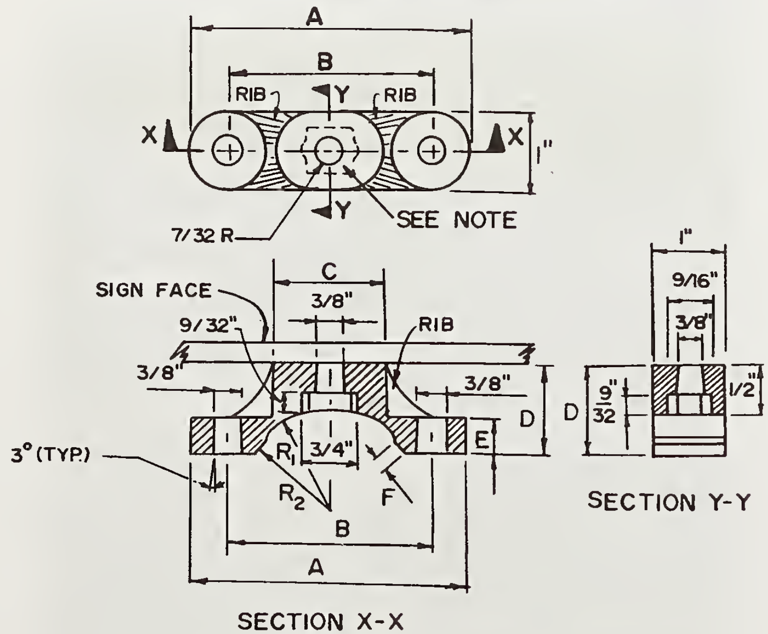


(a) GENERAL VIEW (TESTS 10 AND 11)

(b) CLOSE-UP VIEW

Figure 20. Photos of anti-twist plate, tests 10, 11, and 18.

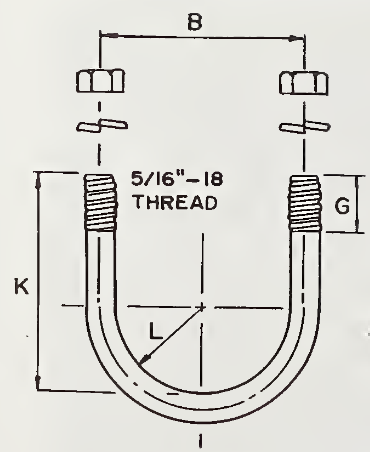
NOTE: SLOT TO HOLD HEAD OF 5/16" SQ. HEAD BOLT. THE BOLT SHALL BE 1" LONG FOR METAL SIGNS AND 1 1/2" LONG FOR PLYWOOD SIGNS, WITH FULL THREAD AND A MEDIUM WASHER. THE HEAD MUST NOT TURN IN SLOT.



PIPE CLAMP CASTING

PIPE CLAMP CASTING SHALL BE ALUMINUM ALLOY A344-T4 OR 356-F.

ALL SIGN MOUNTING CLAMP PARTS NOT MADE FROM ALUMINUM SHALL BE STAINLESS STEEL OR GALVANIZED STEEL IN CONFORMANCE WITH ITEM 422 OF THE STANDARD SPECIFICATIONS.



U-BOLT

U-BOLT TO BE MADE IN ACCORDANCE WITH STANDARD MANUFACTURING PROCEDURE, 9/32" DIA. STOCK IS PERMISSIBLE. AMERICAN STANDARD REGULAR SEMI-FINISHED HEX. NUTS & SPRING LOCKWASHERS.

Metric Conversion:

1 in. = 2.54 cm.
1 ft. = 0.305 m

DIMENSIONS FOR MOUNTING CLAMP

STANDARD PIPE SIZE	A	B	C	D	E	F	G	K	L	R_1	R_2
2"	3 3/4"	2 3/4"	1 1/2	1 1/8"	1/2"	3/16	1"	2 11/16	1 7/32	1 1/4"	1 3/16"
2 1/2"	4 1/4"	3 1/4"	2"	1 1/4"	1/2	1/4"	1"	3 3/16"	1 15/32"	1 1/2"	1 7/16"

FIGURE 21. MOUNTING CLAMP DETAILS

(a) CLOSE-UP OF CLAMP

(b) PANEL ATTACHED TO POST

Figure 22. Photos of pipe clamp casting.

(a) TESTS 10 AND 11

(b) TEST 18

Figure 23. Sign system, tests 10, 11, and 18.

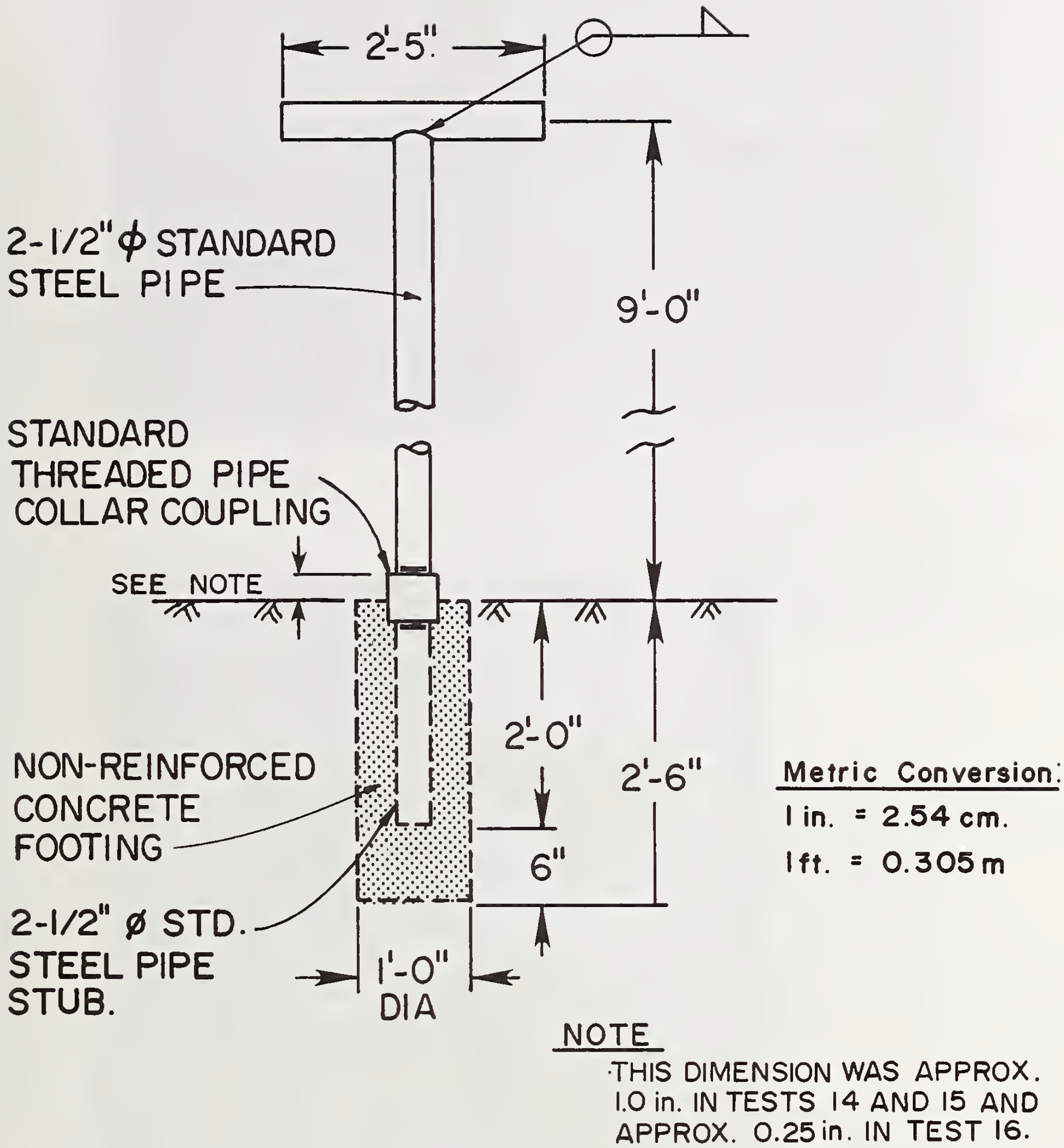


Figure 24. Steel pipe with breakaway coupling, tests 14, 15, and 16.

(a) FOOTING

(b) SIGNPOST

Figure 25. Installation of pipe with breakaway collar, tests 14, 15, and 16.

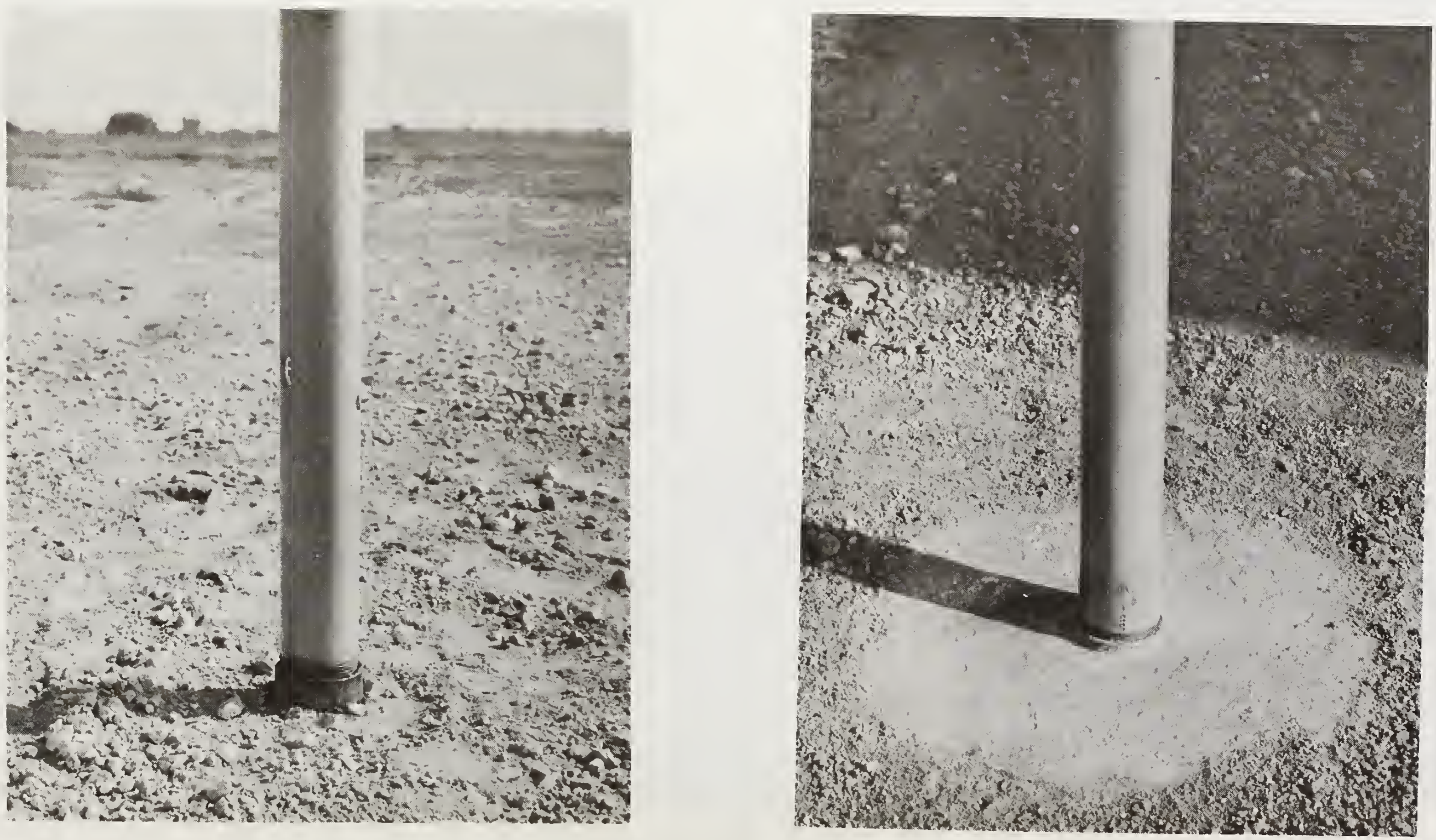
signpost would pull out of the collar, stripping the collar threads. If the post fractured, the remaining threaded part of the signpost could be extracted from the collar. If the post pulled out of the collar, the collar could be removed, if its threads were damaged, and a new collar attached. However, neither of the anticipated failure modes occurred in tests 14 and 15. Failure occurred when the stub fractured just below the collar, and refurbishment would have required replacement of the footing and stub. In test 16 the stub was embedded to within 0.25 in. (0.64 cm) of the top of the concrete (see Figure 24), and the post fractured just above the collar as desired. Refurbishment would have required replacement of only the signpost. Further discussion of the results is given in Section A-3. Photos of the two different bases are shown in Figure 26. Photos of the completed installation are shown in Figure 27. Note that the pipe clamp casting shown in Figure 22 was used to attach the panel to the post.

A-2-6. Square Steel Tubing

Test 7 involved a square telescoping tube design, a commercially available sign support system (17). To install the system, a stub is first driven in the ground into which a signpost is inserted. In this test a 3 in. (7.62 cm) by 3 in. (7.62 cm) by 0.1875 in. (0.48 cm) tube was driven into the ground approximately 35 in. (88.9 cm). Then a 2½ in. (6.35 cm) by 2½ in. (6.35 cm) by 0.135 in. (0.34 cm) perforated signpost, with panel attached, was inserted about 6 in. (15.2 cm) into the stub; and a 3/8 in. (0.953 cm), grade 2, hexhead steel bolt was used for a stub-to-post connection. These steps are illustrated in Figure 28. For smaller post sizes, the manufacturer (17) recommends that a sleeve about 18 in. (45.7 cm) in length be placed over the stub for added stiffness. Figure 29 shows the completed installation.

A-2-7. Aluminum Post

An aluminum "type 3X" post was evaluated in test 8. This post, together with other sizes, is commercially available (11). It is



(a) TESTS 14 AND 15

(b) TEST 16

Figure 26. Base configuration, tests 14, 15, and 16.

(a) REAR VIEW (b) FRONT VIEW

Figure 27. Sign system, tests 14, 15, and 16.

(a) DRIVING STUB

(b) SIGNPOST INSTALLATION

Figure 28. Installation of square steel tube system, test 7.

(a) REAR VIEW

(b) FRONT VIEW

Figure 29. Sign system, test 7.

extruded and has a cross-sectional shape similar to that of the back-to-back steel U-posts. Appendix D of Reference 1 contains the various size posts available and their cross-sectional properties. Figure 30 shows the cross-sectional shape of the type 3X post and the installation of the post. Figure 31 shows the completed installation.

A-3. Test Results

Presented in this section is a description of the test results on a test-by-test basis. Reference should be made to Chapter III for a summary of these results and what they mean in terms of current evaluation criteria.

Data acquisition and data reduction procedures were in accordance with recognized guidelines (2,3). Test results consist of data derived from accelerometer readings, photos of the impact phase, and photos of the damage to the sign installation and the vehicle. Three plots are presented for each test, namely deceleration versus time, change in vehicle momentum versus time, and "free missile travel" versus time. The deceleration-versus-time plot is obtained from the filtered accelerometer signals. Details of the accelerometers are given in Appendix D. Change in momentum is obtained by first integrating the deceleration over a given time interval, which gives the change in vehicle velocity during the interval. Change in vehicle velocity is then multiplied by the vehicle's mass to obtain the change in momentum. Free missile travel for a given period of time is obtained by double integration of the deceleration over that period of time.

Since change in momentum is time dependent, a time duration must be specified for its computation. Current guidelines for determining this duration are as follows (3).

> "For yielding supports (such as base-bending signs) change in vehicle momentum to be used in the acceptance criteria of this section shall be computed on the basis of time integration of the vehicle deceleration signal over a 'duration of the event'. This duration shall be defined as the lesser of the following: (1) time between

(a) CROSS SECTION

(b) INSTALLATION

Figure 30. Aluminum type 3X post shape and installation, test 8.

(a) REAR VIEW

(b) FRONT VIEW

Figure 31. Sign system, test 8.

> incipient contact and loss of contact between the vehicle and the yielding support, or (2) the time for a free missile to travel a distance of 24 in. starting from rest with the same magnitude of vehicle deceleration."

Free missile travel is explicitly determined from measured accelerometer data. "Time between incipient contact and loss of contact between the vehicle and the yielding support" is not so explicit. High-speed film would seem to be the logical means with which this time duration could be determined. However, it is often difficult to ascertain the time that "loss of contact" occurs with precision. In a low-speed impact, the vehicle may bend the post down and travel over it. "Apparent contact" can occur over a relatively large time period, although there may be no appreciable contact forces. In a high-speed impact, the post may wrap around and remain with the vehicle after it has fractured or pulled from the ground. Again, "apparent contact" is still being made with no appreciable contact forces. Compounding the problem is the fact that filtering accelerometer output causes slight phase shifts in the filtered data.

To overcome these difficulties with computation of "contact time", a simple procedure was adopted in which only the accelerometer data were used. In effect, contact time was defined as the duration between initial contact and the time at which the deceleration essentially returned to and remained at zero. Obviously, deceleration does not remain at zero unless the vehicle reaches a constant velocity or comes to a stop. However, in most tests contact was followed by a period where wind drag and rolling resistance were the only forces on the vehicle. These forces decelerate the vehicle at a level which is small in comparison with that caused by contact forces. Subsequent to that period the brakes were applied. Film data was used as a check or backup to insure there were no gross discrepancies in the contact time derived from accelerometer data.

Damage to the vehicle was assessed in terms of two nationally recognized rating scales. These were the Vehicle Damage Scale published by the Traffic Accident Data Project (TAD) (18) and the Collision

Deformation Classification recommended by the Society of Automotive Engineers (SAE) (19).

All tests were conducted with the vehicle impacting the sign installation in a head-on orientation. In each test, impact point on the vehicle was approximately 15 in. (38.1 cm) either to the left or right of the center of the front bumper.

A-3-1. Test No. 1

Table 9 summarizes the results of test 1. Figure 32 contains sequential photos from the high-speed film taken during impact, and Table 10 contains a time-displacement-event summary. Note that upon impact the wood post fractured at or near bumper height and at or near ground level. Also note that the panel and post were rotated down and projected out in front of the vehicle. Figures 33, 34, and 35 contain deceleration, change in momentum, and free missile travel versus time data. Figure 36 shows damage to the sign installation. Restoration would involve the installation of a new post. The panel and hardware were reusable after some refurbishment to the panel. Figure 37 shows the vehicle damage. Vehicle damage was assessed according to the TAD and SAE scales and is given in Table 9.

Table 9. Summary of results, test 3254-1.

Impact Velocity = 21.2 mph

POST DATA			
Type	Wood - Southern Pine, Grade 2		
Size	4 in. x 4 in. (Full Dimensions)		
Embedment Method	Drill and Backfill		
Embedment Depth (ft)	4.0		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1973		
Weight (lb)	2290		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA	Left		Right
Change in Momentum (lb-sec)	495		472
Duration of Event (sec)*		0.204	
Peak Deceleration (G's)	5.01		5.46
Maximum 0.050 Sec Average Deceleration (G's)	2.92		2.62
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-1		
SAE	12FLEN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

*Time of contact

Metric Conversions:

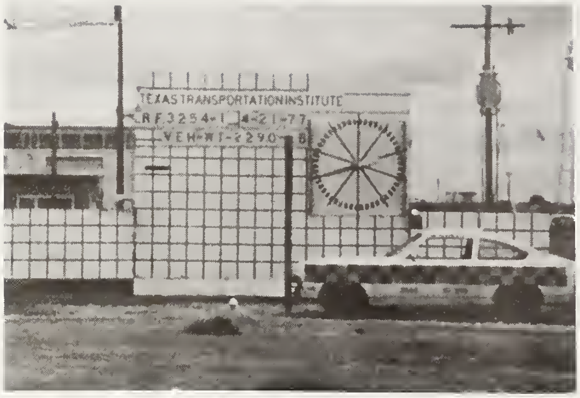
1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

Table 10. Time displacement event summary for test 3254-1.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0	Impact
0.052	1.45	Posts begin to split
0.110	2.86	Post breaks
0.256	6.24	Loss of contact
0.367	8.75	Post hits car bumper
0.412	9.76	Car runs over base post

Metric Conversion:

1 ft = 0.305 m



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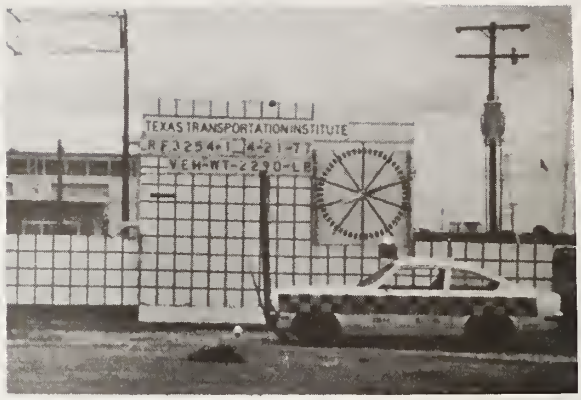

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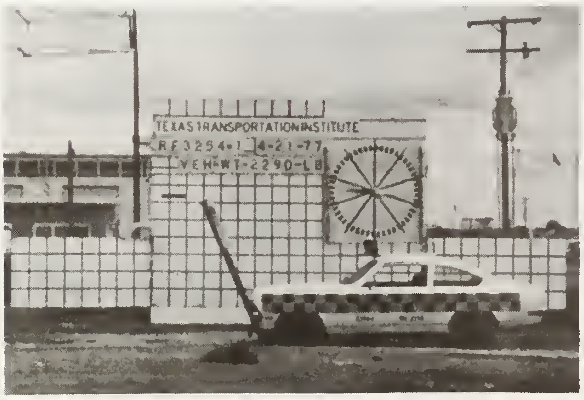

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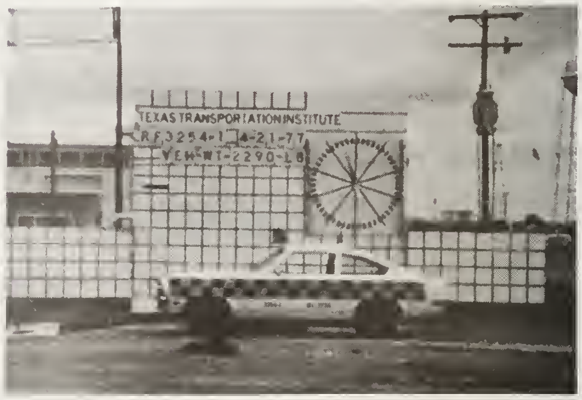

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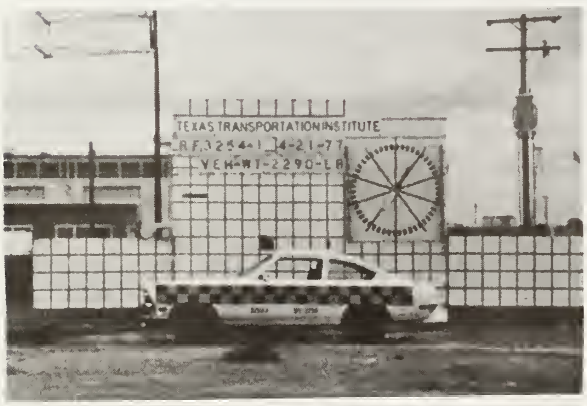
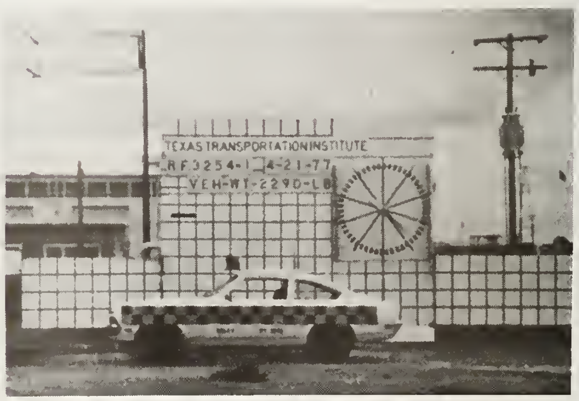


0.367 sec



0.412 sec

Figure 32. Sequential photos, test 1.

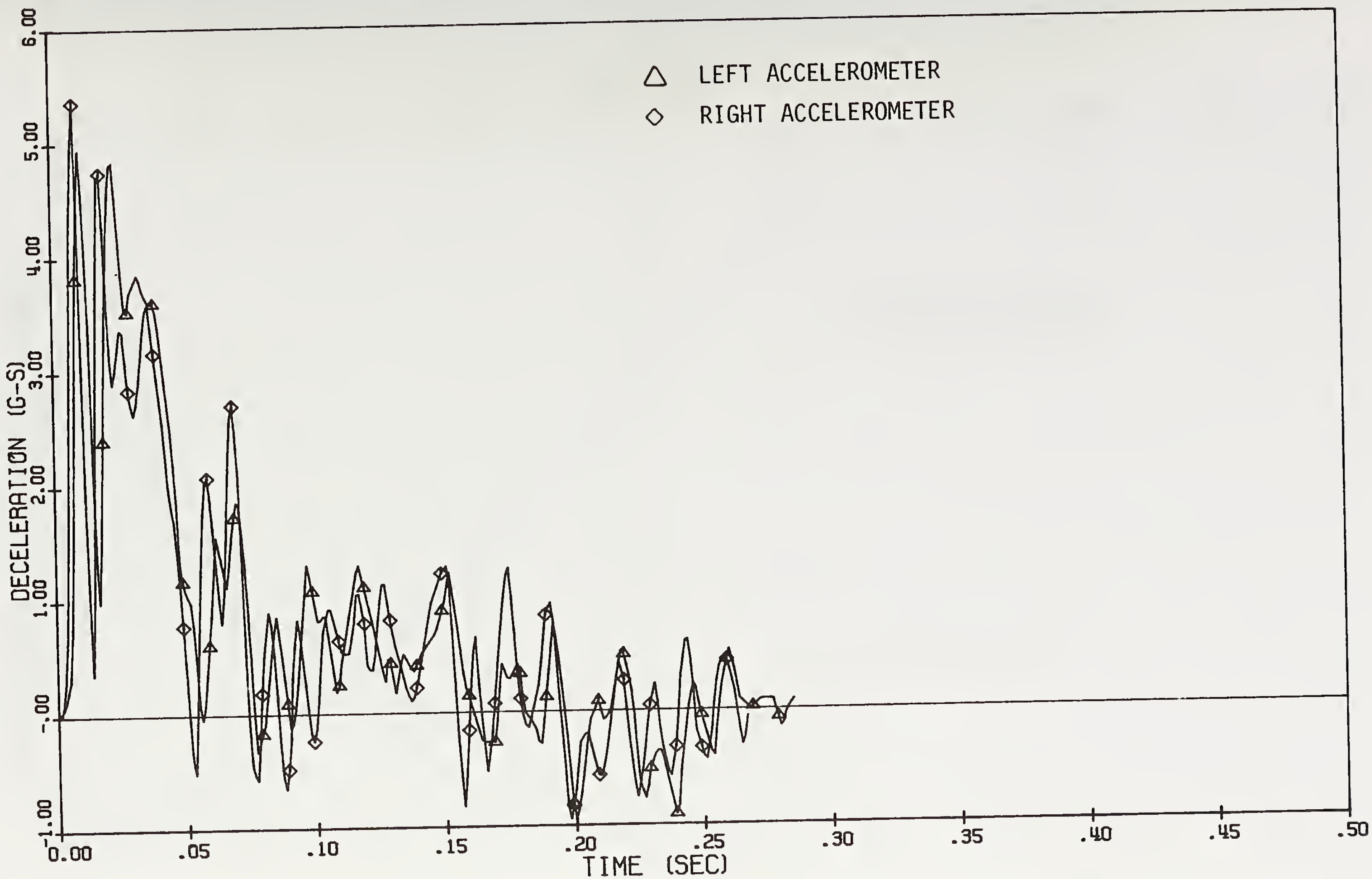


Figure 33. Deceleration vs. time, test 1.

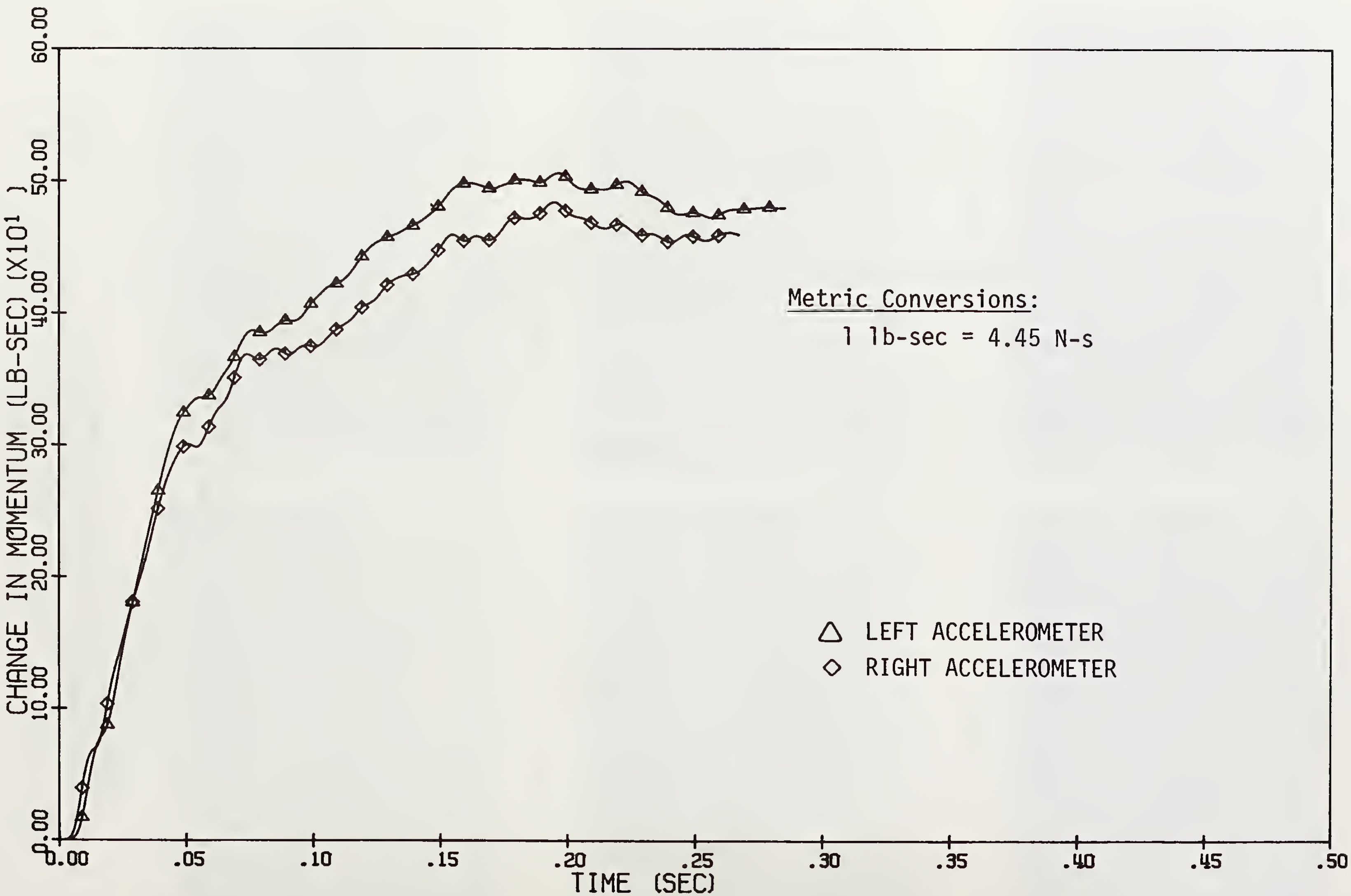


Figure 34. Change in momentum vs. time, test 1.

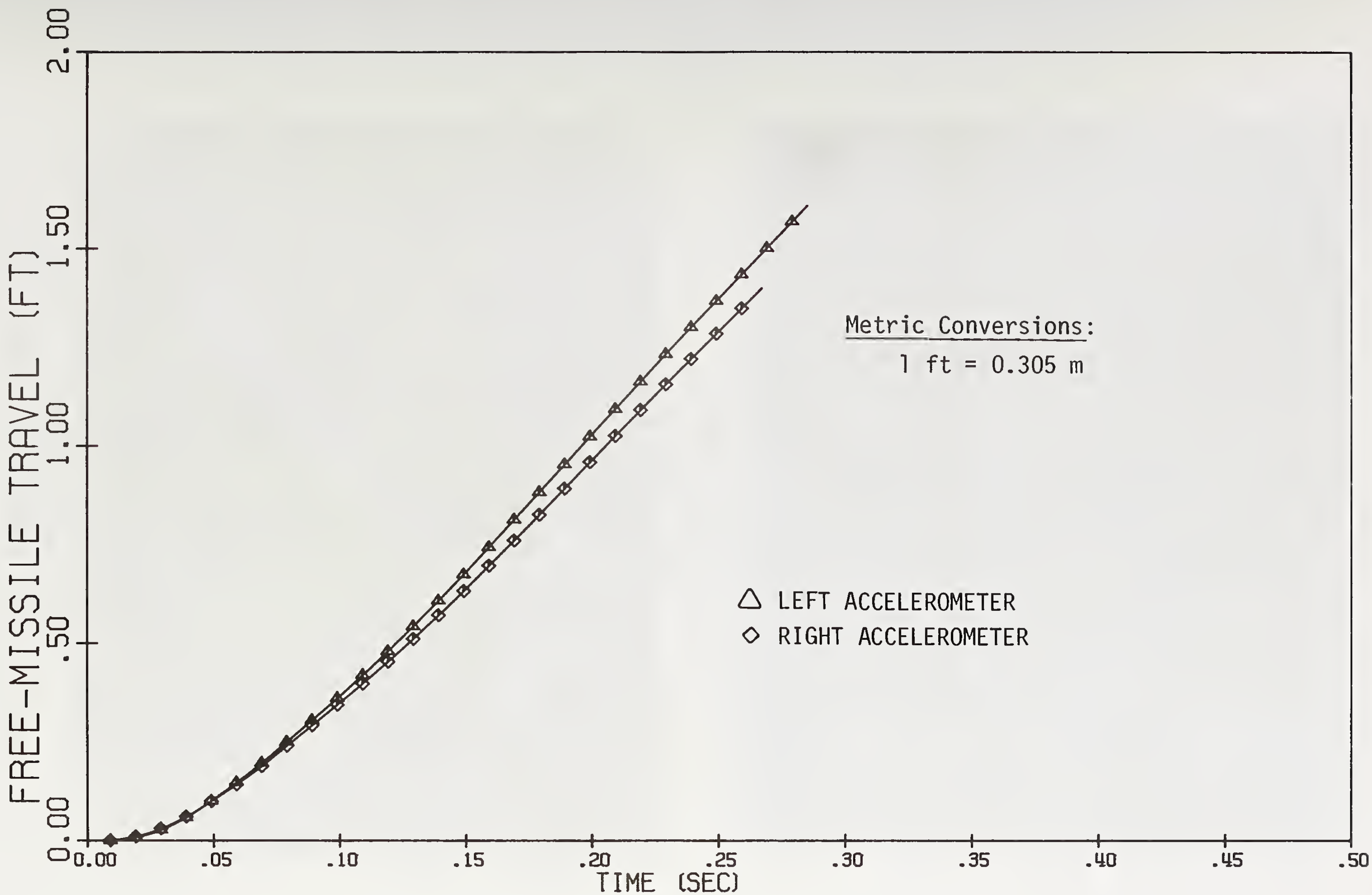
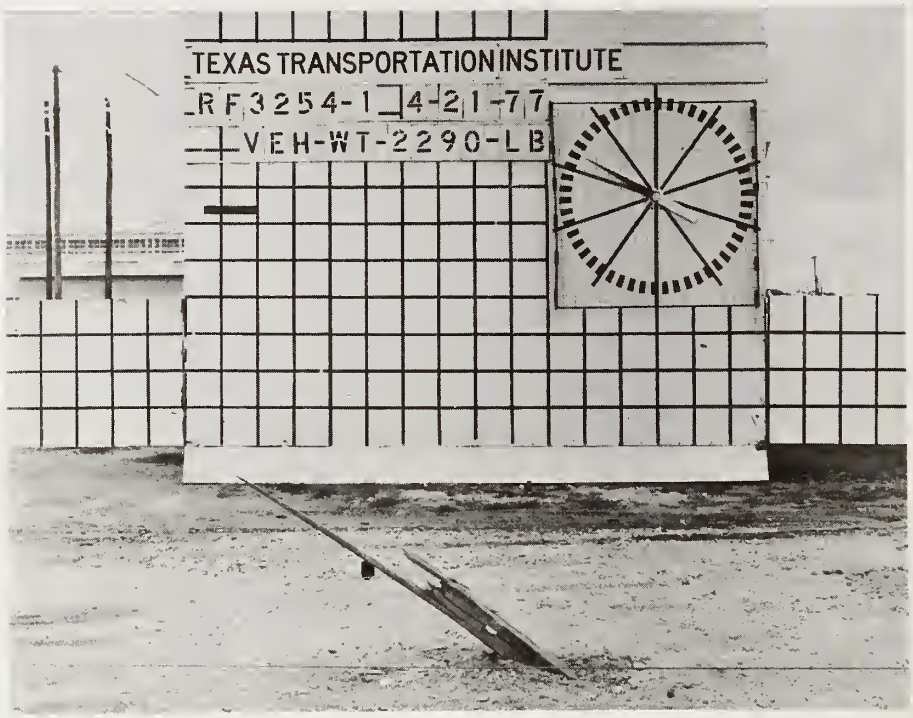
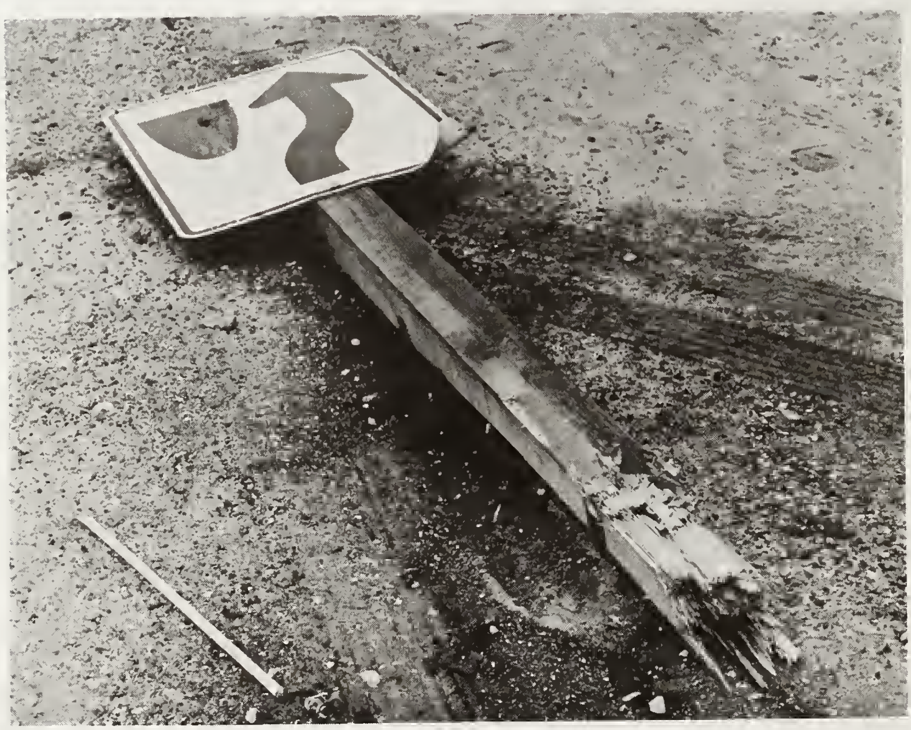


Figure 35. Free missile travel vs. time, test 1.



(a) SIDE VIEW



(b) PANEL AND POST

Figure 36. Sign installation damage, test 1.

(a) FRONT VIEW

(b) TOP VIEW

Figure 37. Vehicle damage, test 1.

A-3-2. Test No. 2

Table 11 summarizes the results of test 2. Figure 38 contains sequential photos from high-speed film taken during impact, and Table 12 contains a time-displacement-event summary. Note that upon impact the base of the post was kicked up and the panel rotated down on the roof. Although the panel appeared to move little in the horizontal direction until impact with the roof, the horizontal velocity of the post-panel combination was computed to be approximately 65 ft/sec (19.8 m/s). Vehicle velocity was about 89 ft/sec (27.2 m/s) when the panel hit the roof. During contact, friction between the panel and the roof slightly accelerated the post-panel combination in the horizontal direction. One can only speculate as to the results if a larger vehicle had hit the installation. The hood of a full-size automobile, which is higher than the Vega, would change the kinematics of the panel-post combination after impact, probably resulting in a larger longitudinal and rotational velocity. The length of the hood is longer on the full-size car, and this could increase the potential for windshield impact by the panel. However, after studying this test, and the other 21 tests in the project, it is the authors' opinion that although impact with the windshield may occur, test article penetration into the passenger compartment can be prevented to a large degree by making sure the panel remains on the post after impact. Design criteria for panel-to-post fasteners are given in Chapter III.

Figures 39, 40, and 41 contain deceleration, change in momentum, and free missile travel versus time data. Figure 42 shows the damage to the sign installation. Restoration would involve the installation of a new post. The panel and hardware were reusable after some refurbishment to the panel. Figure 43 shows the vehicle damage. Damage is that on the right side of the vehicle. (Damage on the left side was the result of test 1.) Vehicle damage was assessed according to the TAD and SAE scales and is given in Table 11.

Table 11. Summary of results, test 3254-2.

Impact Velocity = 64.6 mph

POST DATA		
Type	Wood - Southern Pine, Grade 2	
Size	4 in. x 4 in. (Full Dimensions)	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1973	
Weight (lb)	2290	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	384	571
Duration of Event (sec)*	0.174	
Peak Deceleration (G's)	8.52	10.69
Maximum 0.050 Sec Average Deceleration (G's)	1.73	2.26
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-1	
SAE	12FREN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes, by sign panel	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

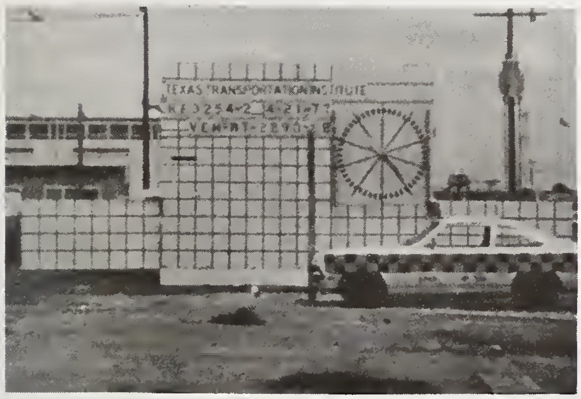
*Time of contact

Table 12. Time displacement event summary for test 3254-2.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.020	1.90	Post breaks
0.055	5.16	Post is clear of car
0.076	7.00	Post hits roof of car
0.164	14.98	Post is clear of car
0.215	19.60	Post is airborne

Metric Conversion:

1 ft = 0.305 m



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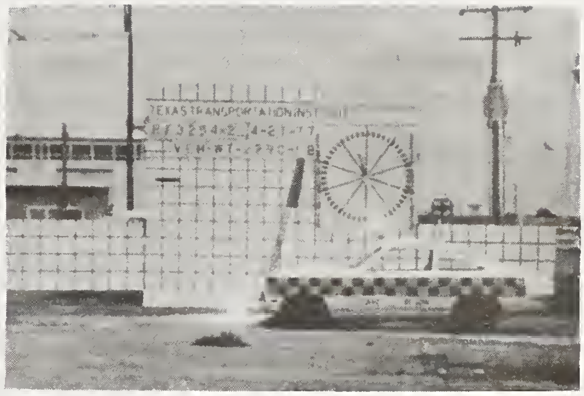

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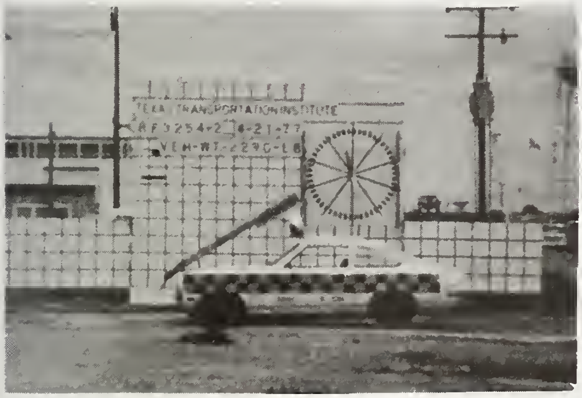

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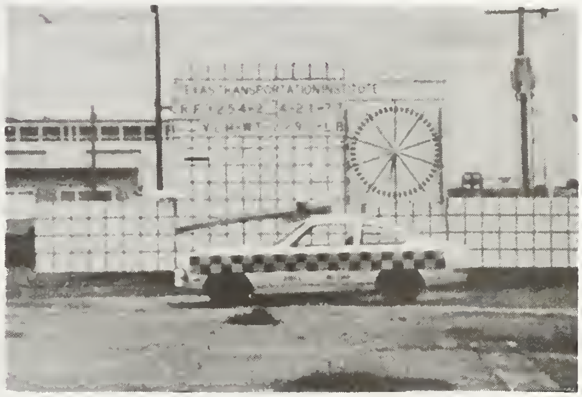

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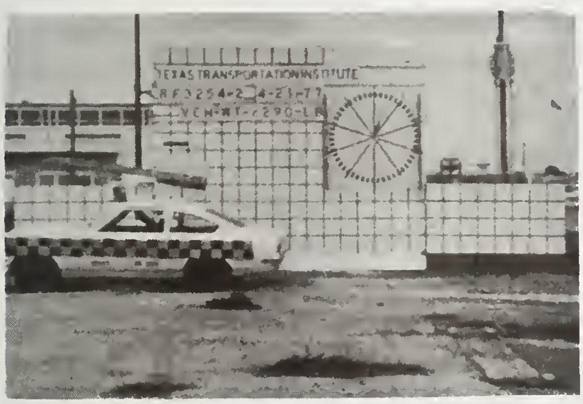

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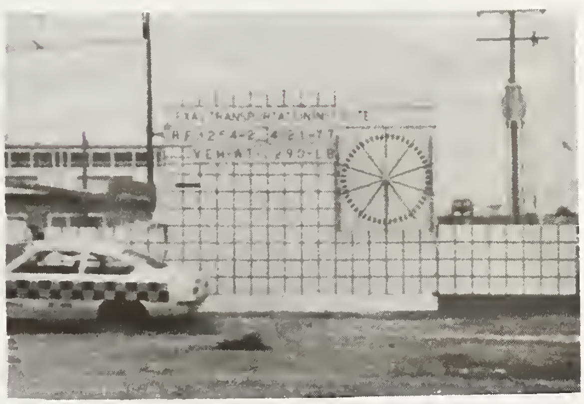

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Figure 38. Sequential photos, test 2.

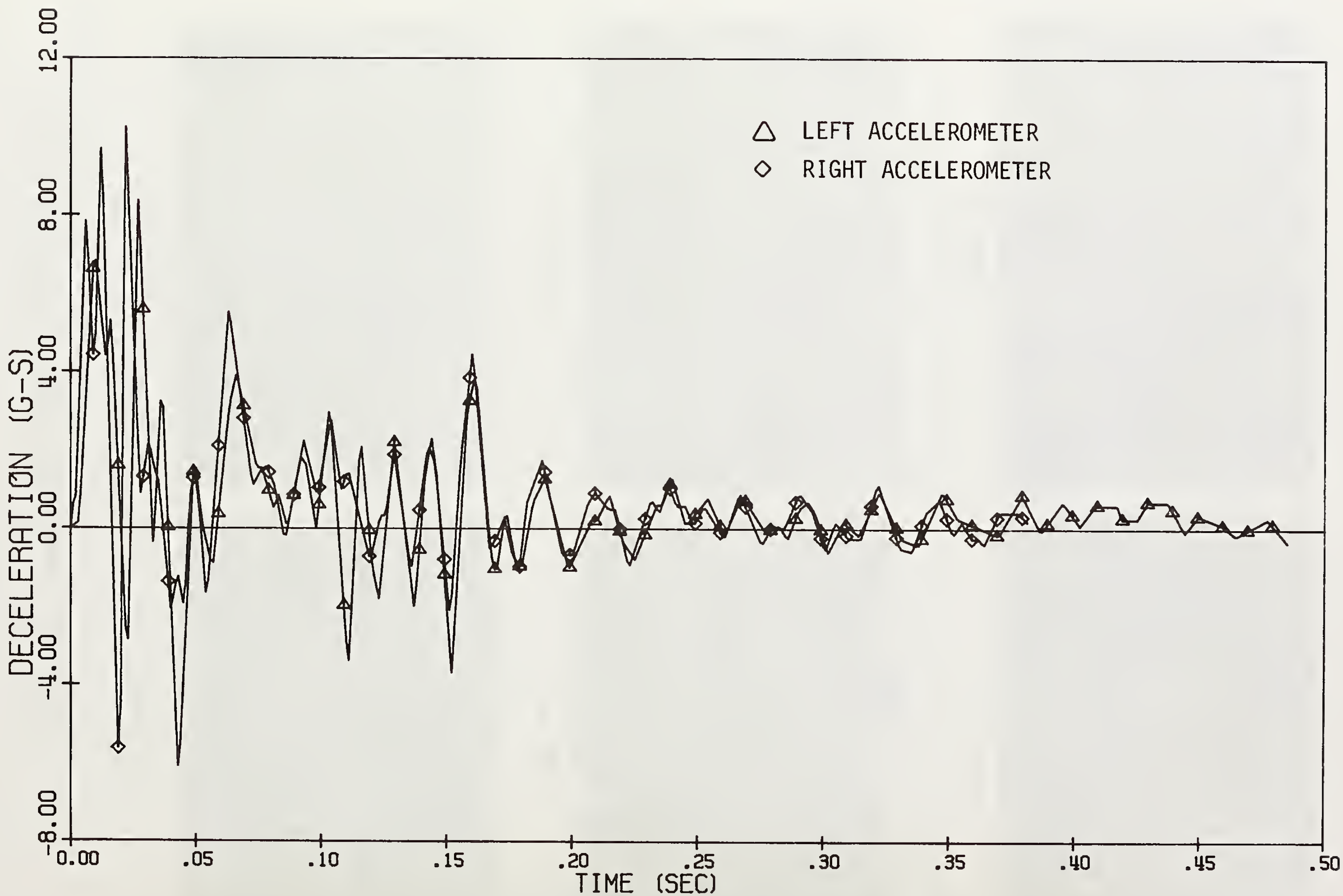


Figure 39. Deceleration vs. time, test 2.

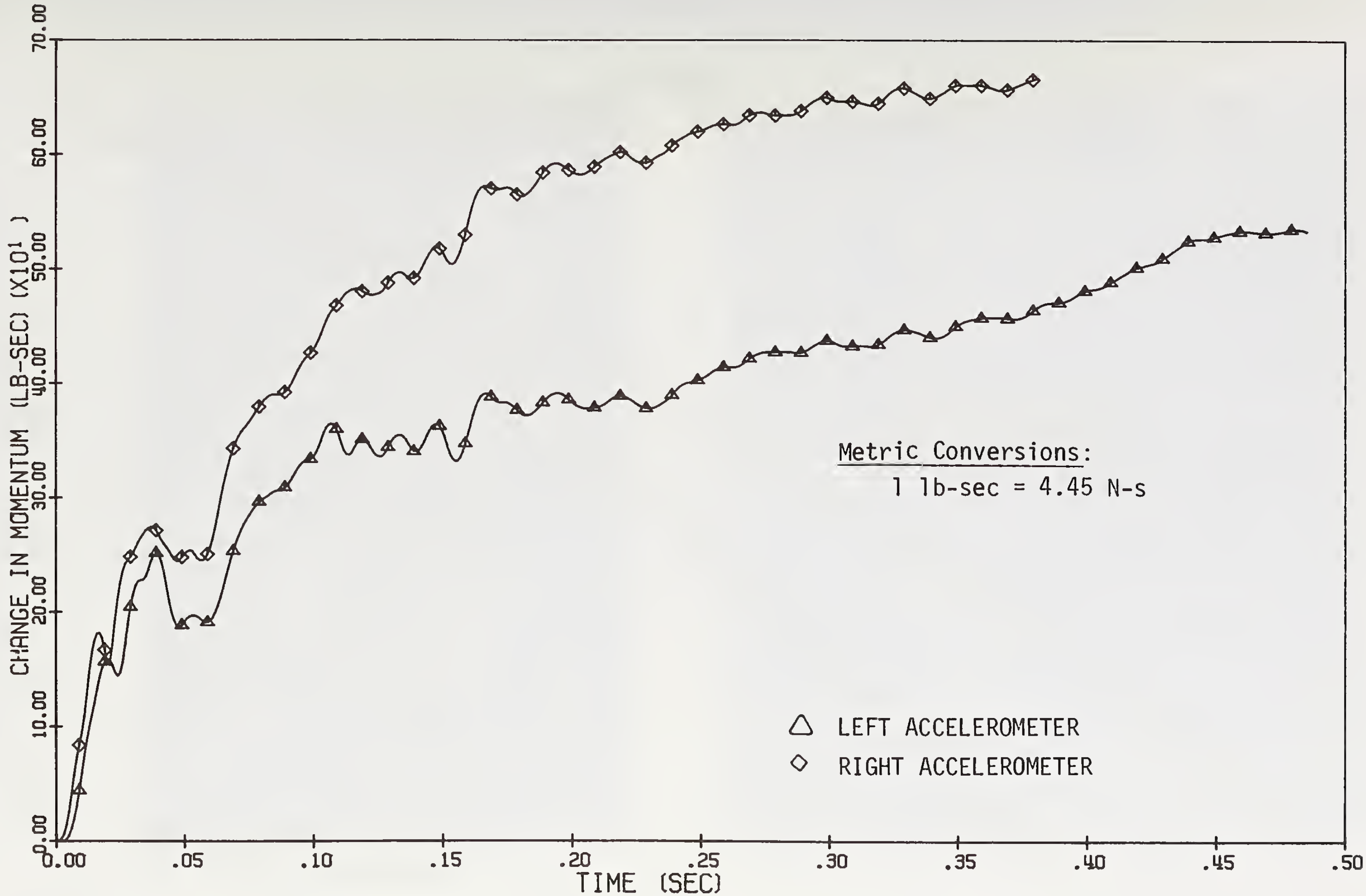


Figure 40. Change in momentum vs. time, test 2.

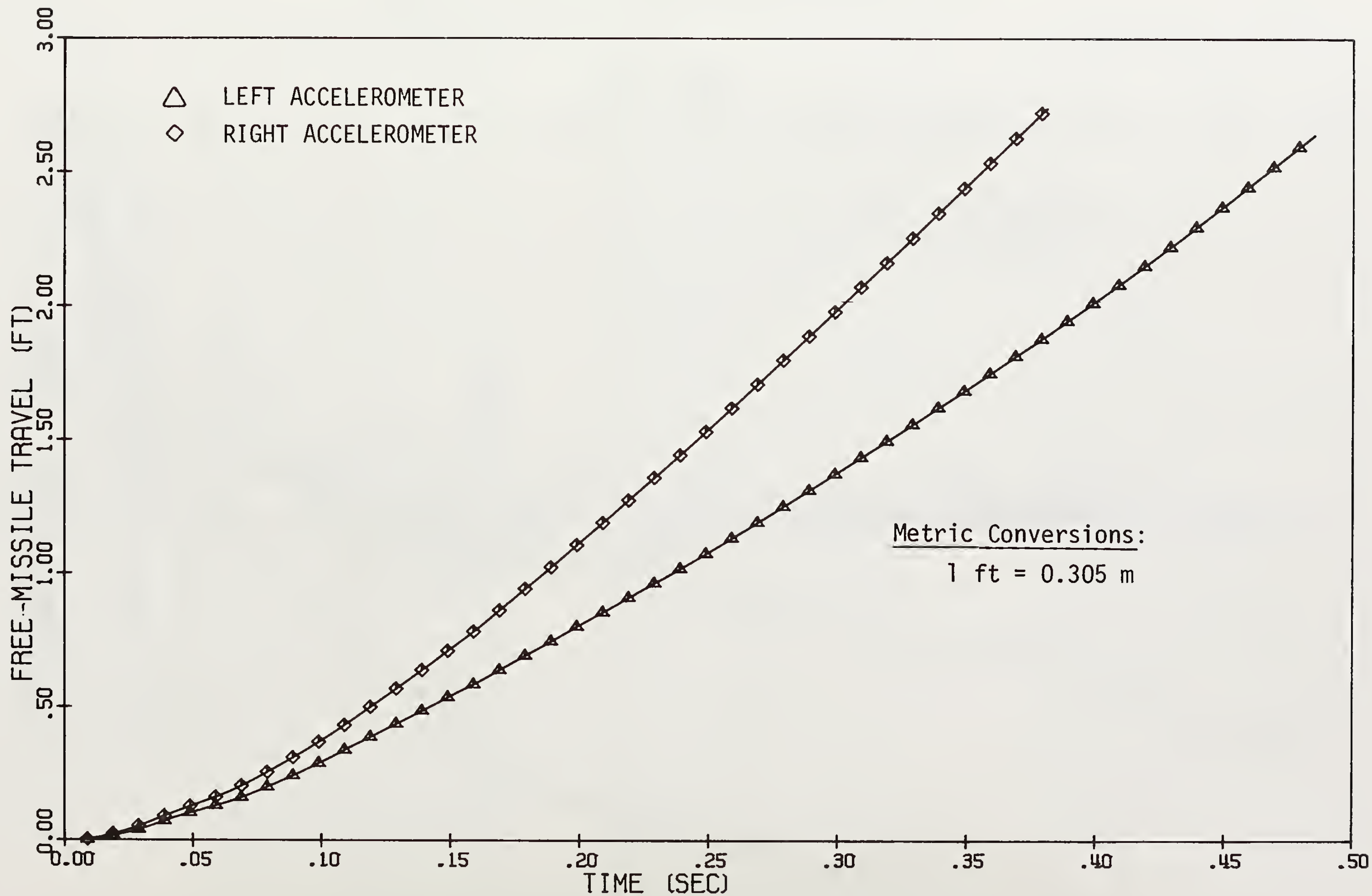
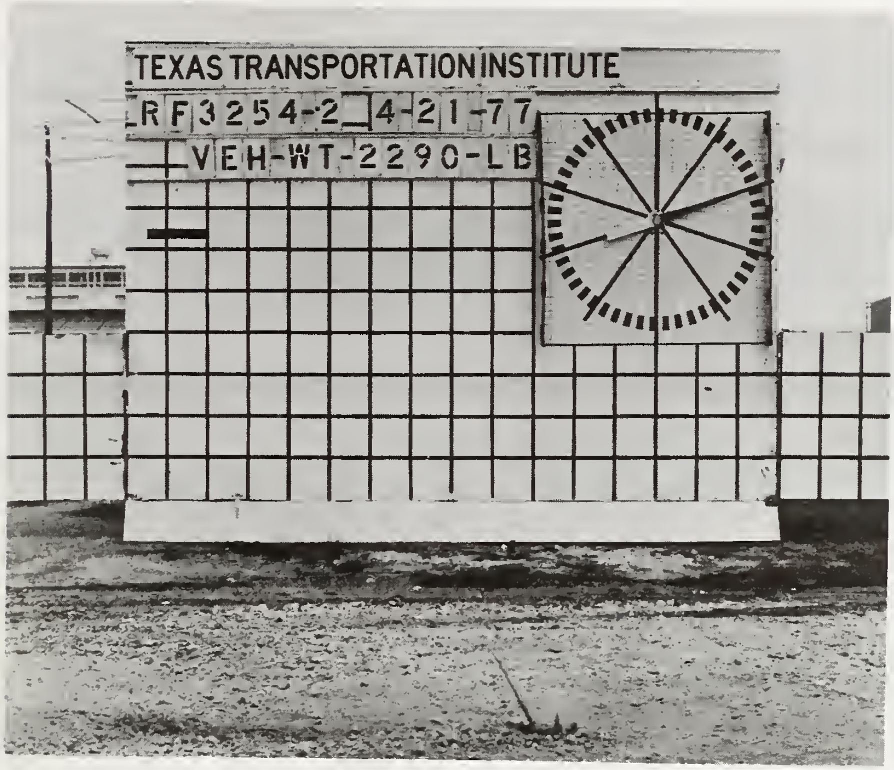


Figure 41. Free missile travel vs. time, test 2.



(a) SIDE VIEW

(b) POST AND PANEL

Figure 42. Sign installation damage, test 2.

(a) FRONT VIEW

(b) TOP VIEW

Figure 43. Vehicle damage, test 2.

A-3-3. Test No. 3

Table 13 summarizes the results of test 3. Figure 44 contains sequential photos from high-speed film taken during impact, and Table 14 contains a time-displacement-event summary. Upon impact, the post bent near the groundline and was ridden down by the vehicle. Figures 45, 46, and 47 contain deceleration, change in momentum, and free missile travel versus time data. Figure 48 shows damage to the sign installation. Restoration would involve the installation of a new post. The panel and hardware were reusable. As shown in Figure 49 there was little vehicle damage. Vehicle damage was assessed according to the TAD and SAE scales and is given in Table 13.

Table 13. Summary of results, test 3254-3.

Impact Velocity = 20.8 mph

POST DATA		
Type	Steel U-Post** (Billet Steel)	
Size	3 lb/ft	
Embedment Method	Driven	
Embedment Depth (ft)	3.5	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1972	
Weight (lb)	2270	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	276	359
Duration of Event (sec)*	0.133	
Peak Deceleration (G's)	3.07	3.99
Maximum 0.050 Sec Average Deceleration (G's)	1.52	1.70
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-0	
SAE	12FLEN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Armco Steel Corporation post

Table 14. Time displacement event summary for test 3254-3.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.059	1.66	Post deformed
0.119	3.14	Post twisting and rotating
0.169	4.26	Initial separation
0.179	4.55	Sign on ground
0.966	22.56	Car clears sign and post

Metric Conversion:

1 ft = 0.305 m

0.000 sec

0.059 sec

0.119 sec

0.169 sec

0.179 sec

0.966 sec

Figure 44. Sequential photos, test 3.

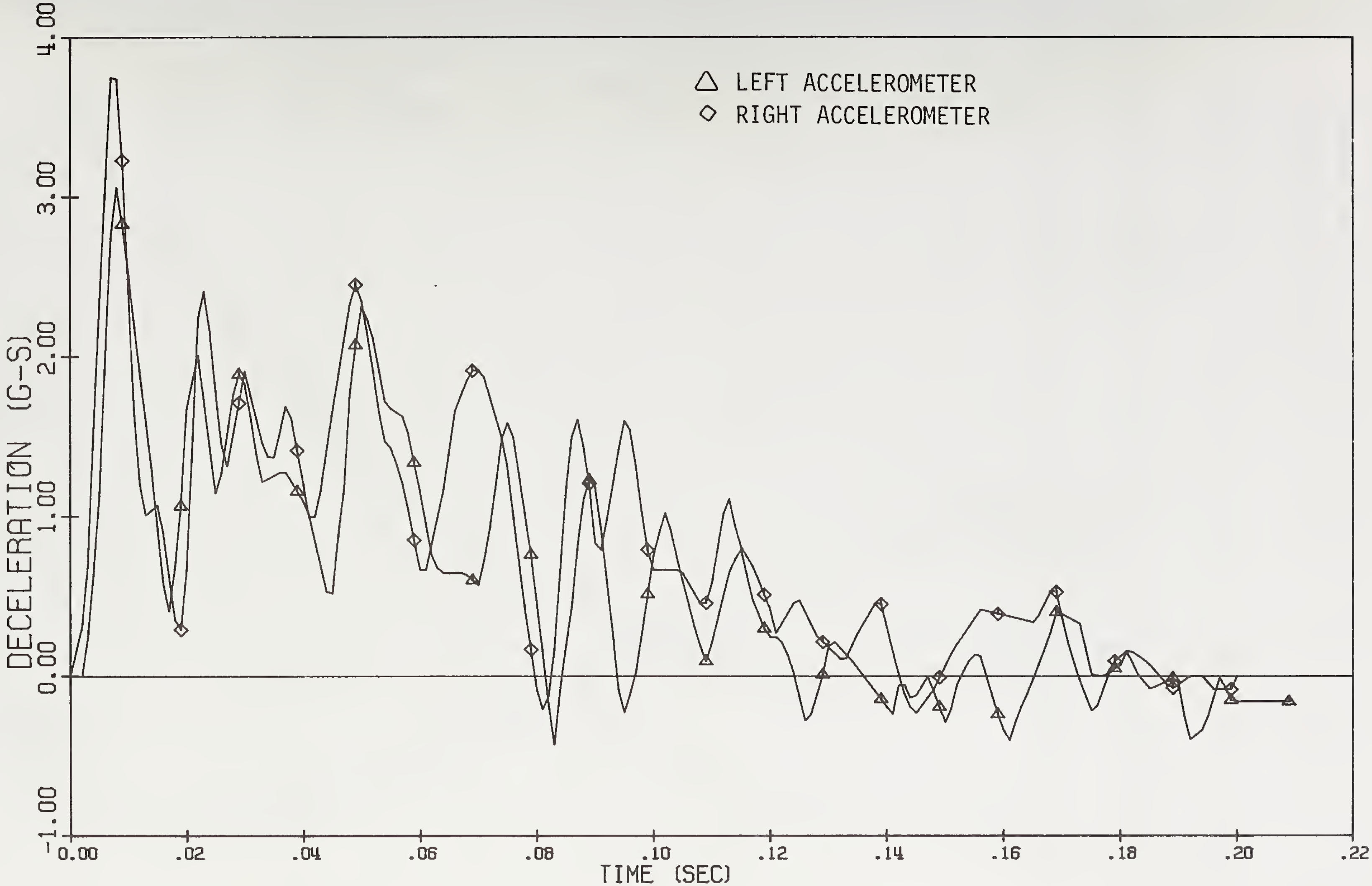


Figure 45. Deceleration vs. time, test 3.

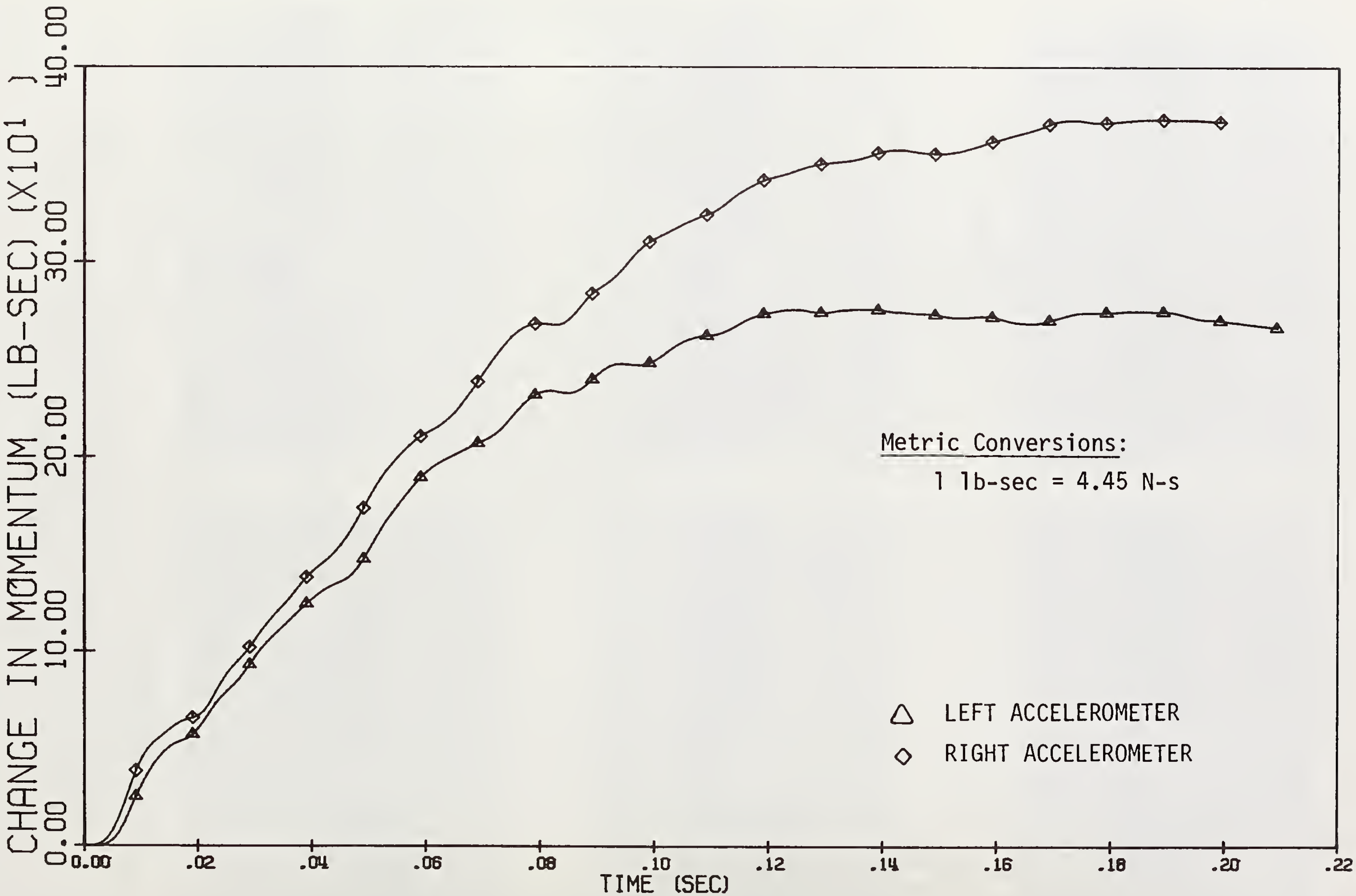


Figure 46. Change in momentum vs. time, test 3.

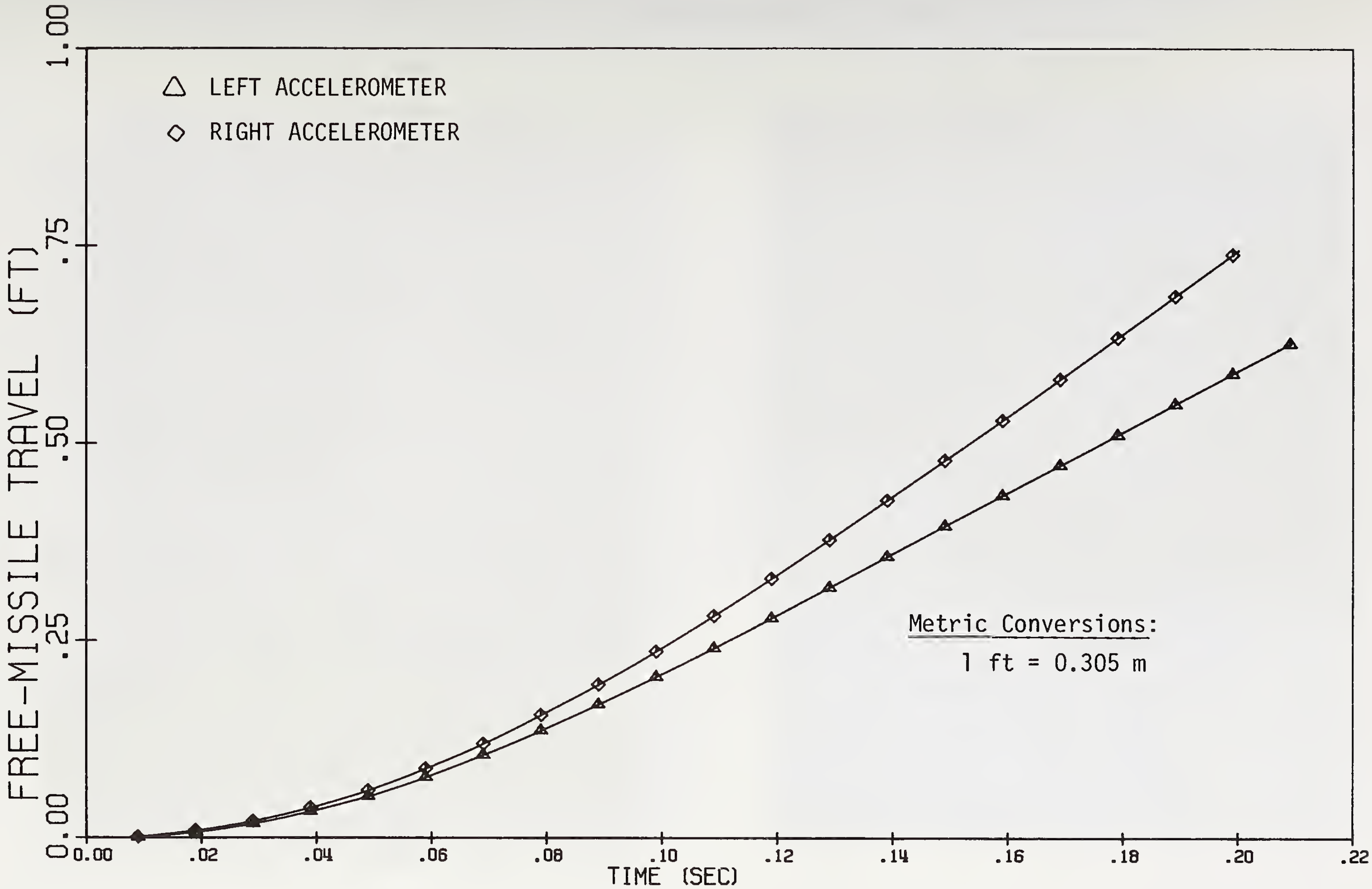


Figure 47. Free missile travel vs. time, test 3.

(a) FRONT VIEW

(b) SIDE VIEW

Figure 48. Sign installation damage, test 3.

(a) SIDE VIEW

(b) FRONT VIEW

Figure 49. Vehicle damage, test 3.

A-3-4. Test No. 4

Table 15 summarizes the results of test 4. Figure 50 contains sequential photos from high-speed film taken during impact, and Table 16 contains a time-displacement-event summary. After impact, the post underwent considerable bending and momentarily wrapped around the hood of the vehicle. As the vehicle continued its forward motion, the post was straightened out and ridden down. Note that the panel was stripped from the post. Although the post was torn, it did not fracture. As a consequence of this action, the post imparted significant resistance to the vehicle's forward movement, producing a relatively large change in momentum. Although it did not occur, the vehicle appeared to be near rollover in test 4. After impact the vehicle began to yaw and roll. Then the cable guidance applied a steer correction which stabilized the yaw and roll motions and apparently prevented rollover. Further discussion of the impact performance of this type post is given in Section A-3-22.

Figures 51, 52, and 53 contain deceleration, change in momentum, and free missile travel versus time data. Figure 54 shows damage to the sign installation. Restoration would involve replacement of the complete installation. Figure 55 shows damage to the vehicle. Vehicle damage was assessed according to the TAD and SAE scales and is given in Table 15.

Table 15. Summary of results, test 3254-4.

Impact Velocity = 61.2 mph

POST DATA			
Type	Steel U-Post** (Billet Steel)		
Size	3 lb/ft		
Embedment Method	Driven		
Embedment Depth (ft)	3.5		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1972		
Weight (lb)	2270		
Impact Point	15 in. to right of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		783	1116
Duration of Event (sec)*		0.200	
Peak Deceleration (G's)		7.67	9.04
Maximum 0.050 Sec Average Deceleration (G's)		3.22	4.38
VEHICLE DAMAGE CLASSIFICATION			
TAD	FR-4		
SAE	12FREN3		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact and free missile travel time

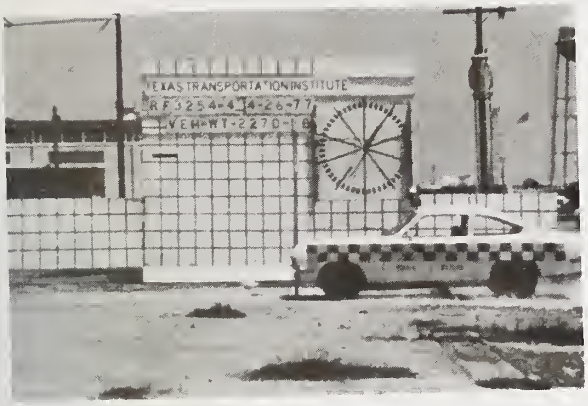
**Armco Steel Corporation post

Table 16. Time displacement event summary for test 3254-4.

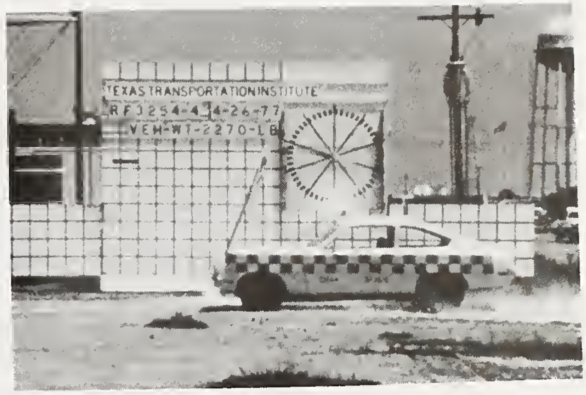
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.024	2.11	Post bends
0.050	4.43	Sign hits hood
0.072	6.22	Post wrapped around hood
0.113	9.61	Sign panel separates
0.145	12.14	Vehicle pitches down slightly

Metric Conversion:

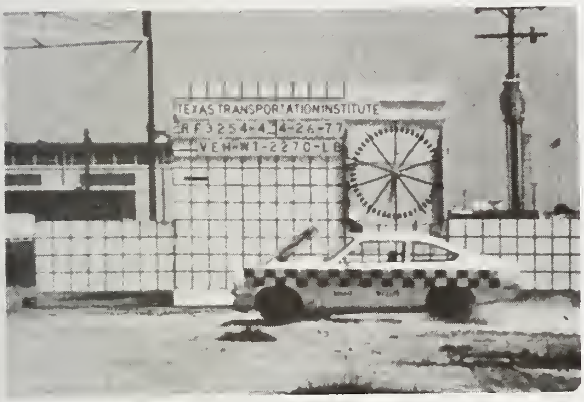
1 ft = 0.305 m



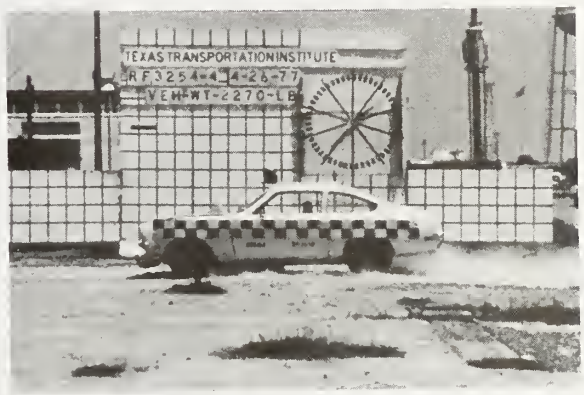
0.000 sec



0.024 sec



0.050 sec



0.072 sec

0.113 sec

0.145 sec

Figure 50. Sequential photos, test 4.

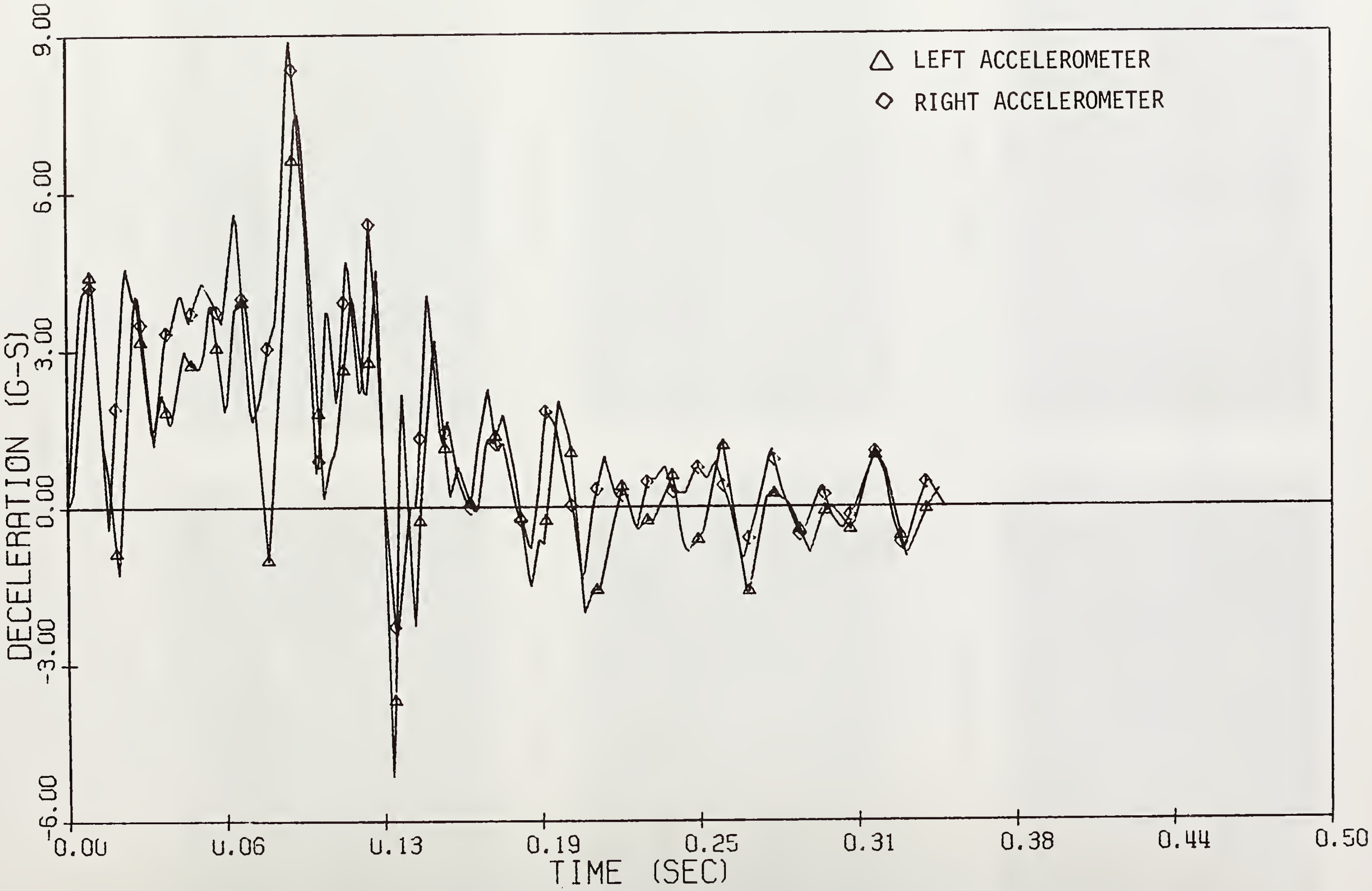


Figure 51. Deceleration vs. time, test 4.

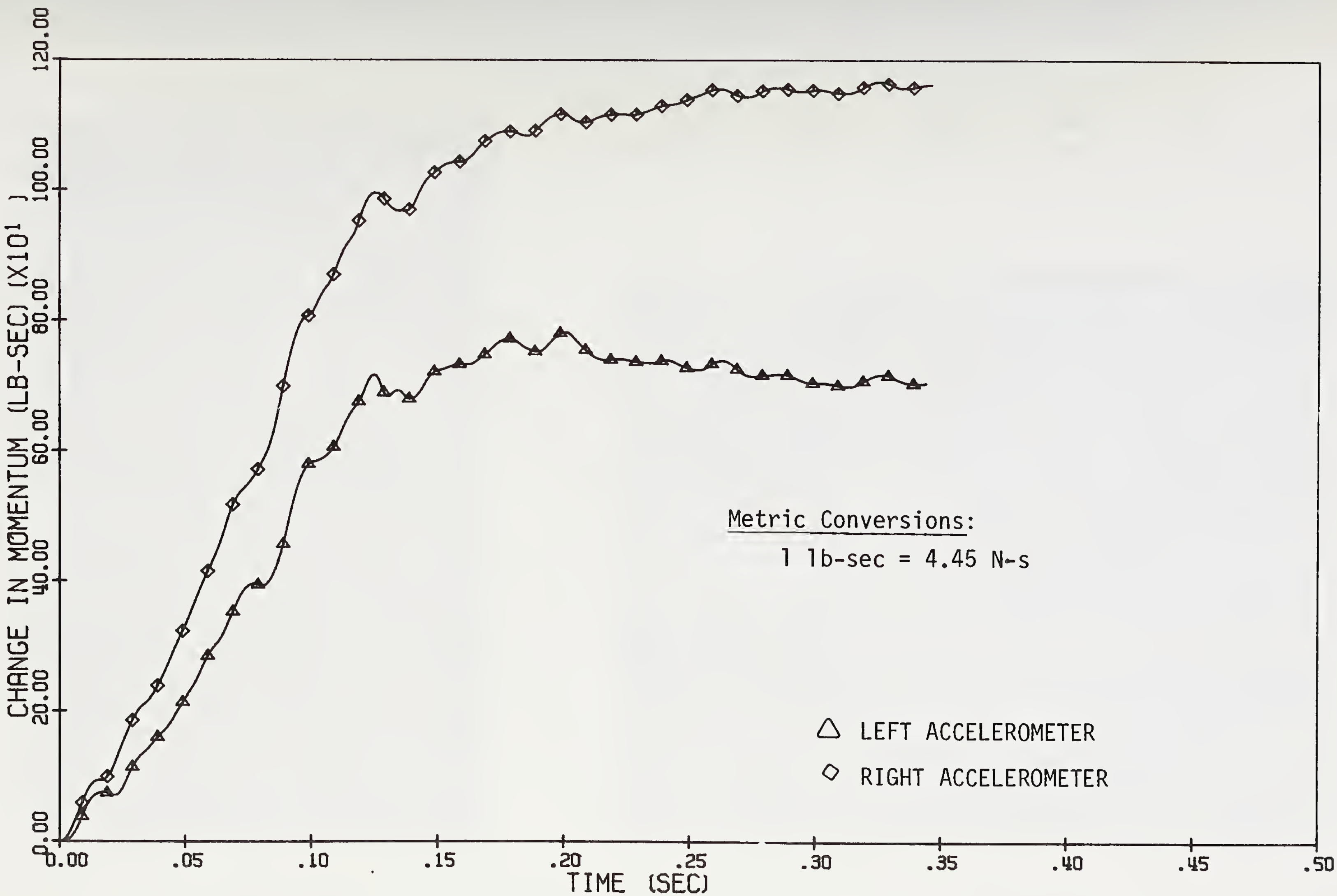


Figure 52. Change in momentum vs. time, test 4.

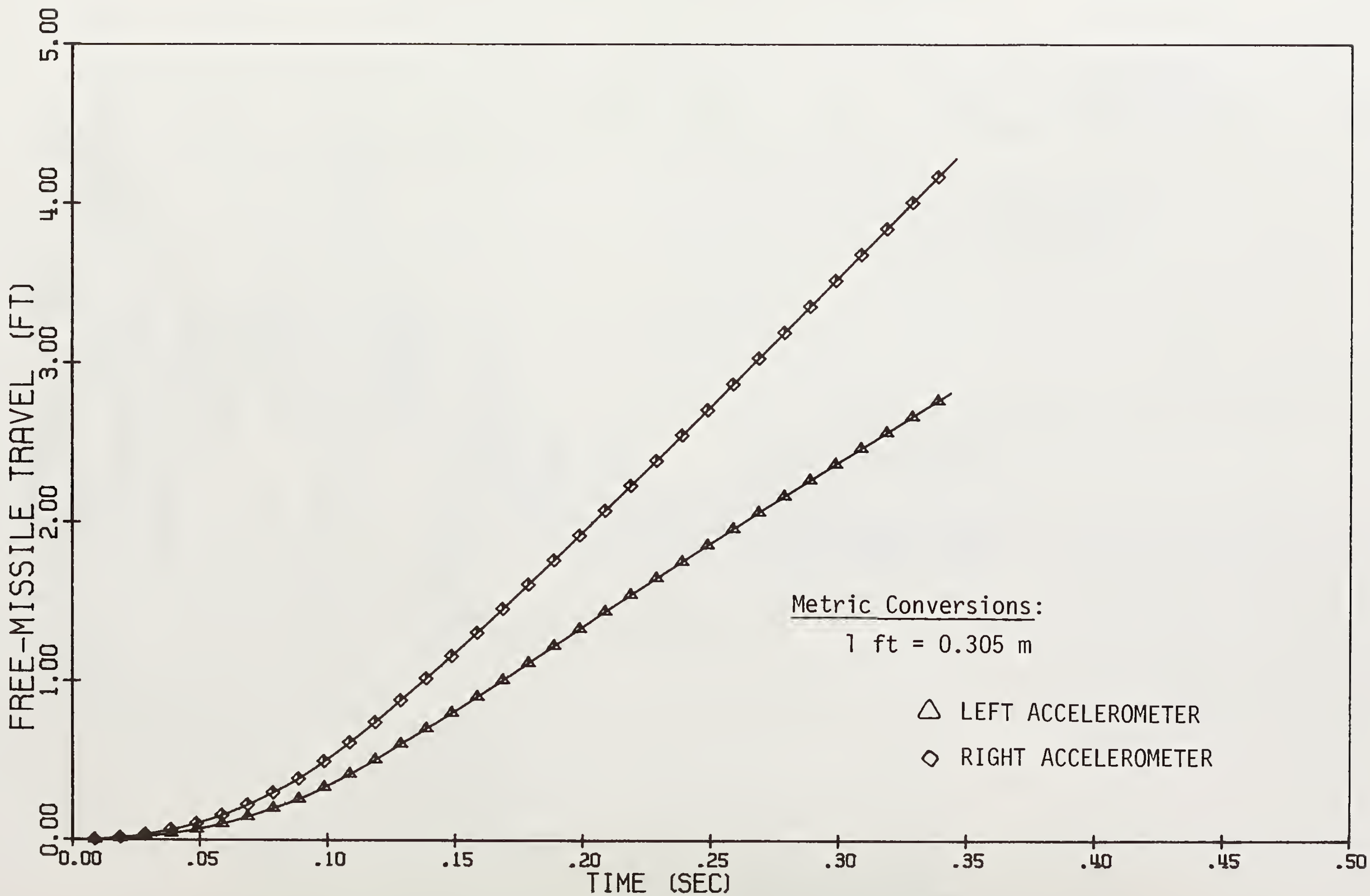
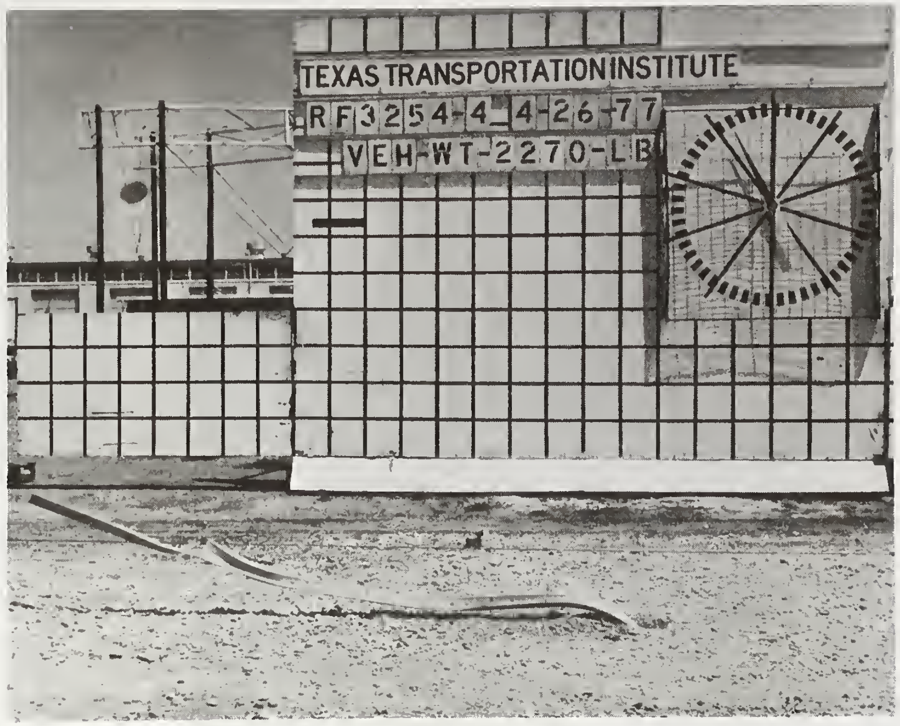


Figure 53. Free missile travel vs. time, test 4.

(a) FRONT VIEW



(b) SIDE VIEW

Figure 54. Sign installation damage, test 4.

(a) FRONT VIEW (b) TOP VIEW

Figure 55. Vehicle damage, test 4.

A-3-5. Test No. 5

Table 17 summarizes the results of test 5. Figure 56 contains sequential photos from high-speed film taken during impact, and Table 18 contains a time-displacement-event summary. After impact, the post began to bend slightly at the bumper position. At about 0.023 sec after impact the coupling broke and the post began to move forward and rotate down. Then the two retaining straps bottomed out and held the base of the post for a short duration. This restraining action at the base along with the inertia resistance from the upper portion of the post and the panel combined to cause a relatively large bending moment in the post. The end result was a bent signpost and a slight bend in the stub post. It appears that removal of the retaining straps would reduce impact damage to both the signpost and the stub post. Also, the retaining ability of the straps, which was their intended purpose, seems doubtful since they fractured in this low-speed impact. Further testing is needed to evaluate the design without the straps.

Figures 57, 58, and 59 contain deceleration, change in momentum, and free missile travel versus time data. Figure 60 shows damage to the sign installation. Restoration would involve replacement of the signpost, coupling, and retaining straps. The stub could possibly have been straightened and reused. The sign panel was reusable. A noteworthy characteristic of this system is that the signpost, if damaged, will usually have salvage value. It can be cut and used as a stub(s). Figure 61 shows damage to the vehicle. Vehicle damage was assessed according to the TAD and SAE scales and is given in Table 17.

Table 17. Summary of results, test 3254-5.

Impact Velocity = 21.9 mph

POST DATA		
Type	Steel U-Post with Frangible Coupling**	
Size	3 lb/ft	
Embedment Method	Driven	
Embedment Depth (ft)	3.08 (stub)	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2260	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	273	260
Duration of Event (sec)*	0.130	
Peak Deceleration (G's)	4.34	3.58
Maximum 0.050 Sec Average Deceleration (G's)	1.61	1.33
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-0	
SAE	12FLEN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Armco post with General Post Corporation frangible coupling

Table 18. Time displacement event summary for test 3254-5.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.005	0.14	Post bending
0.022	2.69	Coupling breaks away
0.129	3.59	Post rotating down to ground
0.200	5.41	Sign hits ground
0.322	8.62	Car rides over post

Metric Conversion:

1 ft = 0.305 m

0.000 sec

0.005 sec

0.022 sec

0.129 sec

0.200 sec

0.322 sec

Figure 56. Sequential photos, test 5.

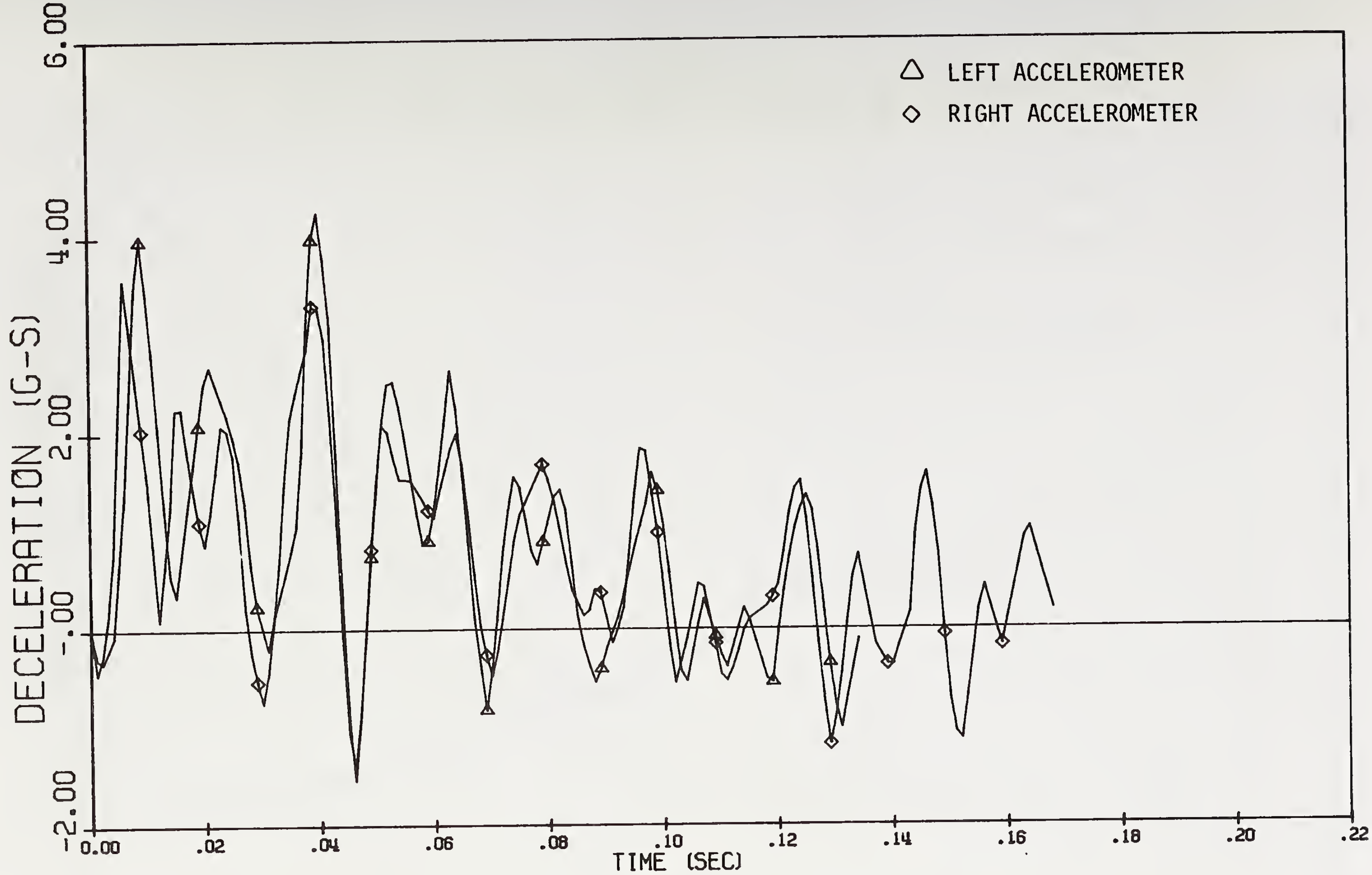


Figure 57. Deceleration vs. time, test 5.

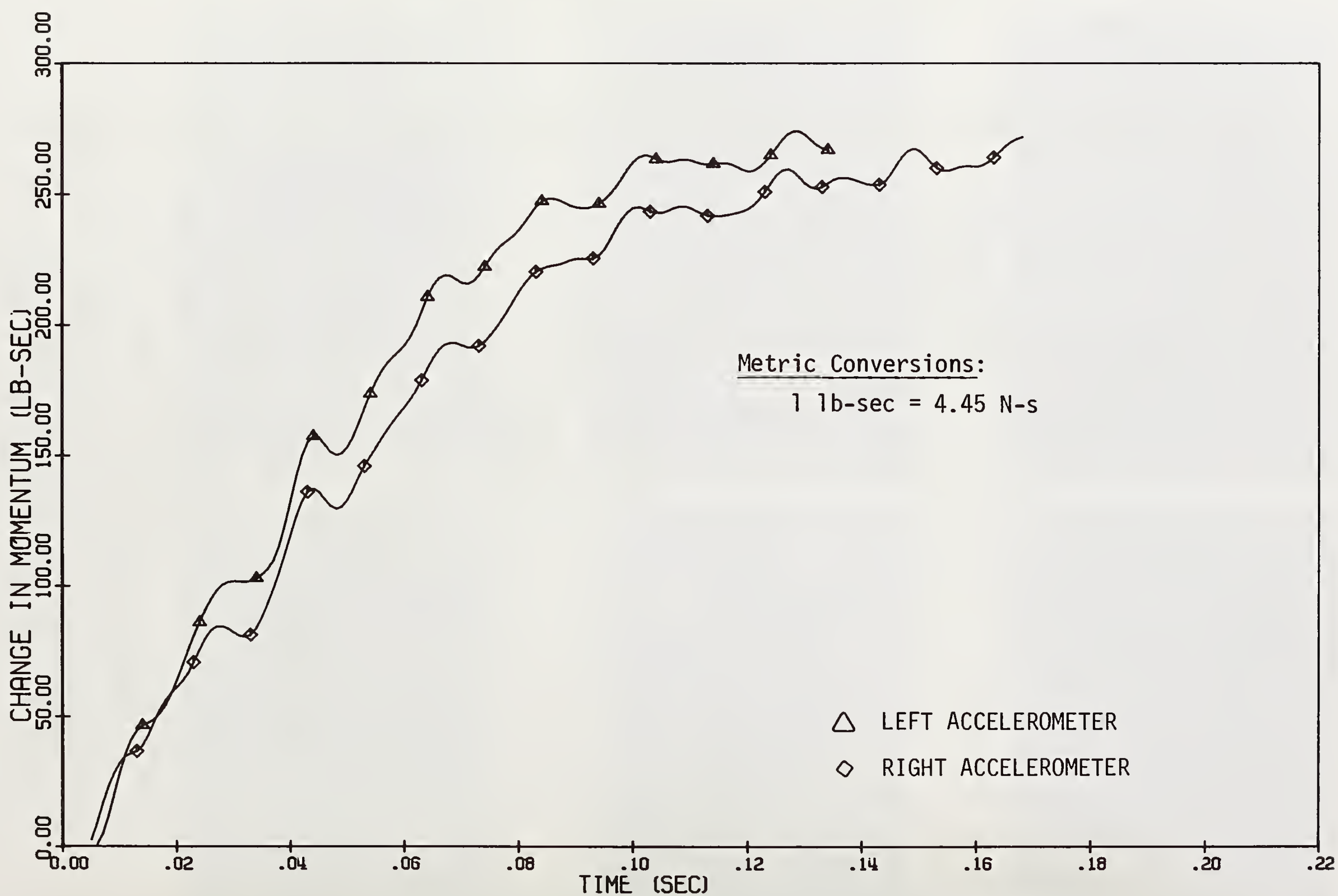


Figure 58. Change in momentum vs. time, test 5.

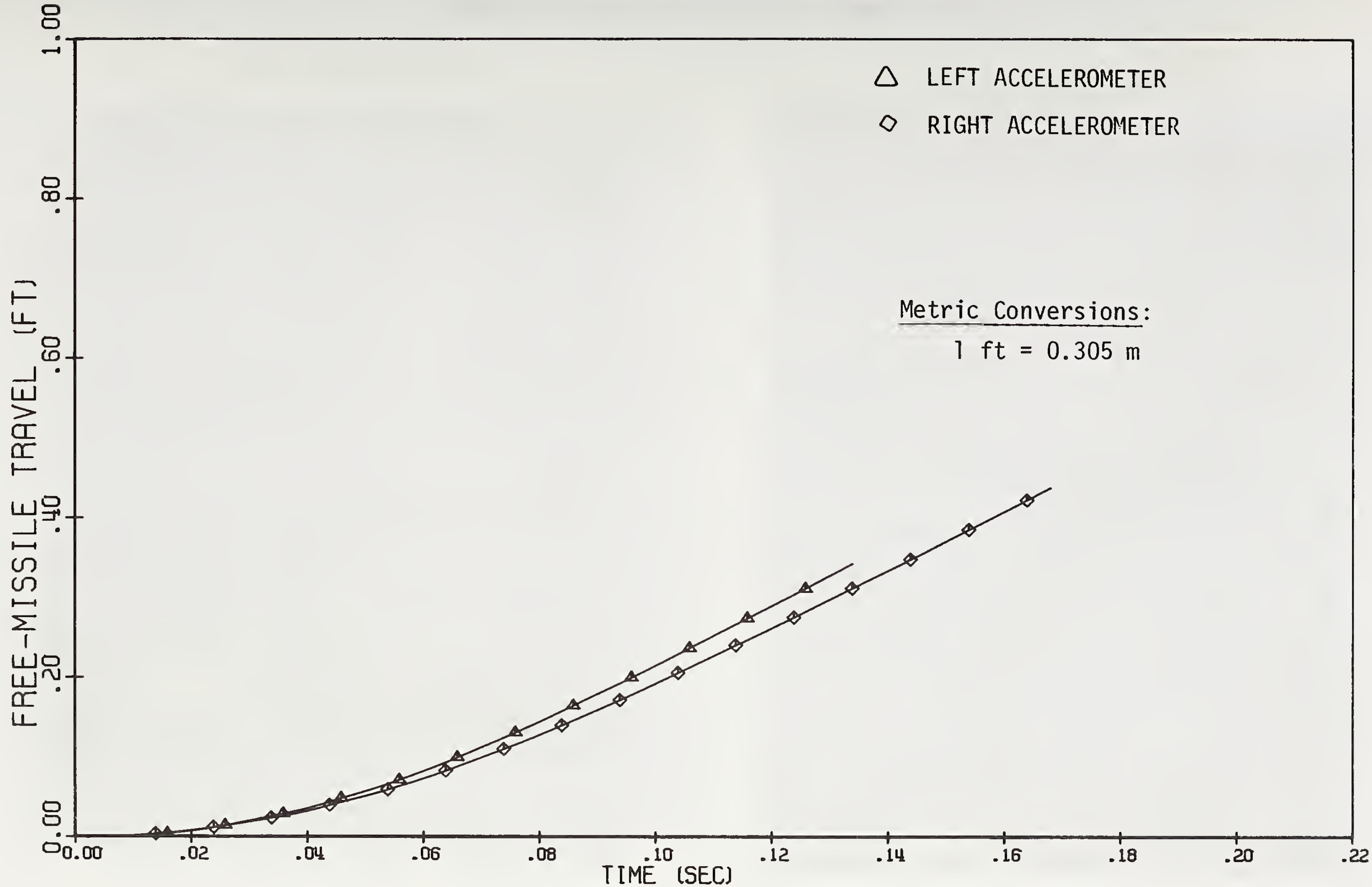


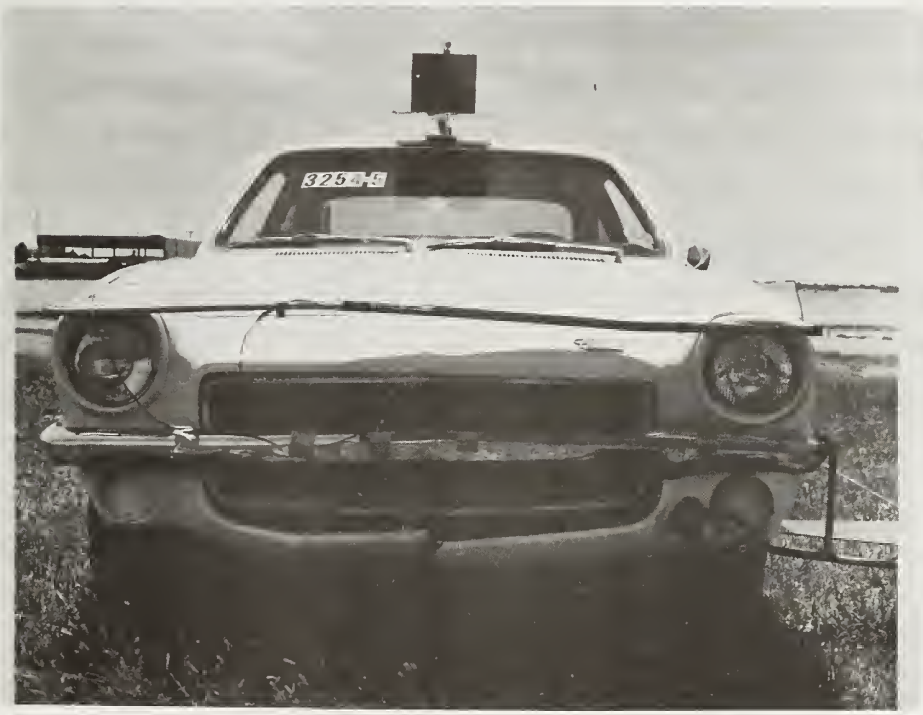
Figure 59. Free missile travel vs. time, test 5.

(a) GENERAL VIEW

(b) POST AND COUPLING

Figure 60. Sign installation damage, test 5.

(a) SIDE VIEW



(b) FRONT VIEW

Figure 61. Vehicle damage, test 5.

A-3-6. Test No. 6

Table 19 summarizes the results of test 6. Figure 62 contains sequential photos from high-speed film taken during impact, and Table 20 contains a time-displacement-event summary. Shortly after impact the coupling and the retainer straps fractured. The post then rotated and was projected forward. The sign panel impacted the top edge of the windshield and the roof. After impact the velocity of the post and panel was only slightly less than that of the vehicle.

Figures 63, 64, and 65 contain deceleration, change in momentum, and free missile travel versus time data. Figures 66 and 67 show sign installation damage. Damage was similar to that in test 5. Although the signpost was not bent as much as the post in test 5, the stub post was bent more in test 6 than in test 5. Removal of the retainer straps would likely reduce the impact damage to the signpost and the stub. However, full-scale testing would be necessary to evaluate the design without straps. Restoration after the high-speed tests would involve replacement of the coupling, retainer straps, and the stub. It is questionable as to whether the signpost could have been straightened. If not, it would have had salvage value since it could have been cut and used as a stub(s).

Figure 68 shows damage to the vehicle. Damage to the right front of the vehicle was caused by test 6, and damage to the left front was caused by test 5. Damage caused by test 6 was assessed according to the TAD and SAE scales and is given in Table 19.

Table 19. Summary of results, test 3254-6.

Impact Velocity = 66.1 mph

POST DATA			
Type	Steel U-Post with Frangible Coupling**		
Size	3 lb/ft		
Embedment Method	Driven		
Embedment Depth (ft)	3.08 (stub)		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1971		
Weight (lb)	2260		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		274	299
Duration of Event (sec)*		0.120	
Peak Deceleration (G's)		7.04	9.04
Maximum 0.050 Sec Average Deceleration (G's)		1.92	2.15
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-1		
SAE	12FLEN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	Yes, by sign panel		

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Armco post with General Post Corporation frangible coupling

Table 20. Time displacement event summary for test 3254-6.

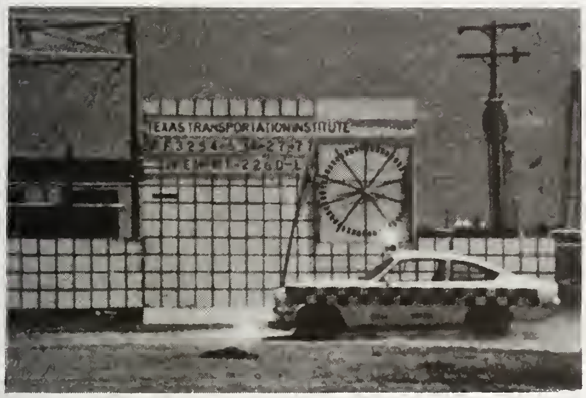
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.007	0.73	Coupling begins to fracture
0.015	1.67	Coupling breaks and post hangs on car
0.058	5.84	Signpost rotating down
0.083	7.75	Sign hits car roof
0.127	11.76	Loss of contact

Metric Conversion:

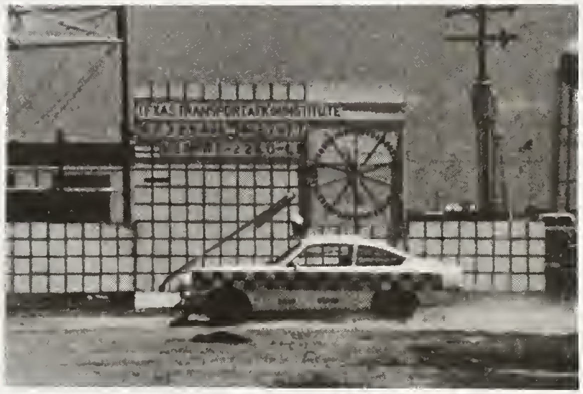
1 ft = 0.305 m

0.000 sec

0.007 sec



0.015 sec



0.058 sec

0.083 sec

0.127 sec

Figure 62. Sequential photos, test 6.

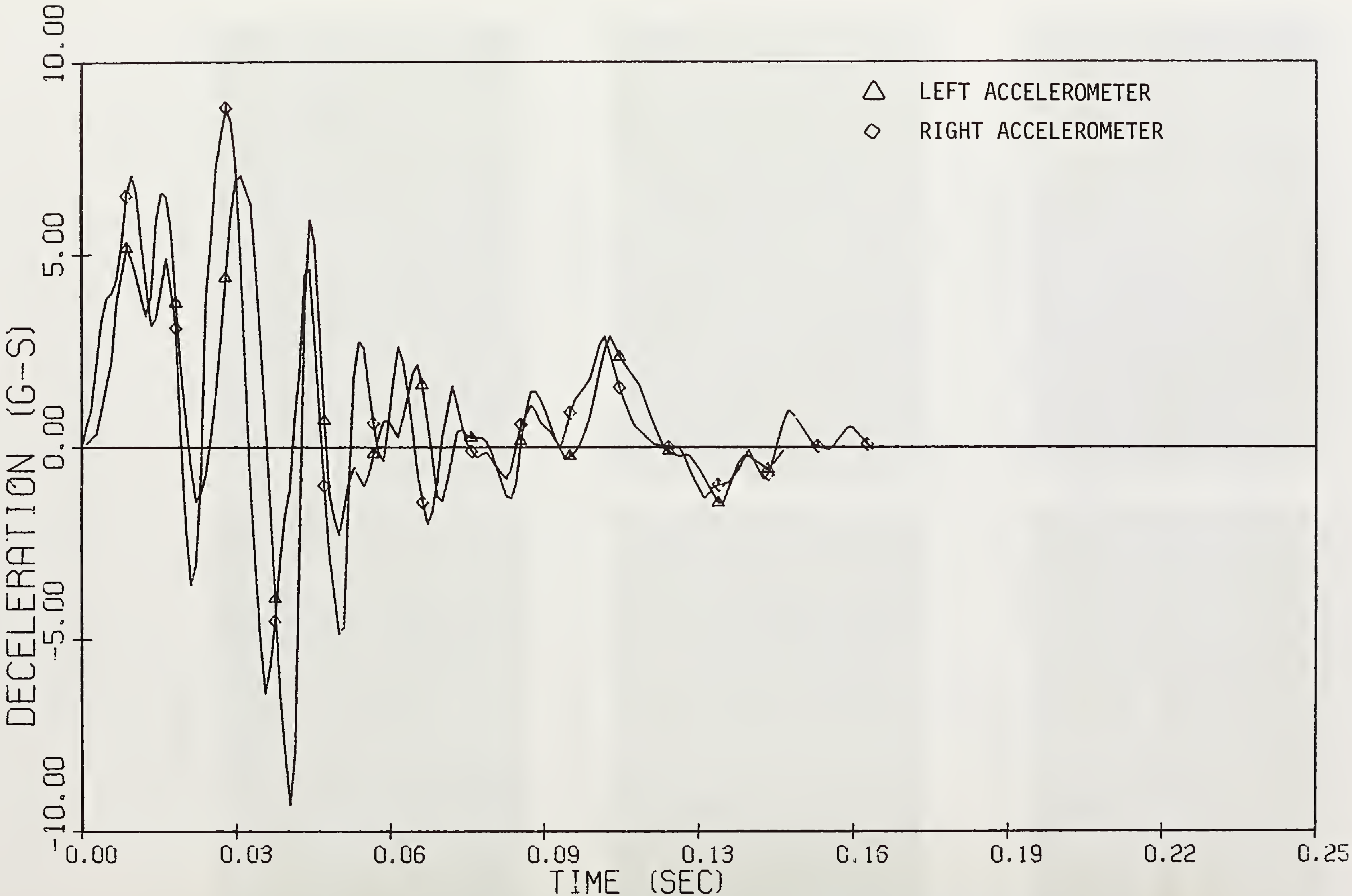


Figure 63. Deceleration vs. time, test 6.

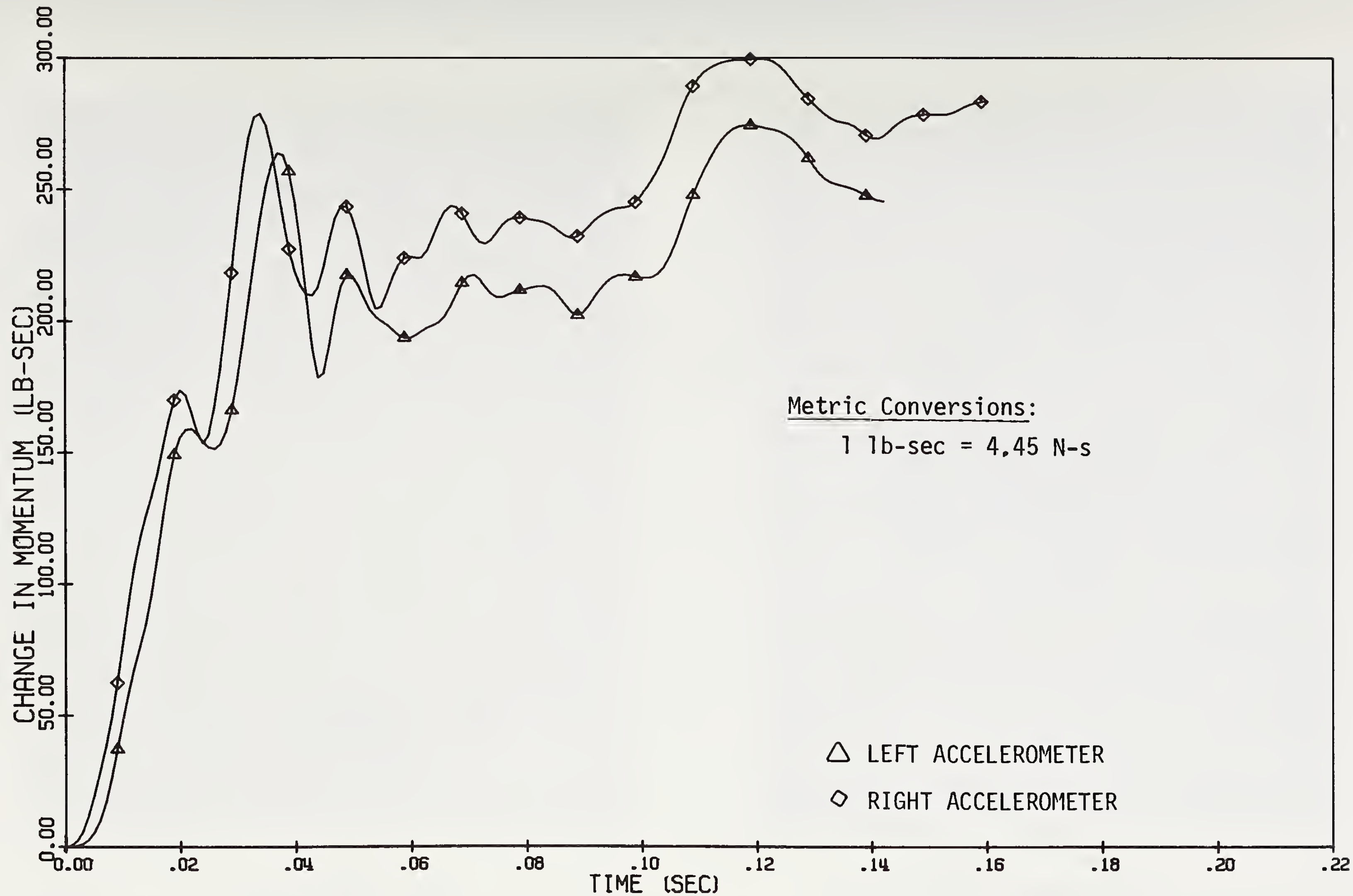


Figure 64. Change in momentum vs. time, test 6.

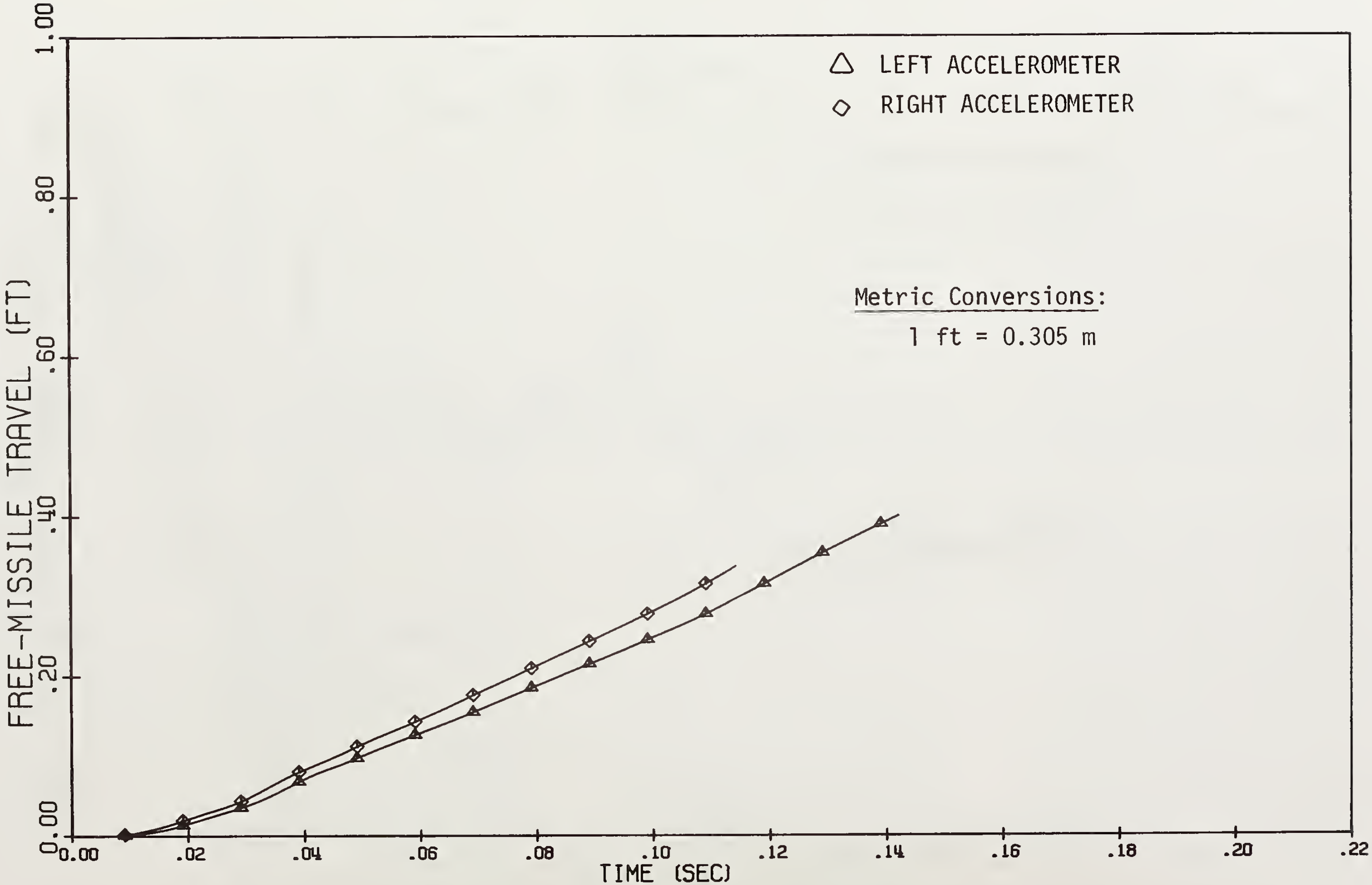
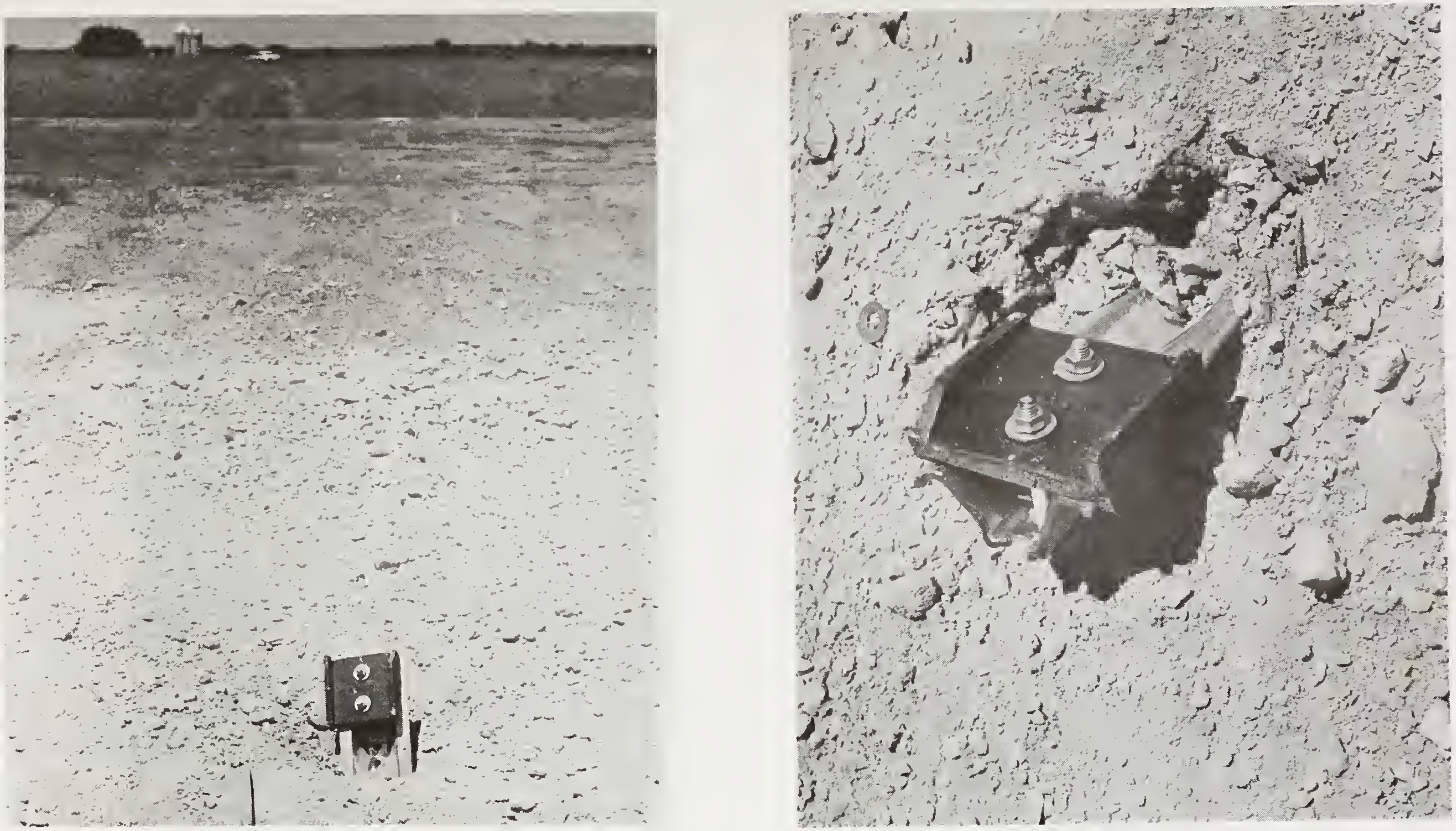


Figure 65. Free missile travel vs. time, test 6.



(a) GENERAL VIEW (b) CLOSE-UP VIEW

Figure 66. Damage to stub, test 6.

(a) PANEL AND POST

(b) POST AND COUPLING

Figure 67. Post damage, test 6.

A-3-7. Test No. 7

Table 21 summarizes the results of test 7. A 20 mph (32 km/h) test was not conducted on this system since recent tests by others had indicated satisfactory performance at low speeds (see Table B-6 of Reference 1). Figure 69 contains sequential photos from high-speed film taken during impact, and Table 22 contains a time-displacement-event summary. Upon impact the post began to bend at bumper height. Continued vehicle movement caused the post to fracture at its juncture with the stub. The post continued to wrap around the hood of the vehicle, pushing the hood into the windshield. Although the windshield was broken, the hood did not penetrate through to the passenger compartment. The post and panel remained with the vehicle for about 75 ft (22.9 m) before falling to the ground.

Figures 70, 71, and 72 contain deceleration, change in momentum, and free missile travel versus time data. Figure 73 shows the sign installation damage. Restoration would involve replacement of the signpost. The panel, stub, and hardware were reusable. It should be noted that in most cases the signpost will have salvage value in that it can be used as a stub for a smaller signpost.

Figure 74 shows the damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 21.

Table 21. Summary of results, test 3254-7.

Impact Velocity = 61.4 mph

POST DATA			
Type	Steel Square Perforated Tube**		
Size	$2\frac{1}{2} \times 2\frac{1}{2}$ in. 10 gauge		
Embedment Method	Driven		
Embedment Depth (ft)	2.92 (stub)		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1972		
Weight (lb)	2260		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		688	430
Duration of Event (sec)*		0.115	
Peak Deceleration (G's)		10.54	9.25
Maximum 0.050 Sec Average Deceleration (G's)		4.64	3.05
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-4		
SAE	12FLEN3		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	Yes, due to hood hitting it		

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Telespar post

Table 22. Time displacement event summary for test 3254-7.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.049	4.24	Post breaks-hood pushed into windshield
0.101	7.99	Post broken free, collapsing hood
0.126	10.50	Sign lying on hood
0.158	12.58	Sign leaving hood
0.186	14.86	Sign leaving hood

Metric Conversion:

1 ft = 0.305 m

(a) FRONT VIEW

(b) TOP VIEW

Figure 68. Vehicle damage, test 6.

0.000 sec

0.049 sec

0.101 sec

0.126 sec

0.158 sec

0.186 sec

Figure 69. Sequential photos, test 7.

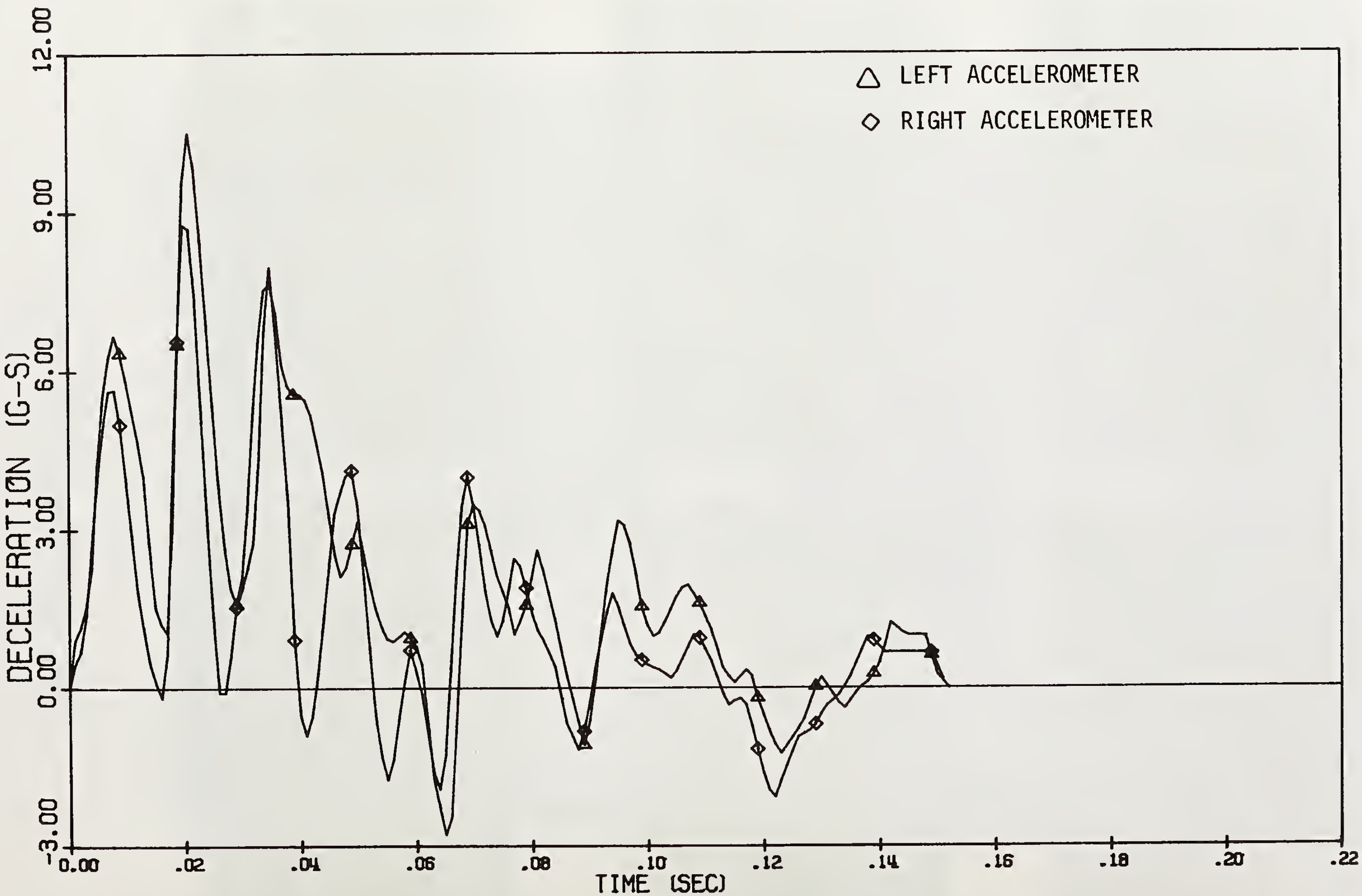


Figure 70. Deceleration vs. time, test 7.

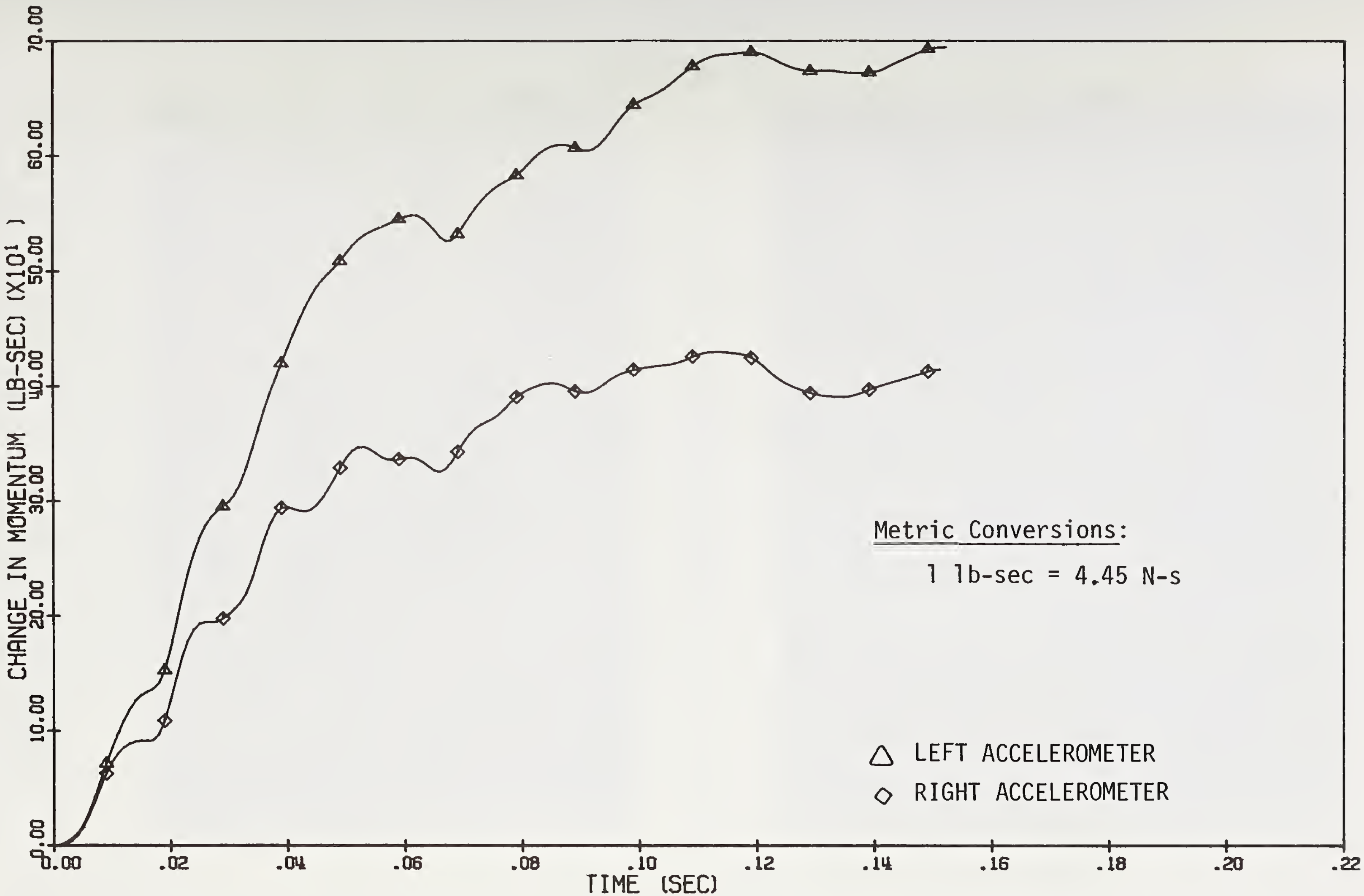


Figure 71. Change in momentum vs. time, test 7.

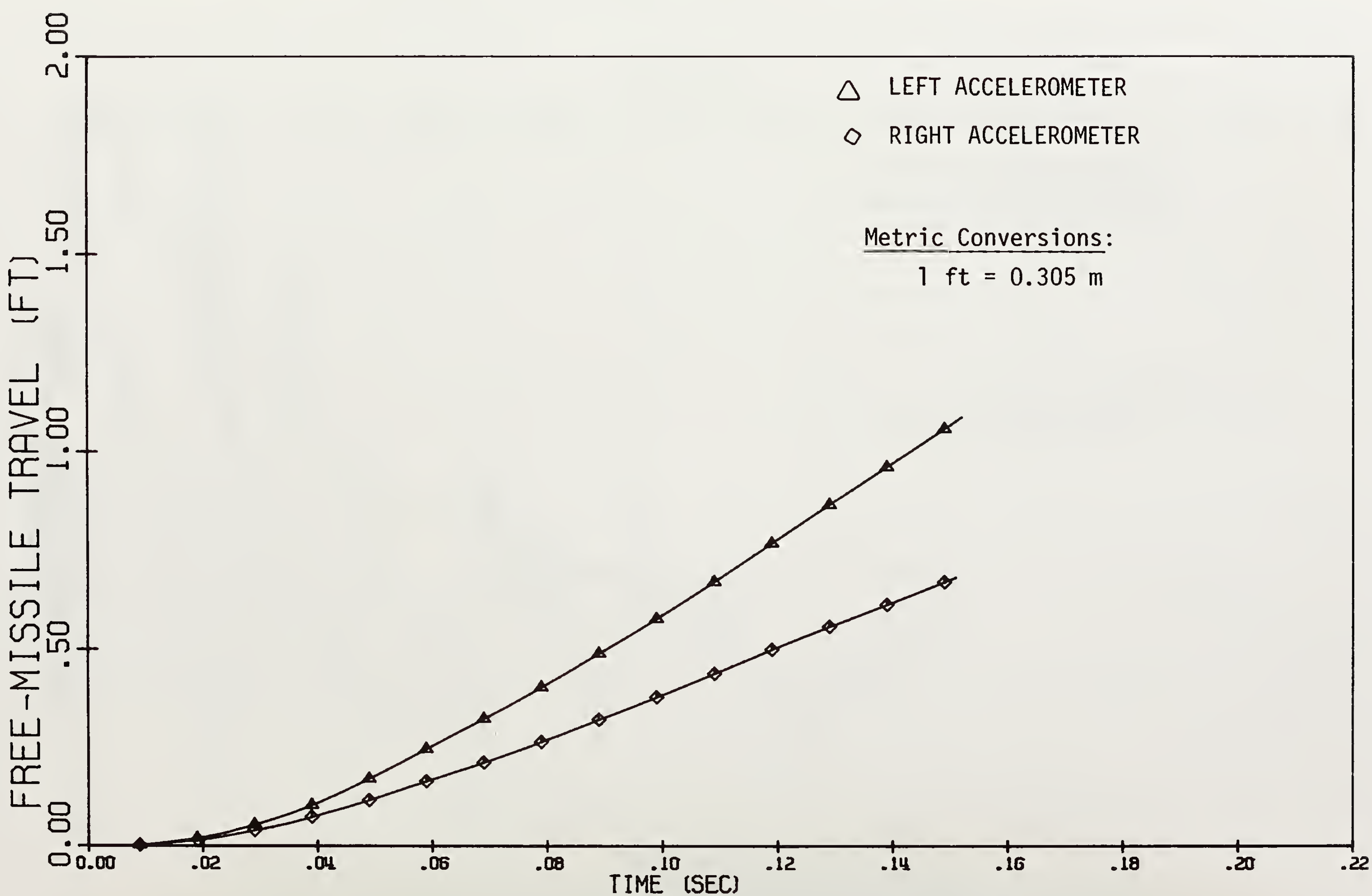


Figure 72. Free missile travel vs. time, test 7.

(a) POST AND PANEL

(b) STUB

Figure 73. Sign installation damage, test 7.

(a) FRONT VIEW

(b) TOP VIEW

Figure 74. Vehicle damage, test 7.

A-3-8. <u>Test No. 8</u>

Table 23 summarizes the results of test 8. Based on results of tests 3 and 4, it was concluded that a high-speed impact with yielding or base bending supports was more severe than a low-speed impact. The aluminum type 3X post was therefore impacted at a high speed only. Figure 75 contains sequential photos from high-speed film taken during impact, and Table 24 contains a time-displacement-event summary. After impact the post wrapped around the hood and then the post fractured at ground level. The post and panel were carried along with the vehicle until it stopped. It can be seen that the panel and post were never in any danger of impacting the windshield. Impact performance of the system was considered to be very good.

Figures 76, 77, and 78 contain deceleration, change in momentum, and free missile travel versus time data. Figure 79 shows sign installation damage. Restoration would involve replacement of the signpost. The panel could probably have been straightened and reused.

Figure 80 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 23.

Table 23. Summary of results, test 3254-8.

Impact Velocity = 63.7 mph

POST DATA		
Type	Aluminum Type X**	
Size	3X	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	3.5	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1972	
Weight (lb)	2280	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	339	488
Duration of Event (sec)*	0.210	
Peak Deceleration (G's)	2.96	4.93
Maximum 0.050 Sec Average Deceleration (G's)	1.25	2.53
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-1	
SAE	12FREN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Magnode Products, Inc., post

Table 24. Time displacement event summary for test 3254-8.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.030	2.76	Sign bends around car
0.050	4.49	Sign wrapped around front end
0.075	6.80	Post broken loose
0.112	10.16	Car carrying sign
0.152	13.52	Sign starts rebounding

Metric Conversion:

1 ft = 0.305 m

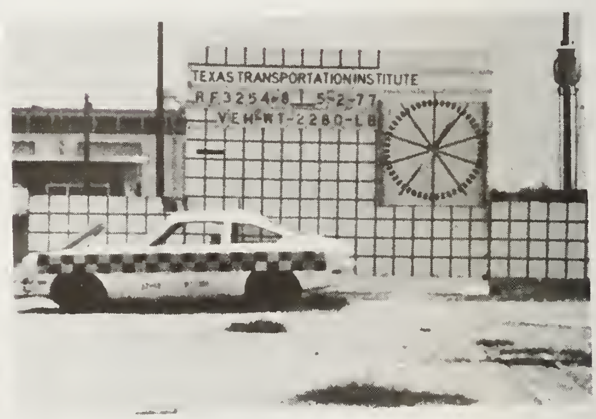
0.000 sec

0.030 sec

0.050 sec

0.075 sec

0.112 sec



0.152 sec

Figure 75. Sequential photos, test 8.

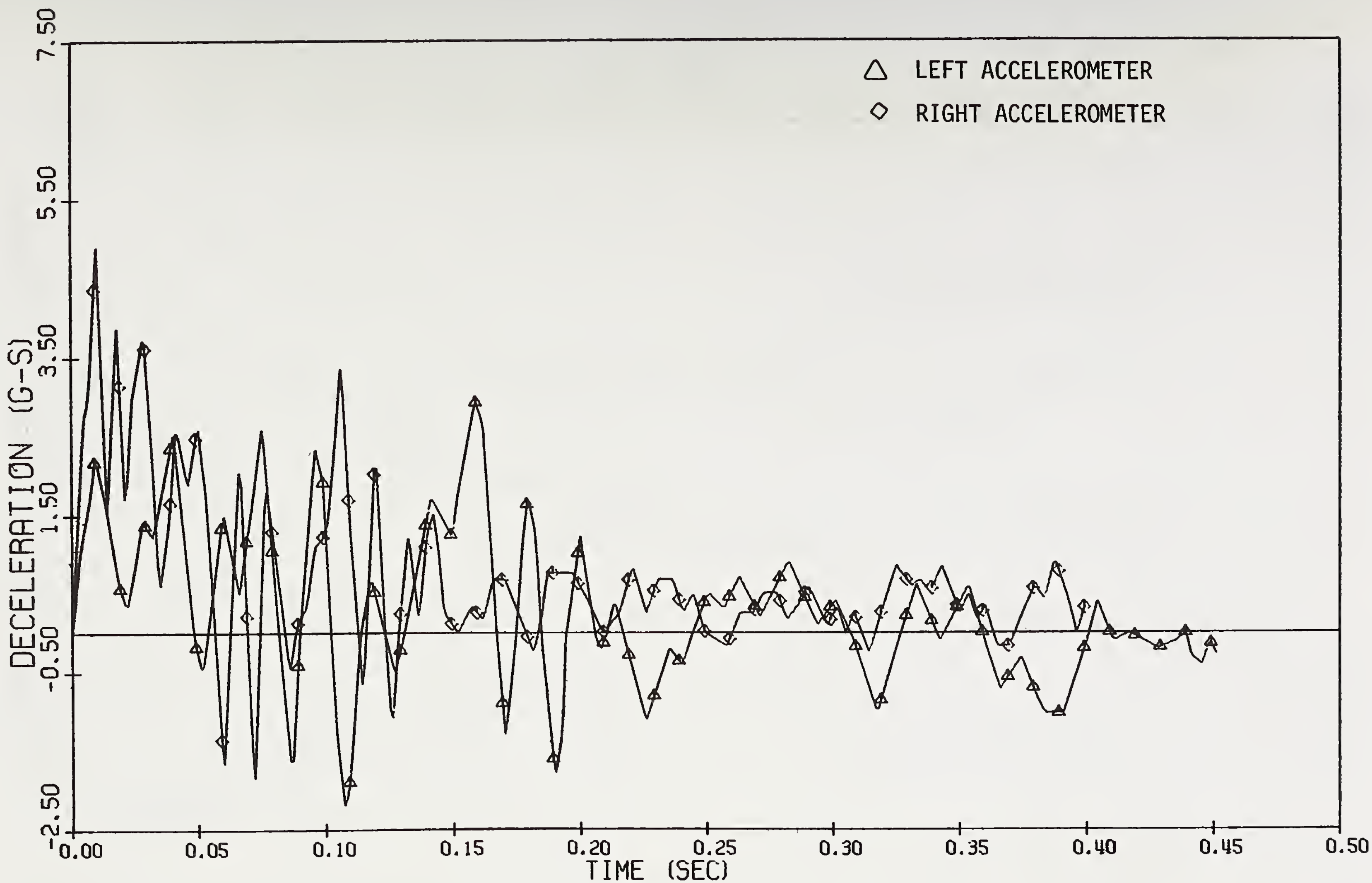


Figure 76. Deceleration vs. time, test 8.

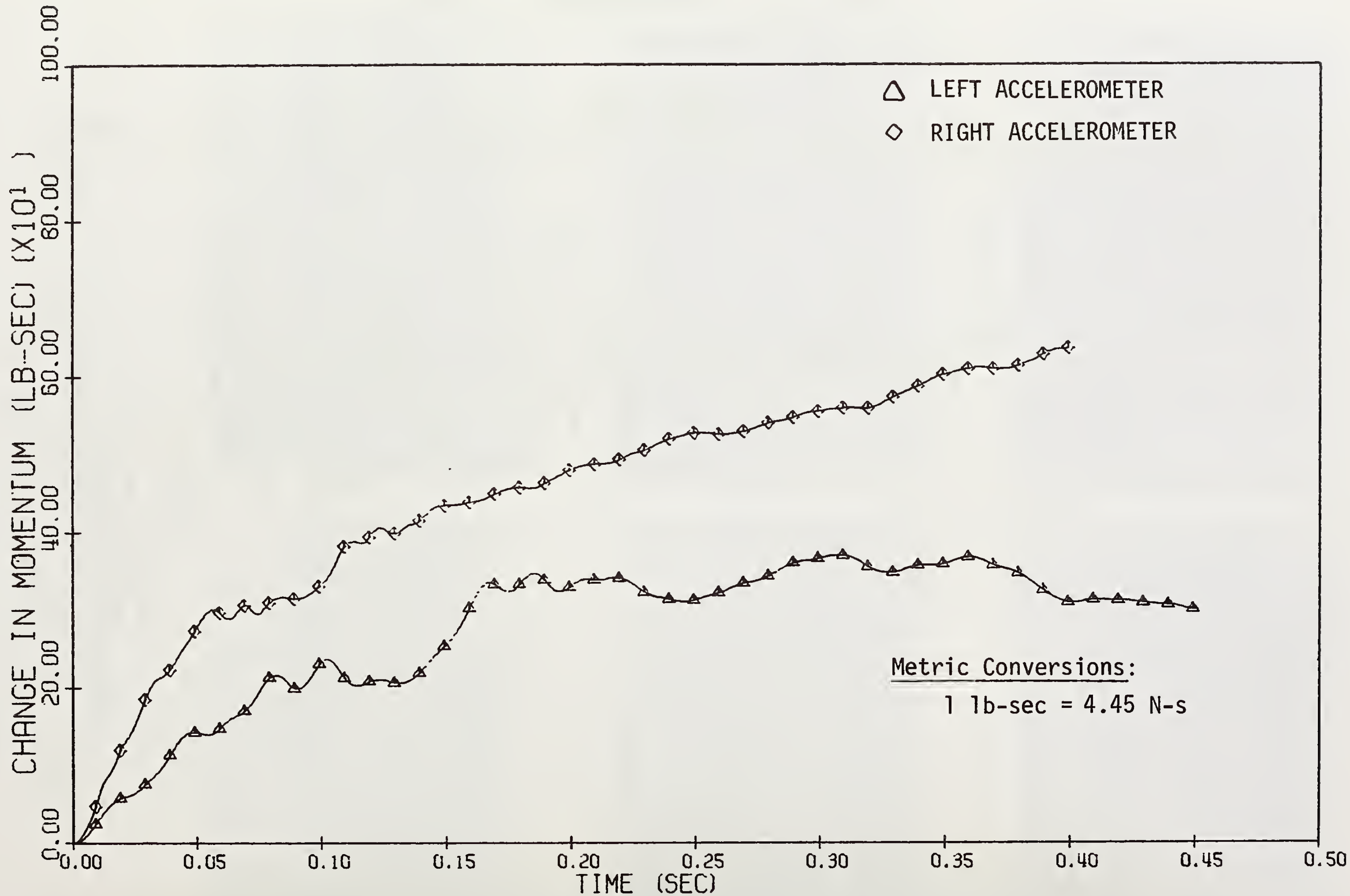


Figure 77. Change in momentum vs. time, test 8.

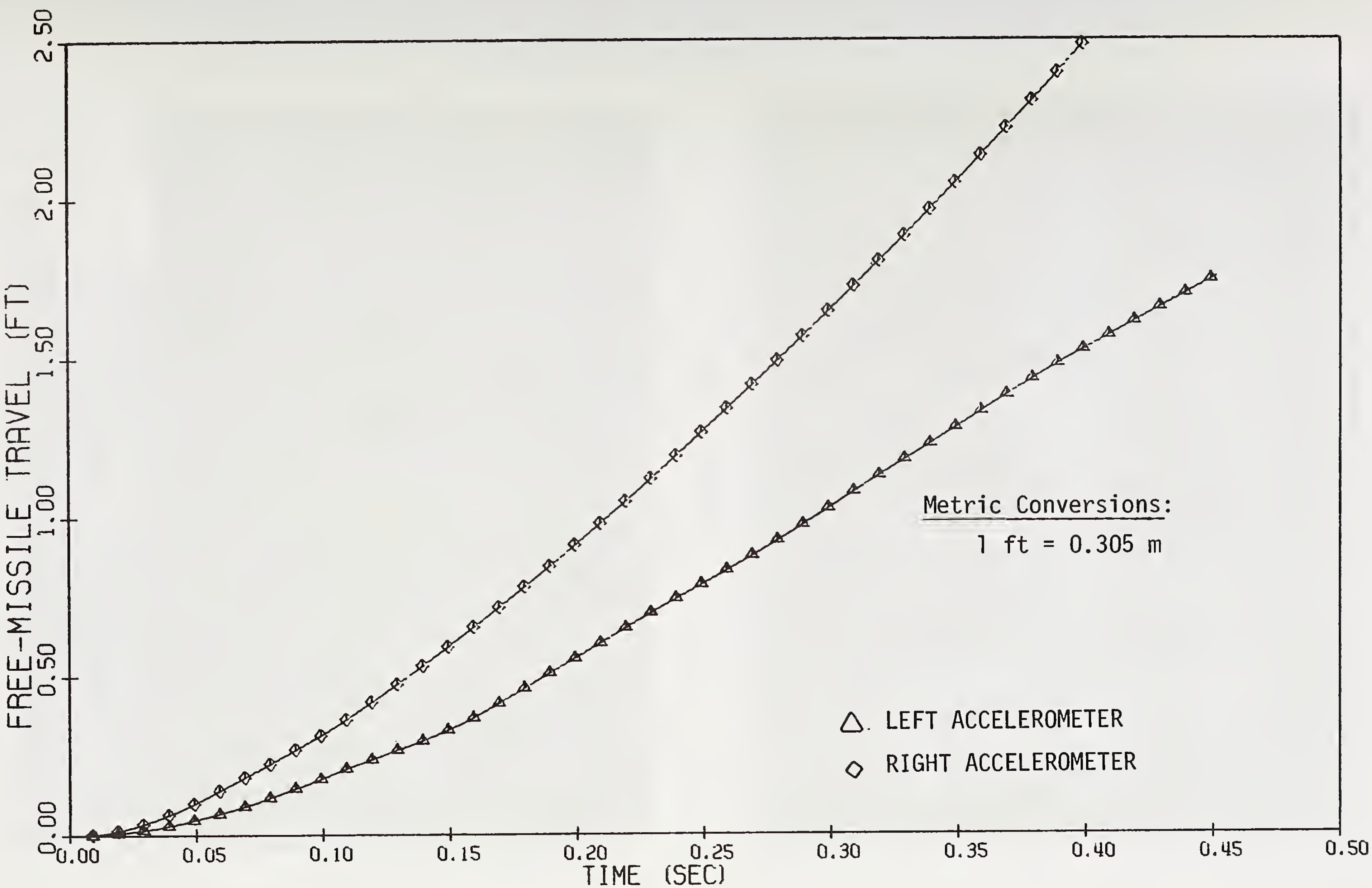


Figure 78. Free missile travel vs. time, test 8.

(a) PANEL AND POST

(b) BASE

Figure 79. Sign installation damage, test 8.

(a) FRONT VIEW

(b) TOP VIEW

Figure 80. Vehicle damage, test 8.

A-3-9. Test No. 9

Table 25 summarizes the results of test 9. Based on results of tests 3 and 4, it was concluded that a high-speed impact with this system would be more severe than a low-speed impact. Hence, the system was tested at the high speed only. Figure 81 contains sequential photos from high-speed film taken during impact, and Table 26 contains a time-displacement-event summary. After impact the post wrapped around the hood and imparted relatively high forces to the vehicle. The hood was pushed back into the windshield but did not penetrate into the passenger compartment. Continued forward movement of the vehicle stripped the panel off the post and straightened out the post. Neither of the 3 lb/ft (4.5 kg/m) posts fractured. The bolts used to fasten the two posts in a back-to-back configuration were sheared off. After impact the vehicle spun about 200 degrees and almost rolled over. It came to rest about 50 ft (15.3 m) beyond the point of impact. Further discussion of the impact performance of this type post is given in Section A-3-22.

Figures 82, 83, and 84 contain deceleration, change in momentum, and free missile travel versus time data. Figure 85 shows damage to the sign installation. Restoration would involve replacement of the complete installation. Figure 86 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 25.

Table 25. Summary of results, test 3254-9.

Impact Velocity = 61.2 mph

POST DATA		
Type	Steel U-Post Back-to-Back** (Billet Steel)	
Size	6 lb/ft	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1972	
Weight (lb)	2280	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	2363	2135
Duration of Event (sec)*	0.150	
Peak Deceleration (G's)	13.00	13.75
Maximum 0.050 Sec Average Deceleration (G's)	9.18	8.30
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-5	
SAE	12FLEN4	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes, due to hood hitting it	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Free missile travel time

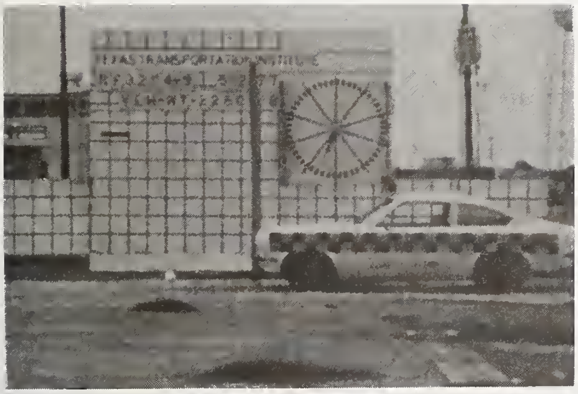
**Armco Steel Corporation posts

Table 26. Time displacement event summary for test 3254-9.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.062	5.14	Sign strikes hood
0.077	6.27	Sign begins to tear hood off
0.108	8.31	Sign distorts left front bumper
0.131	9.59	Sign rips from post
0.183	12.48	Back wheels off ground, hood flying up

Metric Conversion:

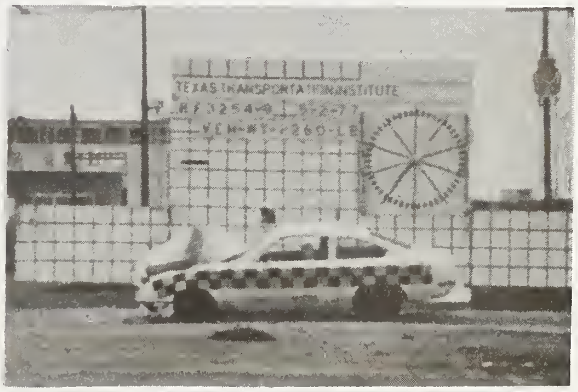
1 ft = 0.305 m



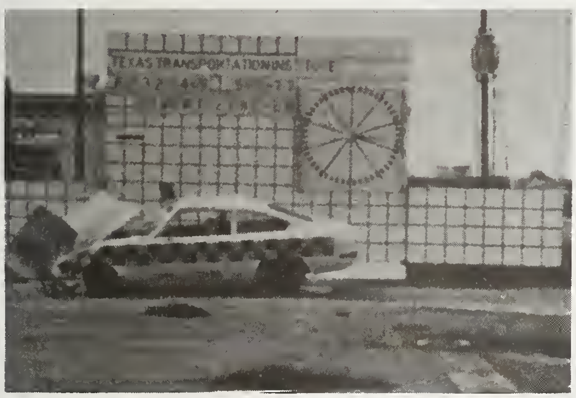
0.000 sec

0.062 sec

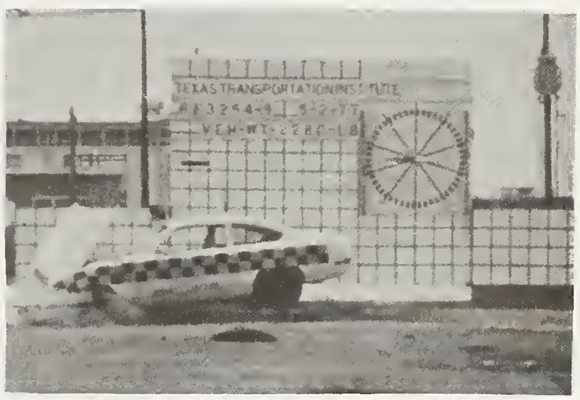
0.077 sec



0.108 sec



0.130 sec



0.183 sec

Figure 81. Sequential photos, test 9.

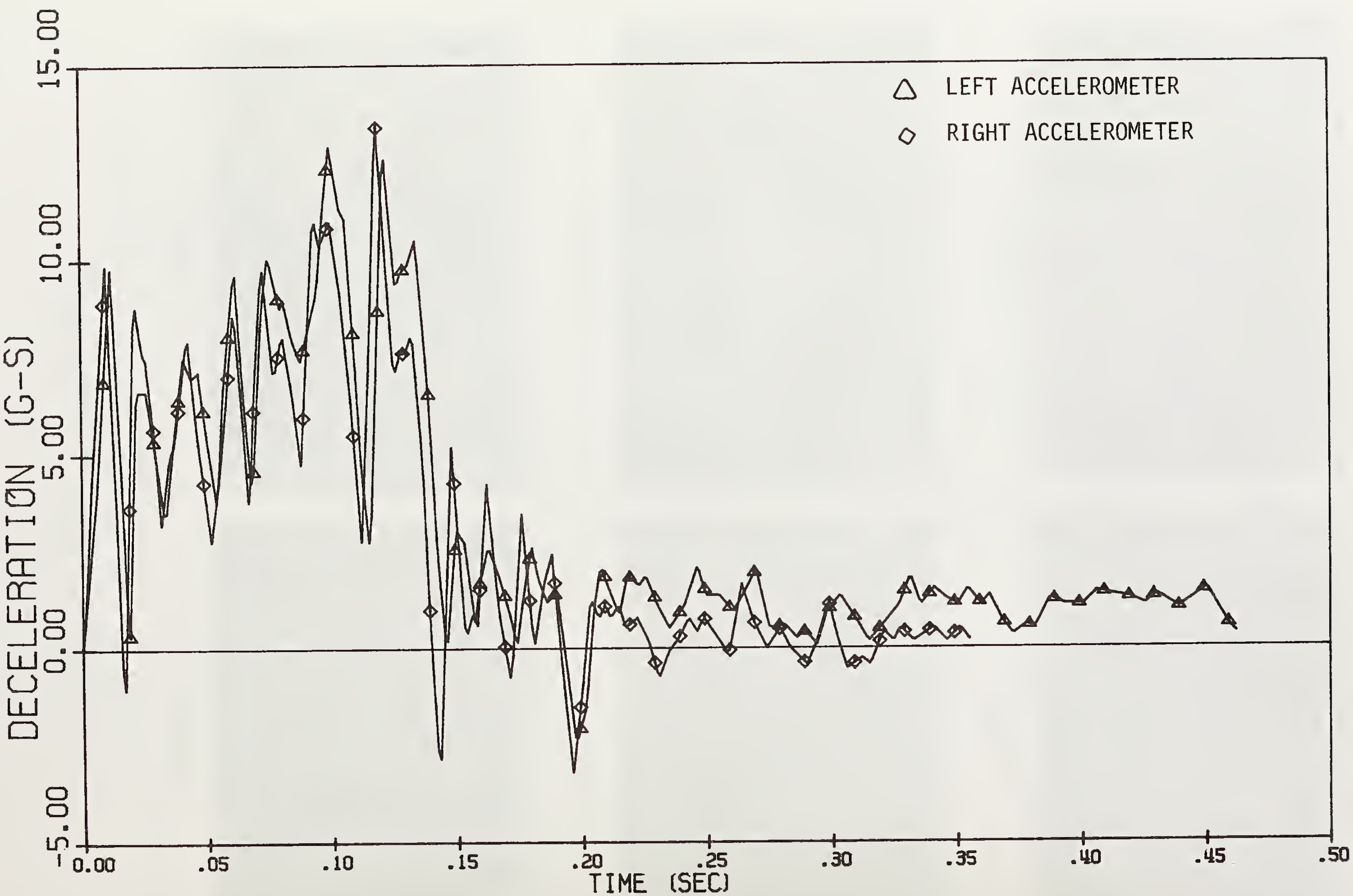


Figure 82. Deceleration vs. time, test 9.

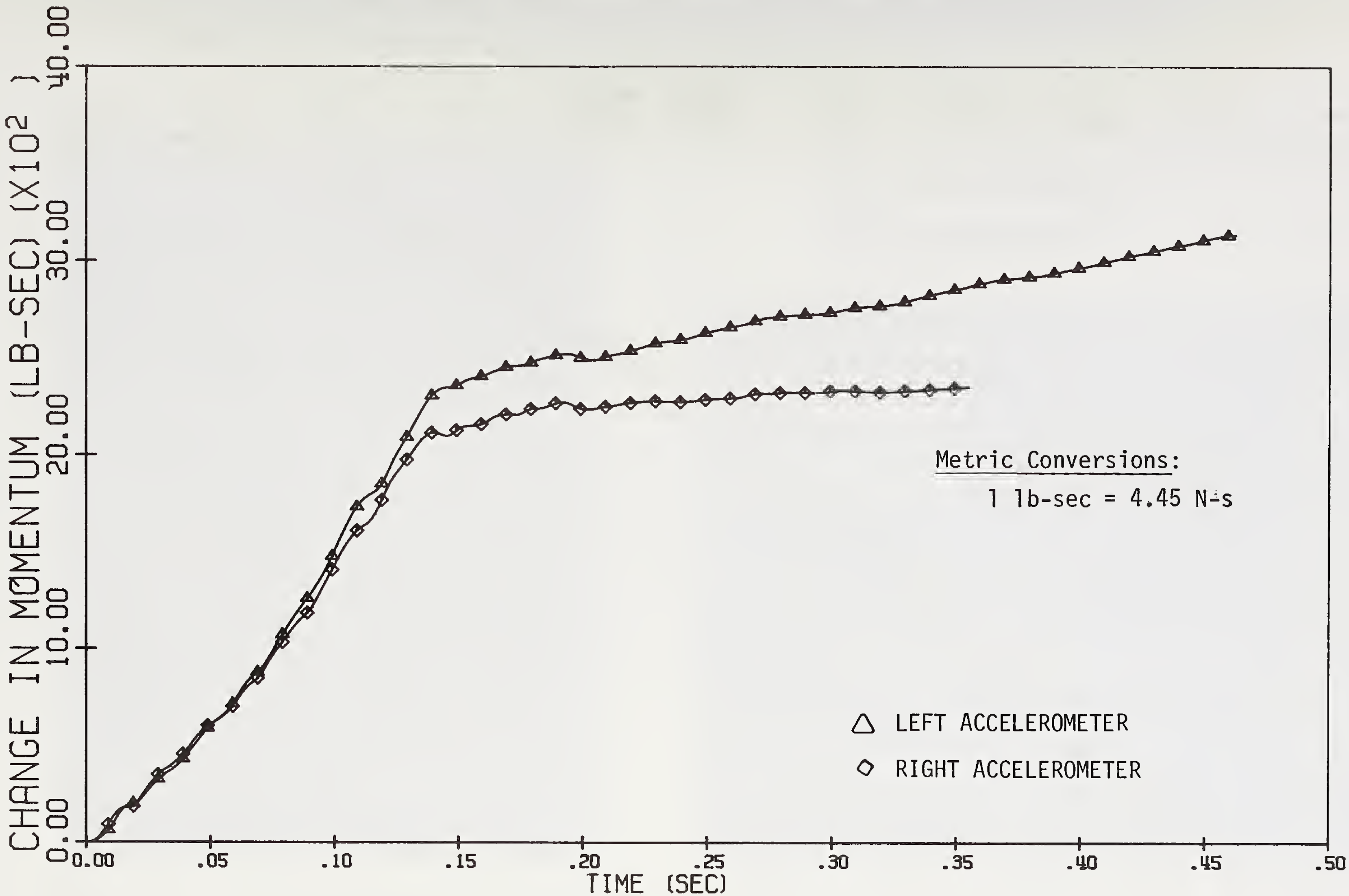


Figure 83. Change in momentum vs. time, test 9.

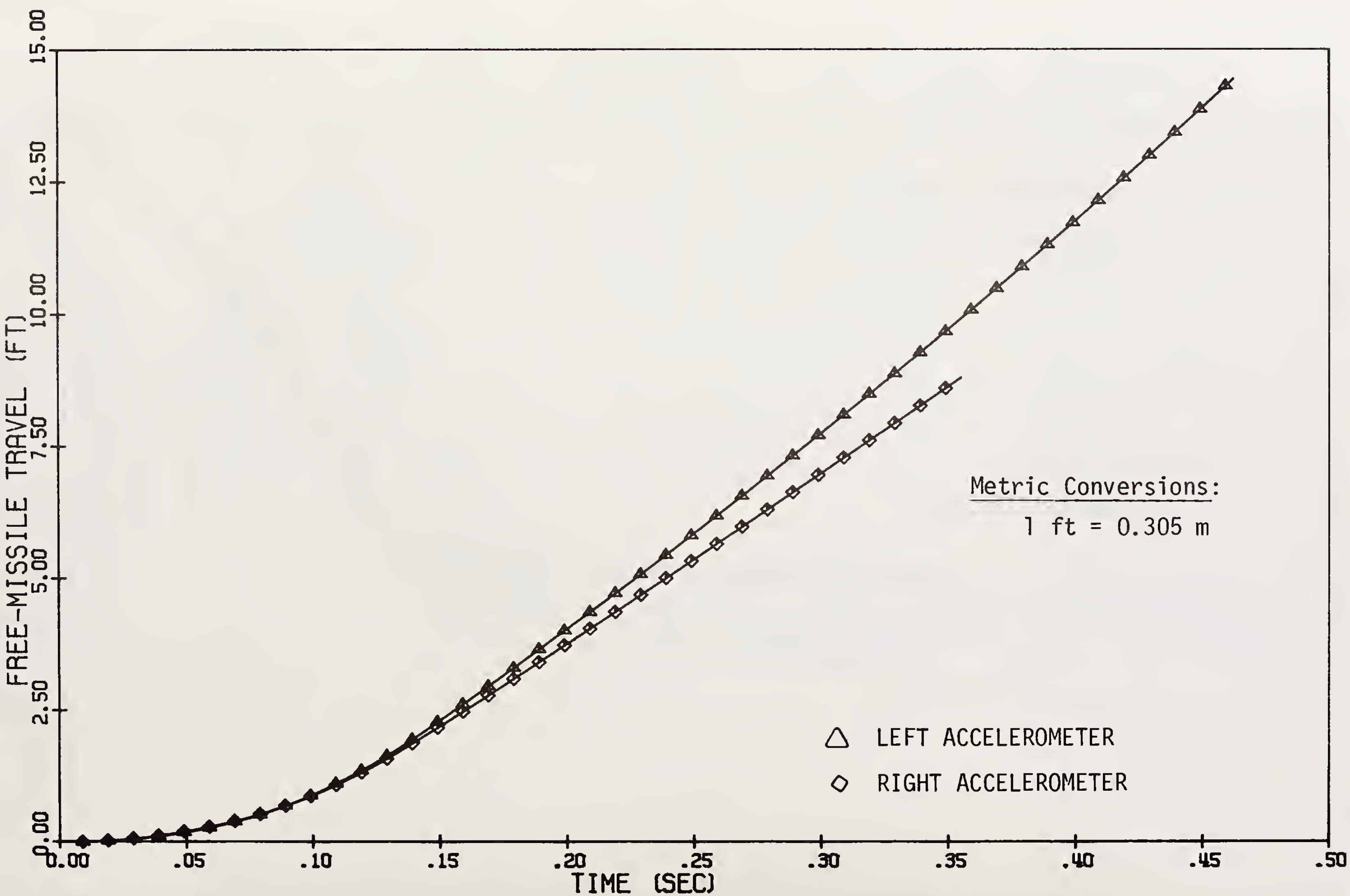
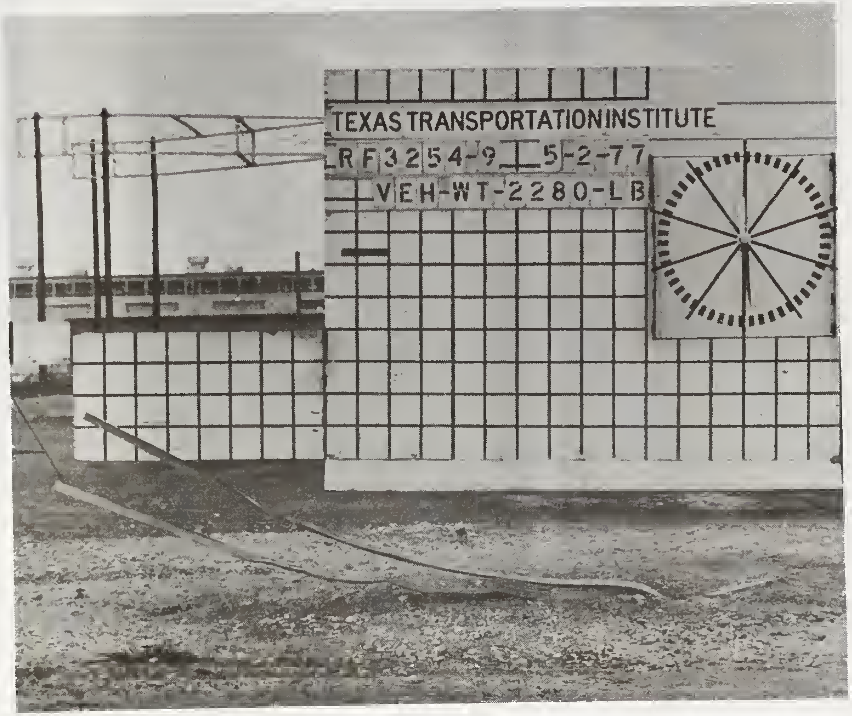


Figure 84. Free missile travel vs. time, test 9.

(a) FRONT VIEW



(b) SIDE VIEW

Figure 85. Sign installation damage, test 9.

(a) FRONT VIEW

(b) TOP VIEW

Figure 86. Vehicle damage, test 9.

A-3-10. Test No. 10

Table 27 summarizes the results of test 10. Figure 87 contains sequential photos from high-speed film taken during impact, and Table 28 contains a time-displacement-event summary. As shown in the photographs, the vehicle pitched up as it rode the post down. As the vehicle continued to move forward, the post and panel contacted the bottom of the vehicle, which impacted additional retarding forces.

Figures 88, 89, and 90 contain deceleration, change in momentum, and free missile travel versus time data. Figure 91 shows damage to the sign installation. Restoration would involve replacement of the signpost and repair to the sign panel.

Figure 92 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 27.

Table 27. Summary of results, test 3254-10.

Impact Velocity = 18.9 mph

POST DATA			
Type	Standard Steel Pipe		
Size	2.5 in. ϕ		
Embedment Method	Drill and Backfill		
Embedment Depth (ft)	4.0		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1971		
Weight (lb)	2270		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		849	916
Duration of Event (sec)*		0.230	
Peak Deceleration (G's)		7.33	6.73
Maximum 0.050 Sec Average Deceleration (G's)		3.69	6.73
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-1		
SAE	12FLEN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

Metric Conversions:

1 in.	= 2.54 cm
1 ft	= 0.305 m
1 lb_m	= 0.454 kg
1 lb -sec	= 4.45 N-s
1 mph	= 1.609 km/h

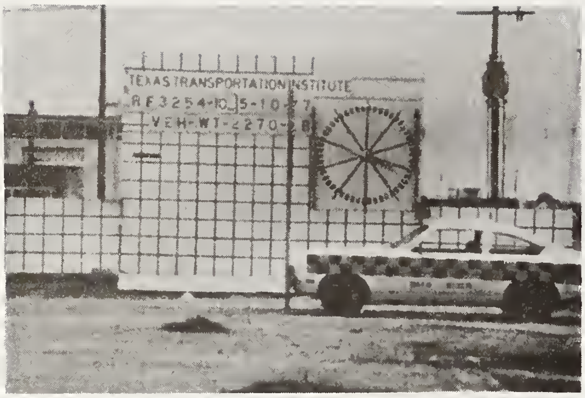
*Free missile travel time

Table 28. Time displacement event summary for test 3254-10.

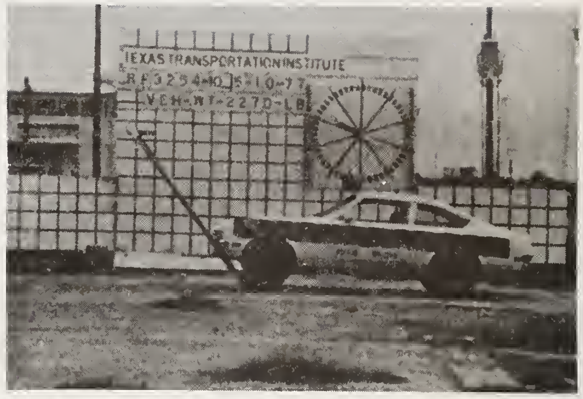
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.158	2.91	Front wheels lifted off ground
0.351	5.53	Front wheels lifted off ground
0.681	9.00	Sign touches ground
0.881	10.69	Sign dragging underneath car
1.272	13.83	Sign dragging underneath car

Metric Conversion:

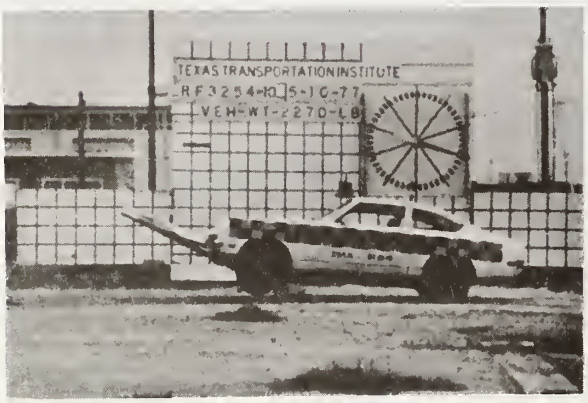
1 ft = 0.305 m



0.000 sec

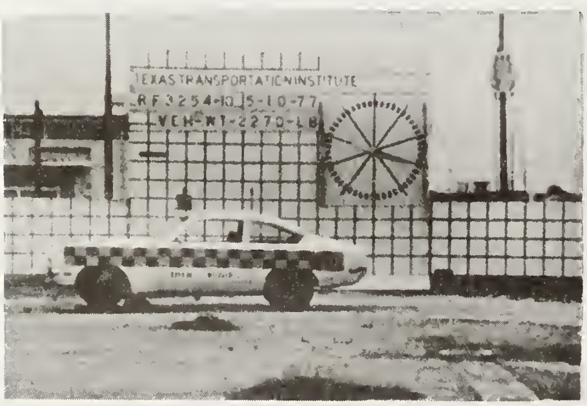


0.158 sec



0.351 sec

0.681 sec



0.881 sec

1.272 sec

Figure 87. Sequential photos, test 10.

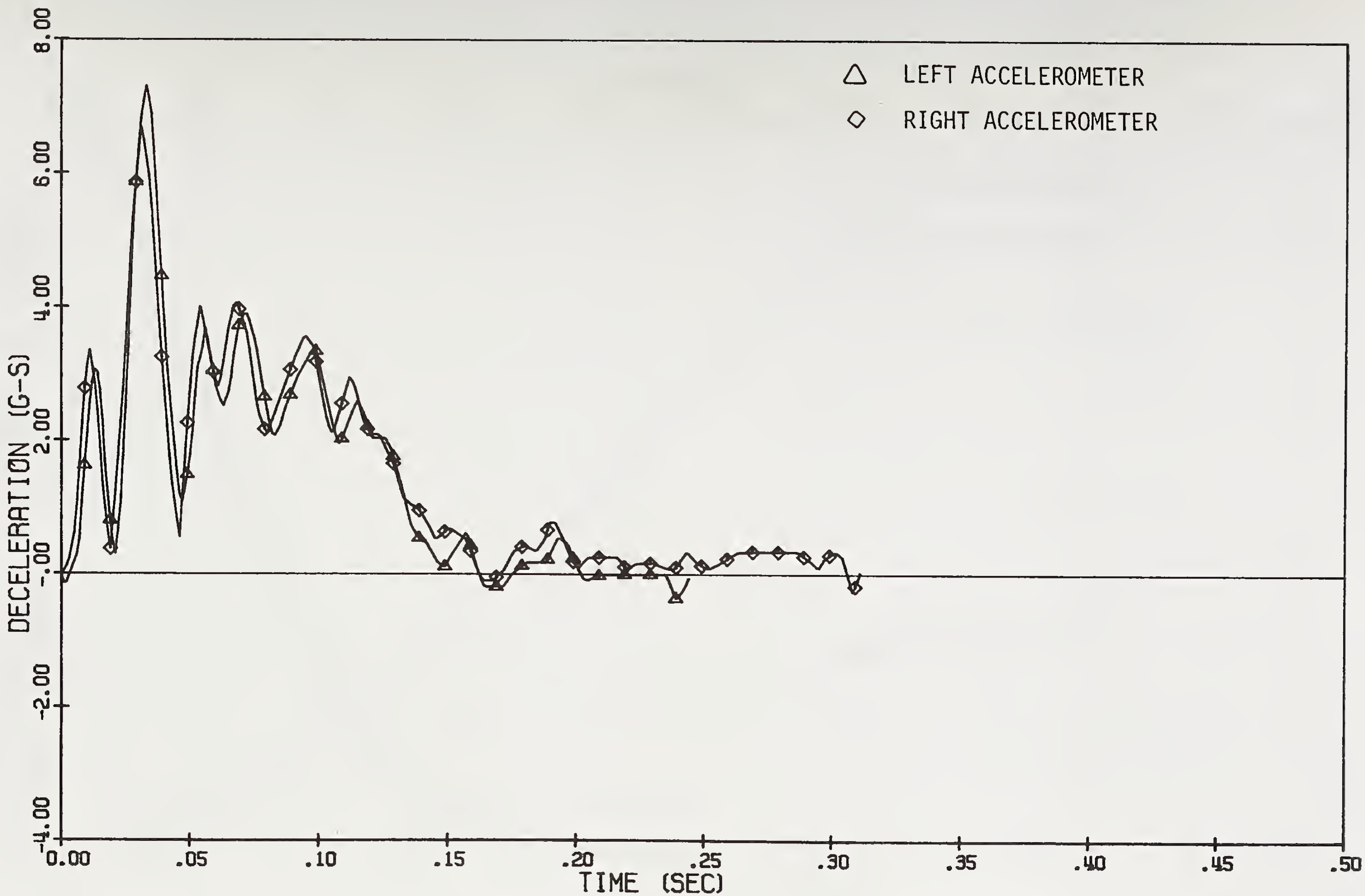


Figure 88. Deceleration vs. time, test 10.

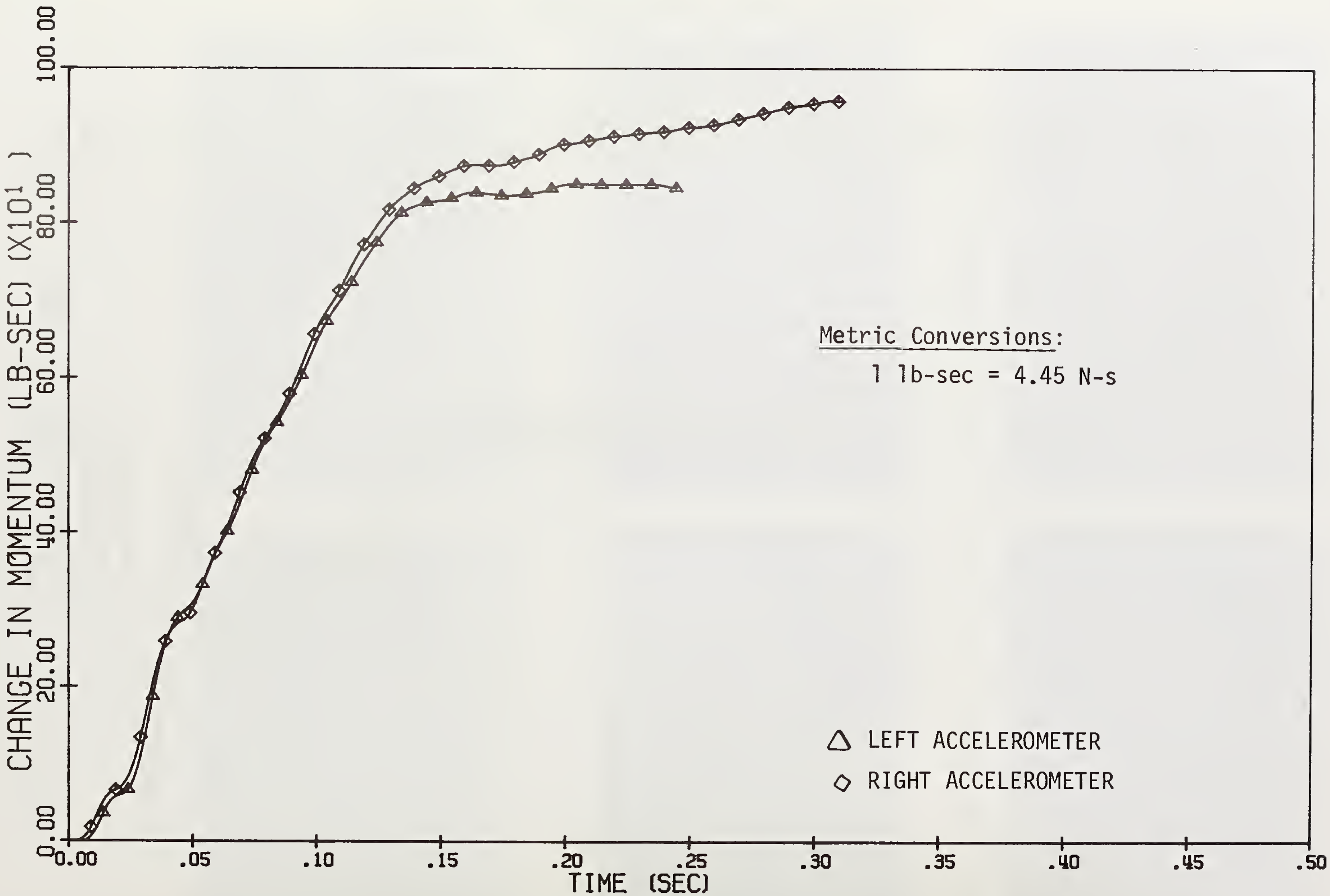


Figure 89. Change in momentum vs. time, test 10.

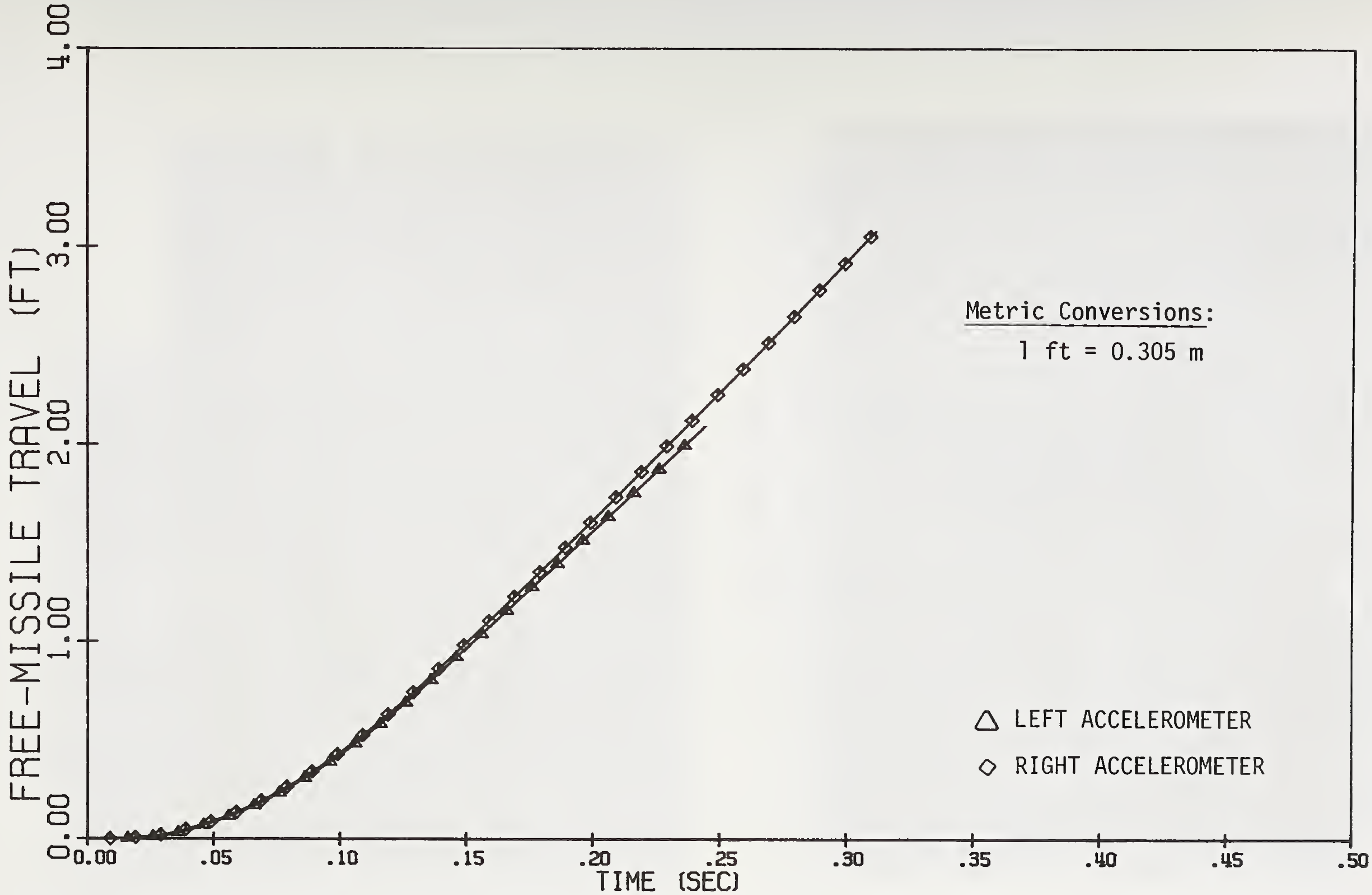
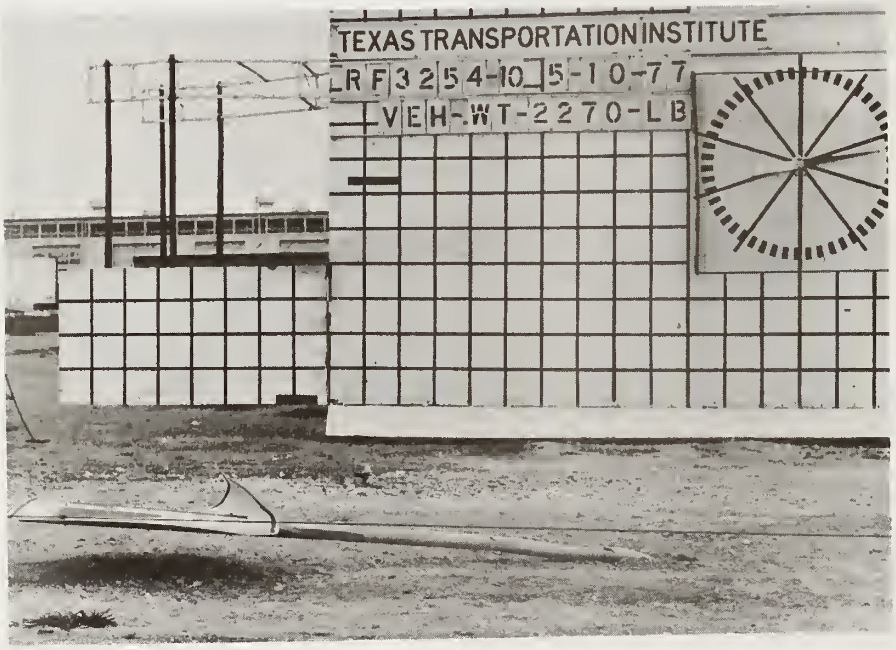


Figure 90. Free missile travel vs. time, test 10.

(a) FRONT VIEW



(b) SIDE VIEW

Figure 91. Sign installation damage, test 10.

(a) FRONT VIEW

(b) TOP VIEW

Figure 92. Vehicle damage, test 10.

A-3-11. Test No. 11

Table 29 summarizes the results of test 11. Figure 93 contains sequential photos from high-speed film taken during impact, and Table 30 contains a time-displacement-event summary. After impact, the post wrapped around the hood and imparted significant restraining forces to the vehicle. Continued forward motion of the vehicle straightened the post out and stripped the panel from the post. The post did not fracture. During contact the vehicle began to pitch down, yaw, and roll. After loss of post contact, the vehicle obtained a significant yaw and roll motion which resulted in complete loss of stability. The vehicle rolled over three times and was a total loss.

Figures 94, 95, and 96 contain deceleration, change in momentum, and free missile travel versus time data. Figure 97 shows damage to the sign installation. Restoration would involve replacement of the post. The panel could have possibly been repaired.

Figure 98 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 27.

Table 29. Summary of results, test 3254-11.

Impact Velocity = 61.4 mph

POST DATA		
Type	Standard Steel Pipe	
Size	2.5 in. ϕ	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2270	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	1070	1433
Duration of Event (sec)*	0.186	
Peak Deceleration (G's)	6.45	7.67
Maximum 0.050 Sec Average Deceleration (G's)	4.89	5.95
VEHICLE DAMAGE CLASSIFICATION		
TAD	LT-5/RT-5/FR-4	
SAE	00TBA01	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes, due to car rollover	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

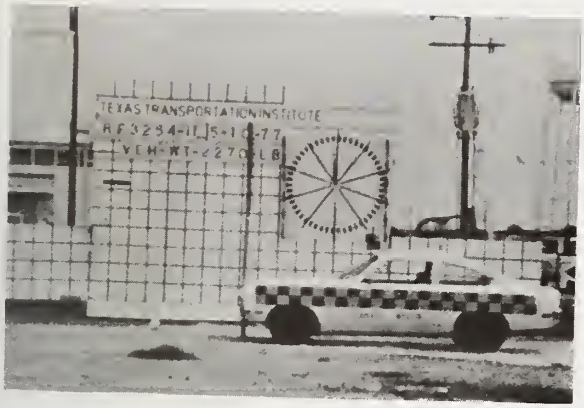
*Free missile travel time

Table 30. Time displacement event summary for test 3254-11.

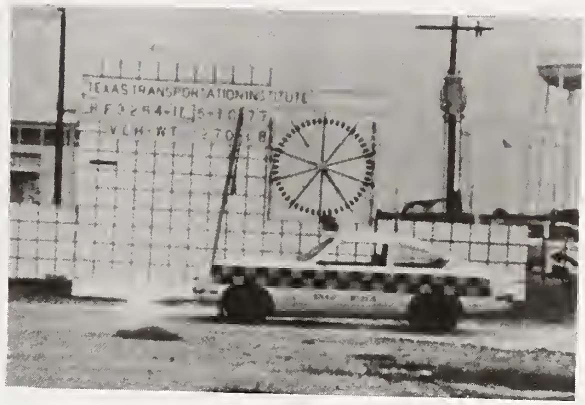
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Sign impact
0.015	1.31	Post begins to bend
0.064	5.48	Panel rotating into hood
0.100	8.41	Post wrapped around hood
0.122	10.10	Car starts to pitch and yaw
0.240	19.16	Car starts to yaw and roll

Metric Conversion:

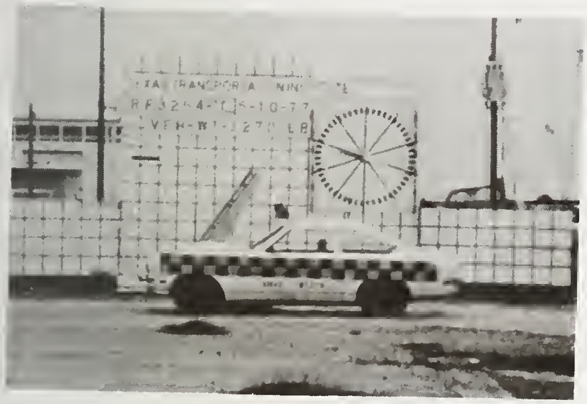
1 ft = 0.305 m



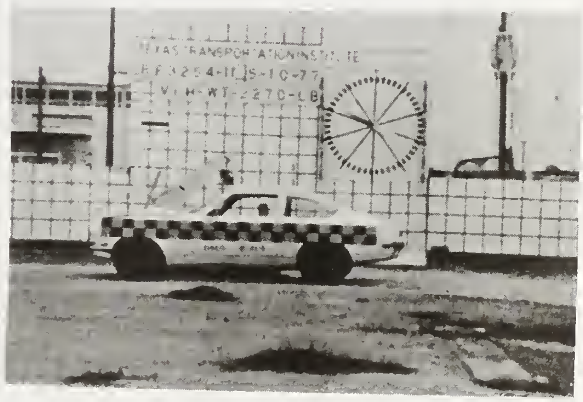
0.000 sec



0.014 sec

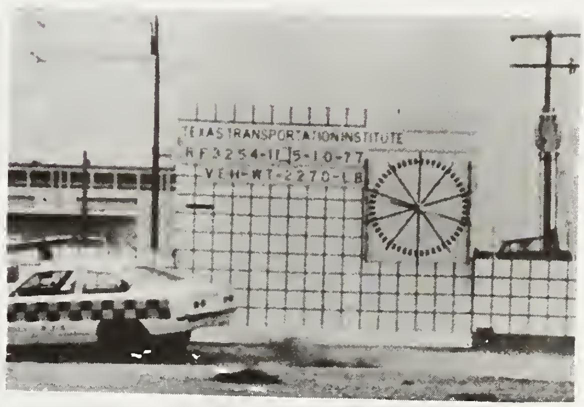


0.063 sec



0.100 sec

0.122 sec



0.239 sec

Figure 93. Sequential photos, test 11.

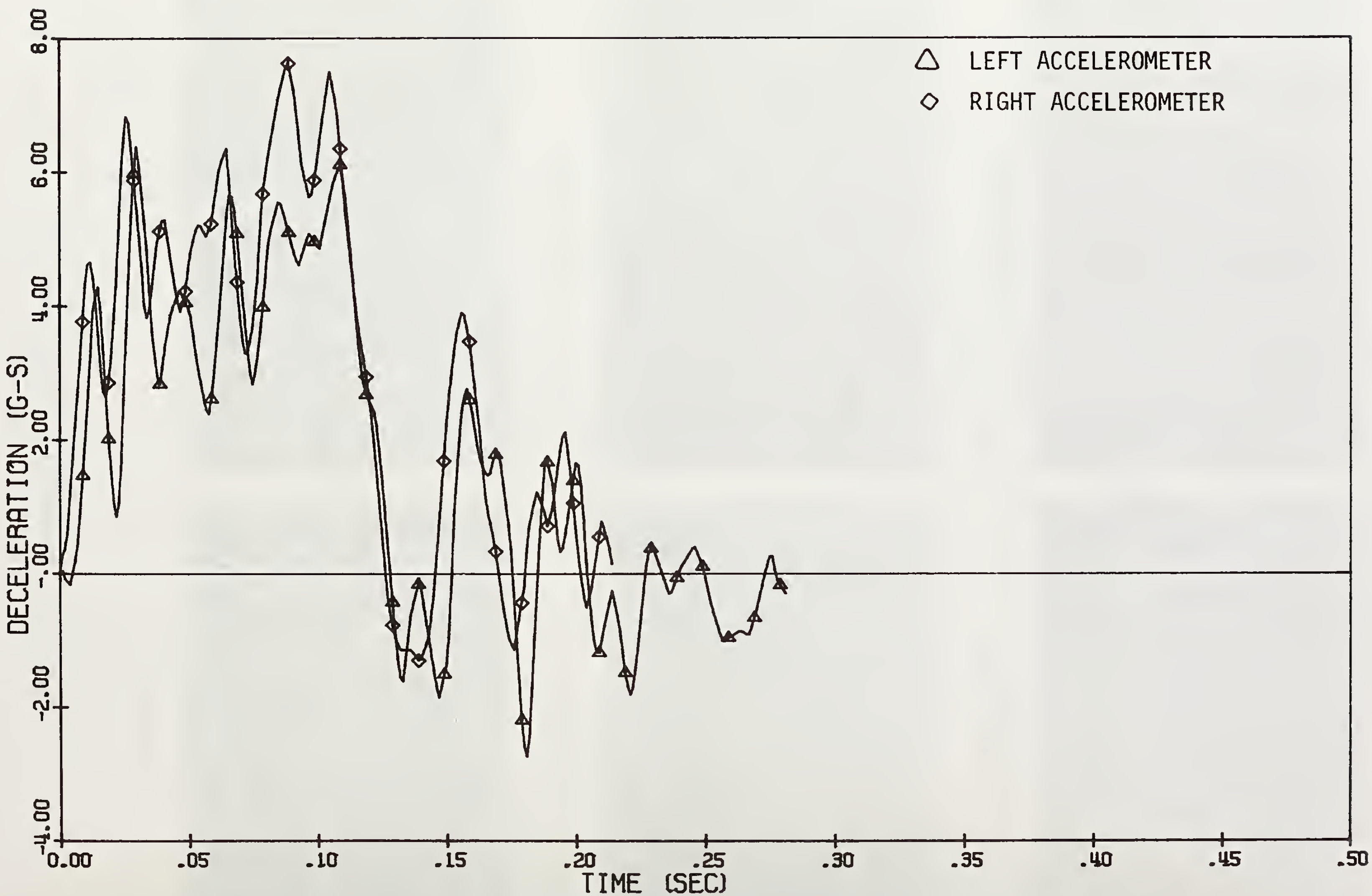


Figure 94. Deceleration vs. time, test 11.

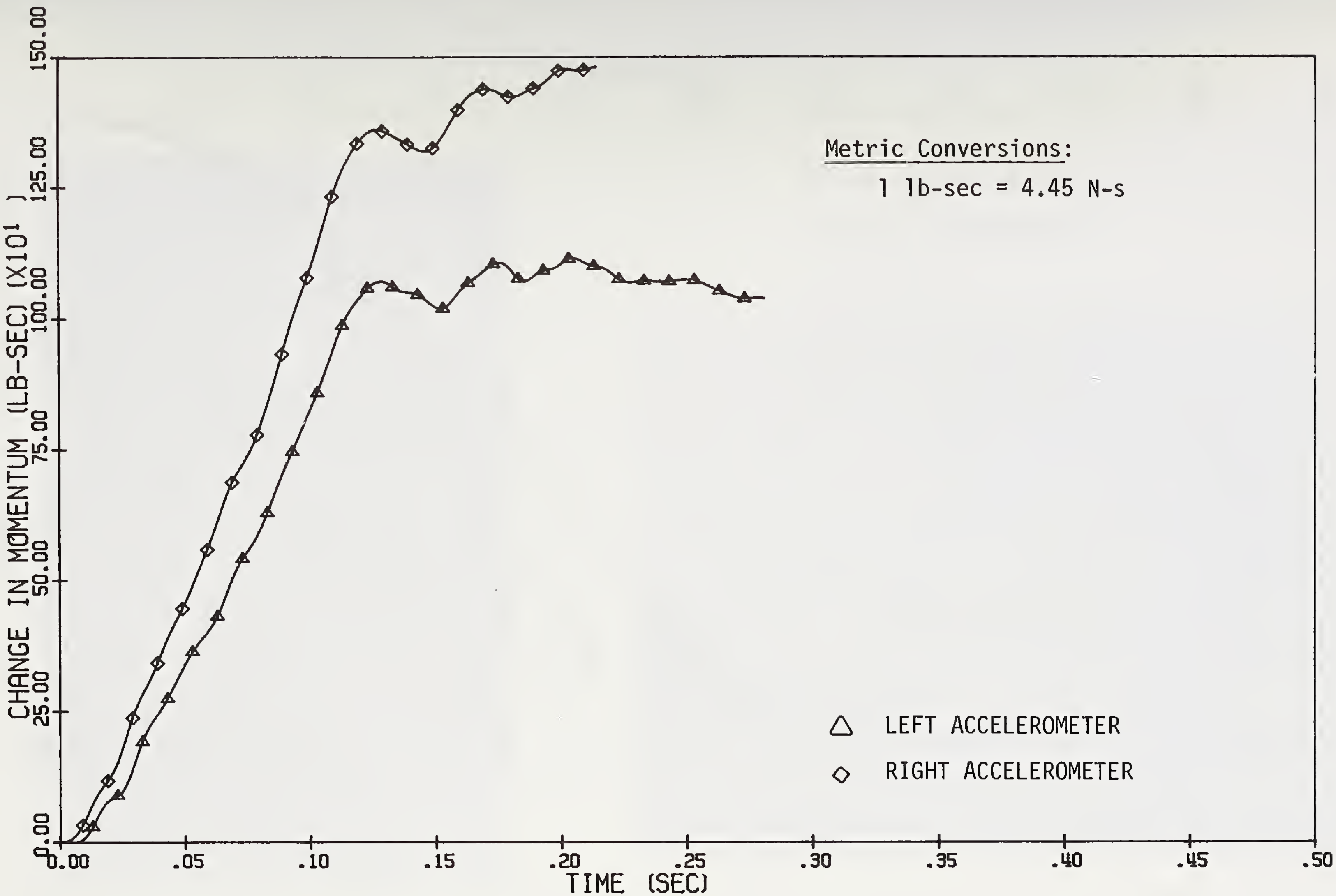


Figure 95. Change in momentum vs. time, test 11.

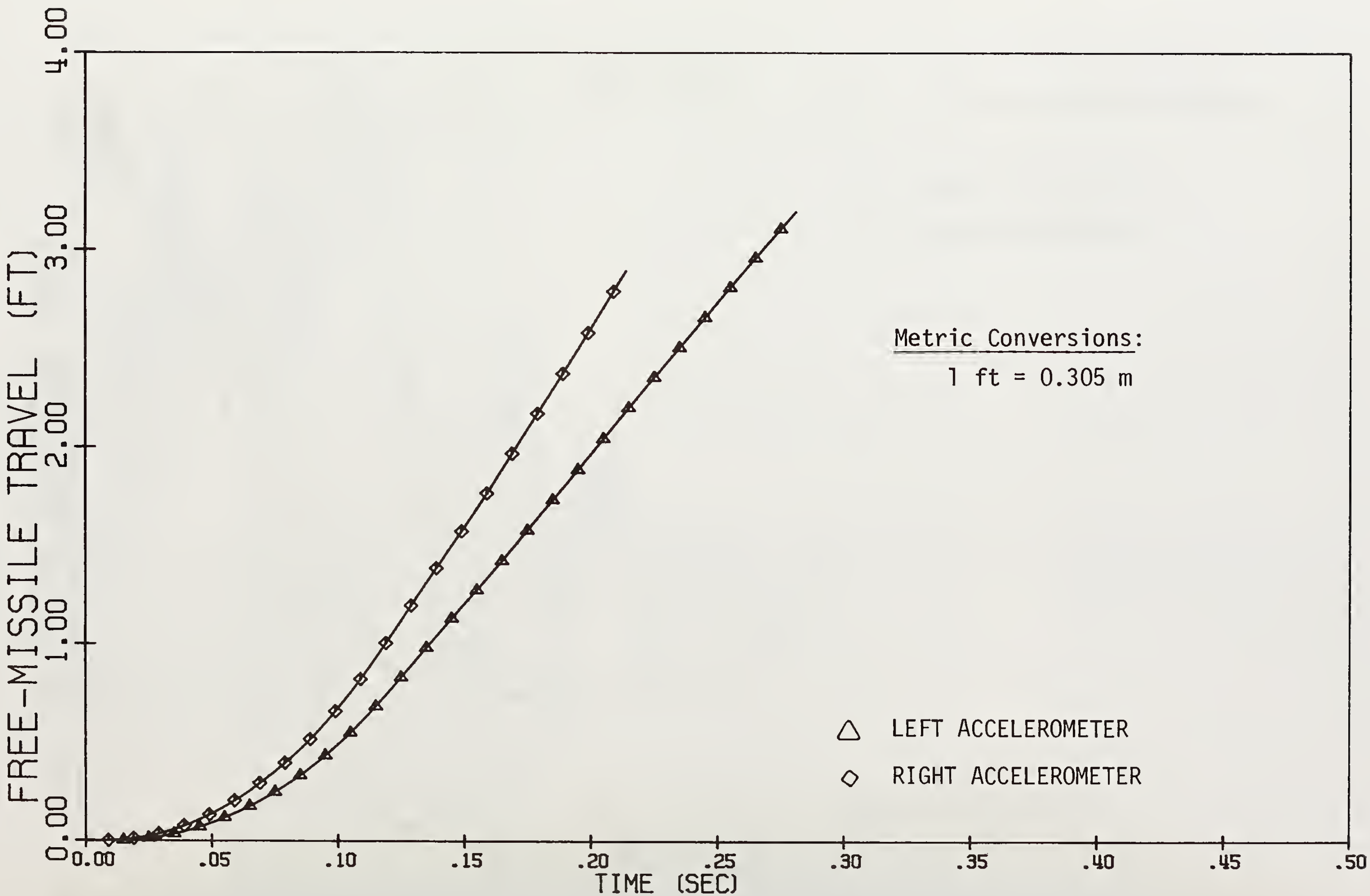
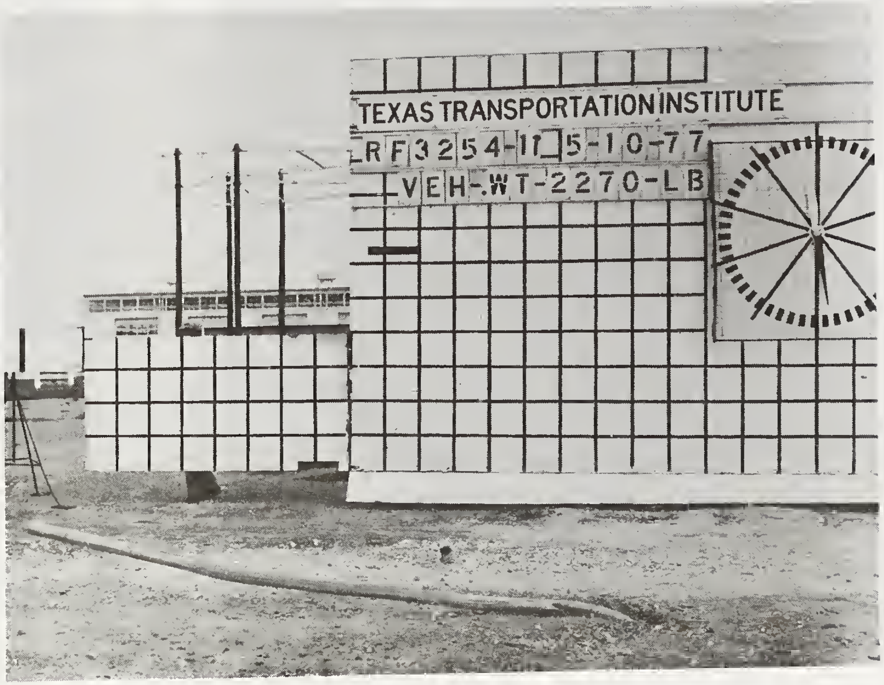


Figure 96. Free missile travel vs. time, test 11.

(a) GENERAL VIEW



(b) SIDE VIEW

Figure 97. Sign installation damage, test 11.

(a) SIDE VIEW

(b) TOP VIEW

Figure 98. Vehicle damage, test 11.

A-3-12. Test No. 12

Analysis of tests 1 and 2 showed two things. First, a full dimension 4 in. by 4 in. (10.2 cm by 10.2 cm) wood post met current performance specifications for sign posts. Second, the low-speed impact was slightly more severe in terms of the average change in momentum than the high-speed impact. Hence, the next logical test was a larger post at a low-speed impact.

Table 31 summarizes the results of test 12. Figure 99 contains sequential photos from high-speed film taken during impact, and Table 32 contains a time-displacement-event summary. It can be seen that the post fractured near the bumper contact point and near the ground. The post and panel were then projected out in front of the vehicle.

Figures 100, 101, and 102 contain deceleration, change in momentum, and free missile travel versus time data. Figure 103 shows damage to the sign installation. Restoration would involve replacement of the signpost.

Figure 104 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 31.

Table 31. Summary of results, test 3254-12.

Impact Velocity = 20.7 mph

POST DATA			
Type	Wood - Southern Pine, Grade 2		
Size	4 in. x 6 in. (Nominal Dimensions)		
Embedment Method	Drill and Backfill		
Embedment Depth (ft)	4.0		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1971		
Weight (lb)	2270		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		529	520
Duration of Event (sec)*		0.109	
Peak Deceleration (G's)		8.19	7.30
Maximum 0.050 Sec Average Deceleration (G's)		4.12	3.98
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-2		
SAE	12FLEN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

*Time of contact

Metric Conversions:

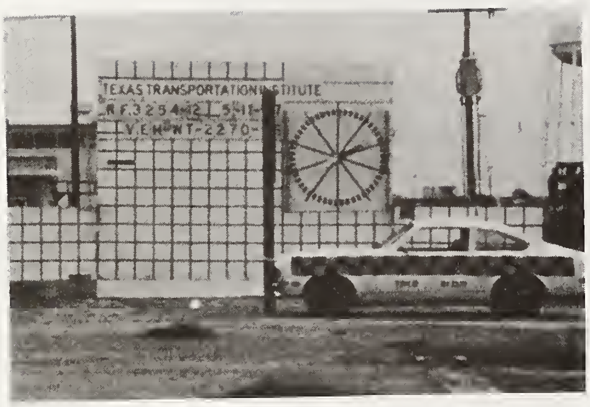
1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

Table 32. Time displacement event summary for test 3254-12.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.077	1.88	Post breaks
0.167	3.80	Post projected in front of car
0.251	5.15	Post in front of car
0.366	7.55	Post strikes ground

Metric Conversion:

1 ft = 0.305 m

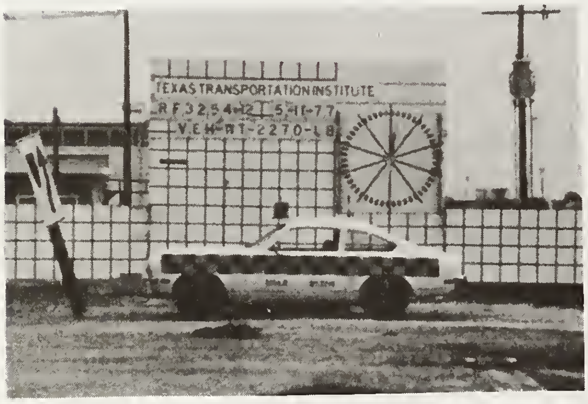


0.000 sec

0.077 sec

0.167 sec

0.251 sec



0.366 sec

0.633 sec

Figure 99. Sequential photos, test 12.

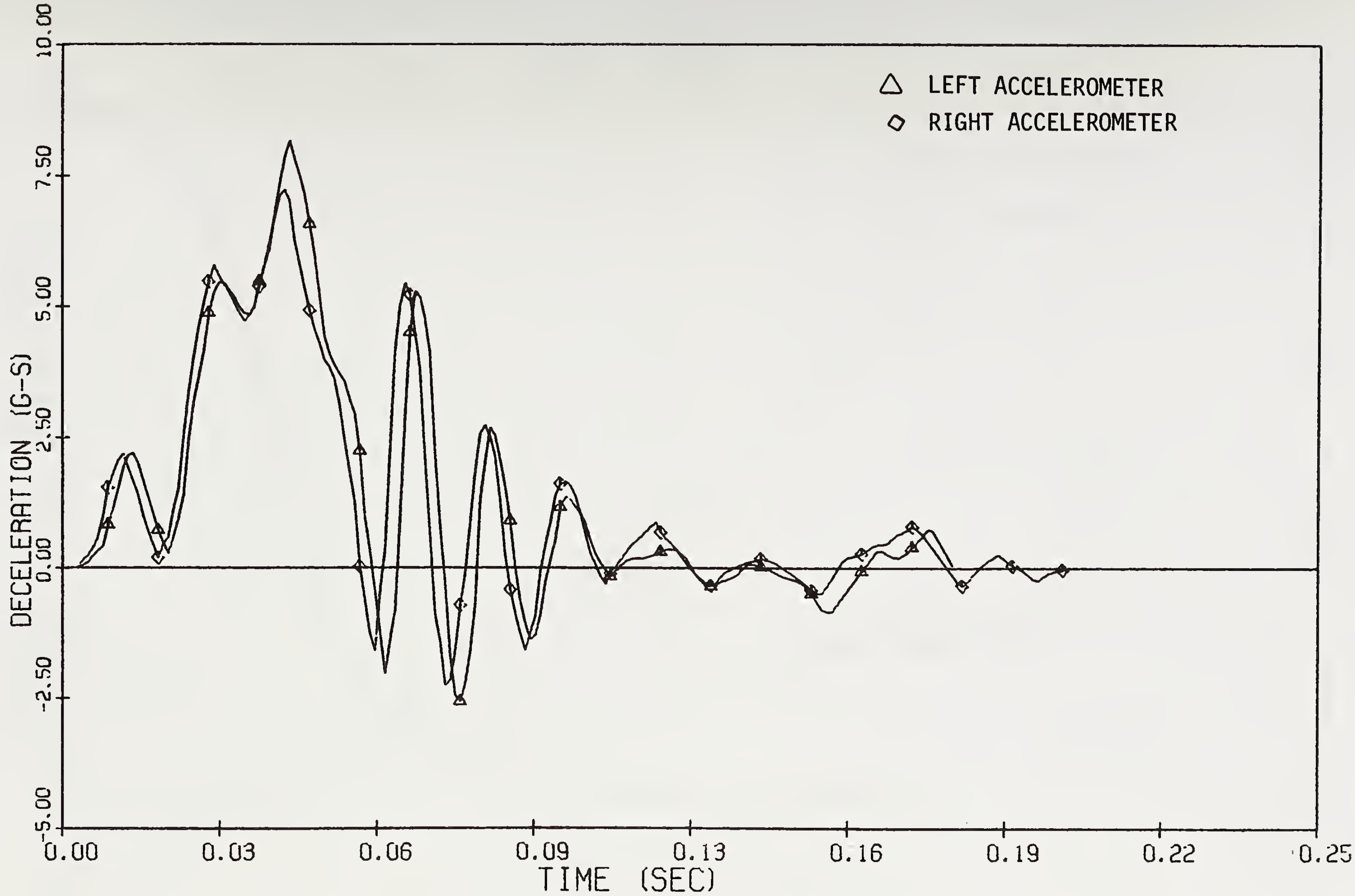


Figure 100. Deceleration vs. time, test 12.

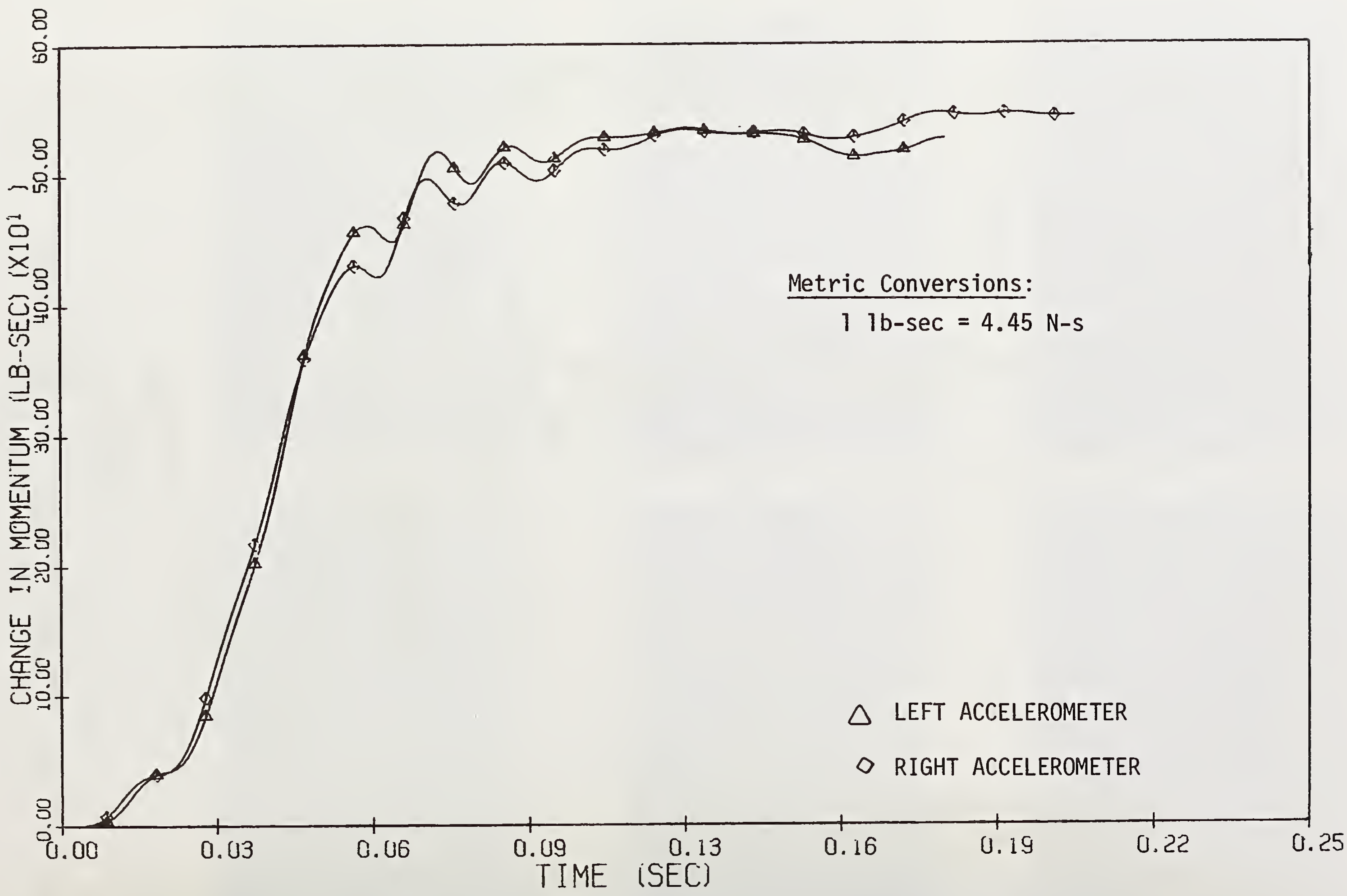


Figure 101. Change in momentum vs. time, test 12.

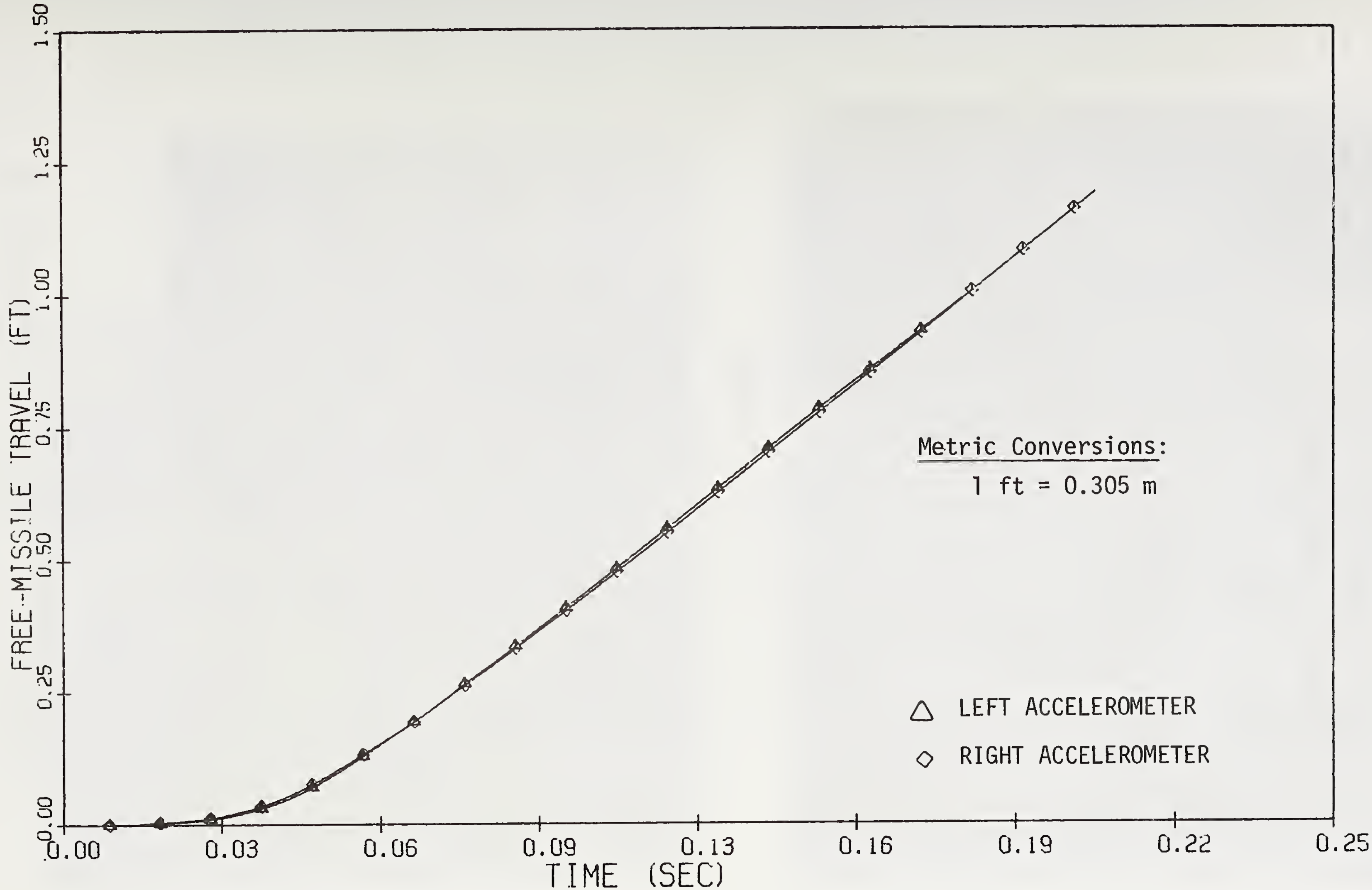
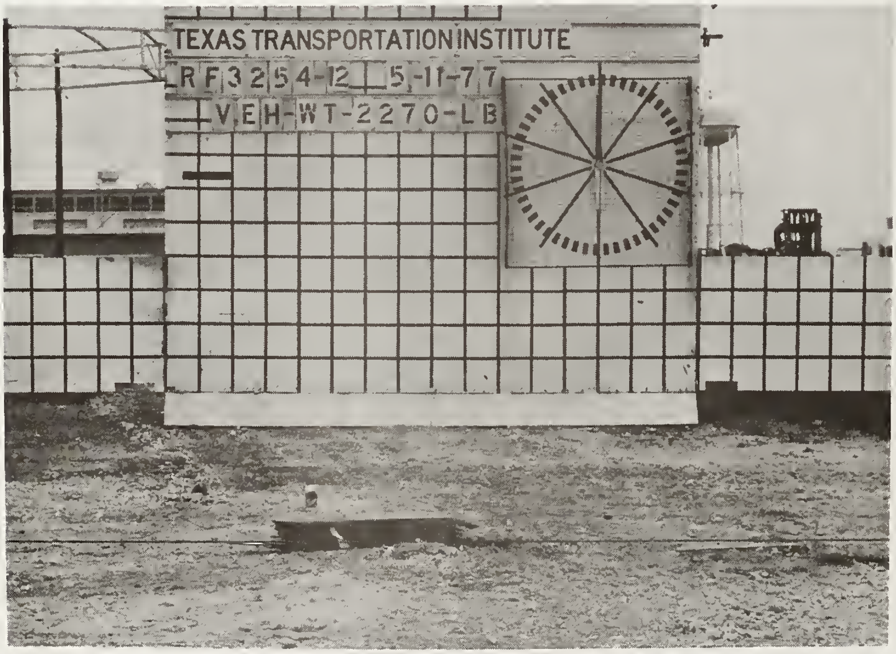


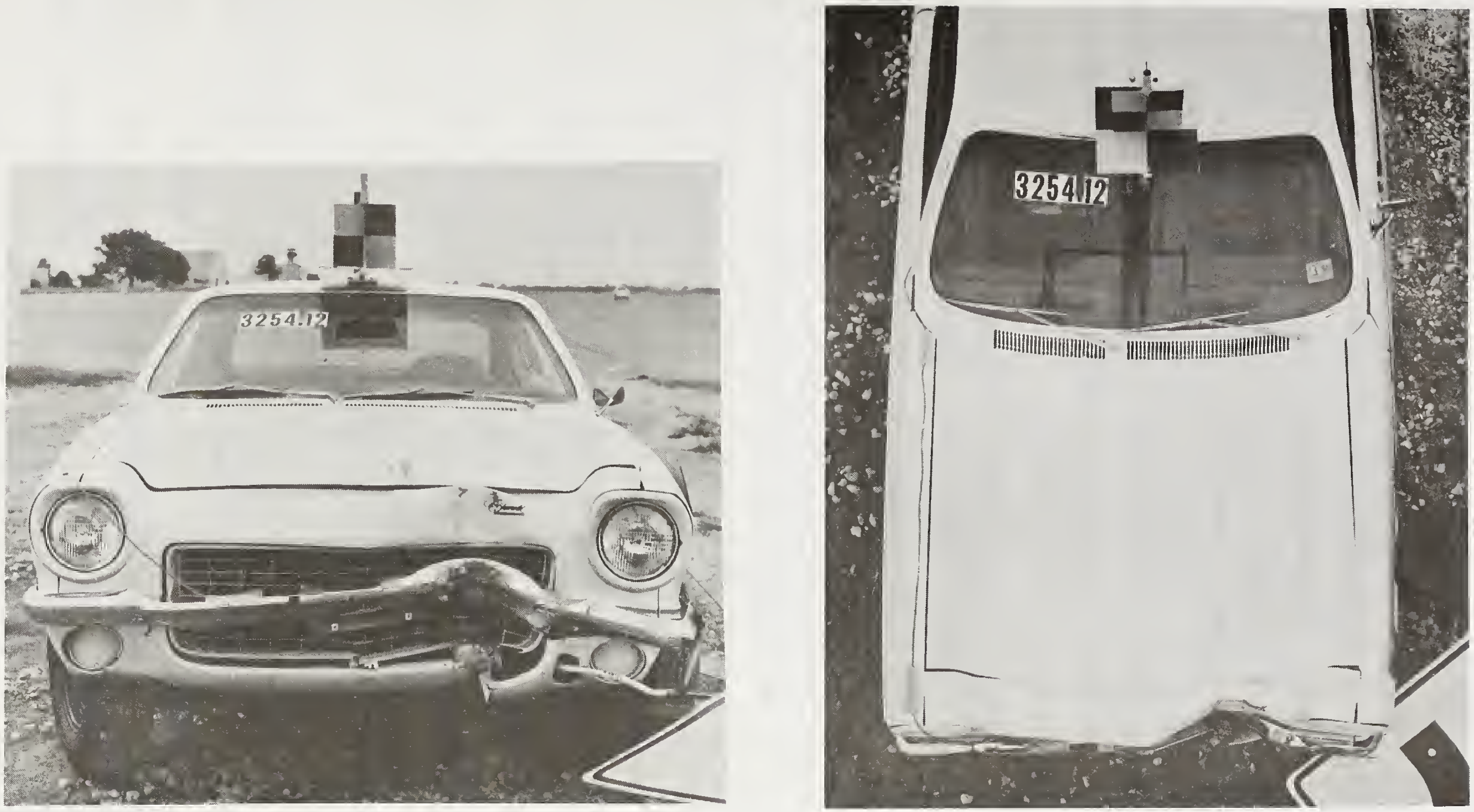
Figure 102. Free missile travel vs. time, test 12.

(a) POST AND PANEL



(b) BASE

Figure 103. Sign installation damage, test 12.



(a) FRONT VIEW

(b) TOP VIEW

Figure 104. Vehicle damage, test 12.

A-3-13. Test No. 13

Analysis of tests 4 and 9 showed that the billet steel U-post exhibited undesirable impact behavior. In these tests, the post underwent large deformations upon impact and showed a significant amount of toughness. The post did not fracture in either test and as a consequence large impact forces were imposed on the vehicle. In contrast, tests of rail steel U-posts with a bolted base assembly demonstrated that rail steel would fracture on impact (8). Test 13 was therefore scheduled to evaluate the impact behavior of a full-length rail steel U-post.

Table 33 summarizes the results of test 13. Figure 105 contains sequential photos from high-speed film taken during impact, and Table 34 contains a time-displacement-event summary. It can be seen that immediately after impact the post fractured near the bumper contact point. The post was then projected forward, and the panel was rotated down into the windshield. Although the windshield was broken and dished considerably, the panel did not penetrate through into the passenger compartment. Subsequent to impacting the windshield, the post and panel were projected along with the vehicle. Reference should be made to Section A-3-2 for comments regarding the trajectory hazard of the small sign installations.

Figures 106, 107, and 108 contain deceleration, change in momentum, and free missile travel versus time data. Figure 109 shows damage to the sign installation. Restoration would involve the replacement of the signpost. The panel and hardware were reusable.

Figure 110 shows damage to the vehicle. Note that damage to the left front of the vehicle was caused by test 12. Damage to the right portion of the vehicle was caused by test 13. Damage was assessed according to the TAD and SAE scales and is given in Table 33.

Table 33. Summary of results, test 3254-13.

Impact Velocity = 63.8 mph

POST DATA		
Type	Steel U-Post** (Rail Steel)	
Size	3 lb/ft	
Embedment Method	Driven	
Embedment Depth (ft)	3.5	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2270	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	Left	Right
Change in Momentum (lb-sec)	242	268
Duration of Event (sec)*	0.153	
Peak Deceleration (G's)	6.68	6.34
Maximum 0.050 Sec Average Deceleration (G's)	2.00	1.91
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-2	
SAE	12FREN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes, by sign panel	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

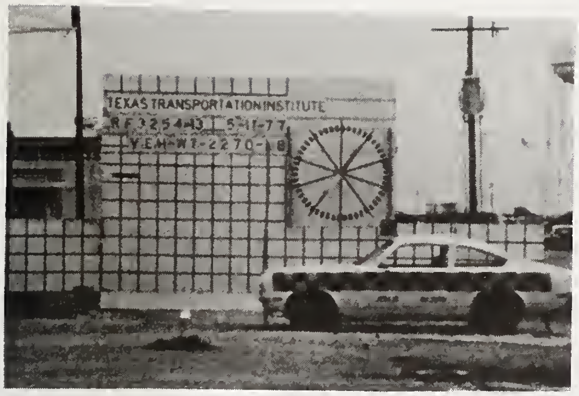
**Franklin Steel Company post

Table 34. Time displacement event summary for test 3254-13.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.033	3.03	Post breaks
0.062	5.57	Sign strikes windshield
0.104	9.24	Sign dishes in windshield
0.114	10.18	Rear axle over initial sign position
0.159	14.11	Post and panel begin to leave car

Metric Conversion:

1 ft = 0.305 m

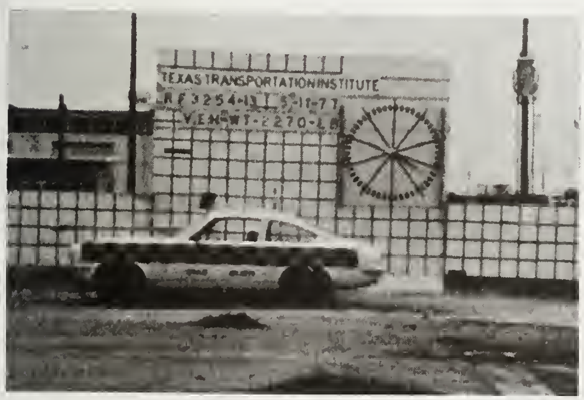


0.000 sec

0.033 sec

0.062 sec

0.104 sec



0.114 sec

0.159 sec

Figure 105. Sequential photos, test 13.

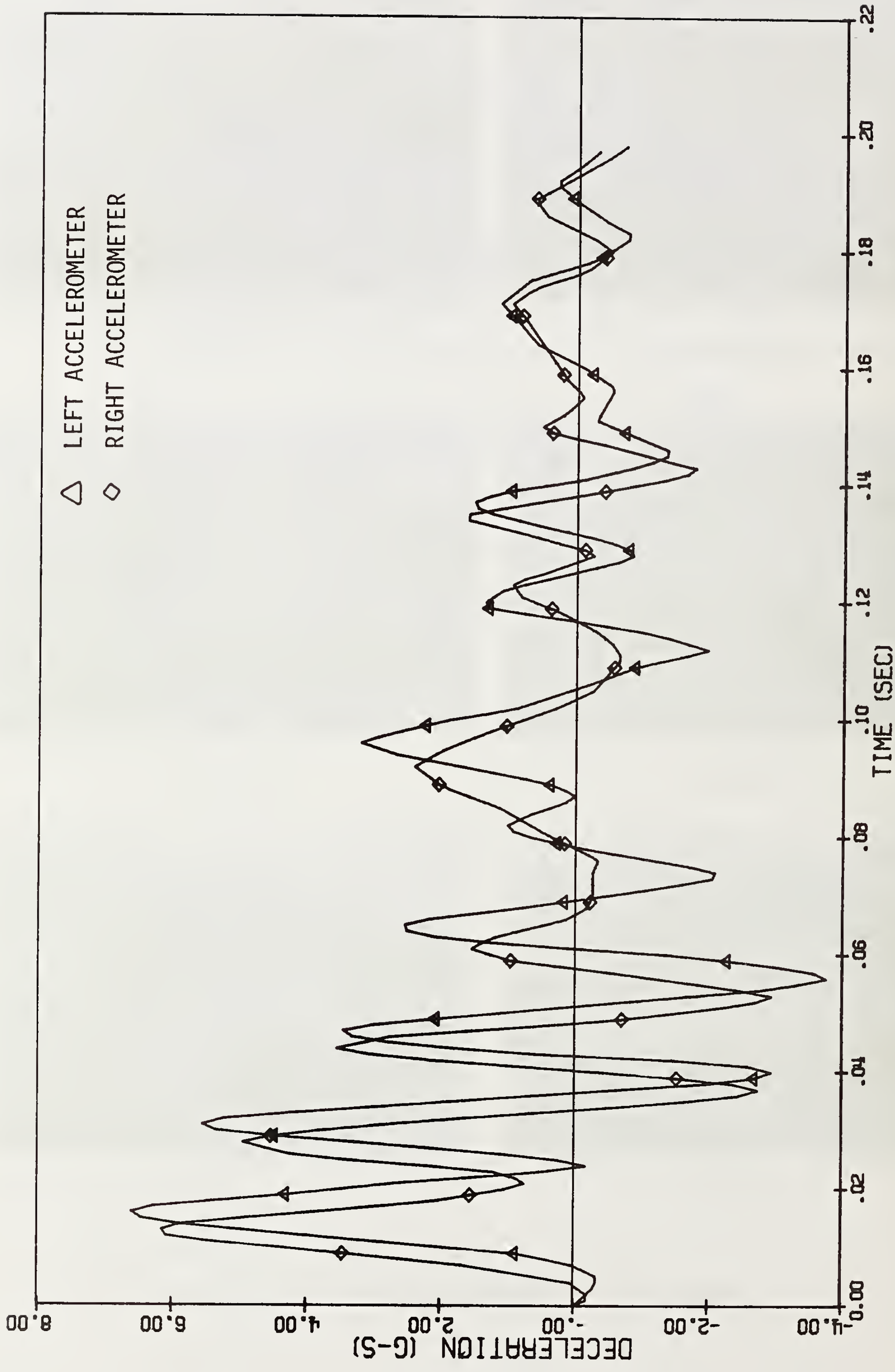


Figure 106. Deceleration vs. time, test 13.

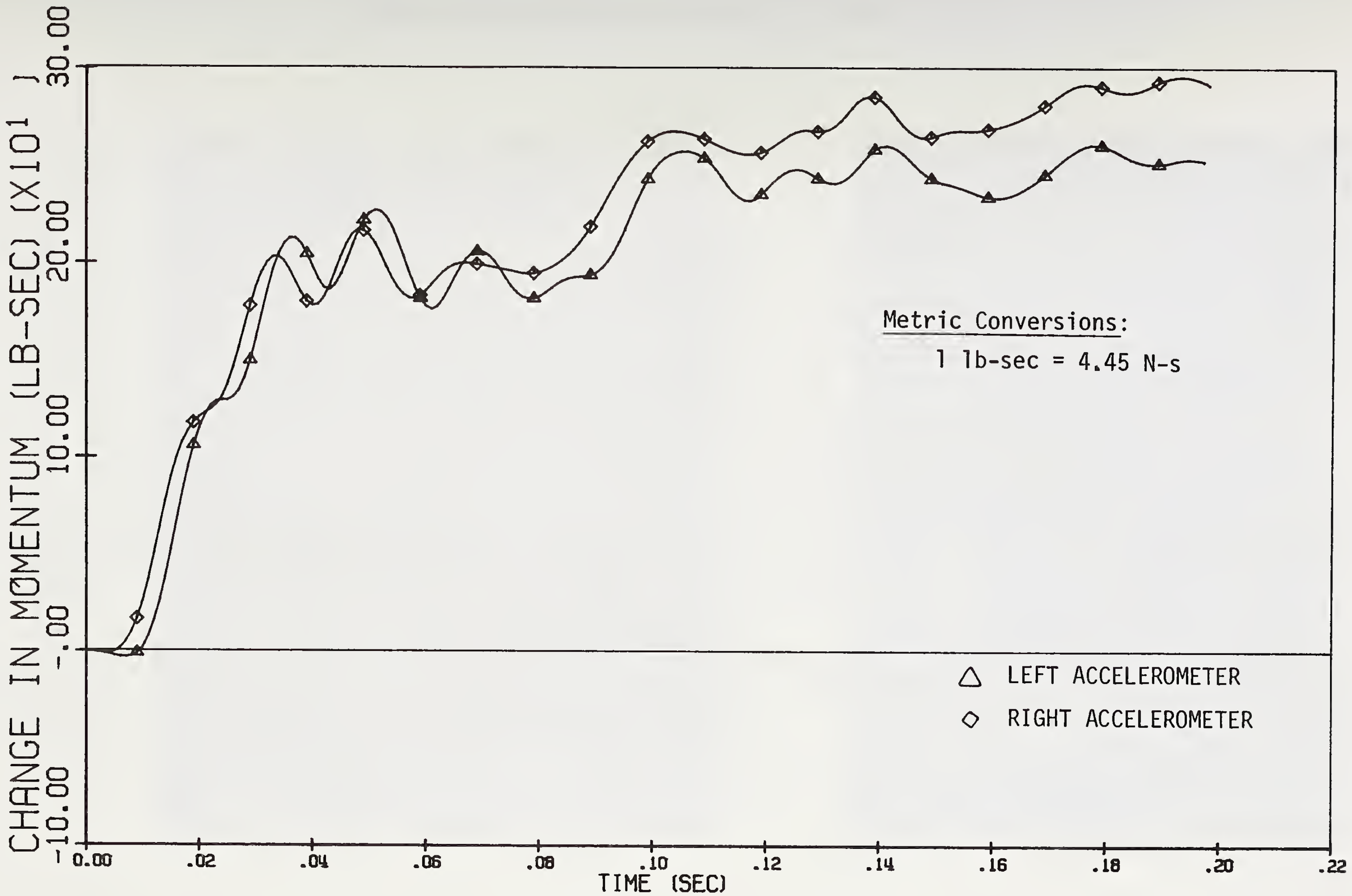


Figure 107. Change in momentum vs. time, test 13.

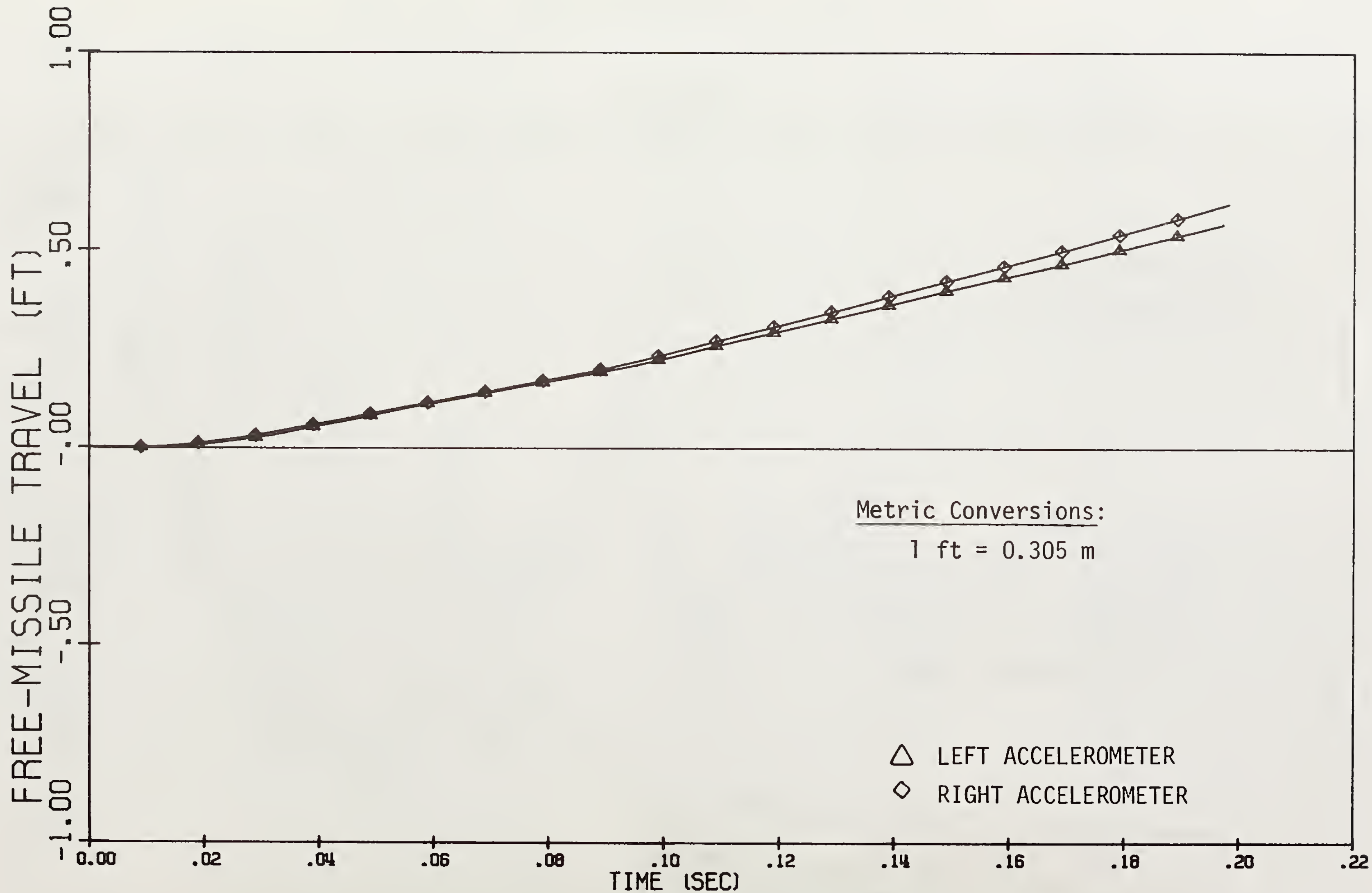
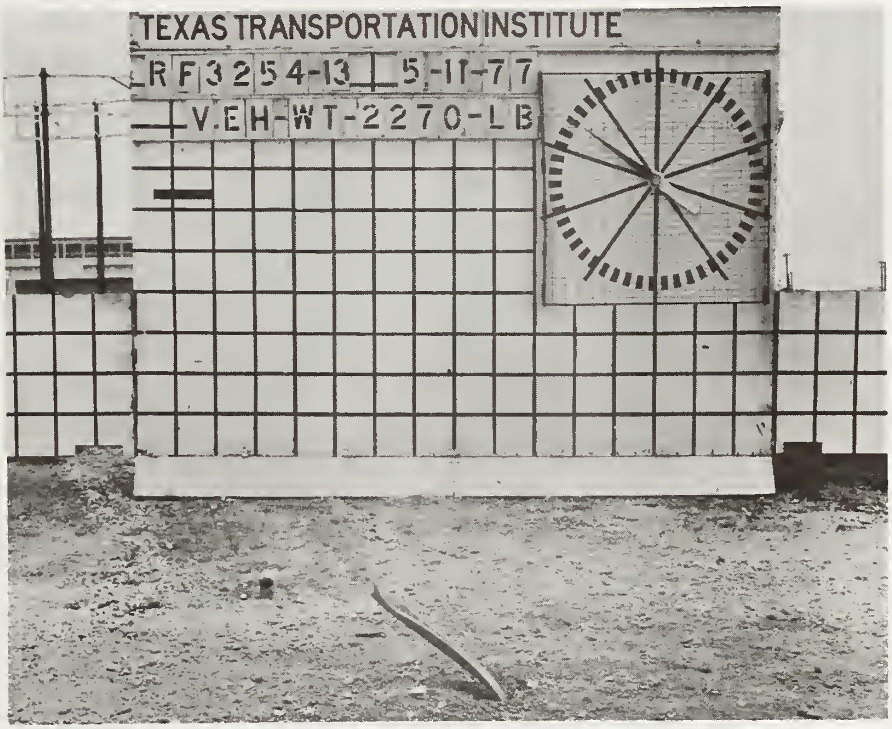


Figure 108. Free missile travel vs. time, test 13.

(a) POST AND PANEL



(b) BASE

Figure 109. Sign installation damage, test 13.

(a) FRONT VIEW

(b) TOP VIEW

Note: Damage caused by test 13 is that on the right side of the vehicle.

Figure 110. Vehicle damage, test 13.

A-3-14. Test No. 14

A summary of test 14 is given in Table 35. Figure 111 contains sequential photos from high-speed film taken during impact, and Table 36 contains a time-displacement-event summary. After impact the vehicle began to pitch upward, and the post was deflected downward. Then the stub post fractured just below the coupling and the post and panel were projected forward.

Figures 112, 113, and 114 contain deceleration, change in momentum, and free missile travel versus time data. Figure 115 shows damage to the sign installation. Restoration would involve replacement of the stub and concrete footing. The signpost could have possibly been straightened. The panel and hardware were reusable. Reference should be made to the discussion in Section A-2-5 regarding this design and the changes made in test 16 to reduce impact damage.

Vehicle damage is shown in Figure 116. Damage was assessed according to the TAD and the SAE scales and is given in Table 35.

Table 35. Summary of results, test 3254-14.

Impact Velocity = 20.3 mph

POST DATA		
Type	Standard Steel Pipe with "Breakaway" Pipe Collar	
Size	2.5 in. ϕ	
Embedment Method	12 in. ϕ, Concrete Footing	
Embedment Depth (ft)	2.0 (stub)	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2250	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	953	650
Duration of Event (sec)*	0.220	
Peak Deceleration (G's)	8.28	7.73
Maximum 0.050 Sec Average Deceleration (G's)	4.62	3.76
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-1	
SAE	12FLEN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

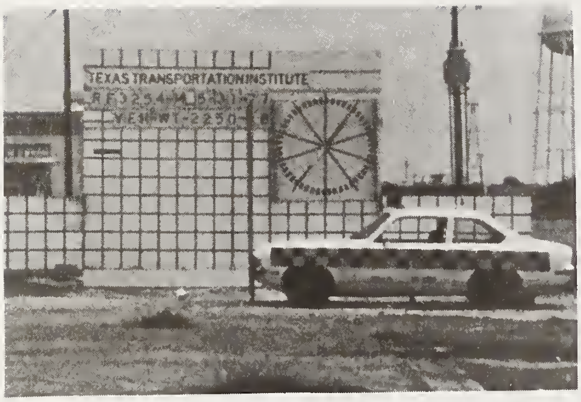
*Free missile travel time

Table 36. Time displacement event summary for test 3254-14.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.148	3.13	Post breaks away; car pitching up
0.283	5.53	Post and panel flying out in front of car
0.414	7.94	Car front wheels back down
0.493	9.47	Car approximately level
0.654	12.52	Front end bottoms out

Metric Conversion:

1 ft = 0.305 m



0.000 sec

0.148 sec

0.283 sec

0.414 sec

0.493 sec

0.654 sec

Figure 111. Sequential photos, test 14.

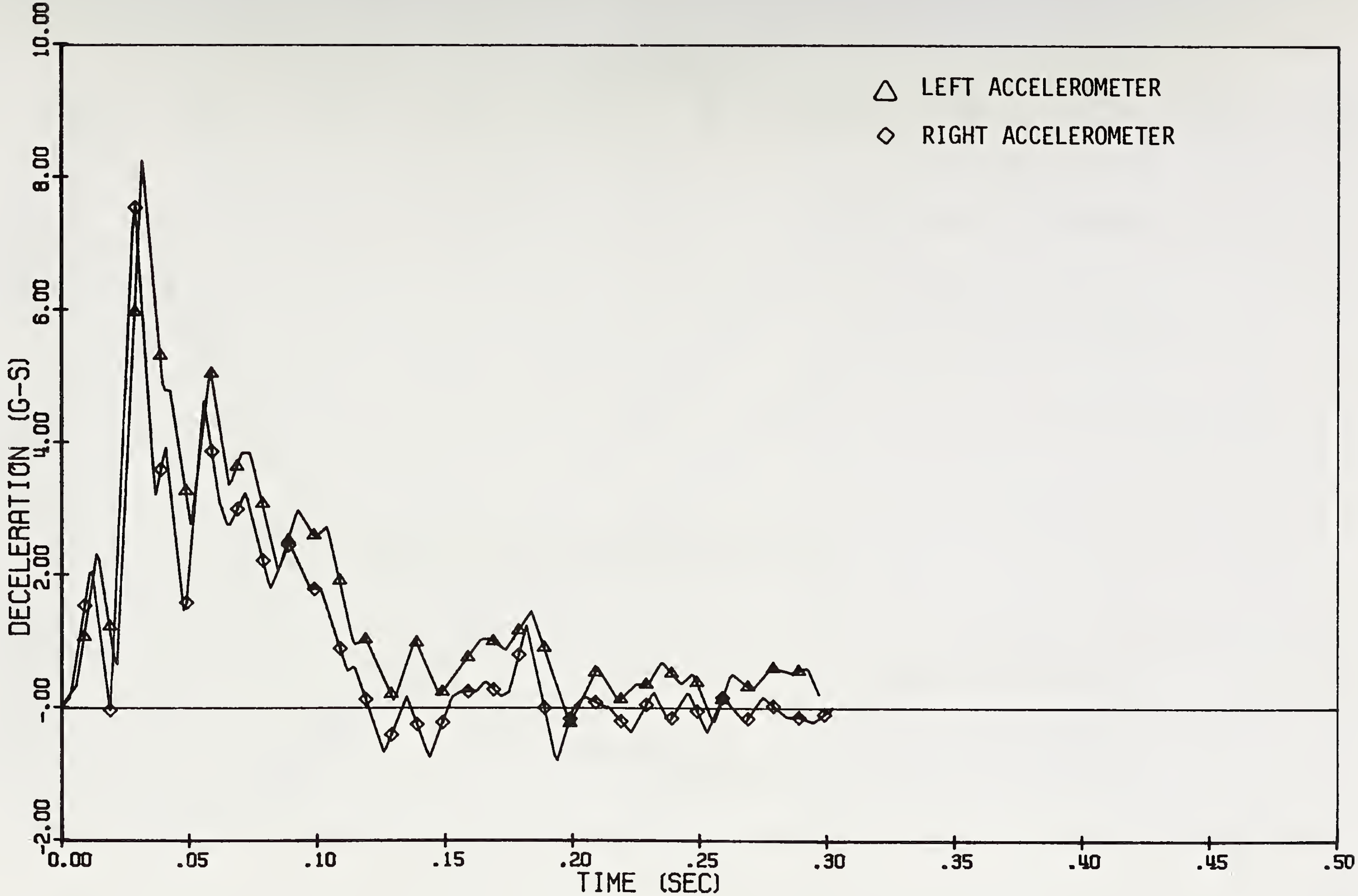


Figure 112. Deceleration vs. time, test 14.

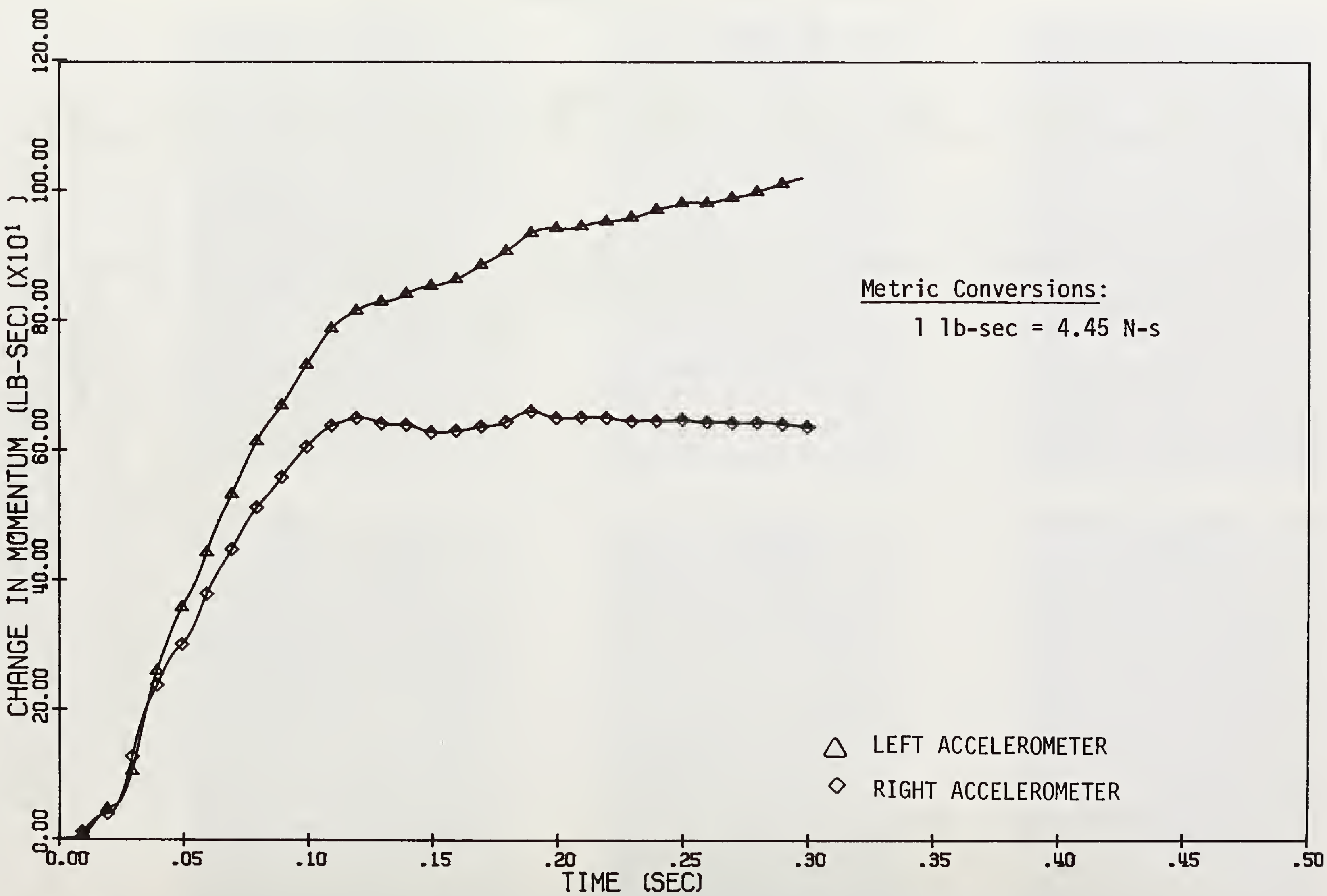


Figure 113. Change in momentum vs. time, test 14.

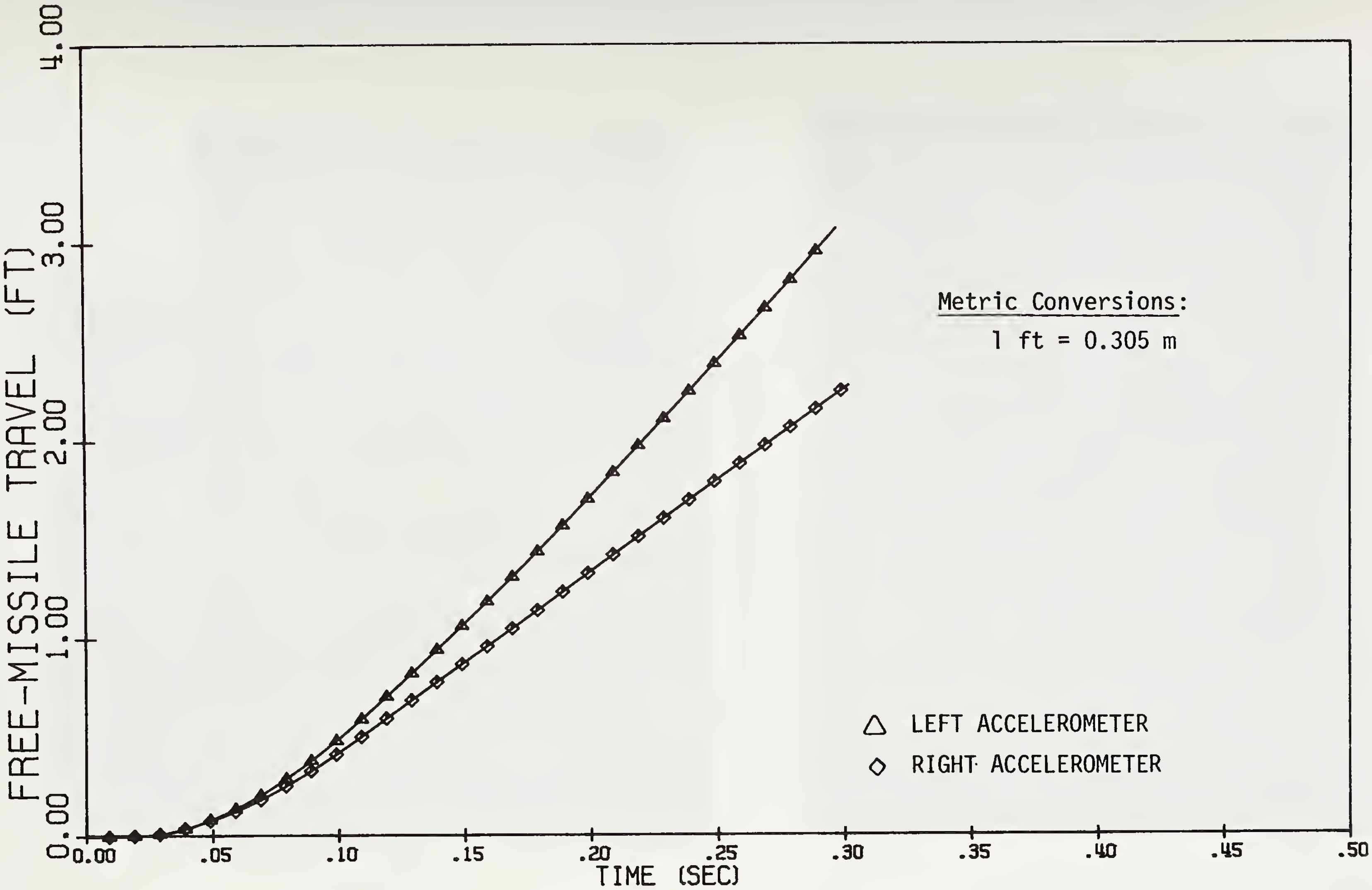
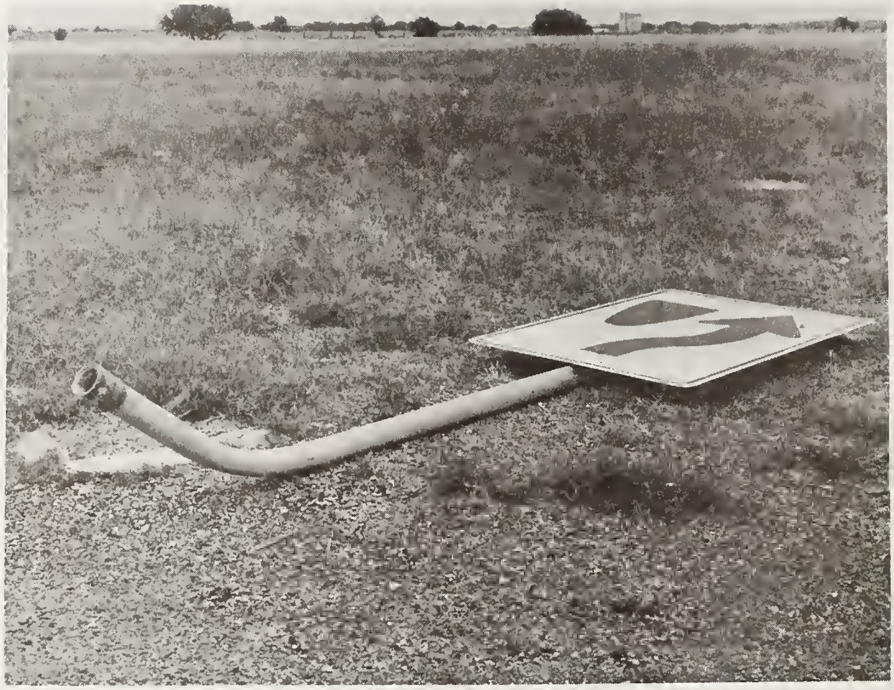
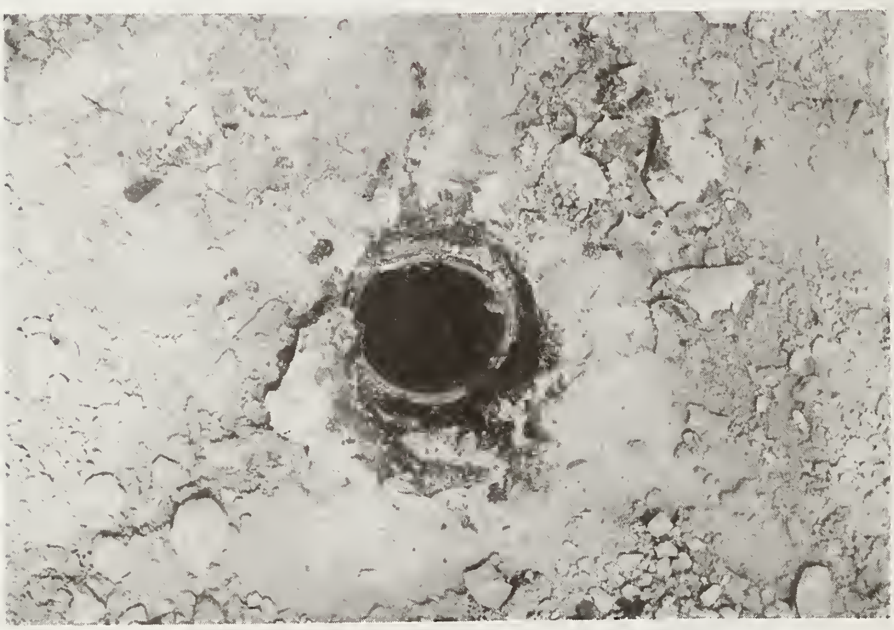


Figure 114. Free missile travel vs. time, test 14.



(a) POST AND PANEL



(b) STUB

Figure 115. Sign installation damage, test 14.

(a) FRONT VIEW

(b) TOP VIEW

Figure 116. Vehicle damage, test 14.

A-3-15. Test No. 15

A summary of test 15 is given in Table 37. Figure 117 contains sequential photos from high-speed film taken during impact, and Table 38 contains a time-displacement-event summary. Shortly after impact the stub post broke just below the coupling. The post was then projected forward and upward, and the panel contacted the rear portion of the roof.

Figures 118, 119, and 120 contain deceleration, change in momentum, and free missile travel versus time data. Sign installation damage is shown in Figure 121. Restoration would involve replacement of the stub and the concrete footing. The signpost could have possibly been straightened, and the panel was reusable. Reference should be made to Section A-2-5 regarding this design and the changes made in test 16 to reduce impact damage.

Vehicle damage is shown in Figure 122. Note that damage to the left front of the vehicle was caused by test 14. Damage was assessed according to the TAD and SAE scales and is given in Table 37.

Table 37. Summary of results, test 3254-15.

Impact Velocity = 63.3 mph

POST DATA		
Type	Standard Steel Pipe with "Breakaway" Pipe Collar	
Size	2.5 in. ϕ	
Embedment Method	12 in. ϕ, Concrete Footing	
Embedment Depth (ft)	2.0 (stub)	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2250	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	332	425
Duration of Event (sec)*	0.087	
Peak Deceleration (G's)	6.82	7.03
Maximum 0.050 Sec Average Deceleration (G's)	2.90	3.41
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-1	
SAE	12FREN2	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

Metric Conversions:

1 in.	= 2.54 cm
1 ft	= 0.305 m
1 lb_m	= 0.454 kg
1 lb -sec	= 4.45 N-s
1 mph	= 1.609 km/h

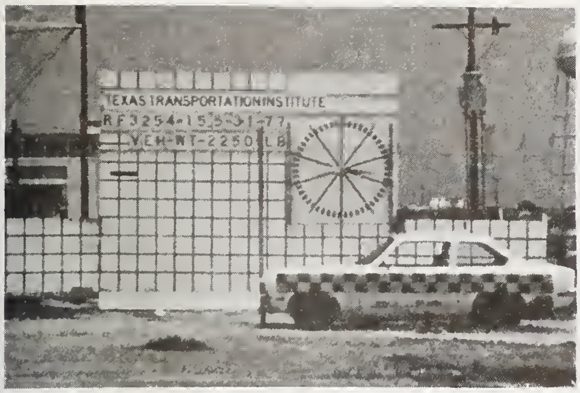
*Time of contact

Table 38. Time displacement event summary for test 3254-15.

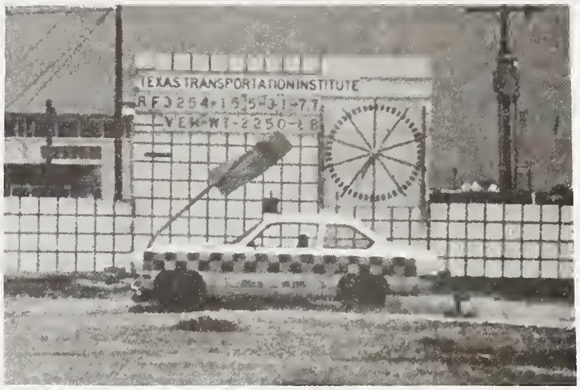
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0	0	Impact
0.081	7.13	Post breaks away
0.106	9.24	Post separates from car
0.133	11.55	Sign is above car hood
0.164	14.12	Sign strikes top of car
0.203	17.53	Full impact of sign on top

Metric Conversion:

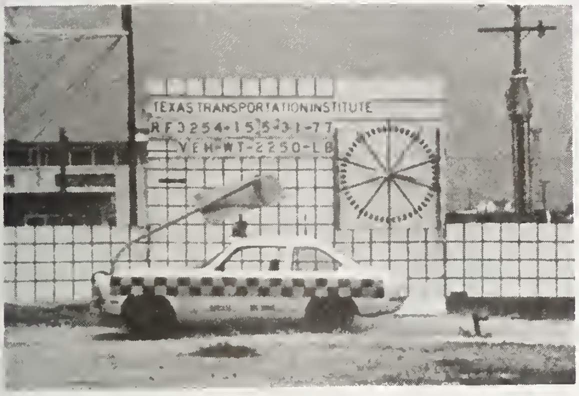
1 ft = 0.305 m



0.000 sec



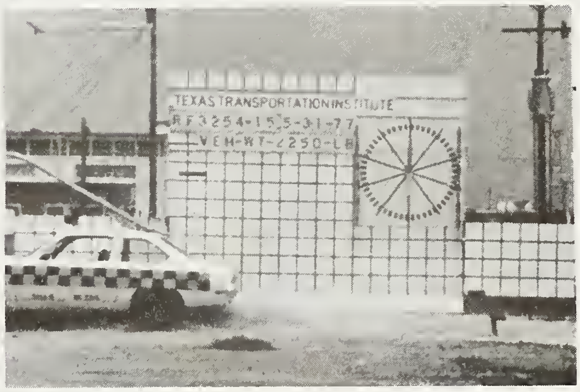
0.081 sec



0.106 sec

0.133 sec

0.164 sec



0.203 sec

Figure 117. Sequential photos, test 15.

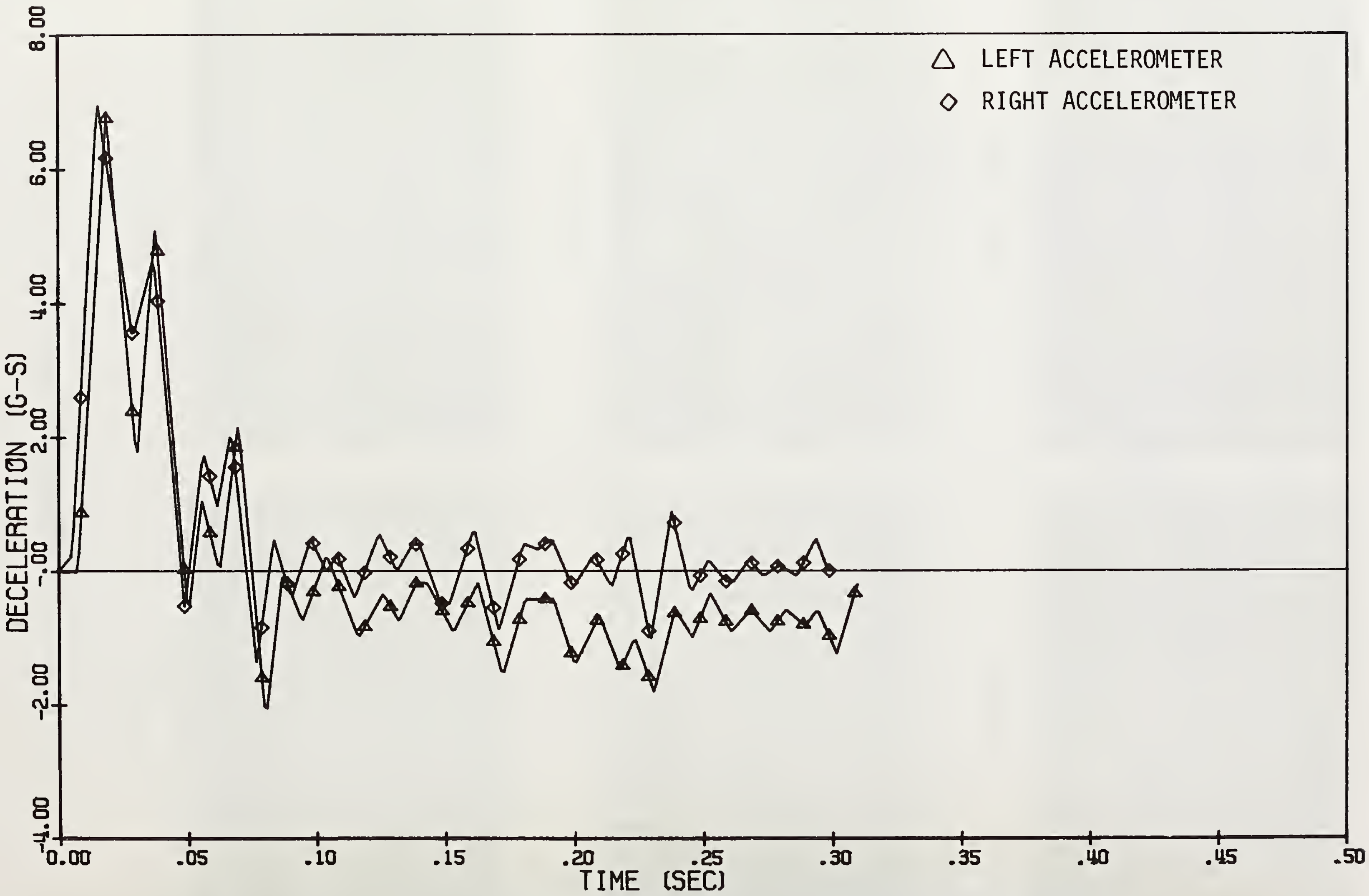


Figure 118. Deceleration vs. time, test 15.

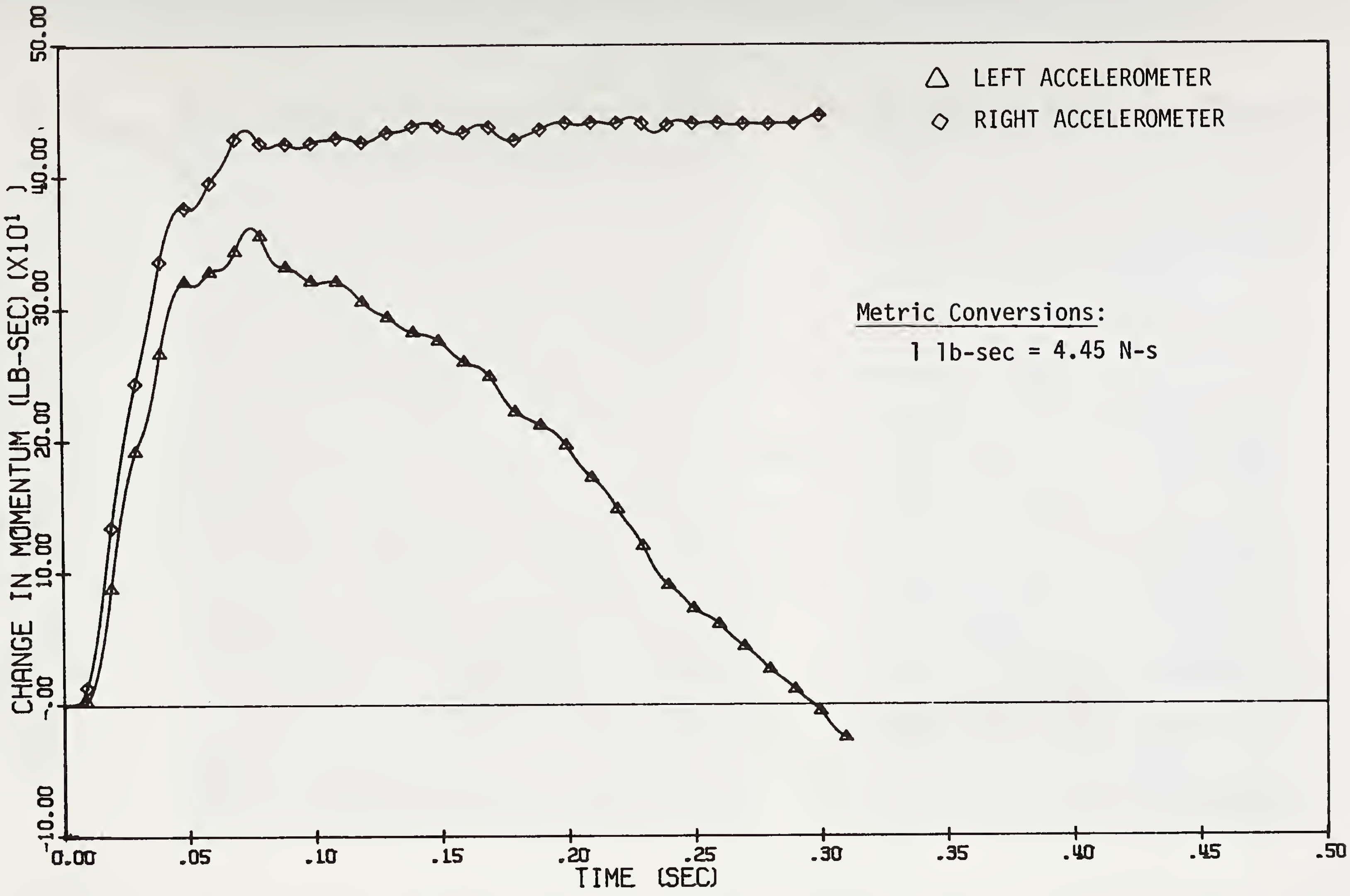


Figure 119. Change in momentum vs. time, test 15.

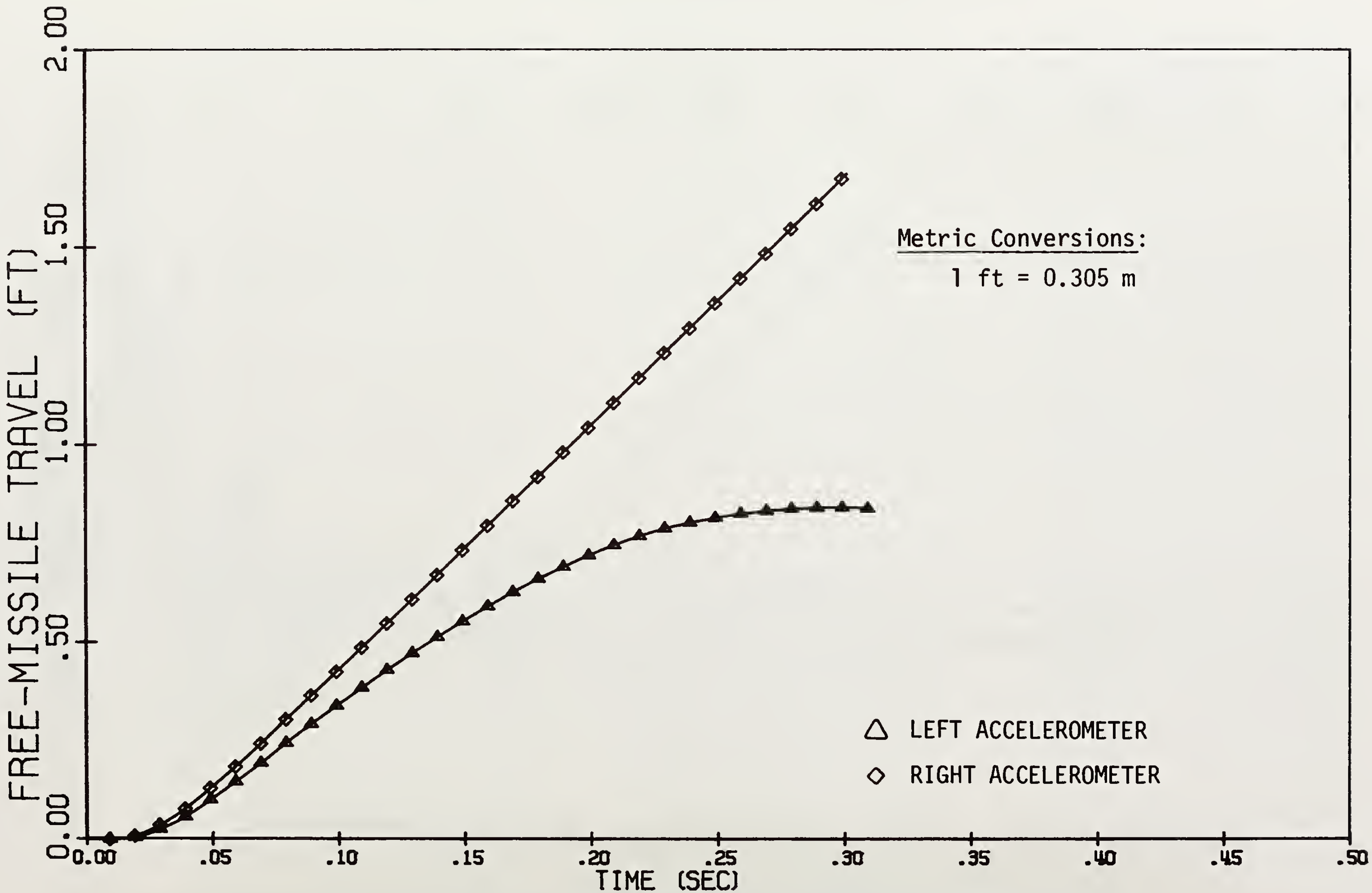


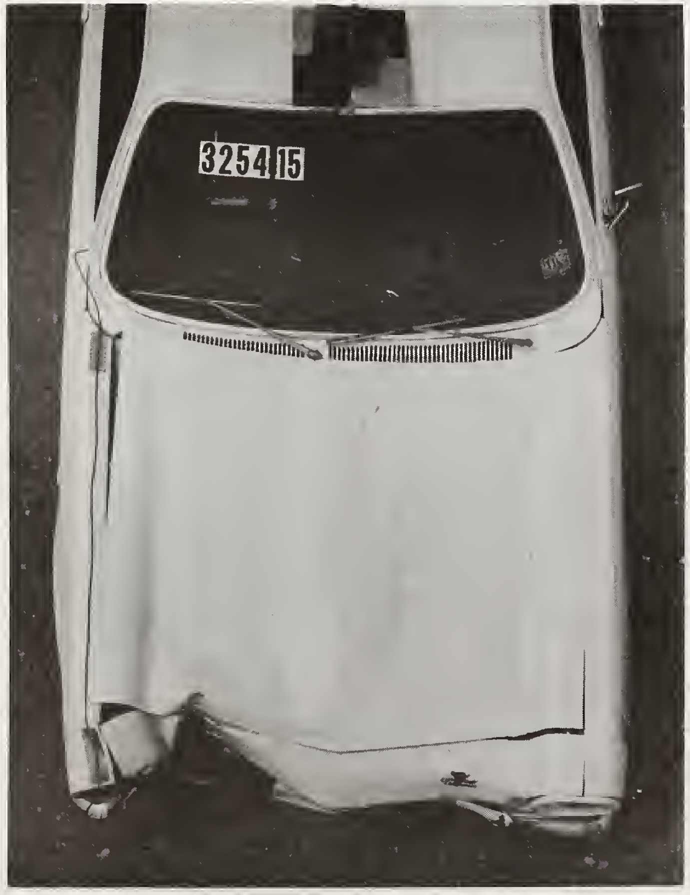
Figure 120. Free missile travel vs. time, test 15.

(a) POST AND PANEL

(b) STUB

Figure 121. Sign installation damage, test 15.

(a) FRONT VIEW



(b) TOP VIEW

Note: Damage caused by test is that on right front of vehicle.

Figure 122. Vehicle damage, test 15.

A-3-16. Test No. 16

This test was scheduled to evaluate a slight design change in the breakaway coupling system. Reference should be made to Section A-2-5 regarding the design and the changes made to reduce the impact damage.

Analysis of tests 14 and 15 showed that impact with this system was more severe at low-speed impacts. Test 16 was therefore conducted at a low speed.

Table 39 contains a summary of test 16. Figure 123 contains sequential photos from high-speed film taken during impact, and Table 40 contains a time-displacement-event summary. Impact behavior was similar to that observed in test 14. However, in this test the post broke just above the coupling, as desired.

Figures 124, 125, and 126 contain deceleration, change in momentum, and free missile travel versus time data. Figure 127 shows damage to the sign installation. At most, restoration would involve replacement of the signpost. Restoration could probably have been accomplished by straightening and rethreading the post. The threaded part of the post remaining in the coupling could be easily removed. The panel and stub were reusable.

Figure 128 shows vehicle damage. Damage was assessed according to the TAD and the SAE scales and is given in Table 39.

Table 39. Summary of results, test 3254-16.

Impact Velocity = 19.2 mph

POST DATA			
Type	Standard Steel Pipe with "Breakaway" Pipe Collar		
Size	2½ in. ϕ		
Embedment Method	12 in. ϕ, Concrete Footing		
Embedment Depth (ft)	2.0 (stub)		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1973		
Weight (lb)	2270		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA	Left		Right
Change in Momentum (lb-sec)	625		650
Duration of Event (sec)*		0.146	
Peak Deceleration (G's)	7.24		6.91
Maximum 0.050 Sec Average Deceleration (G's)	2.66		2.65
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-1		
SAE	12FLEN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

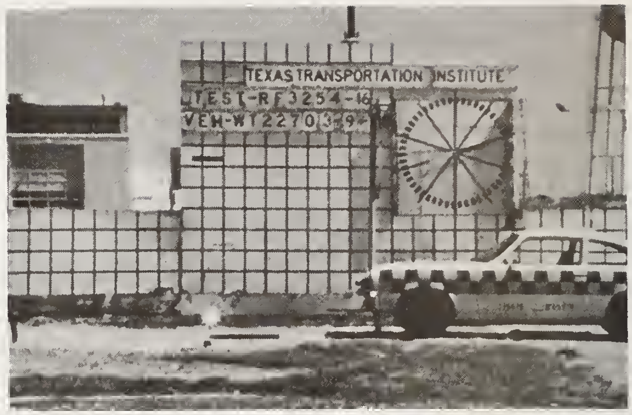
Table 40. Time displacement event summary for test 3254-16.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.034	0.89	Post begins to deflect
0.140	3.07	Front of car begins to rise
0.207	4.26	Post breaks
0.279	5.65	Sign hits ground
0.449	8.58	Sign strikes bumper

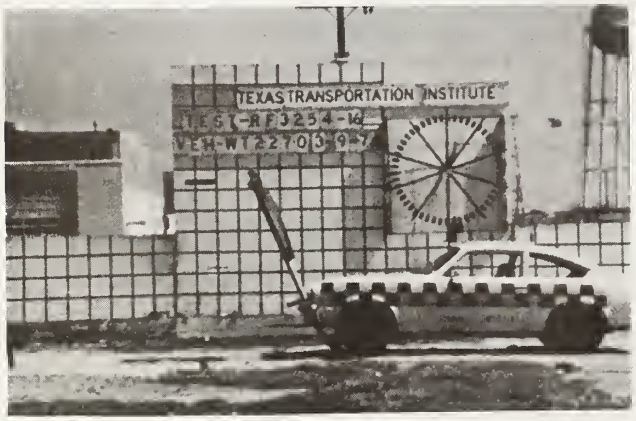
Metric Conversion:

1 ft = 0.305 m

0.000 sec

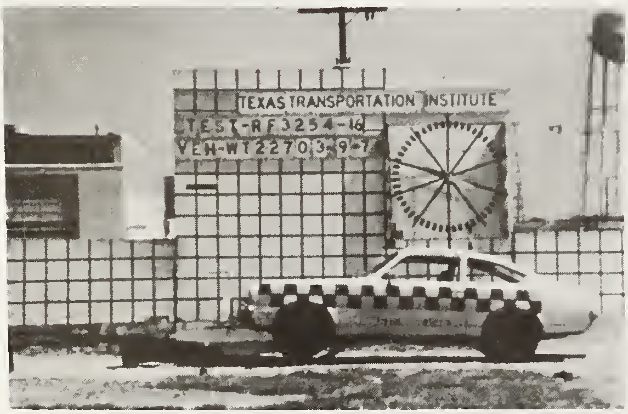


0.034 sec



0.140 sec

0.207 sec



0.279 sec

0.449 sec

Figure 123. Sequential photos, test 16.

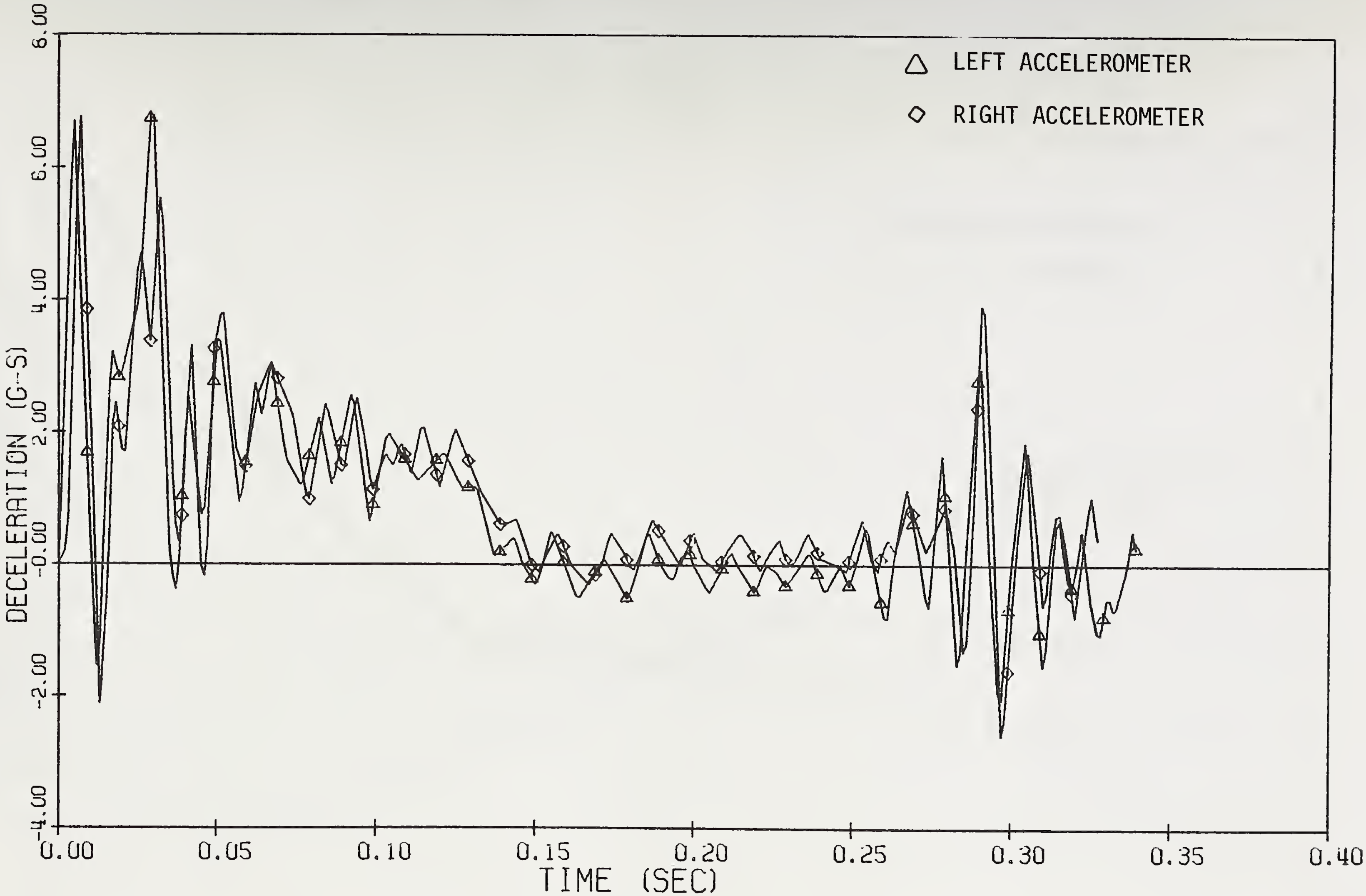


Figure 124. Deceleration vs. time, test 16.

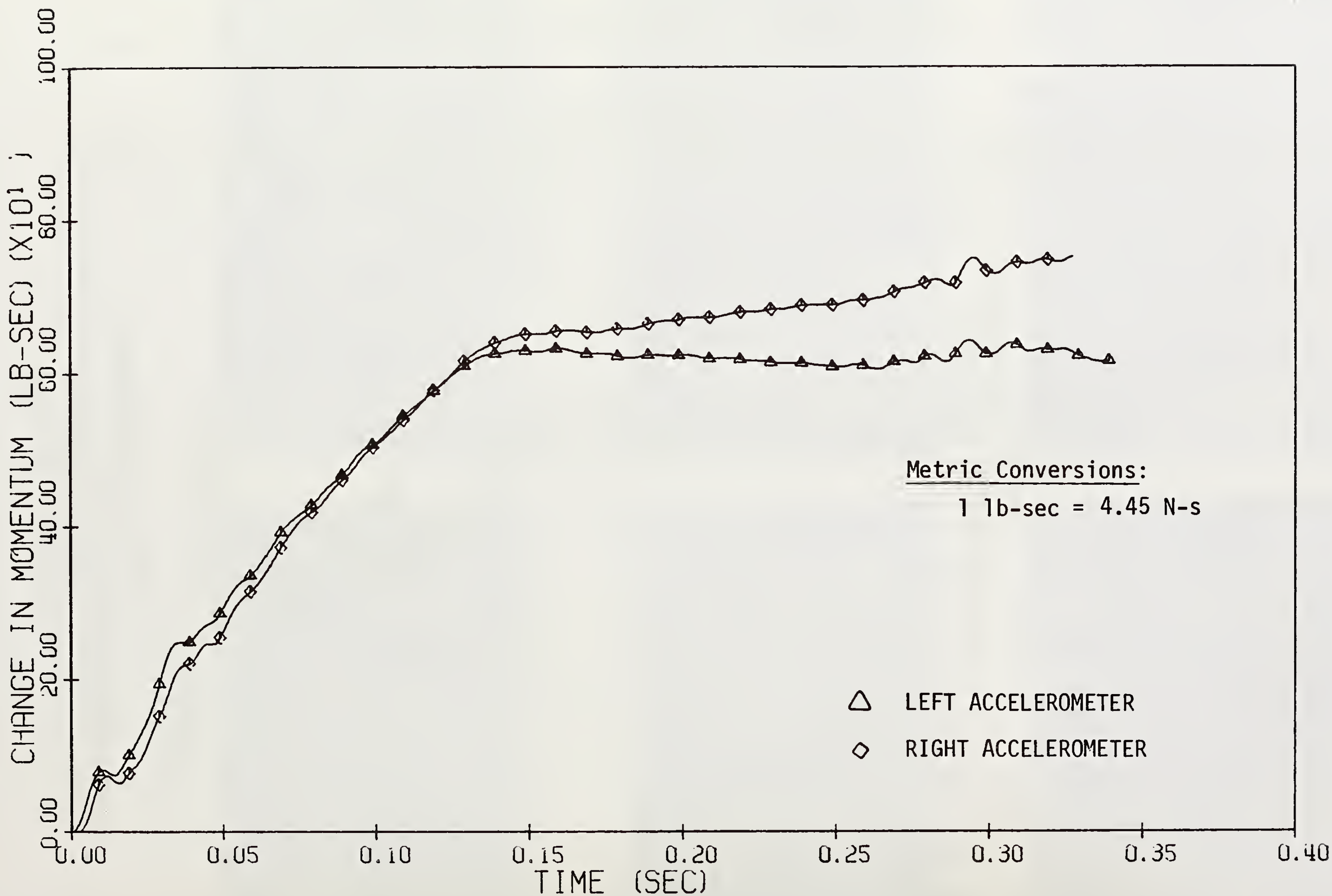


Figure 125. Change in momentum vs. time, test 16.

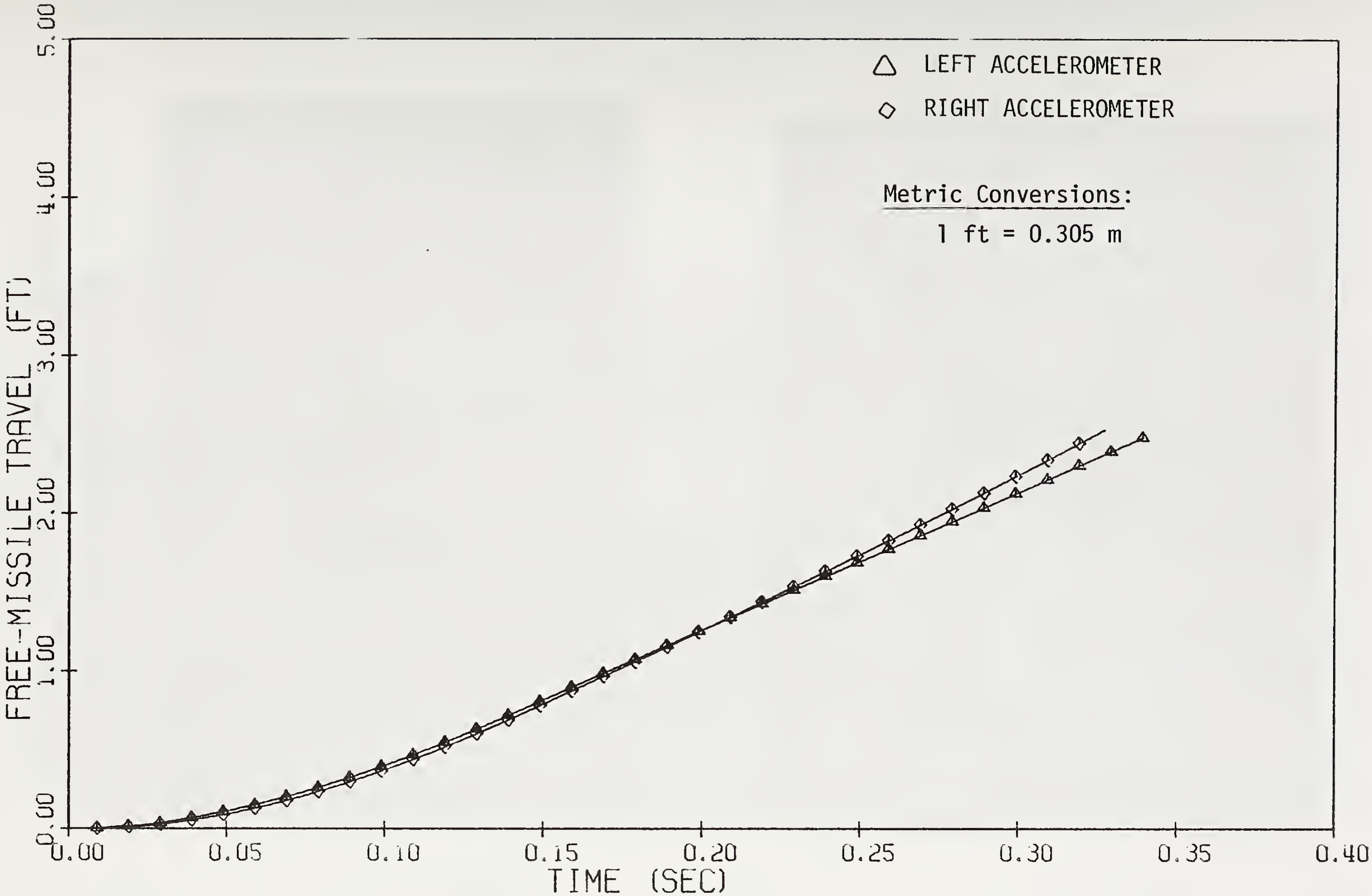
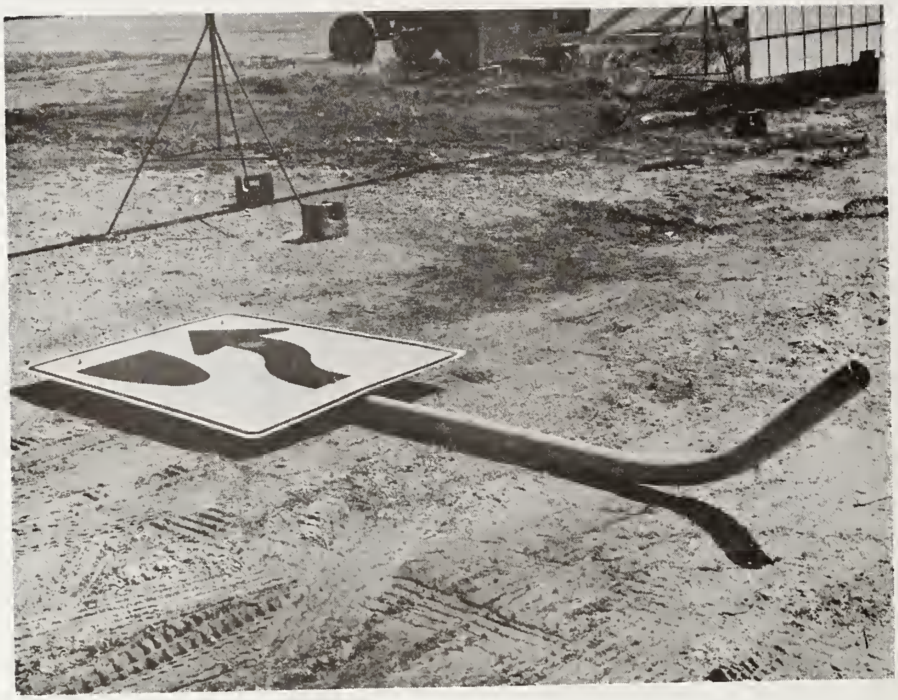


Figure 126. Free missile travel vs. time, test 16.



(a) POST AND PANEL

(b) STUB

Figure 127. Sign installation damage, test 16.

(a) FRONT VIEW

(b) TOP VIEW

Figure 128. Vehicle damage, test 16.

A-3-17. Test No. 17

A summary of test 17 is given in Table 41. Figure 129 contains sequential photos from high-speed film taken during impact, and Table 42 contains a time-displacement-event summary. Upon impact, the vertical post began to bend. Continued movement of the vehicle caused increased loading on the back brace as the vertical member was deflected and pulled down. At about 0.125 sec the back brace collapsed, and the installation was then ridden down. Although damage to the vehicle would not indicate it, the change in momentum was relatively high. By comparing the deceleration versus time plot of test 17, Figure 130, with that of a similar test with a 3 lb/ft (4.5 kg/m) full length post, Figure 45 , it can be seen that the back brace design causes higher decelerations of longer duration than the 3 lb/ft (4.5 kg/m) post.

Figures 131 and 132 contain change in momentum and free missile travel data. Figure 133 shows damage to the sign installation. Restoration would involve replacement of both posts. The panel could possibly have been repaired and reused.

Damage to the vehicle, which was almost undetectable, is shown in Figure 134. Damage was assessed according to the TAD and the SAE scales and is given in Table 41. Reference should be made to Section A-3-19 for the high-speed test of this system.

Table 41. Summary of results, test 3254-17.

Impact Velocity = 19.9 mph

POST DATA			
Type	Steel U-Post with Back Brace** (Billet Steel)		
Size	2 lb/ft		
Embedment Method	Driven		
Embedment Depth (ft)	Vertical Post - 2.5 Back Brace - 2.0		
VEHICLE DATA			
Make	Chevrolet		
Model	Vega		
Year	1973		
Weight (lb)	2270		
Impact Point	15 in. to right of center		
ACCELEROMETER DATA	**Left**		**Right**
Change in Momentum (lb-sec)	846		720
Duration of Event (sec)*		0.240	
Peak Deceleration (G's)	3.81		3.11
Maximum 0.050 Sec Average Deceleration (G's)	2.77		2.35
VEHICLE DAMAGE CLASSIFICATION			
TAD	FR-0		
SAE	12FREN1		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

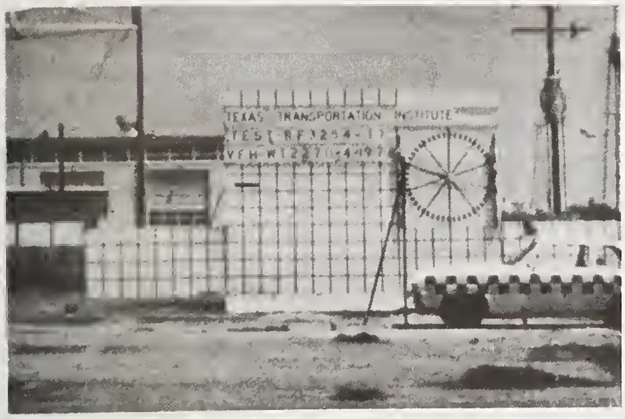
**Armco Steel Corporation posts

Table 42. Time displacement event summary for test 3254-17.

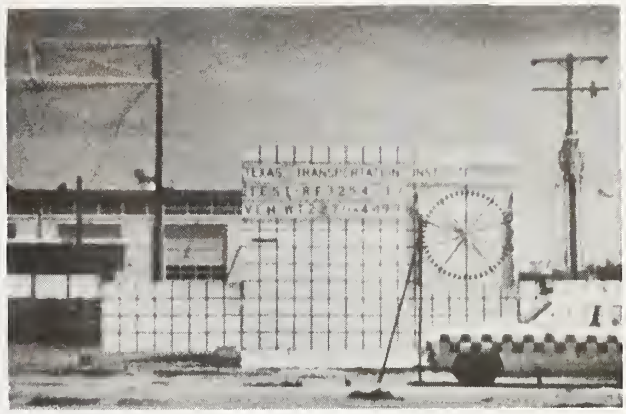
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.002	0.07	First post begins to bend
0.030	0.81	First post pulls out of ground
0.125	3.21	Brace post bends
0.339	7.25	Signposts on ground
0.411	8.34	Sign hits bumper

Metric Conversion:

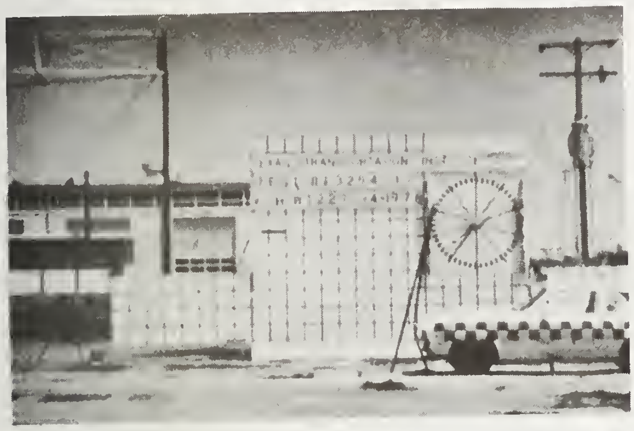
1 ft = 0.305 m



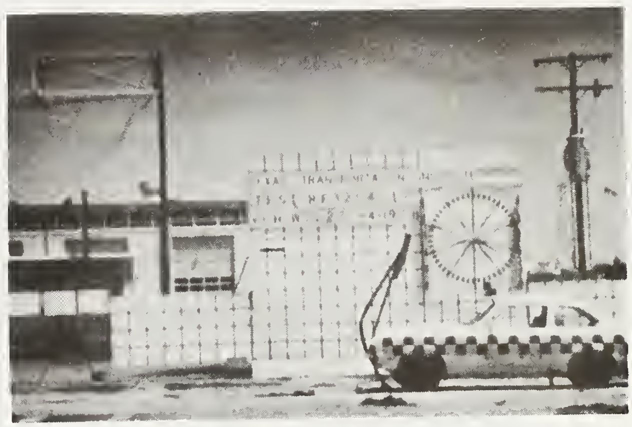
0.000 sec



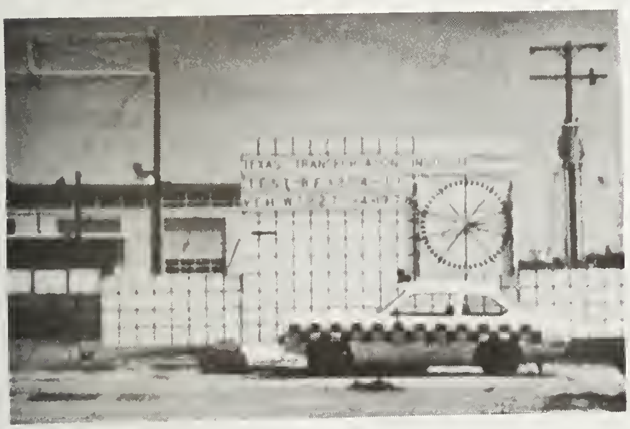
0.002 sec



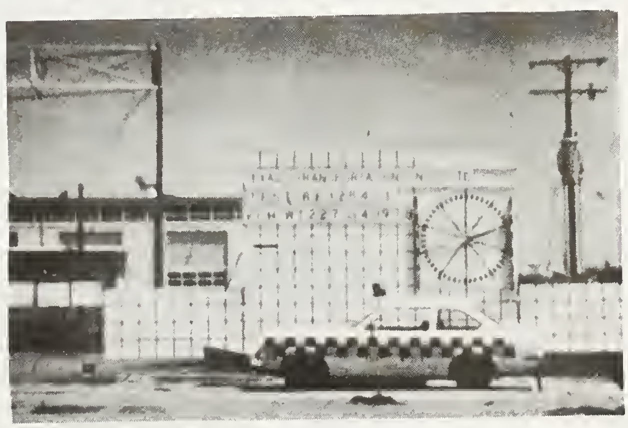
0.030 sec



0.125 sec



0.339 sec



0.411 sec

Figure 129. Sequential photos, test 17.

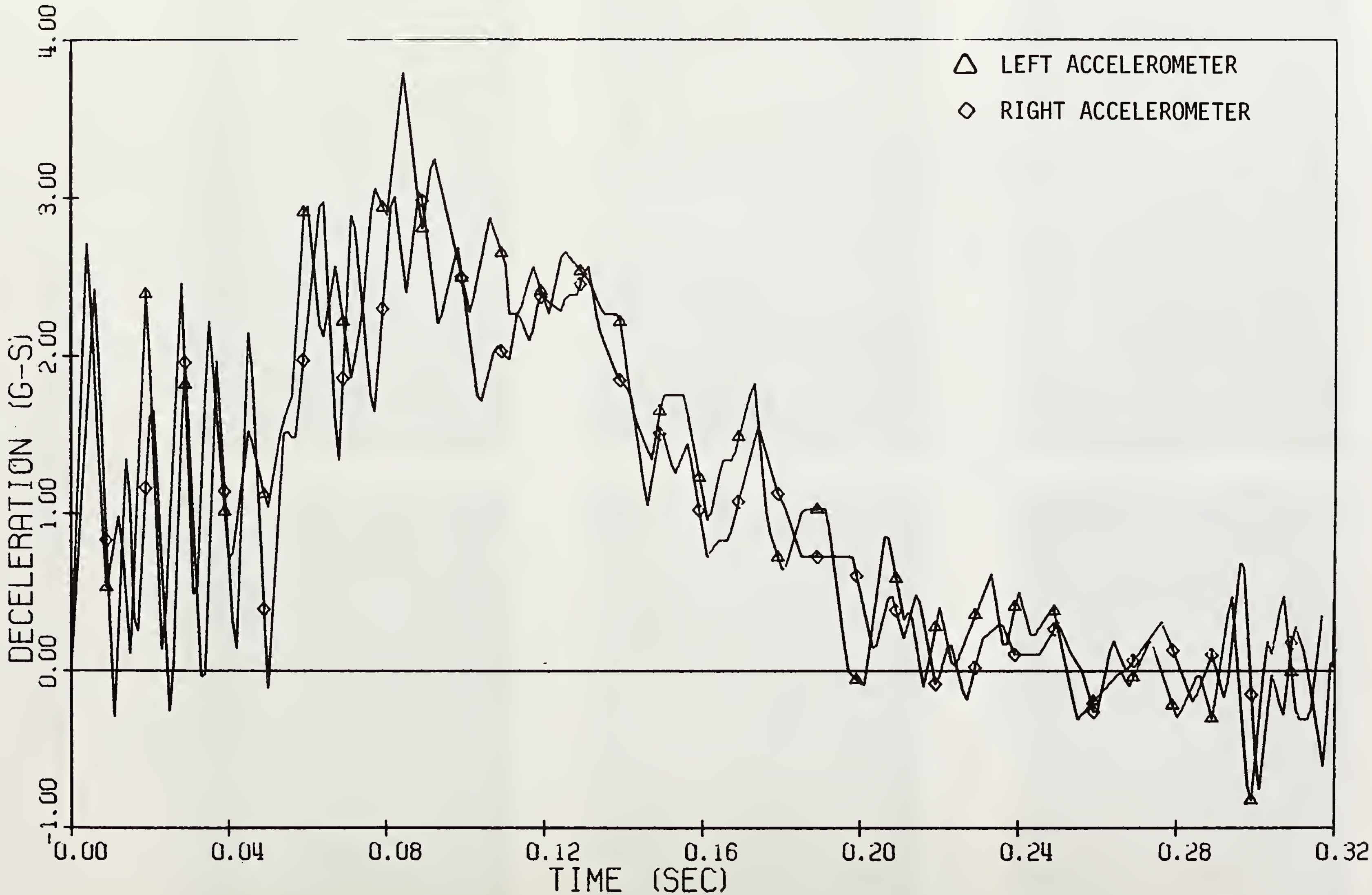


Figure 130. Deceleration vs. time, test 17.

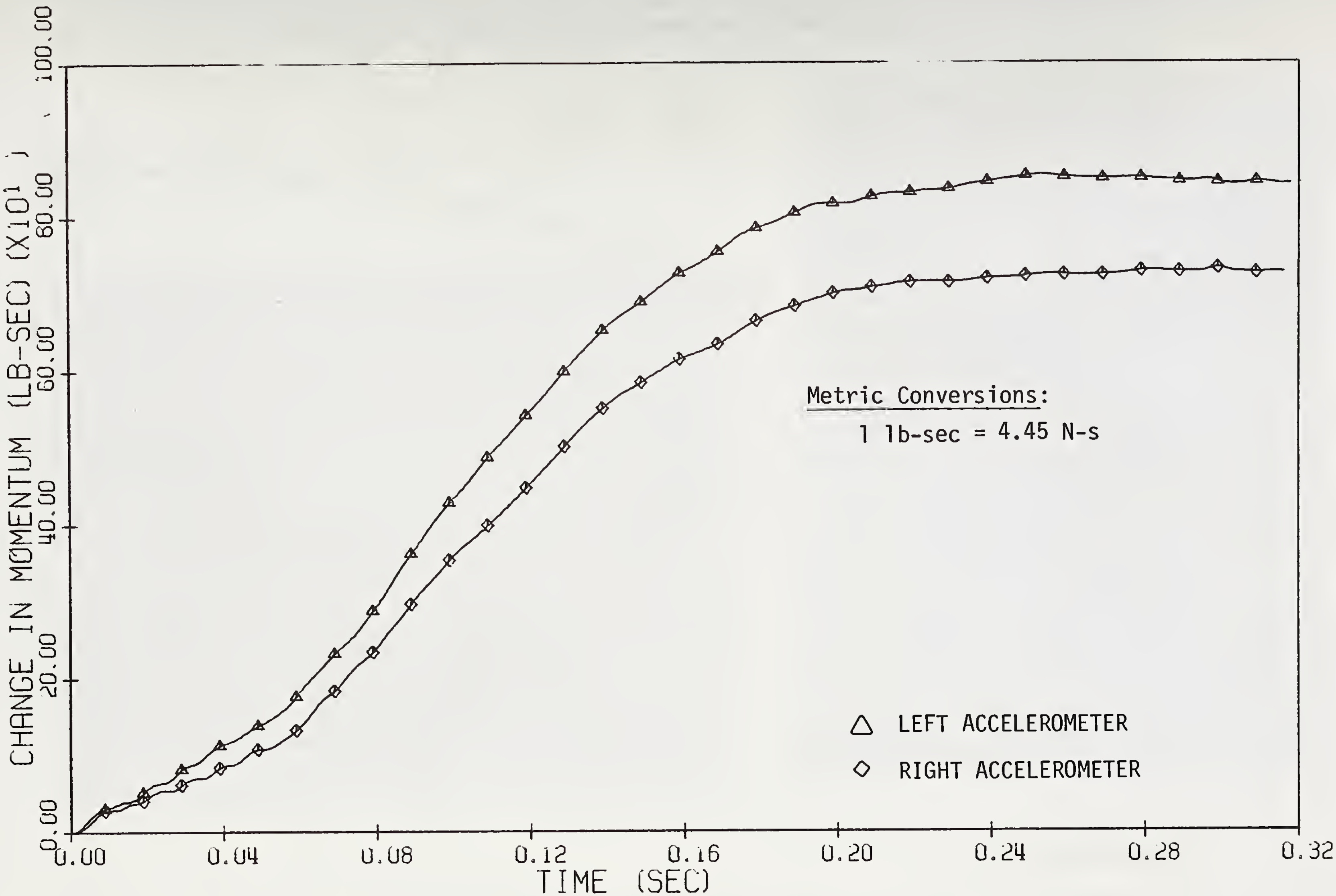


Figure 131. Change in momentum vs. time, test 17.

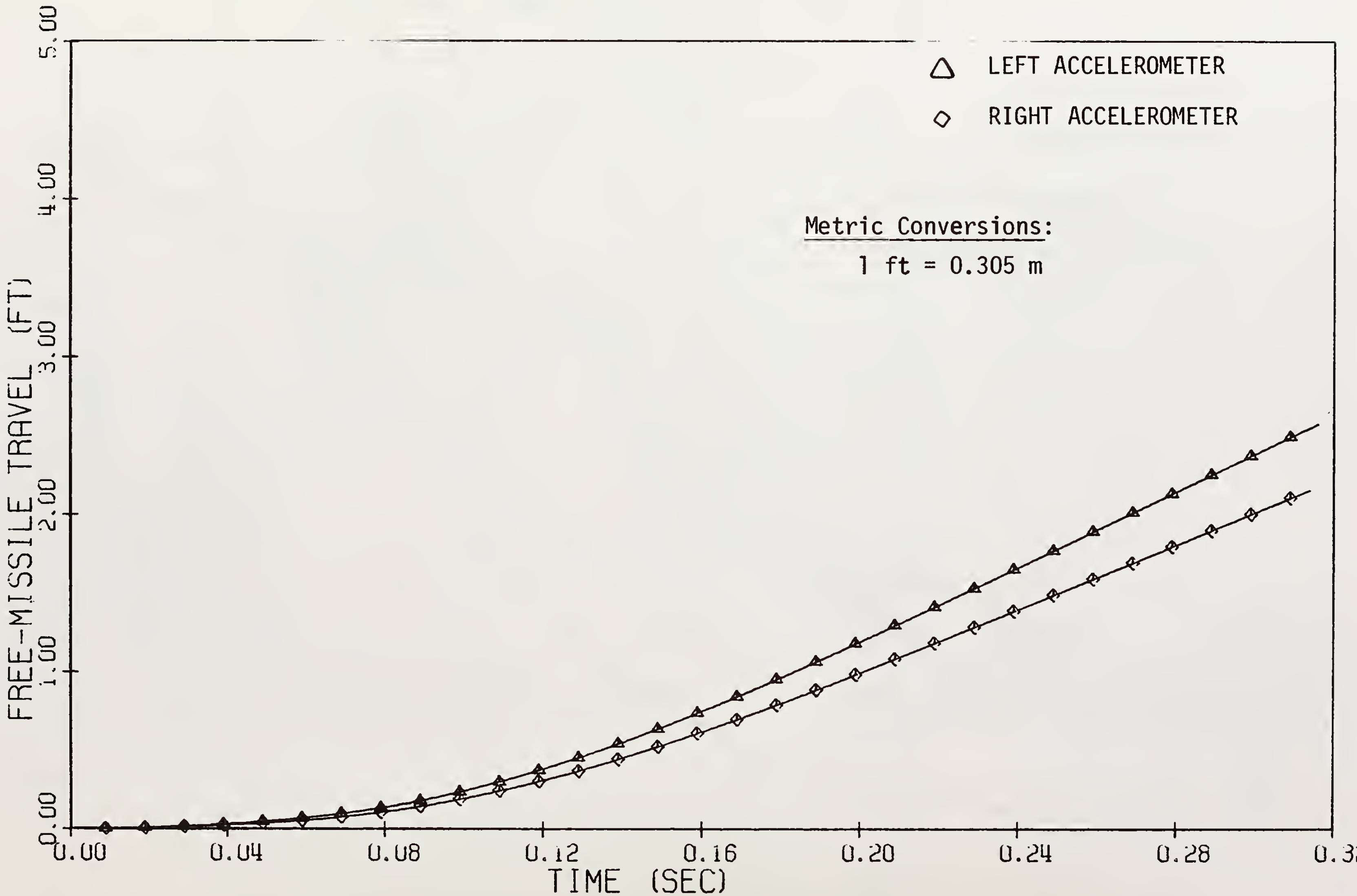
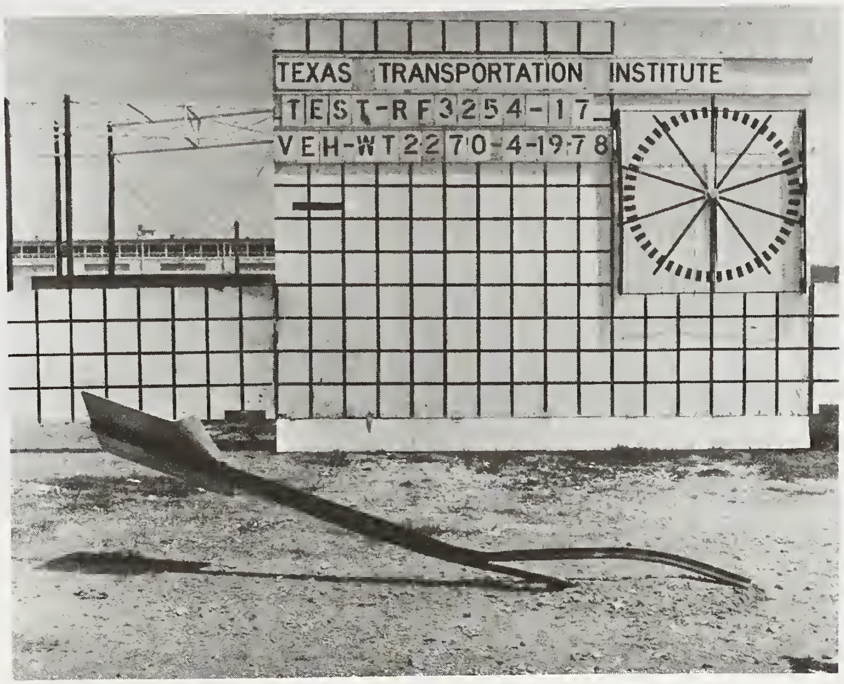


Figure 132. Free missile travel vs. time, test 17.



(a) SIDE VIEW

(b) FRONT VIEW

Figure 133. Sign installation damage, test 17.

(a) FRONT VIEW

(b) SIDE VIEW

Figure 134. Vehicle damage, test 17.

A-3-18. Test No. 18

Tests 10 and 11 showed that a 2½ in. (6.35 cm) diameter standard steel pipe with no breakaway device would not meet current safety standards for signposts. Test 18 was therefore conducted to evaluate the acceptability of a 2 in. (5.1 cm) standard steel pipe post. From tests 10 and 11 it was determined that a high-speed impact was more severe than a low-speed impact.

A summary of test 18 is given in Table 43. Sequential photos from the high-speed film are shown in Figure 135. Table 44 contains a time-displacement-event summary. After impact, the post began to bend and rotate down toward the hood. However, the post was straightened and ridden down before it contacted the hood. This contrasted with the behavior of the larger pipe in test 11 in which the post wrapped around the hood and imparted considerably higher forces to the vehicle. Another factor which reduced the severity of test 18 (versus test 11) was the smaller panel size, 5 ft^2 (0.47 m^2) versus 12 ft^2 (1.12 m^2). Inertia forces and wind resistance would be larger for the larger panel. In addition, it can be seen in Figure 135 that the panel slipped off the post during impact. It is possible that the pipe clamps (see Figure 22) were not securely fastened to the pipe. It can be seen in Figure 139 that the clamps were still fastened to the panel. A "friction cap", placed on the top of the pipe, did little to prevent the clamps from slipping off the post. The friction cap, composed of 24 gauge (0.061 cm) sheet metal, is designed primarily to keep rainwater out of the pipe.

Figures 136, 137, and 138 contain deceleration, change in momentum, and free missile travel versus time data. Sign installation damage is shown in Figure 139. Restoration would involve replacement of the signpost.

Figure 140 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 43.

Table 43. Summary of results, test 3254-18.

Impact Velocity = 56.5 mph

POST DATA		
Type	Standard Steel Pipe	
Size	2 in. ϕ	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2270	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	400	523
Duration of Event (sec)*	0.144	
Peak Deceleration (G's)	6.39	7.73
Maximum 0.050 Sec Average Deceleration (G's)	2.64	3.14
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-1	
SAE	12FREN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	No	

*Time of contact

Metric Conversions:

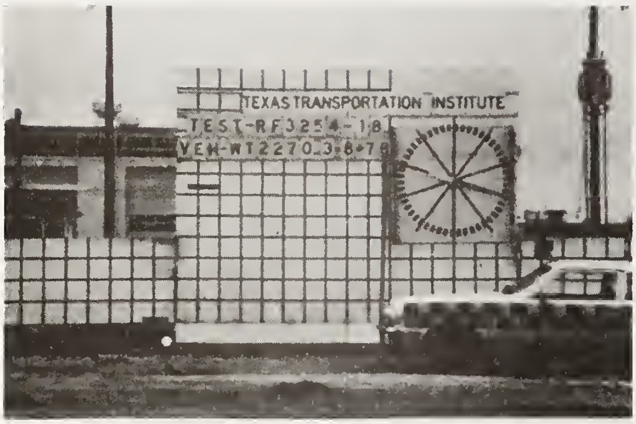
1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

Table 44. Time displacement event summary for test 3254-18.

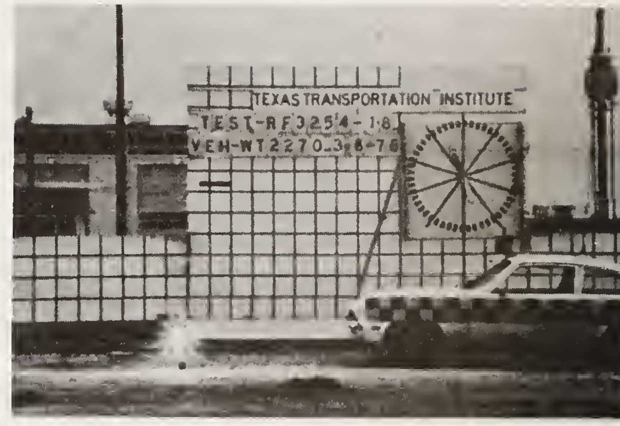
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.024	1.97	Post bends
0.028	2.33	Panel begins to leave post
0.064	5.13	Maximum post penetration
0.100	7.91	Panel strikes windshield
0.124	9.71	Panel free of windshield

Metric Conversion:

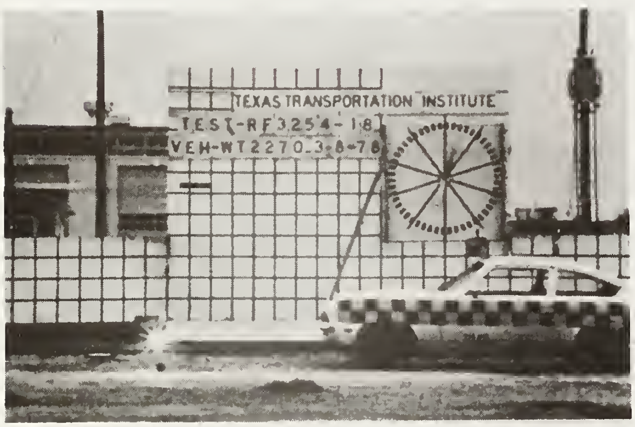
1 ft = 0.305 m



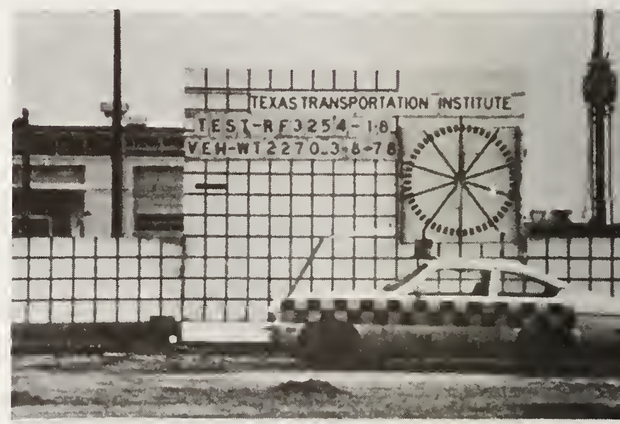
0.000 sec



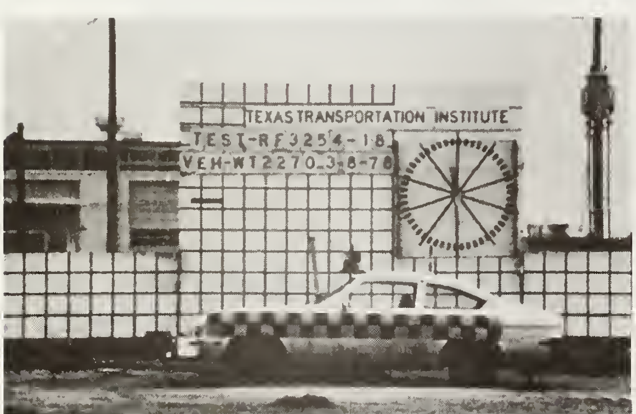
0.024 sec



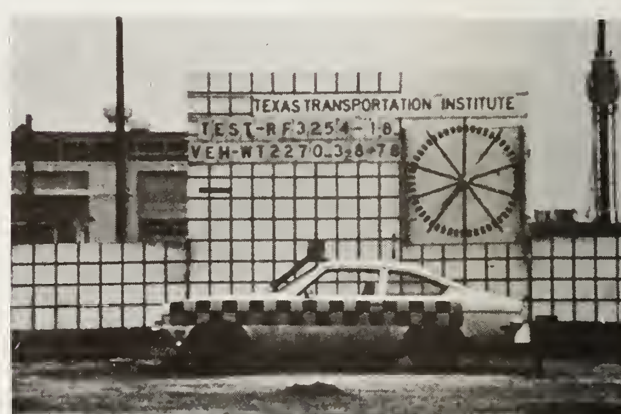
0.028 sec



0.064 sec



0.100 sec



0.124 sec

Figure 135. Sequential photos, test 18.

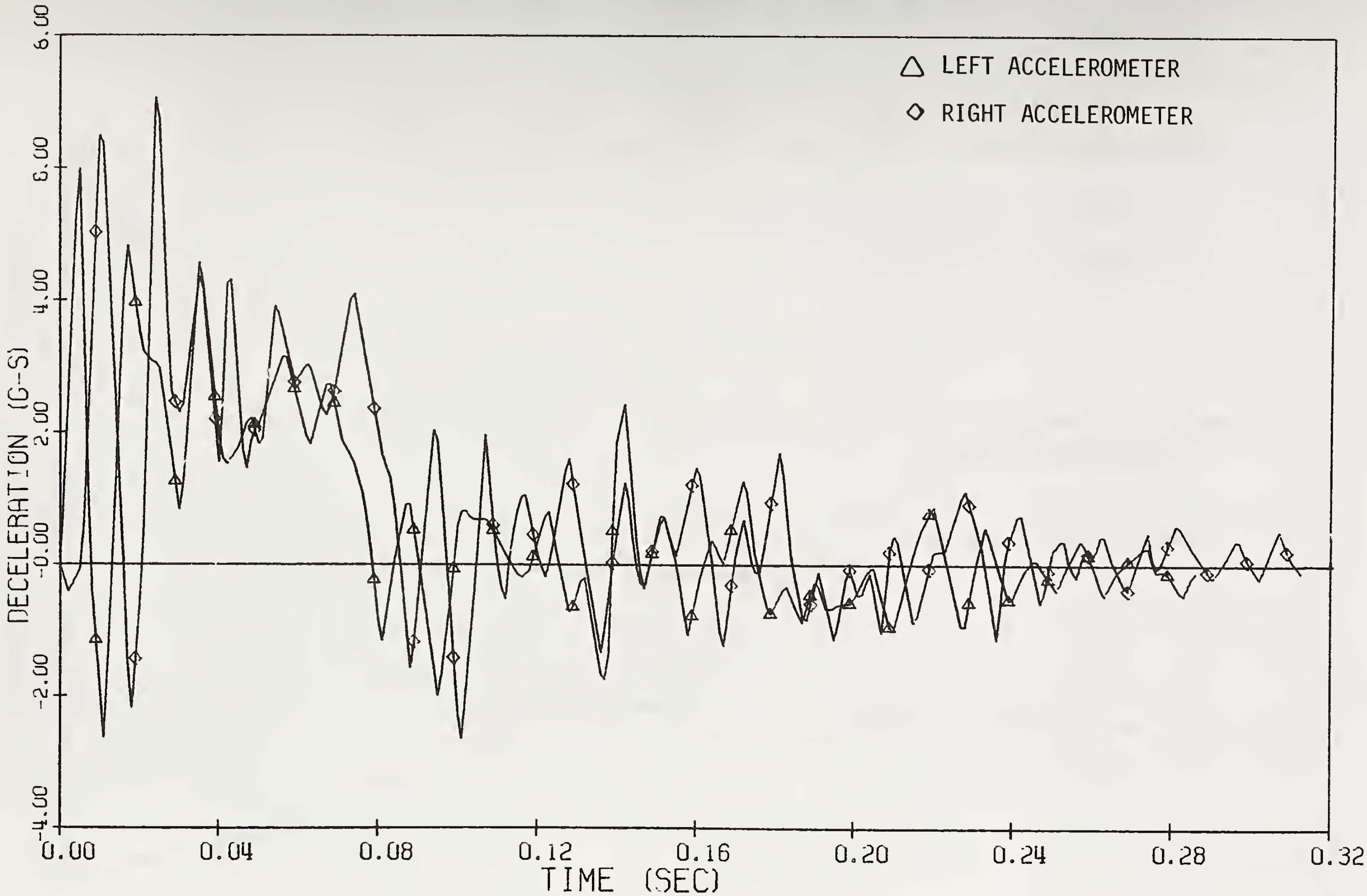


Figure 136. Deceleration vs. time, test 18.

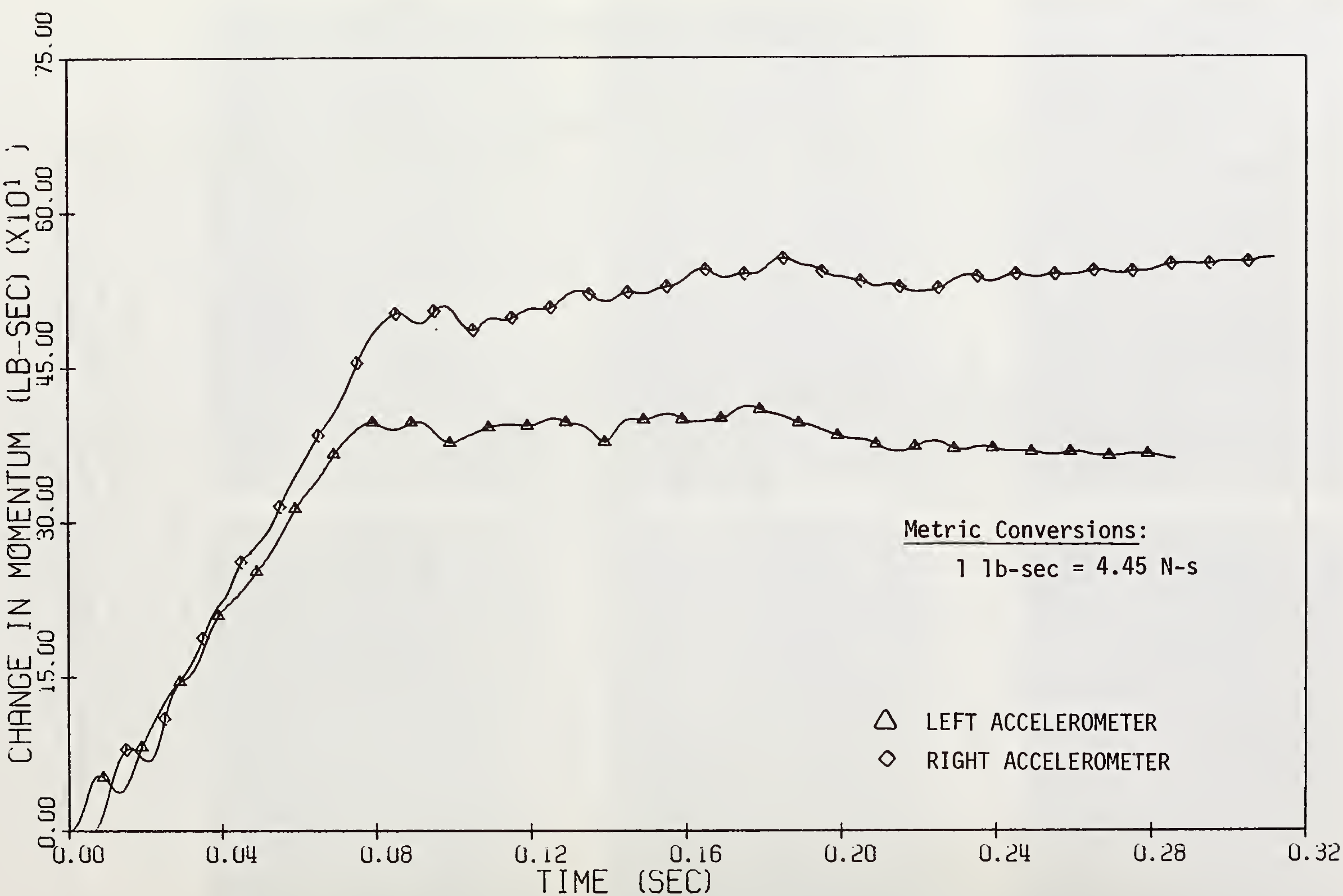


Figure 137. Change in momentum vs. time, test 18.

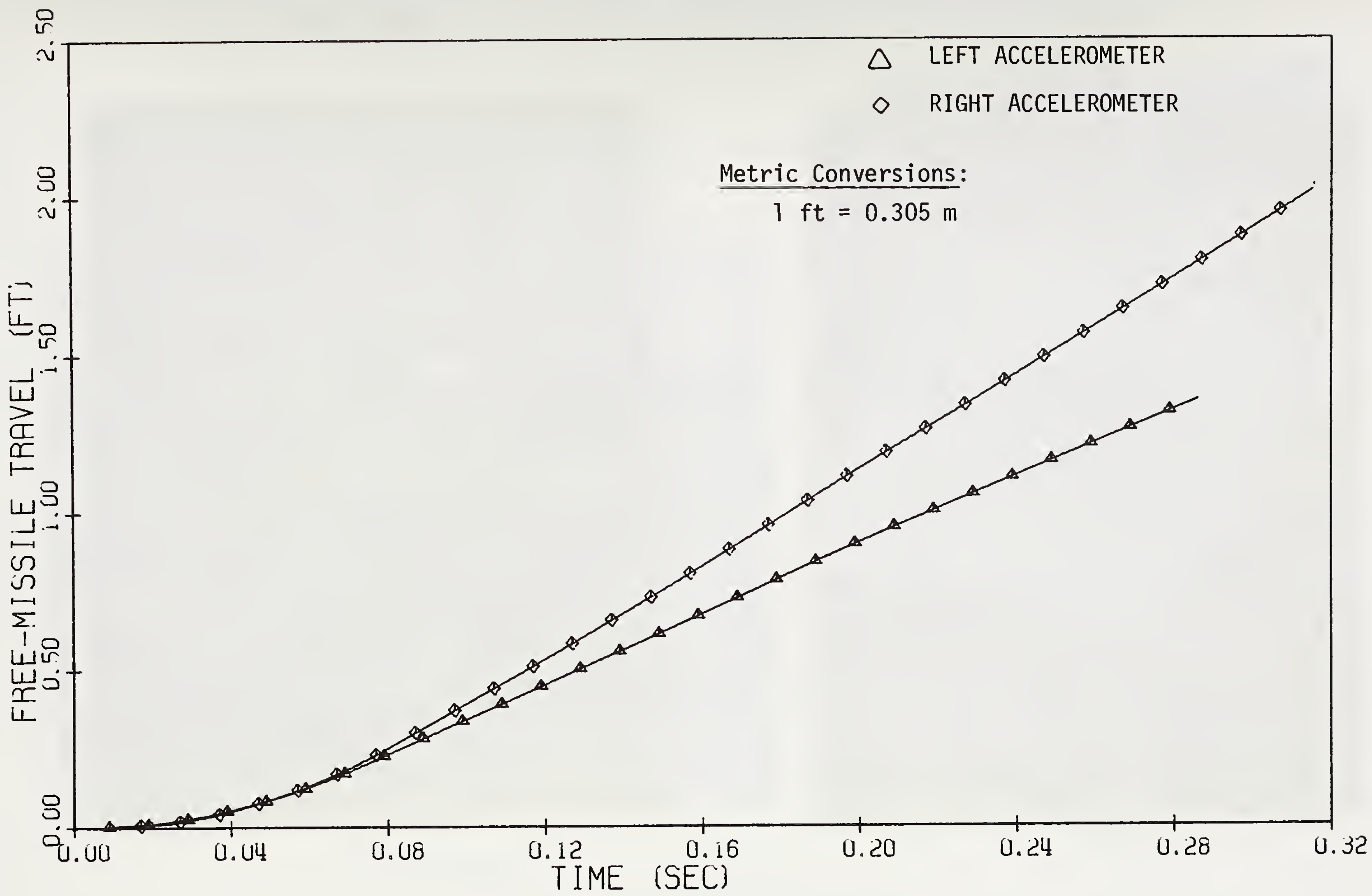
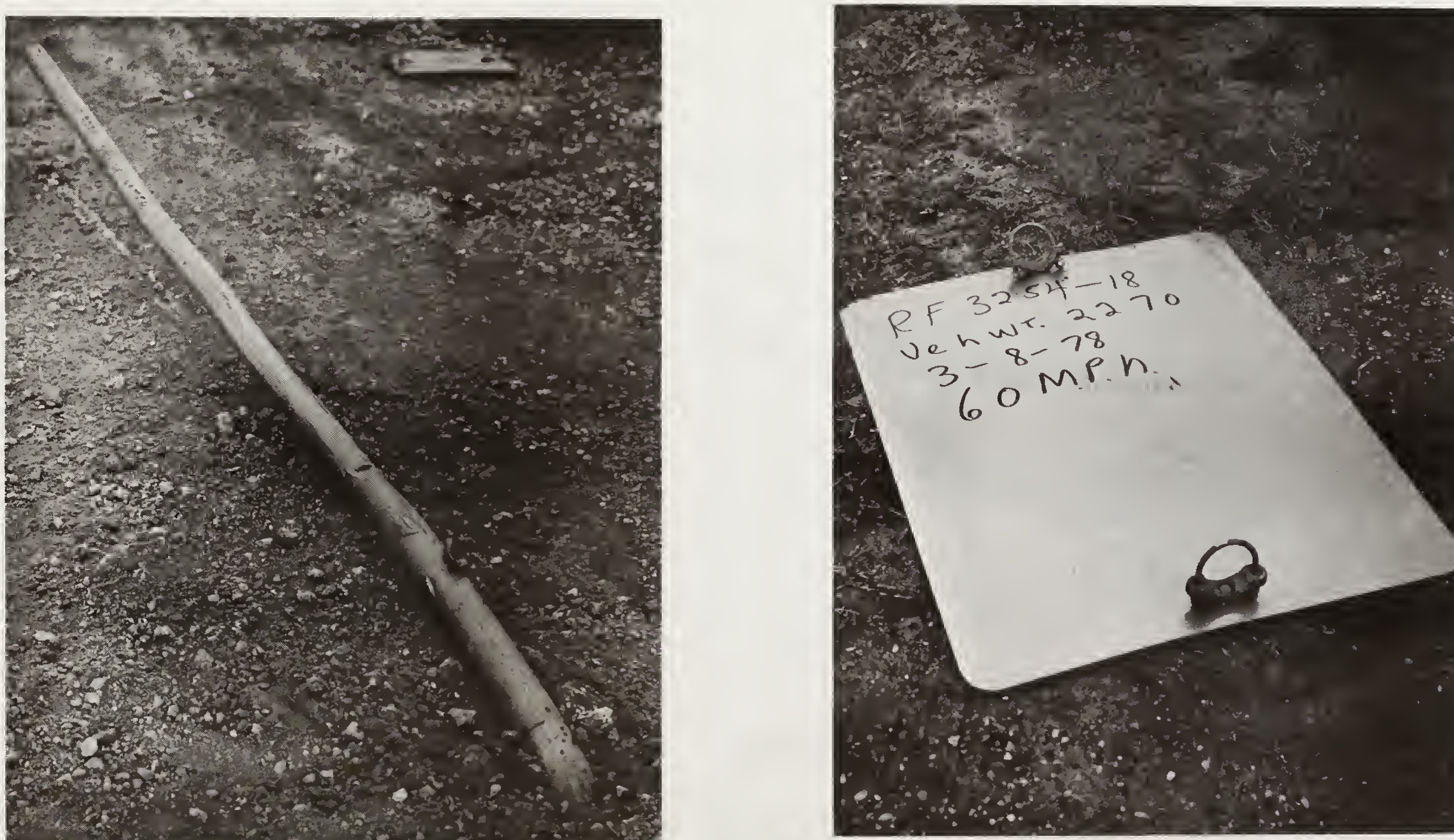
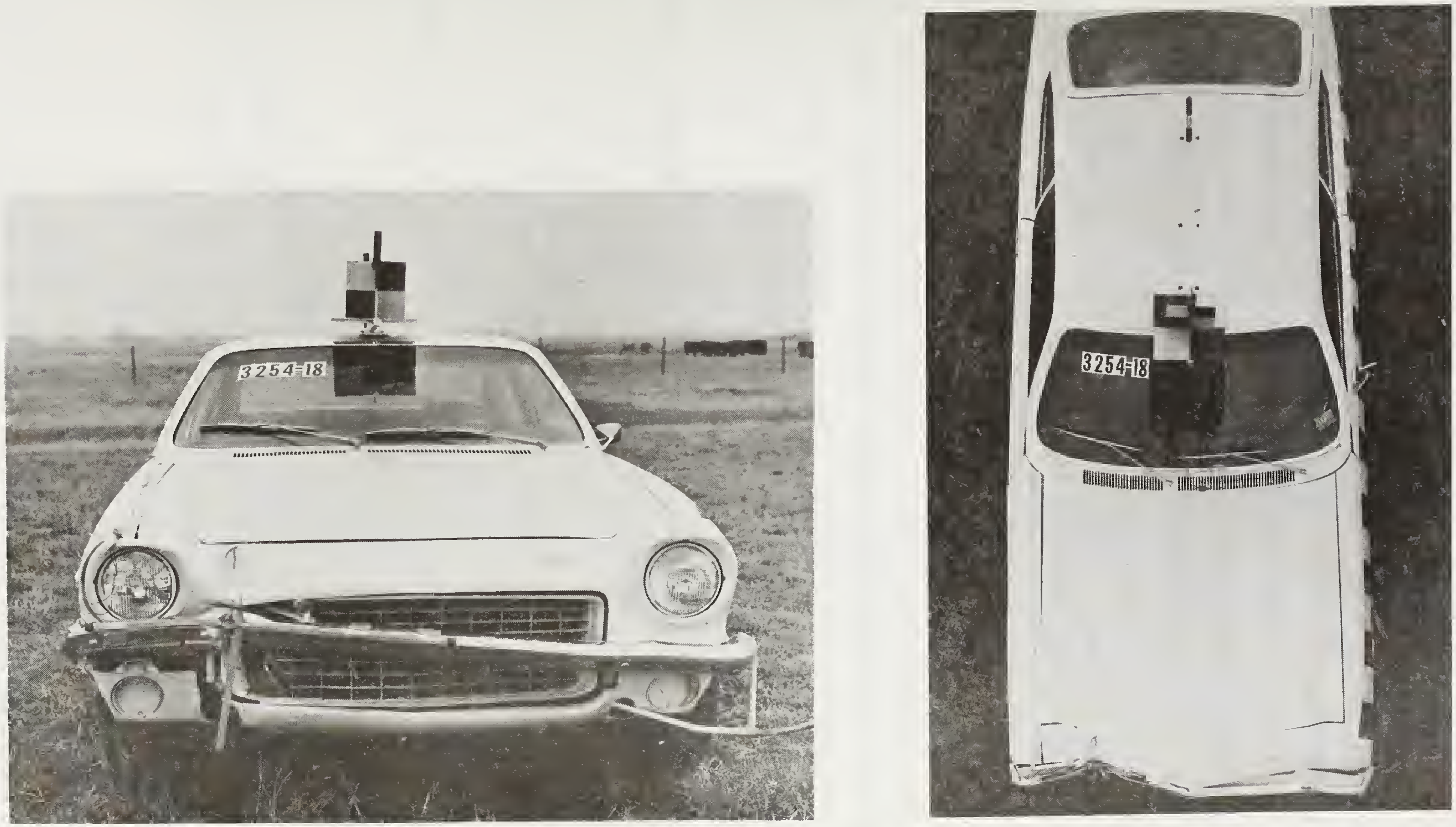


Figure 138. Free missile travel vs. time, test 18.



(a) POST (b) PANEL

Figure 139. Sign installation damage, test 18.



(a) FRONT VIEW

(b) TOP VIEW

Figure 140. Vehicle damage, test 18.

A-3-19. Test No. 19

A summary of test 19 is given in Table 45. Figure 141 shows sequential photos from high-speed film taken during impact, and Table 46 contains a time-displacement-event summary. After impact, the vertical post was bent and pulled down. At about 0.02 sec, the bolt between the back brace and the vertical post sheared. The post and panel then rotated down into the windshield. Although the windshield was dished considerably, the panel did not penetrate through to the passenger compartment. Continued movement of the vehicle pulled the post out of the ground, and the post and panel remained with the vehicle. The back brace was ridden down but was not pulled from the ground.

Figure 142, 143, and 144 contain deceleration, change in momentum, and free missile travel versus time data. Figure 145 shows damage to the sign installation. Restoration would involve replacement of the vertical post and back brace. The sign panel was reusable.

Figure 146 shows damage to the vehicle. Damage was assessed according to the TAD and SAE scales and is given in Table 45.

Table 45. Summary of results, test 3254-19.

Impact Velocity = 60.6 mph

POST DATA		
Type	Steel U-Post with Back Brace** (Billet Steel)	
Size	2 lb/ft	
Embedment Method	Driven	
Embedment Depth (ft)	Vertical Post - 2.5 Back Brace - 2.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1973	
Weight (lb)	2270	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	Left	Right
Change in Momentum (lb-sec)	512	545
Duration of Event (sec)*	0.120	
Peak Deceleration (G's)	9.00	9.86
Maximum 0.050 Sec Average Deceleration (G's)	3.11	3.39
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-3	
SAE	12FLEN2	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

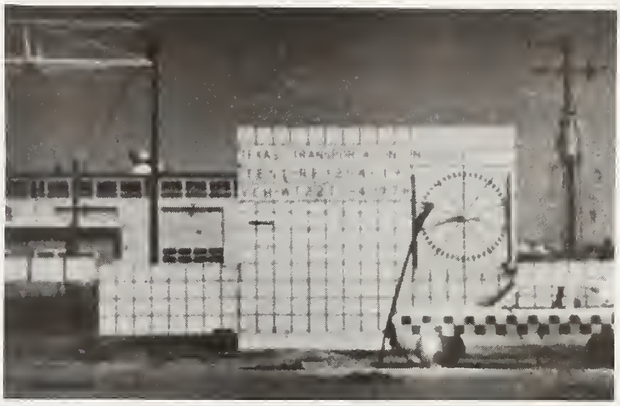
**Armco Steel Corporation posts

Table 46. Time displacement event summary for test 3254-19.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.016	1.62	Brace separates from vertical post
0.061	5.39	Panel hits windshield
0.071	5.93	Brace post bending down
0.080	6.94	Maximum post penetration
0.140	11.63	Panel clear of windshield

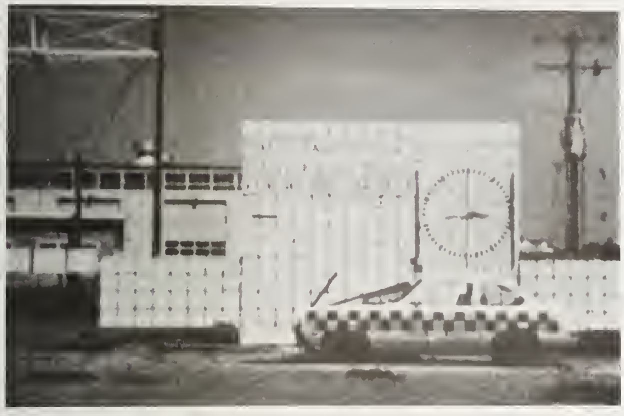
Metric Conversion:

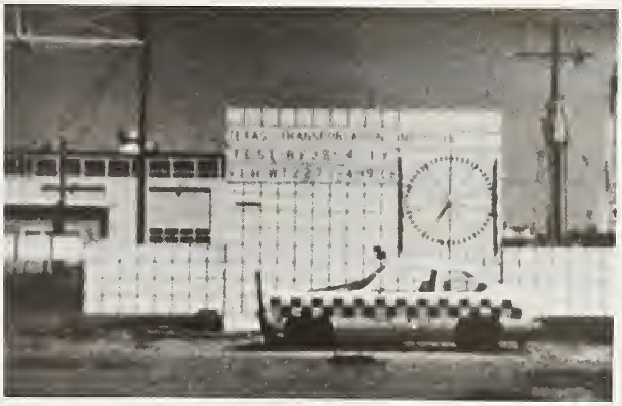
1 ft = 0.305 m



0.000 sec

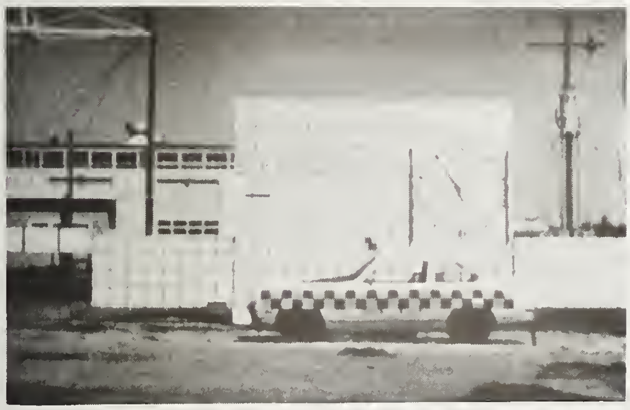
0.016 sec

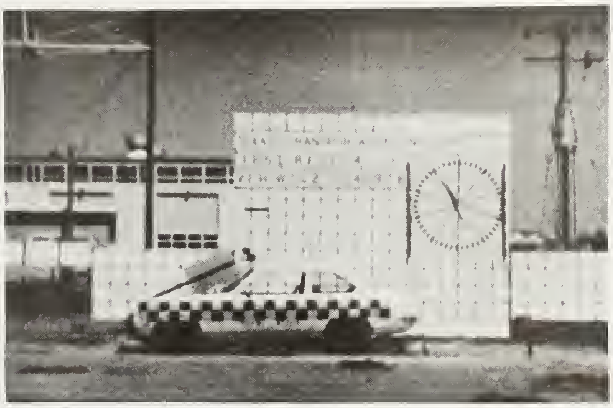




0.061 sec

0.071 sec





0.080 sec

0.140 sec

Figure 141. Sequential photos, test 19.

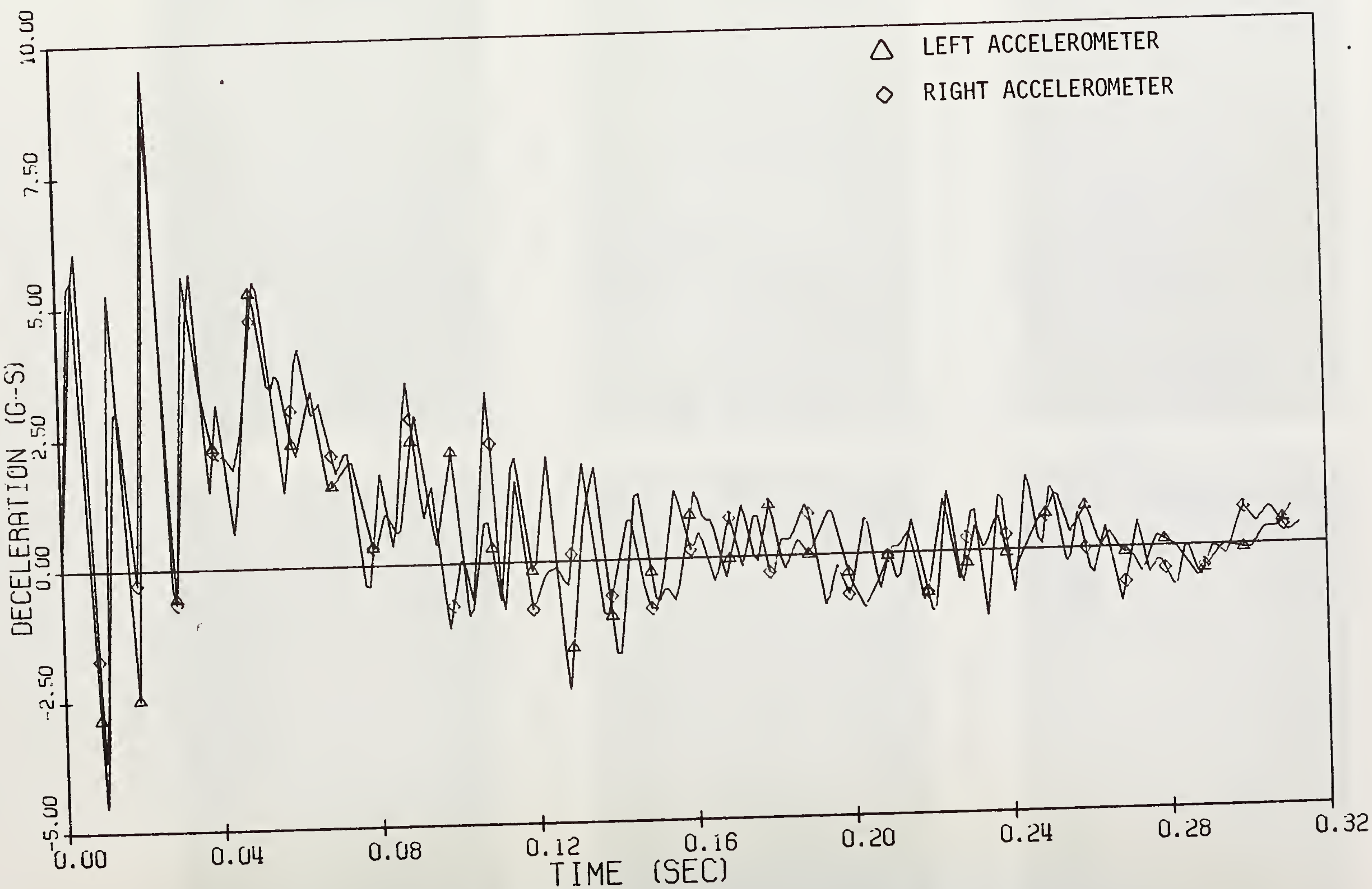


Figure 142. Deceleration vs. time, test 19.

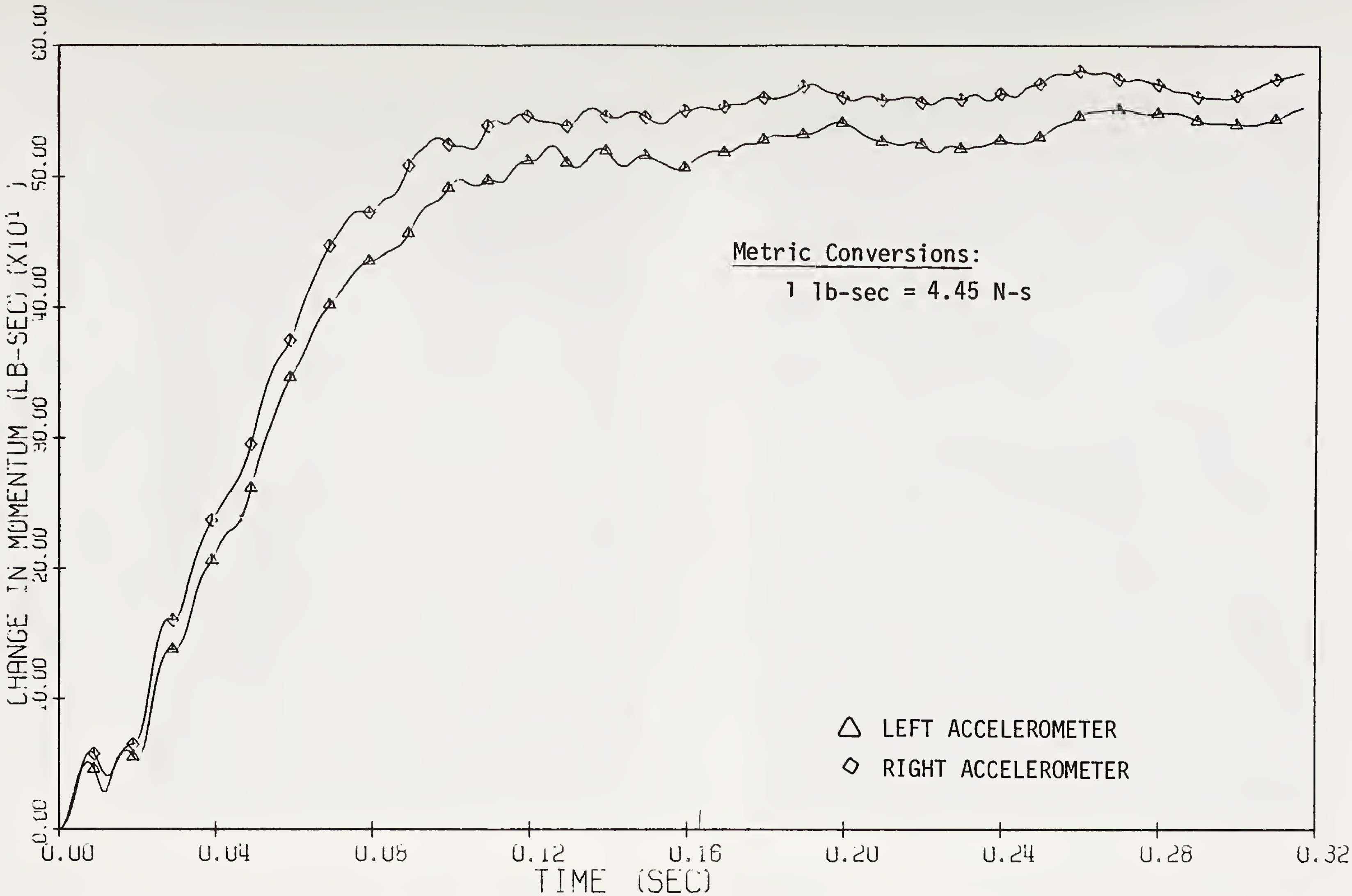


Figure 143. Change in momentum vs. time, test 19.

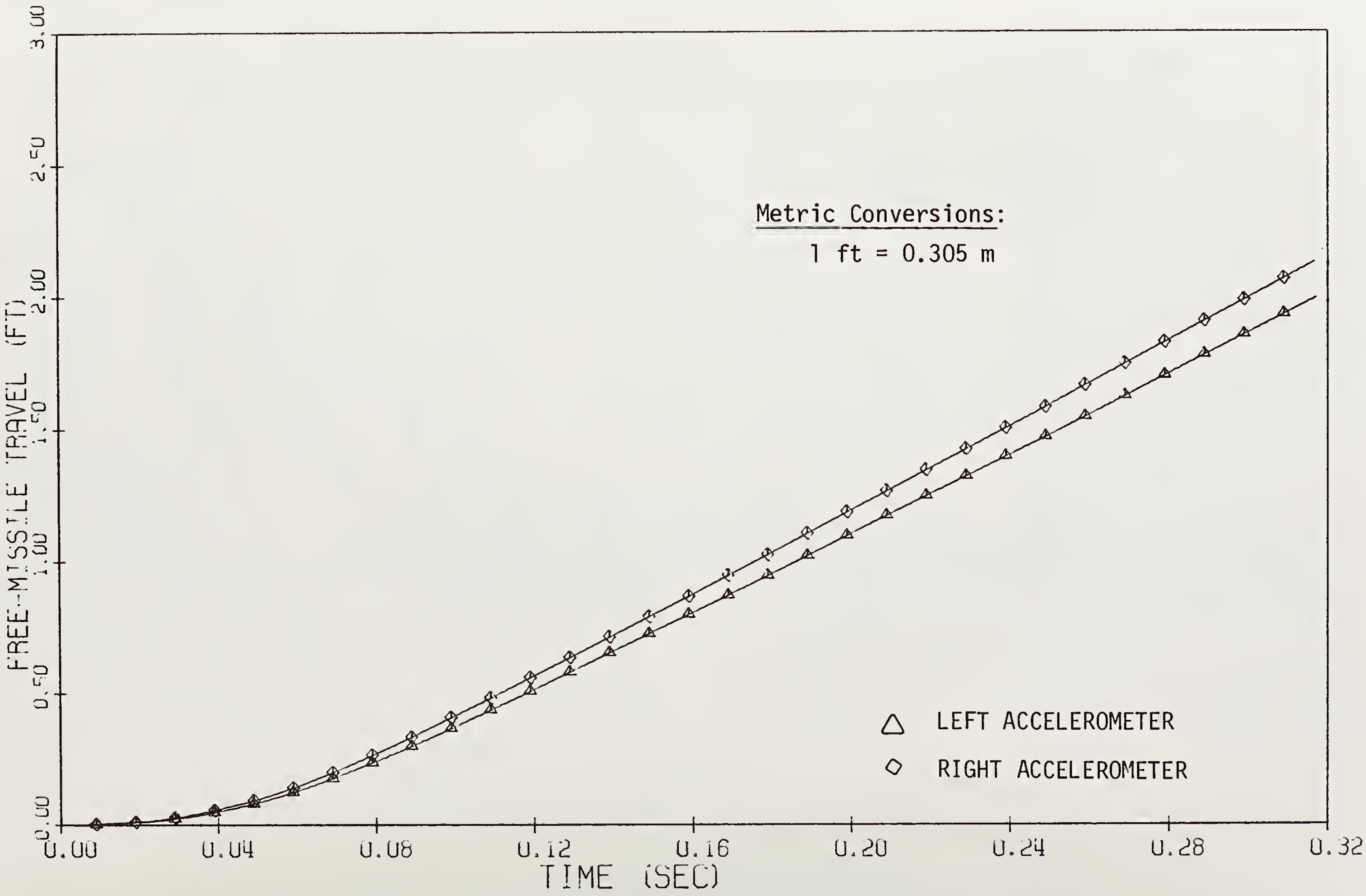
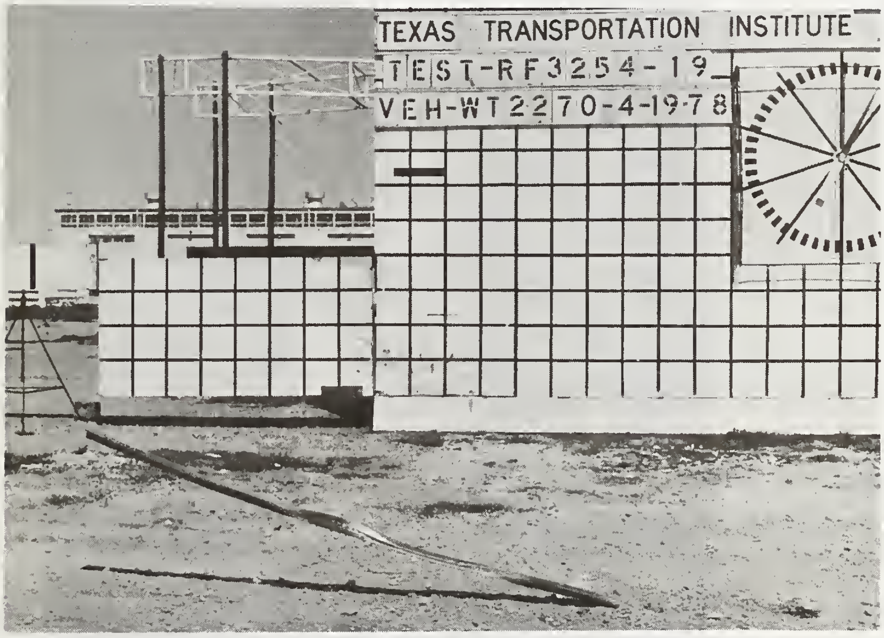


Figure 144. Free missile travel vs. time, test 19.

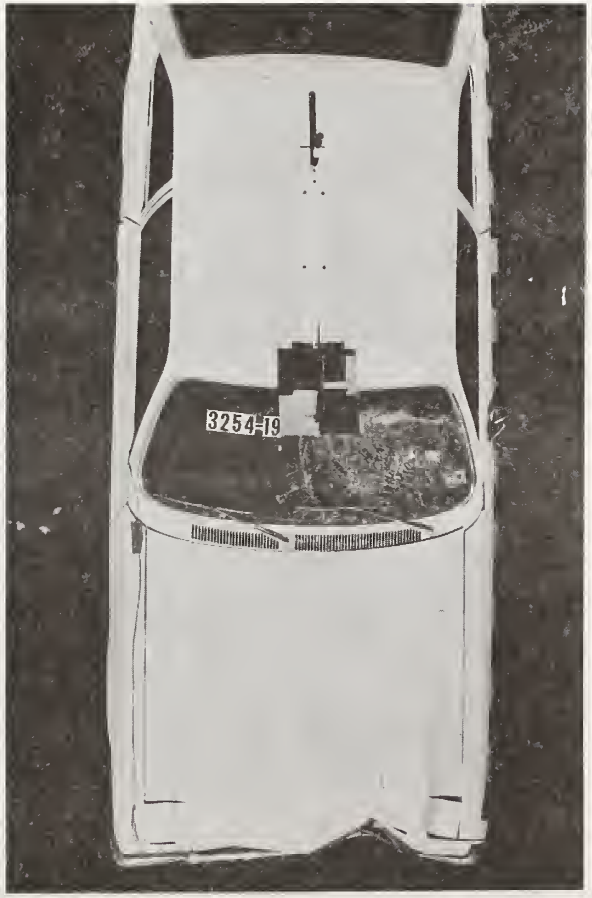
(a) POST AND PANEL



(b) BACK BRACE

Figure 145. Sign installation damage, test 19.

(a) FRONT VIEW



(b) TOP VIEW

Figure 146. Vehicle damage, test 19.

A-3-20. Test No. 20

A summary of test 20 is given in Table 47. It should be noted that the impact speed was 67.3 mph (108.3 km/h), somewhat higher than the intended speed of 60 mph (96.5 km/h). Figure 147 contains sequential photos from high-speed film taken during impact, and Table 48 contains a time-displacement-event summary. Upon impact the post penetrated through the bumper, grille, and front vehicle sheet metal. At about 0.035 sec after impact the post fractured. Then the post and panel began to move forward and rotate down onto the hood, windshield and roof, which produced a relatively large dent in the roof and broke the windshield.

Figures 148, 149, and 150 contain deceleration, change in momentum, and free missile travel versus time data. Figure 151 shows damage to the sign installation. Restoration would involve replacement of the posts. The panel could probably have been repaired and reused.

Damage to the vehicle is shown in Figure 152. Damage was assessed according to the TAD and SAE scales and is given in Table 47.

Table 47. Summary of results, test 3254-20.

Impact Velocity = 67.3 mph

POST DATA		
Type	Steel U-Post Back-to-Back** (Rail Steel)	
Size	6 lb/ft	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1973	
Weight (lb)	2270	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	704	698
Duration of Event (sec)*	0.150	
Peak Deceleration (G's)	12.10	11.84
Maximum 0.050 Sec Average Deceleration (G's)	4.96	4.99
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-5	
SAE	12FREN4	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Franklin Steel Company posts

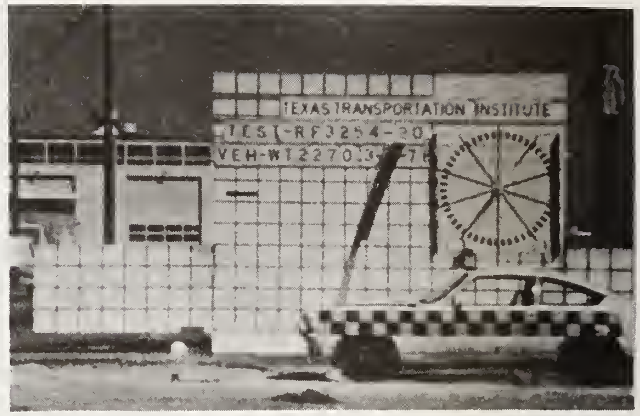
Table 48. Time displacement event summary for test 3254-20.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.032	1.74	Hood begins to release
0.035	2.82	Signpost breaks
0.041	3.37	Maximum post penetration
0.086	8.11	Sign strikes hood, windshield and roof
0.121	11.36	Maximum passenger compartment deflection

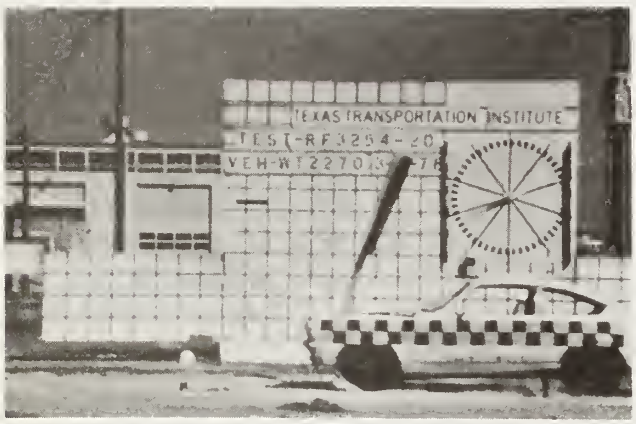
Metric Conversion:

1 ft = 0.305 m

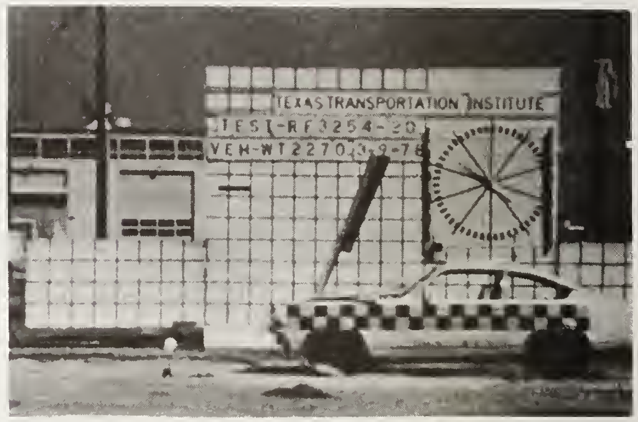
0.000 sec



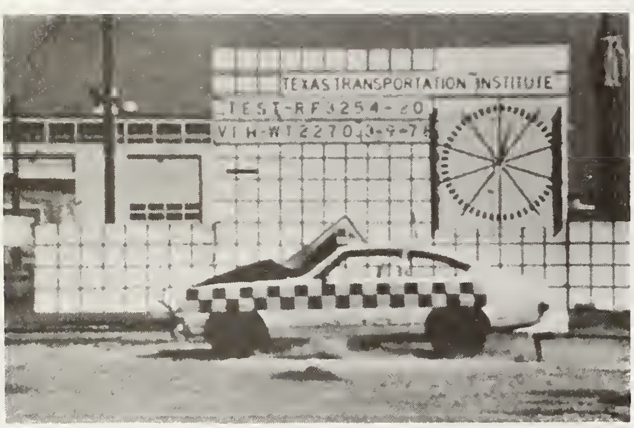
0.032 sec



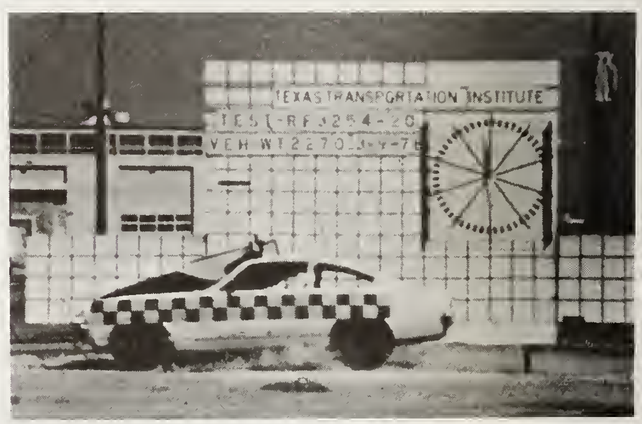
0.035 sec



0.041 sec



0.086 sec



0.121 sec

Figure 147. Sequential photos, test 20.

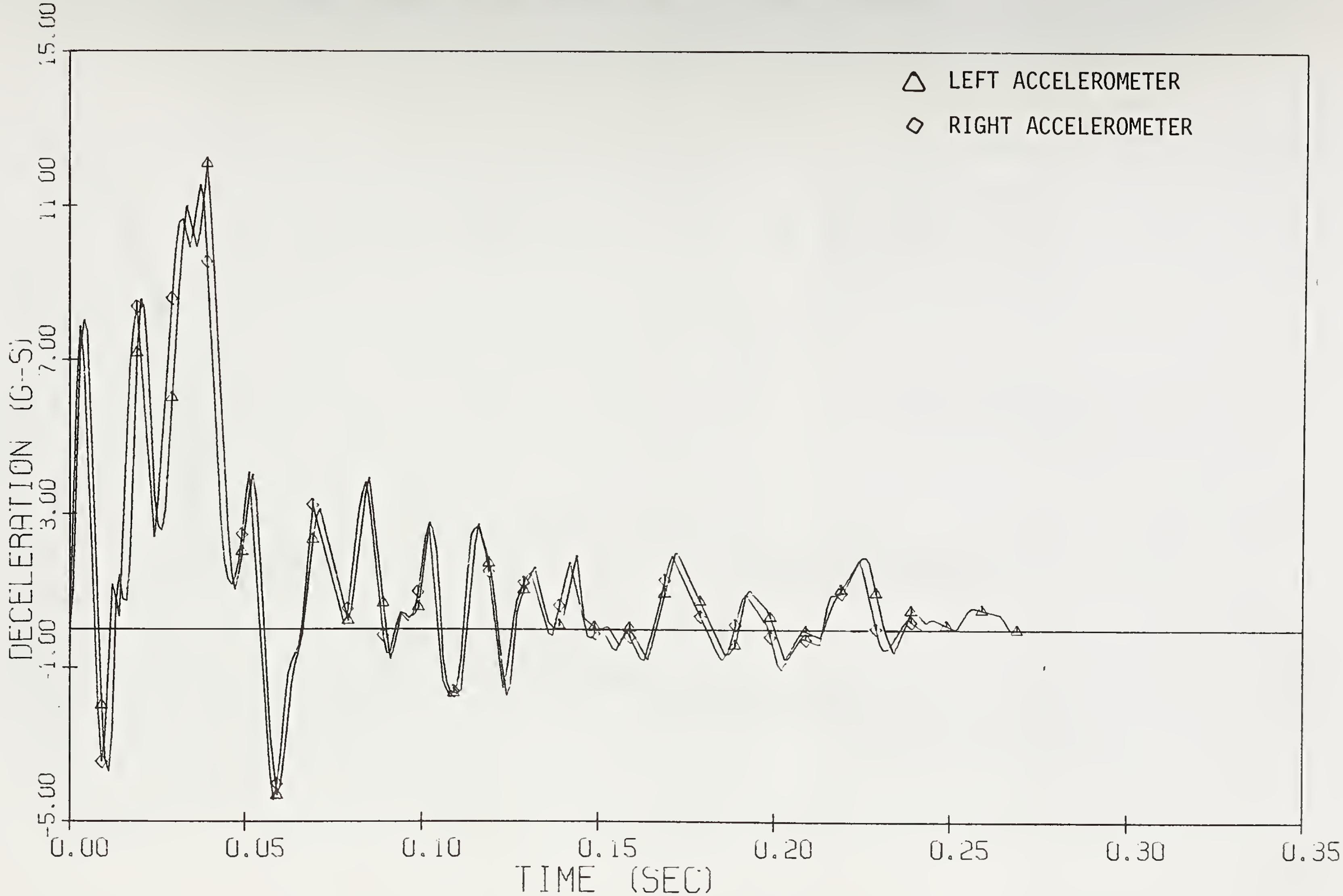


Figure 148. Deceleration vs. time, test 20.

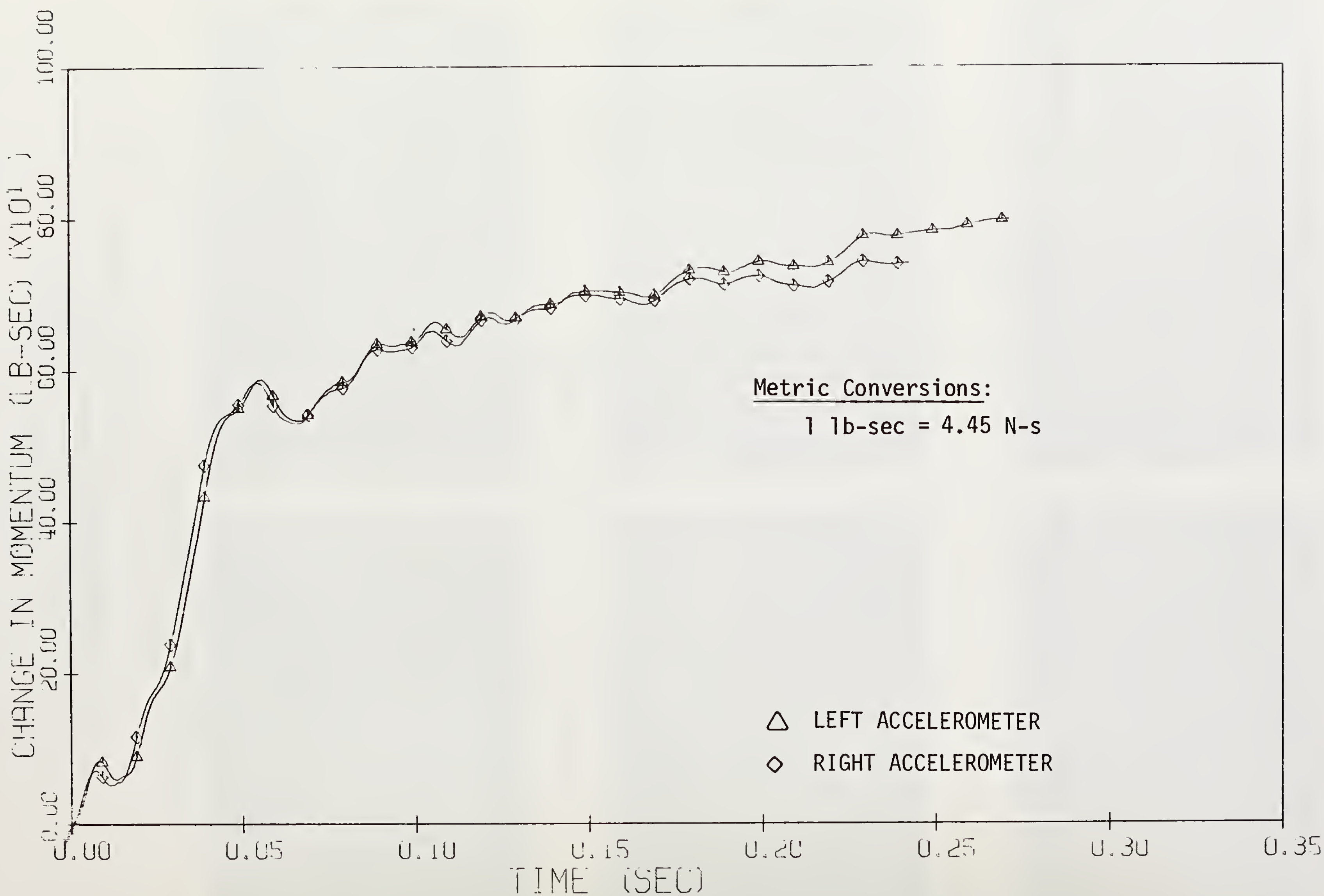


Figure 149. Change in momentum vs. time, test 20.

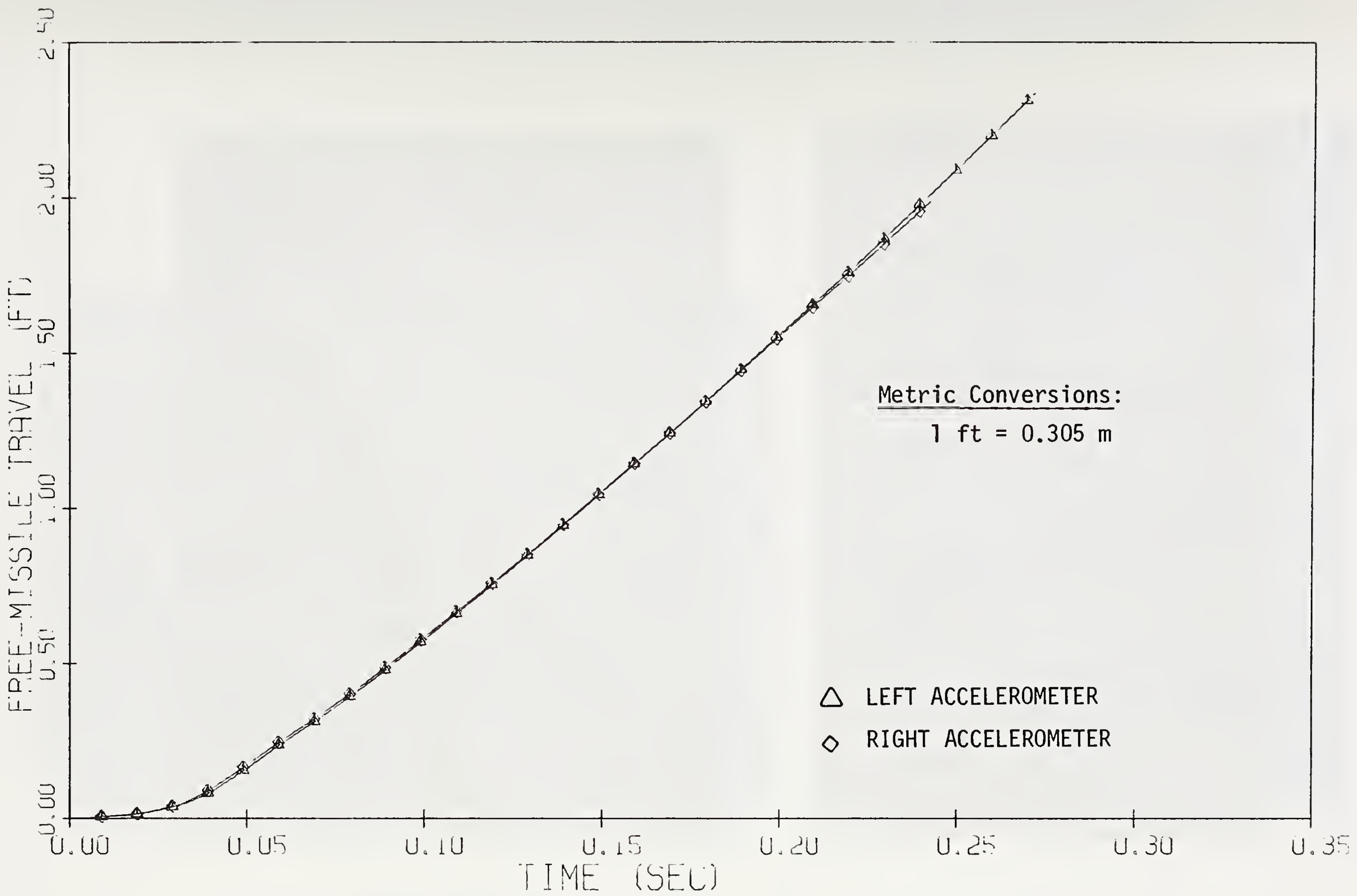


Figure 150. Free missile travel vs. time, test 20.

(b) BASE

(a) POST AND PANEL

Figure 151. Sign installation damage, test 20.

(a) FRONT VIEW (b) TOP VIEW

Figure 152. Vehicle damage, test 20.

A-3-21. Test No. 20A

Test 20A was a repeat of test 20 but at a lower speed. A summary of the test is given in Table 49. Sequential photos of the impact are presented in Figure 153, and a time-displacement-event summary is given in Table 50. Impact behavior of the post in this test was similar to that of test 20. However, the post penetrated considerably less into the front vehicle structure in test 20A (compare Figures 152 and 158). Also, the post and panel did not rotate as far back on test 20A. Panel contact with the roof and windshield produced a dent and broke the windshield. After impacting the roof, the post and panel were carried along with the vehicle for about 50 ft (15.2 m). At that point the brakes were applied to the vehicle causing the panel to slide off the hood onto the ground in front of the vehicle. Application of the brakes also produced a yawing motion to the vehicle. When the panel and post hit the ground the panel dug into the soil (see Figure 157). Then the vehicle hit the post and panel, tripped, and rolled over two times. One can only speculate as to the probability of such an occurrence; however, it is believed to be small.

Figures 154, 155, and 156 contain deceleration, change in momentum, and free missile travel versus time data. Damage to the sign installation is shown in Figure 157. Note the soil penetration produced when the panel tripped the vehicle. Restoration would involve replacement of the complete sign installation.

Damage to the vehicle is shown in Figure 158. Damage was assessed according to the TAD and SAE scales and is given in Table 49.

Table 49. Summary of results, test 3254-20A.

Impact Velocity = 62.9 mph

POST DATA		
Type	Steel U-Post Back-to-Back** (Rail Steel)	
Size	6 lb/ft	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1973	
Weight (lb)	2270	
Impact Point	15 in. to left of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	707	631
Duration of Event (sec)*	0.17[illegible]	
Peak Deceleration (G's)	10.02	8.80
Maximum 0.050 Sec Average Deceleration (G's)	4.44	4.07
VEHICLE DAMAGE CLASSIFICATION		
TAD	FL-2/L&T-4	
SAE	00OTPH03	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes	

Metric Conversions:

1 in.	=	2.54 cm
1 ft	=	0.305 m
1 lb_m	=	0.454 kg
1 lb -sec	=	4.45 N-s
1 mph	=	1.609 km/h

*Time of contact

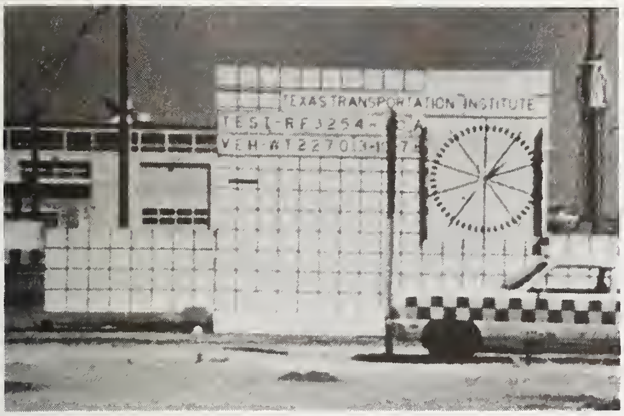
**Franklin Steel Company post

Table 50. Time displacement event summary for test 3254-20A.

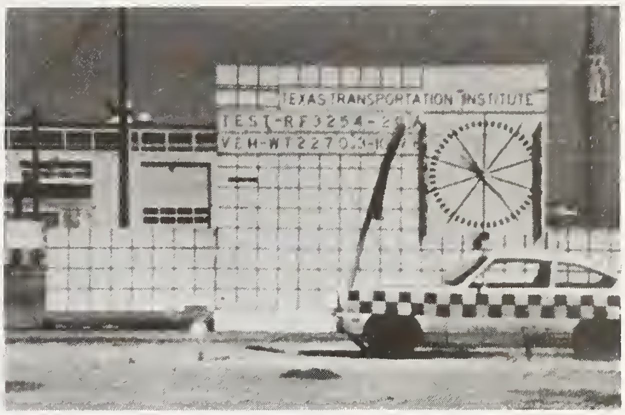
TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.027	2.23	Post breaks
0.051	4.17	Maximum post penetration
0.081	6.58	Panel strikes roof
0.115	9.25	Maximum passenger compartment deflection
0.186	14.91	Post and panel moving with vehicle

Metric Conversion:

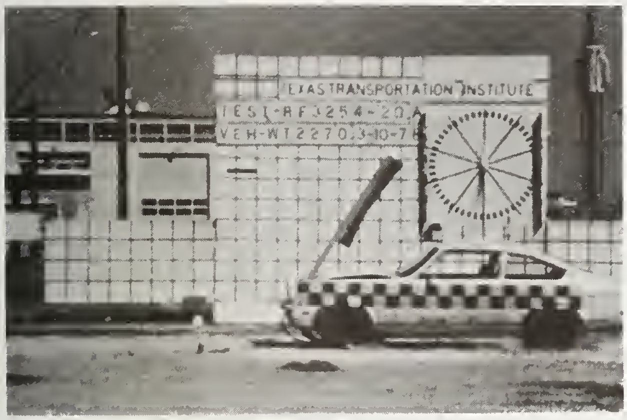
1 ft = 0.305 m



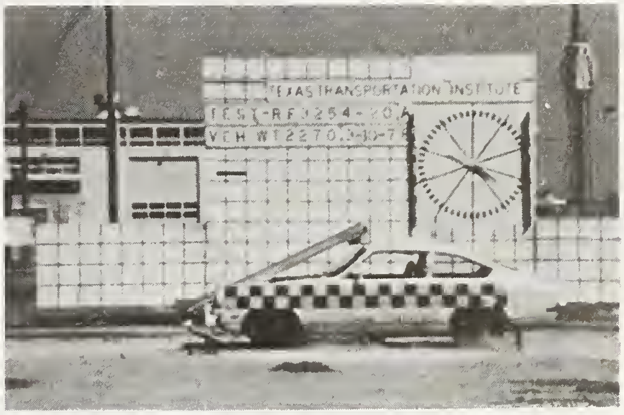
0.000 sec



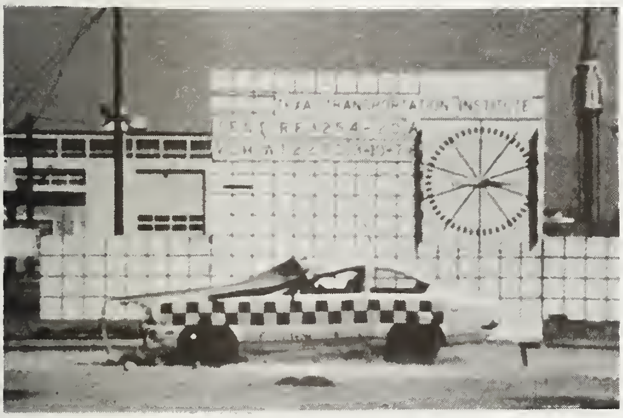
0.027 sec



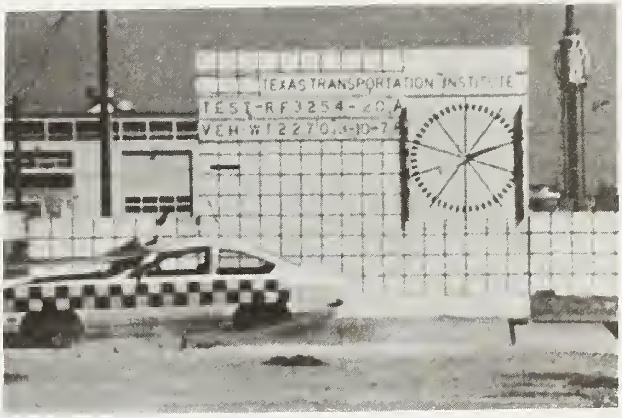
0.051 sec



0.081 sec



0.115 sec



0.186 sec

Figure 153. Sequential photos, test 20A.

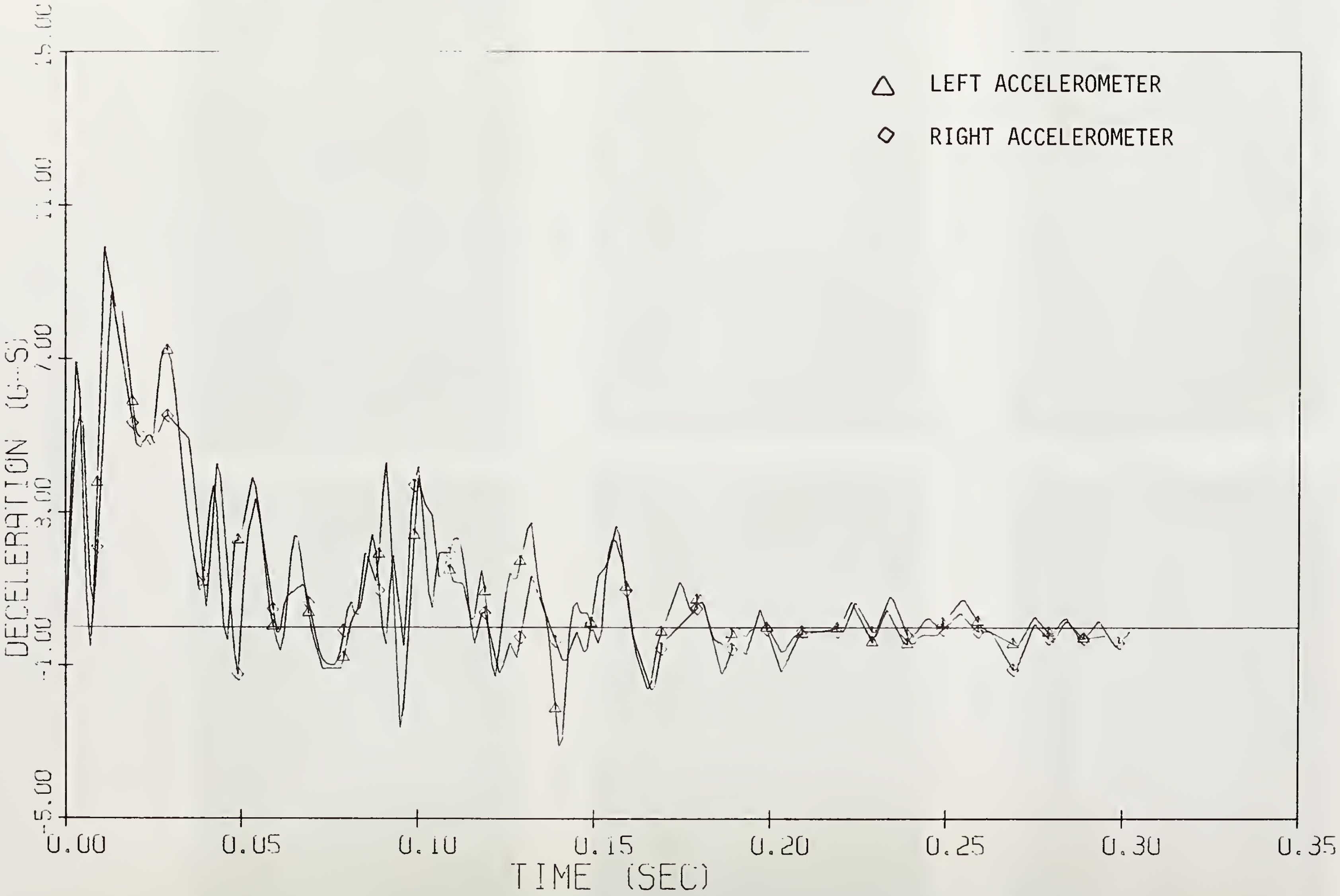


Figure 154. Deceleration vs. time, test 20A.

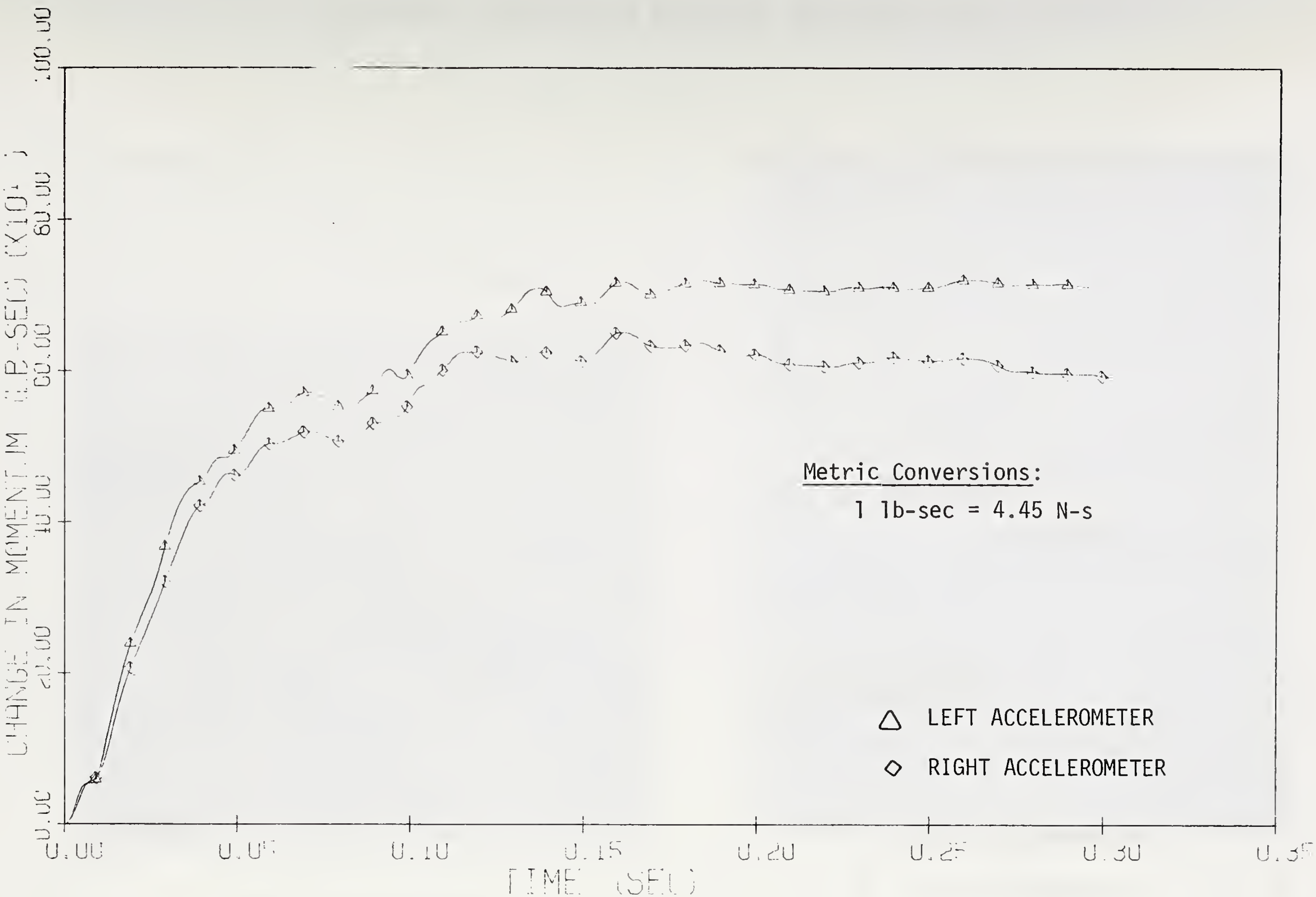


Figure 155. Change in momentum vs. time, test 20A.

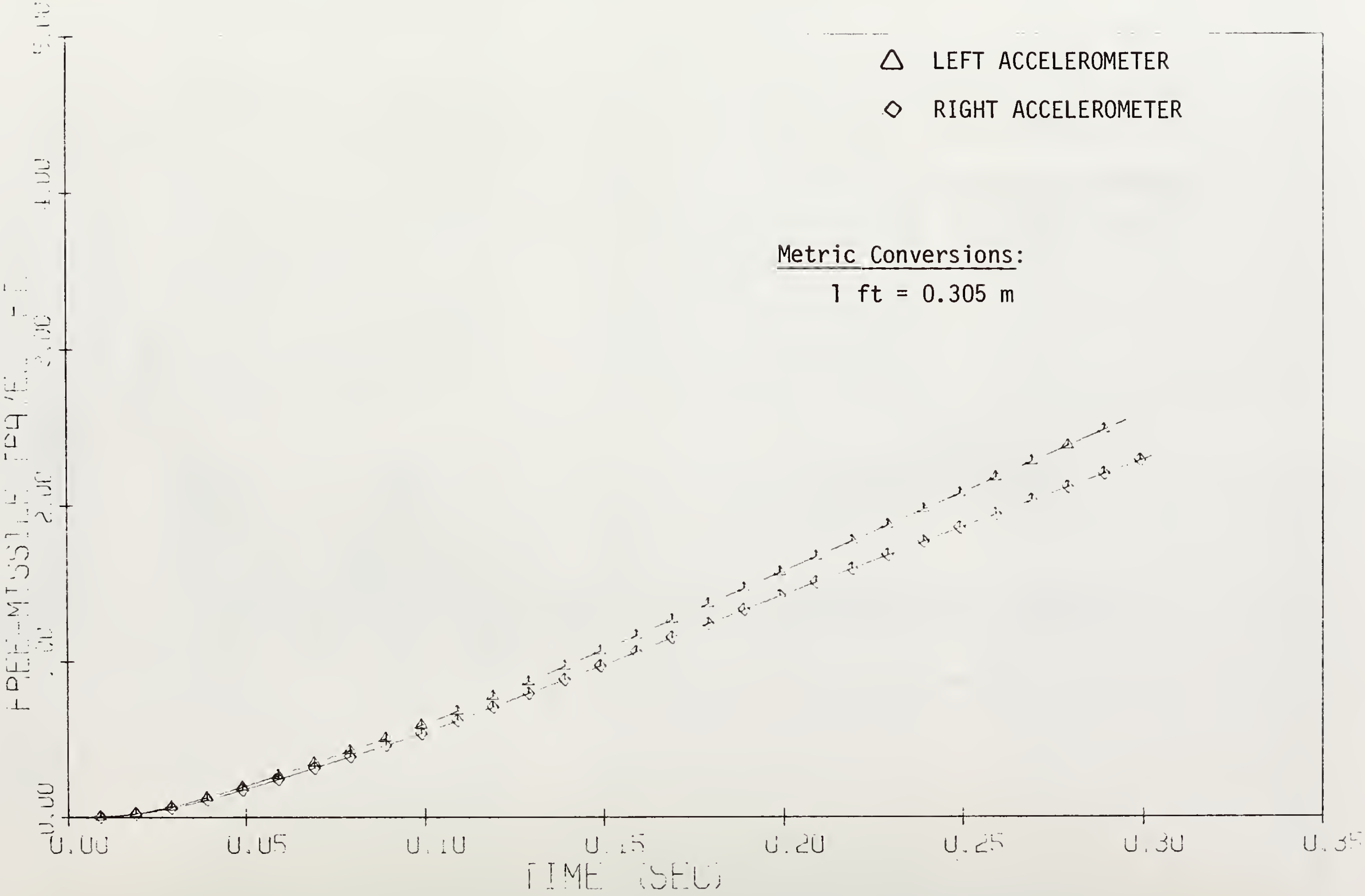
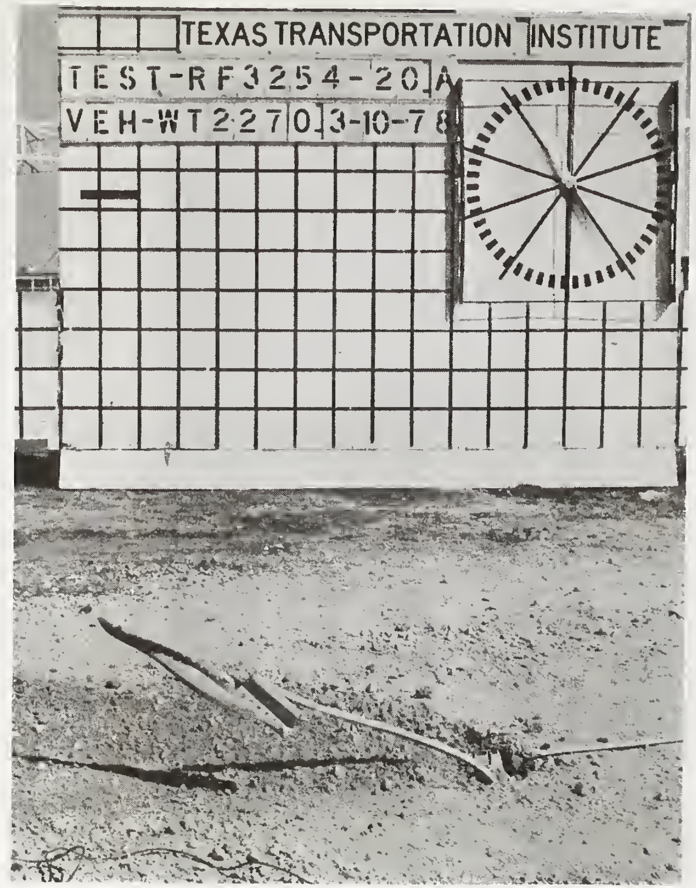


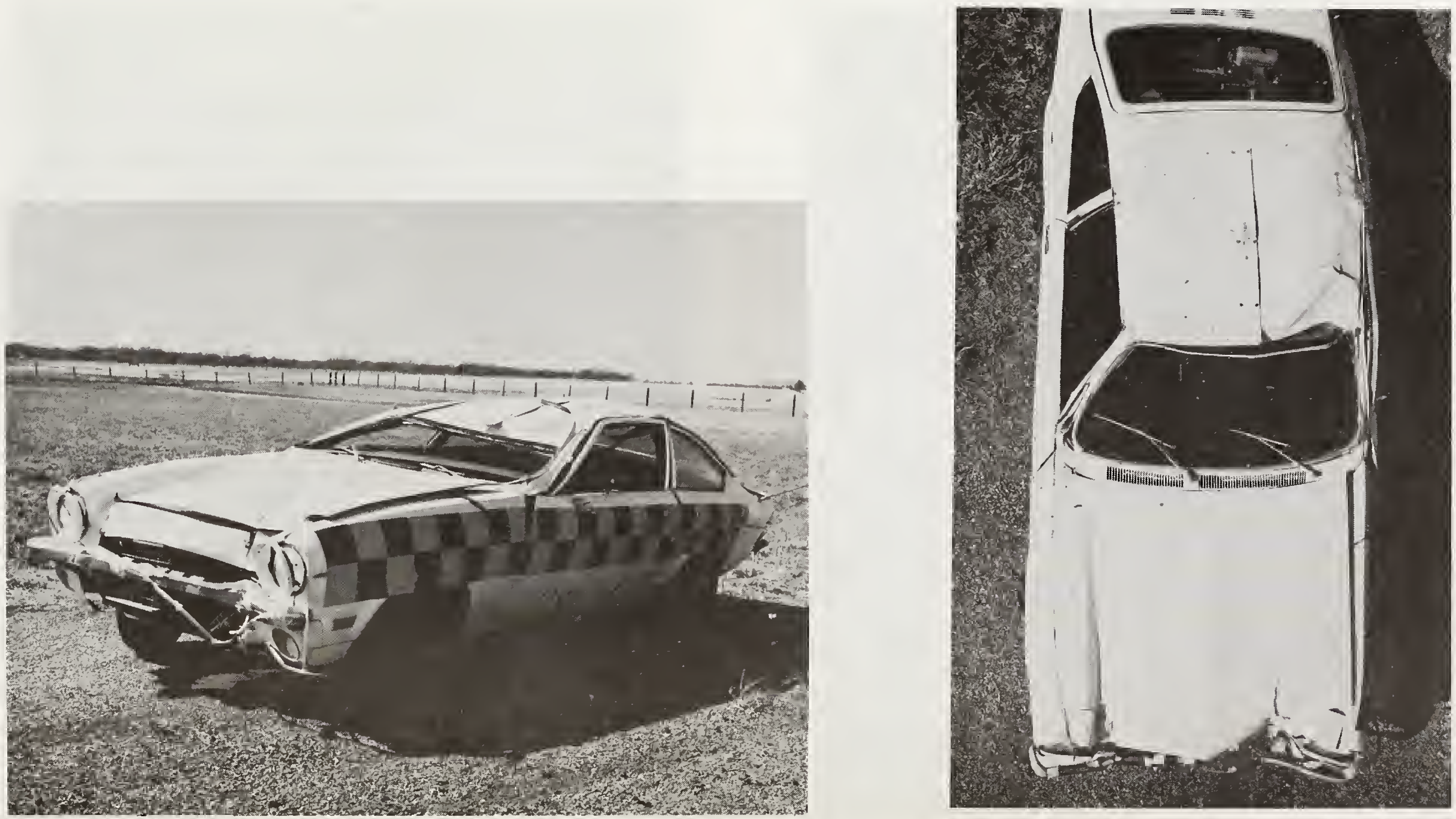
Figure 156. Free missile travel vs. time, test 20A.

(a) POST AND PANEL



(b) BASE

Figure 157. Sign installation damage, test 20A.



(a) SIDE VIEW (b) TOP VIEW

Figure 158. Vehicle damage, test 20A.

A-3-22. Test No. 21

Analysis of tests 4 and 9 showed that the steel U-post rolled from billet steel possessed an ability to absorb a considerable amount of energy during impact. As a consequence, the change in momentum in test 4 was more than the desirable limit of 750 lb-sec (341 kg-sec) and in test 9 the change in momentum was considerably in excess of the upper limit of 1100 lb-sec (499 kg-sec). It should be added that in the past, when larger automobiles were more predominant, these type posts could be ridden down without difficulty. With the advent of the smaller car, the "base bending" or "yielding" type sign support becomes much more critical, especially at the higher speeds, as was evident in tests 4, 9, and 11. A post or a device which fractures on impact appears to be more desirable.

To improve the impact behavior of the billet steel U-post, the manufacturer (14) produced an alloy which exhibited a brittle fracture characteristic during impact loadings. Properties of this steel, along with all the other posts, are given in Appendix B. Test 21 was therefore scheduled to evaluate the impact behavior of this material under full-scale conditions.

A summary of test 21 is given in Table 51. Photos taken during impact are presented in Figure 159. A time-displacement-event summary is given in Table 52.

Comparison of the impact behavior of this post with the rail steel post of test 20A shows a great amount of similarity. The post in test 21 causes less impact damage to the vehicle than the post in test 20A, but this is due in most part to the differences in impact speeds. When compared with the results of test 9, the installation in test 21 was much less critical, as underscored by the much lower change in momentum and vehicle damage.

Figures 160, 161, and 162 contain deceleration, change in momentum, and free missile travel versus time data. Figure 163 shows damage to the sign installation. Restoration would involve replacement of the posts. The panel was repairable.

Table 51. Summary of results, test 3254-21.

Impact Velocity = 57.9 mph

POST DATA		
Type	Steel U-Post (Billet Steel)	
Size	6 lb/ft Back-to-Back	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Vega	
Year	1971	
Weight (lb)	2270	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	394	466
Duration of Event (sec)*	0.138	
Peak Deceleration (G's)	9.48	10.02
Maximum 0.050 Sec Average Deceleration (G's)	3.10	3.30
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-2	
SAE	12FREN1	
Did test article penetrate the passenger compartment?	No	
Was windshield broken?	Yes, by sign panel	

Metric Conversions:

1 in. = 2.54 cm
1 ft = 0.305 m
1 lb_m = 0.454 kg
1 lb -sec = 4.45 N-s
1 mph = 1.609 km/h

*Time of contact

**Armco Steel Corporation posts Experimental Alloy

Table 52. Time displacement event summary for test 3254-21.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.023	1.95	Post breaks
0.033	2.79	Hood begins to buckle
0.046	3.71	Maximum post penetration
0.083	6.68	Panel hits c.g. target
0.119	9.43	Panel hits roof

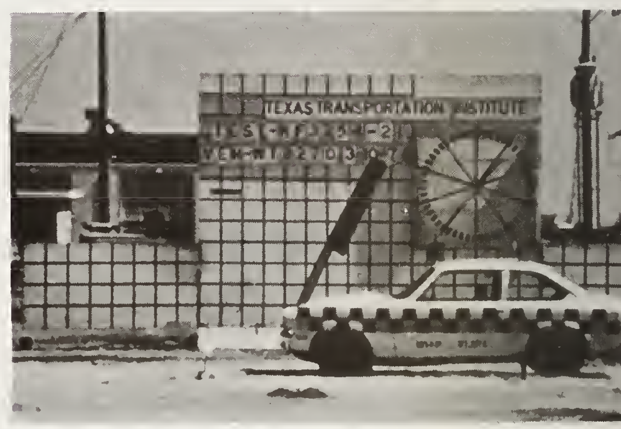
Metric Conversion:

1 ft = 0.305 m

0.000 sec

0.023 sec

0.033 sec



0.046 sec

0.083 sec

0.119 sec

Figure 159. Sequential photos, test 21.

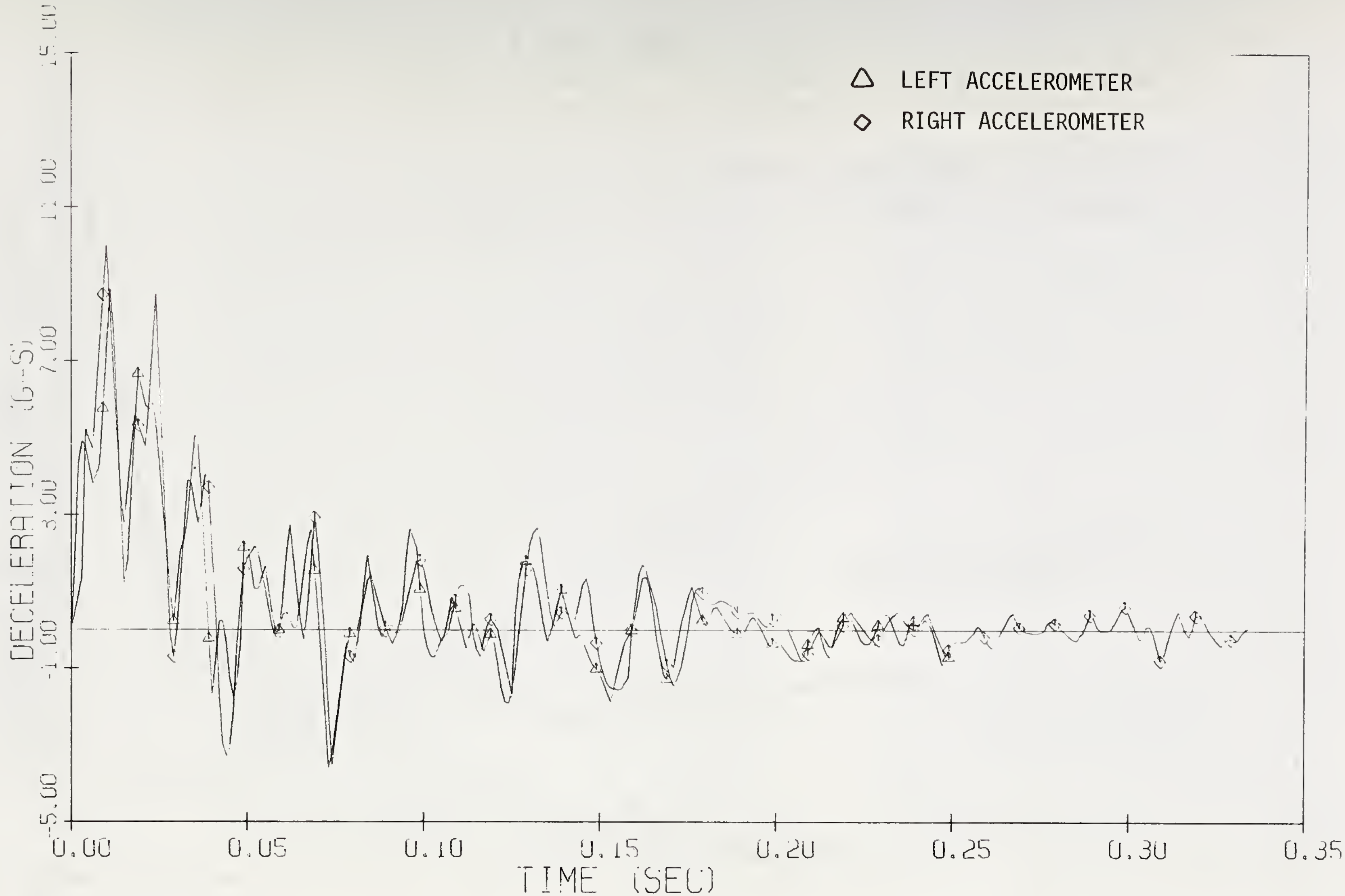


Figure 160. Deceleration vs. time, test 21.

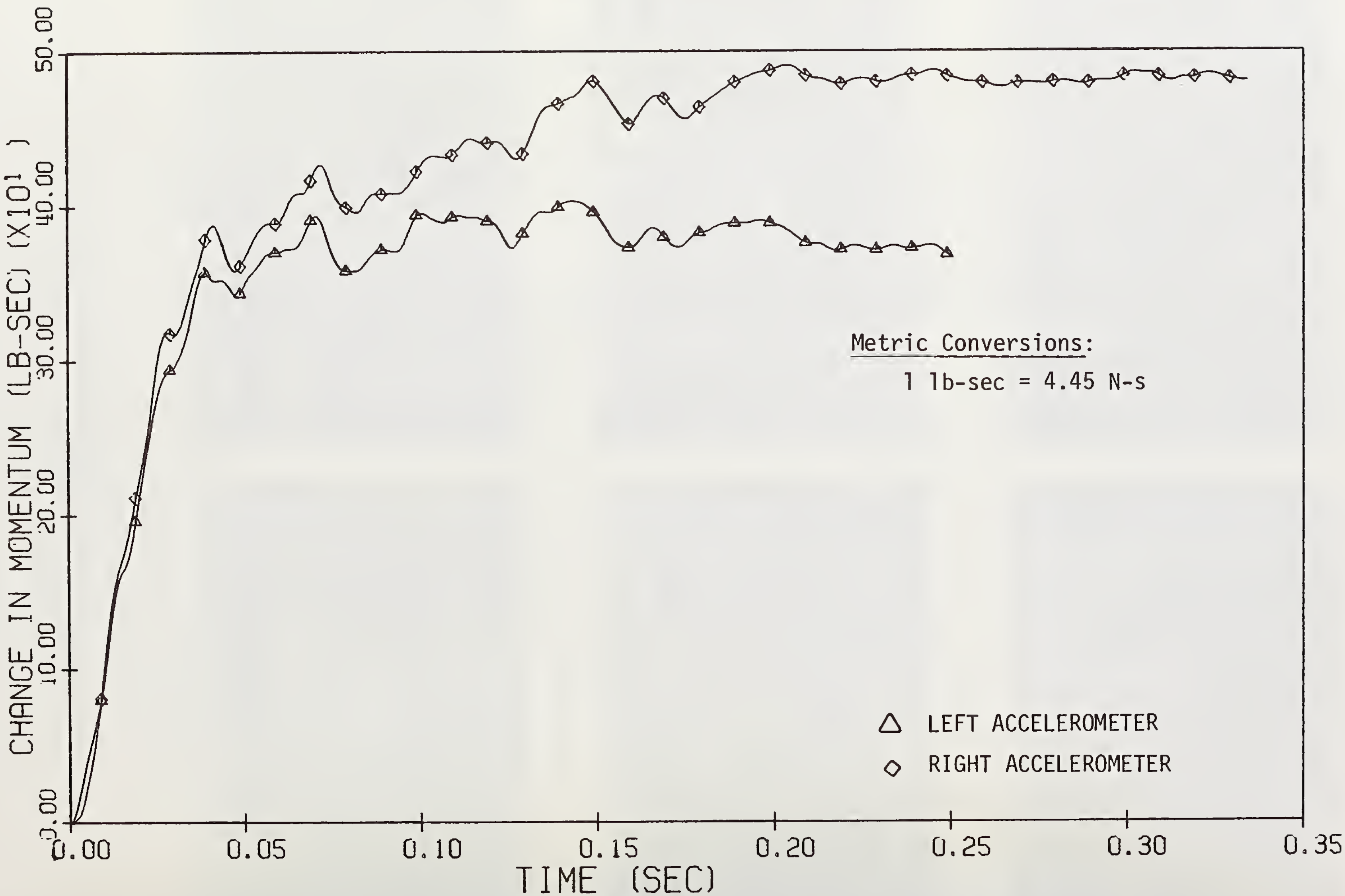


Figure 161. Change in momentum vs. time, test 21.

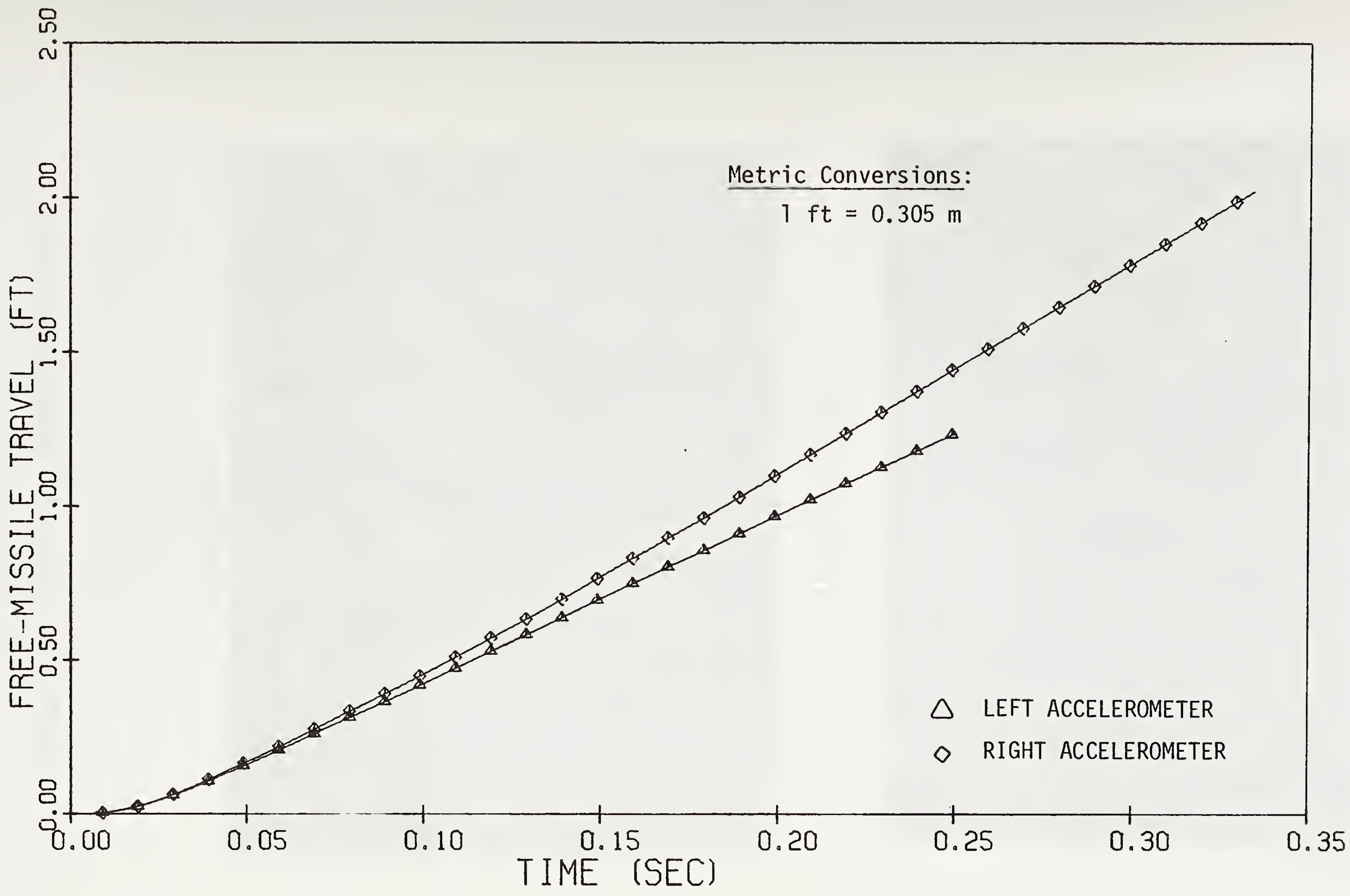


Figure 162. Free missile travel vs. time, test 21.

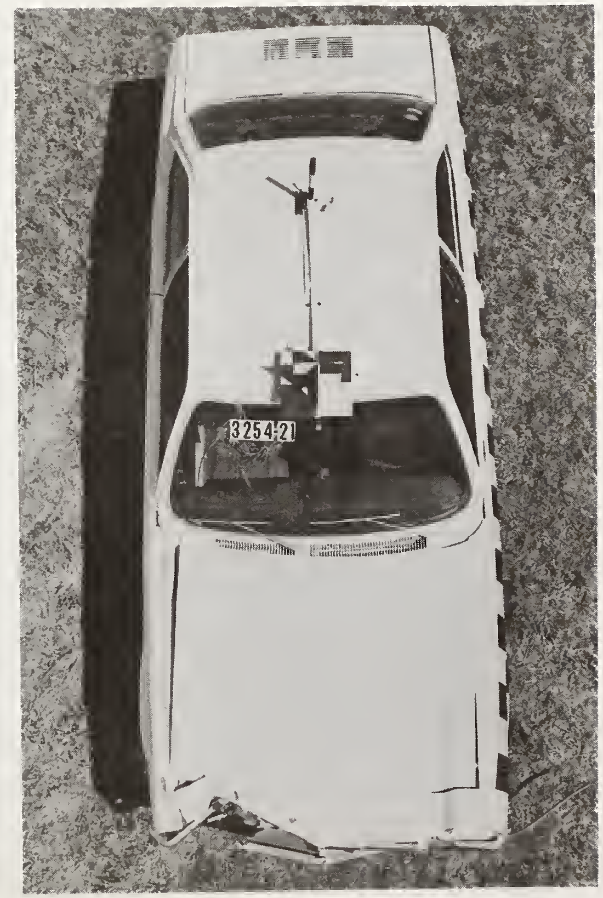
(a) POST AND PANEL

(b) BASE

Figure 163. Sign installation damage, test 21.

Figure 164 shows vehicle damage. Damage was assessed according to the TAD and SAE scales and is given in Table 51.

(a) FRONT VIEW



(b) TOP VIEW

Figure 164. Vehicle damage, test 21.

APPENDIX B. MATERIAL PROPERTIES OF POSTS AND SIGN PANELS

B. MATERIAL PROPERTIES OF POSTS AND SIGN PANELS

B-1. Metal Posts

B-1-1. Mechanical and Chemical Properties

Mechanical and chemical properties of the base bending type metal posts are given in Table 53. Data for posts used in tests 3 through 9, 13, 20, 20A, and 21 were provided by the manufacturers who produce the respective posts. The balance of data was obtained through tests by a local materials laboratory. With regard to the chemical analysis, a dash (-) indicates that no data were provided. It does not necessarily mean that the particular element was not present in the post.

The following should be noted:

(a) Posts used in crash tests 3, 4, 5, 6, and 9 were all rolled from the same alloy.

(b) Both posts used in test 21 were rolled from an experimental alloy.

(c) Material properties of the posts evaluated in crash tests 10 and 17, which were both low-speed tests, were not determined since the high-speed tests (11 and 19) were more critical.

B-1-2. Charpy Impact Tests

Some of the base bending posts fractured during full-scale tests and some did not. Laboratory tests were conducted to determine if there was a relationship between Charpy impact test results and the observed full-scale test results. Simple beam tests of notched specimens were conducted in accordance with ASTM E23-72 specification. Tests were conducted at both the ambient temperature at the time of the full-scale crash test and at 150^{o}F (65.6^{o}C). The latter value was selected as an "upper temperature limit" for a post in the field. In general the fracture energy of a metal post increases as its temperature increases. Hence, if the post exhibits brittle fracture at 150^{o}F (65.6^{o}C) it follows that it would do so at lower temperatures.

Table 53. Mechanical and chemical properties of metal base bending supports.

TEST NO.[c]	POST TYPE AND SIZE	ALLOY TEMPER	ASTM SPEC	NO. OF SPECIMENS	MECHANICAL PROPERTIES			CHEMICAL ANALYSIS														
					YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)	ELONGATION (%)	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Fe	Mg	Zn	Ti	Aℓ	Sn
3,4,5,6, and 9[a]	Billet Steel U-Post 3 lb/ft	Unavail-able	Unavail-able	1	68,000	104,500	13.0	0.38	0.76	0.023	0.028	--	--	--	--	--	--	--	--	--	--	--
7	Square Steel Tube 2½ in. x 2½ in. (10 ga)	Unavail-able	A-446 Grade A	2	41,860 40,480	52,770 52,330	38.0 39.0	0.08	0.34	0.006	0.017	--	--	--	--	0.03	0.7	0.8 -1.2[b]	0.25	0.15	--	--
8	Aluminum Type X 3X	6061-T6	B-221	1	43,500	45,300	10.0	--	0.15	--	--	0.4 -0.8[b]	--	0.04 -0.35[b]	--	0.15 -0.40[b]	--	--	--	--	--	--
11	Standard Steel Pipe 2½ in. Dia	Unavail-able	A-120	2	32,300 32,400	47,400 47,700	38 42	0.042	0.33	0.015	0.009	0.02	0.01	0.02	0.02	--	--	--	--	--	0.002	0.003
13	Rail Steel U-Post 3 lb/ft	Unavail-able	Unavail-able	1	85,300	145,400	9.5	0.78	0.84	0.013	0.022	0.18	0.01	0.02	0.007	0.02	--	--	--	--	--	--
19	Billet Steel U-Post 2 lb/ft	Unavail-able	Unavail-able	2	71,800 67,800	118,500 120,300	12 16	0.50	1.08	0.020	0.020	0.24	0.09	0.11	0.03	--	--	--	--	--	--	--
18	Standard Steel Pipe 2.0 in. Dia	Unavail-able	A-120	2	31,600 30,500	53,100 52,100	37 34	0.11	0.40	0.019	0.012	0.01	0.02	0.02	0.02	--	--	--	--	--	--	--
20	Rail Steel U-Post Two 3 lb/ft Back-to-Back	Unavail-able	Unavail-able	2[d]	81,379 85,517	142,758 149,655	7.5 8.5	0.76 0.77	0.88 0.89	0.017 0.041	0.044 0.032	0.10 0.18	--	--	--	--	--	--	--	--	--	--
20A	Rail Steel U-Post Two 3 lb/ft Back-to-Back	Unavail-able	Unavail-able	2[d]	83,333 80,000	147,826 142,758	11.0 12.0	0.75 0.77	0.87 0.86	0.014 0.030	0.031 0.031	0.13 0.13	--	--	--	--	--	--	--	--	--	--
21	Experimental Billet Steel U-Post Two 3 lb/ft Back-to-Back	Unavail-able	Unavail-able	2[d]	101,000 107,000	159,700 154,400	5.0 5.0	0.70	1.06	0.020	0.030	0.24	0.24	0.23	0.06	0.37	--	--	--	--	--	--

[a]Test 9 was two 3 lb/ft U-posts back-to-back.

[b]Numbers given are chemical composition limits.

[c]These numbers refer to the full-scale crash test numbers - see Appendix A.

[d]One specimen was taken for each of the two posts used in the back-to-back configuration.

Metric Conversions:

1 in. = 2.54 cm
1 lb/ft = 1.489 kg/m
1 psi = 6,895 Pa

For each post evaluated, four Charpy tests were conducted -- two at the ambient temperature and two at 150^{O}F (65.6^{O}C). The thickness of the specimen cross section was that of the post, and the depth of the cross section (at the notch) was held constant at 0.314 $^{+0.001}_{-0.000}$ in. (0.80 $^{+0.00254}_{-0.000}$ cm). Results of the Charpy tests were normalized in terms of fracture energy per square inch of cross section at the notch. The results are presented in Table 54. Note that in tests 20, 20A, and 21, Charpy tests were made on each post of each installation.

Special consideration must be given to the system evaluated in test 7, i.e., the telescoping square steel tube design. Although the signpost bends and fractures on impact, it is not what one normally would classify as a base bending system. By design, this system has a built-in fracture mechanism at the juncture of the signpost with the larger base post. Stress concentrations which occur at this juncture due to the sudden stiffening effect of the base post initiate fracture. Perforations in the signpost at the juncture also contribute to the stress concentrations. Post fracture is therefore a predictable consequence of impact and is not significantly dependent on the material properties of the post. Thus, it would be inappropriate to attempt to relate Charpy impact data for the material of test 7 with full-scale test results.

Figure 165 was prepared to further illustrate the Charpy results in relation to full-scale test results. Fracture energy values shown are averages for the respective posts at 150^{O}F (65.6^{O}C). As shown, posts which fractured during full-scale impacts had fracture energy values below 1600 in.-lb/in.^{2} (2832 cm-N/cm^2) and those that did not had energy values above 2500 in.-lb/in.^{2} (4425 cm-N/cm^2).

It is interesting to note that "elongation", which is a measure of toughness or ductility as determined by a static load test, does not necessarily correlate with toughness under dynamic loads. For example, the posts in tests 9 and 20A had comparable percent

Table 54. Charpy test data.

TEST NO.[a]	POST TYPE AND SIZE	SPECIMEN THICKNESS (in.)	SPECIMEN TEMP. (^{o}F)	CHARPY FRACTURE ENERGY (in.-lb/in.^{2})	DID POST FRACTURE IN CRASH TEST?
4	Billet Steel U-Post 3 lb/ft	0.144 0.144 0.144 0.132	80 80 150 150	1,984 2,249 2,646 2,886	No
7	Square Steel Tube 2½ in. x 2½ in. 10 gauge	0.129 0.129 0.134 0.134	81 81 150 150	8,564 10,040 8,813 9,665	Yes[b]
8	Aluminum Type X 3X	0.093 0.110 0.098 0.100	83 83 150 150	1,024 1,216 1,560 1,529	Yes
9	Billet Steel U-Post Two 3 lb/ft Back-to-Back	0.137 0.137 0.132 0.139	83 83 150 150	2,092 1,813 2,606 2,474	No
11	Standard Steel Pipe 2½ in. Dia	0.158 0.158 0.158 0.158	81 81 150 150	10,401 7,498 11,126 11,610	No
13	Rail Steel U-Post 3 lb/ft	0.146 0.146 0.148 0.154	76 76 150 150	262 393 775 744	Yes
18	Standard Steel Pipe 2 in. Dia	0.118 0.118 0.118 0.118	45 45 150 150	6,154 7,449 7,773 8,421	No

[a]Full-scale test number. See Section A-3 for description of tests.

[b]This post system is actually a type of breakaway system. See text for further discussion.

Table 54. Charpy test data (continued).

TEST NO.[a]	POST TYPE AND SIZE	SPECIMEN THICKNESS (in.)	SPECIMEN TEMP. (°F)	CHARPY FRACTURE ENERGY (in.-lb/in.^{2})	DID POST FRACTURE IN CRASH TEST?
19	Billet Steel U-Post Two 2 lb/ft Back Brace	0.103 0.103 0.103 0.103	75 75 150 150	1,670 1,670 2,968 2,968	No
20 Post 1	Rail Steel U-Post Two 3 lb/ft Back-to-Back	0.164 0.152 0.152 0.156	58 58 150 150	233 251 503 490	Yes
20 Post 2	Rail Steel U-Post Two 3 lb/ft Back-to-Back	0.148 0.148 0.152 0.152	58 58 150 150	387 387 754 764	Yes
20A Post 1	Rail Steel U-Post Two 3 lb/ft Back-to-Back	0.150 0.154 0.150 0.152	73 73 150 150	382 496 764 754	Yes
20A Post 2	Rail Steel U-Post Two 3 lb/ft Back-to-Back	0.153 0.155 0.157 0.158	73 73 150 150	124 246 485 723	Yes
21 Post 1	Experimental Billet Steel U-Post Two 3 lb/ft Back-to-Back	0.121 0.123 0.122 0.129	73 73 150 150	474 621 627 593	Yes
21 Post 2	Experimental Billet Steel U-Post Two 3 lb/ft Back-to-Back	0.126 0.119 0.121 0.125	73 73 150 150	454 480 944 610	Yes

Metric Conversions:

1 in. = 2.54 cm
1 lb/ft = 1.489 kg/m
1 in.-lb/in.^{2} = 1.77 cm-N/cm^2
$t^o_F = 1.8t^o_C + 32$

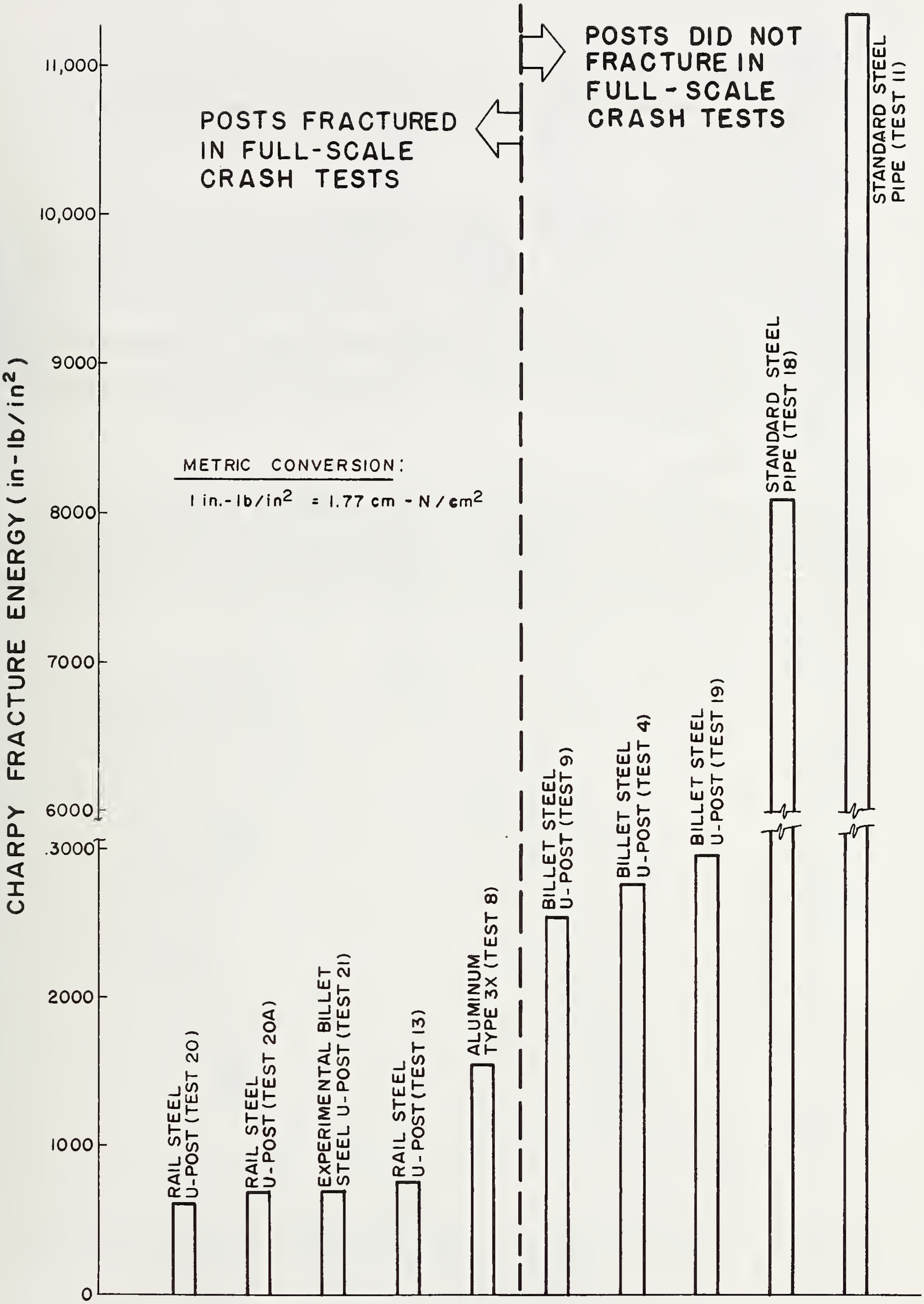


Figure 165. Fracture energy at 150°F (65.6°C) of metal post.

elongations (see Table 53) but exhibited considerably different impact behavior patterns (see Sections A-3-9 and A-3-21 of Appendix A).

B-2. Wood Posts

Southern pine, grade 2, pentachlorophenol treated wood posts were used in tests 1, 2, and 12. In tests 1 and 2, 4 in. x 4 in. (10.2 cm x 10.2 cm) full dimension posts were used while in test 12 a 4 in. x 6 in. (10.2 cm x 15.2 cm) nominal dimension post was used. Simple-beam static load tests were conducted on these posts, and the results are presented in Figures 166 and 167.

B-3. Sign Panels

All sign panels were aluminum sheet, 0.100 in. (0.254 cm) thick, conforming with the requirements of ASTM Specification B209 Alloy 6061-T6 or 5052-H38. Each was coated in accordance with ASTM Specification B449 Class 2.

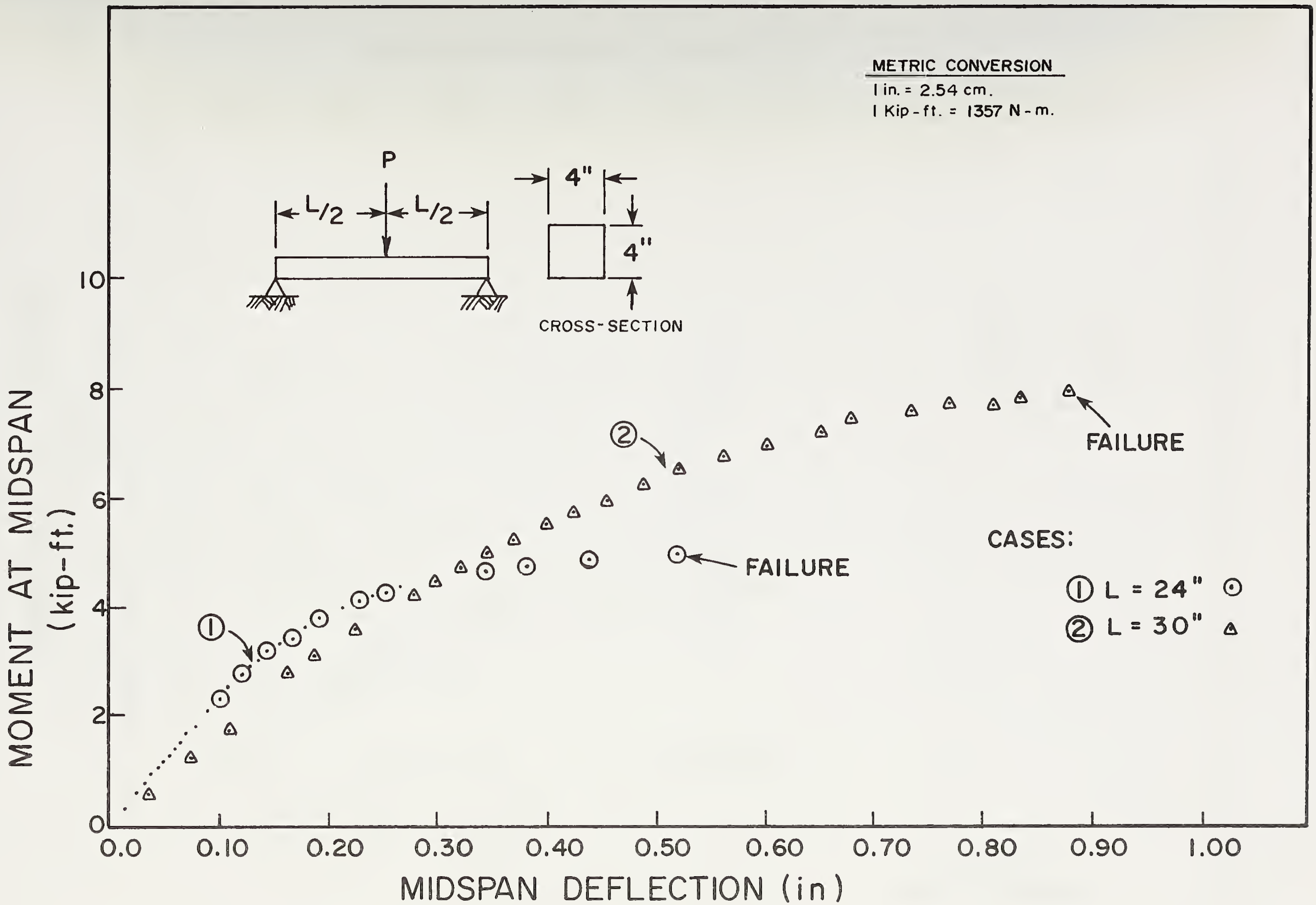


Figure 166. Moment vs. deflection, wood post used in tests 1 and 2.

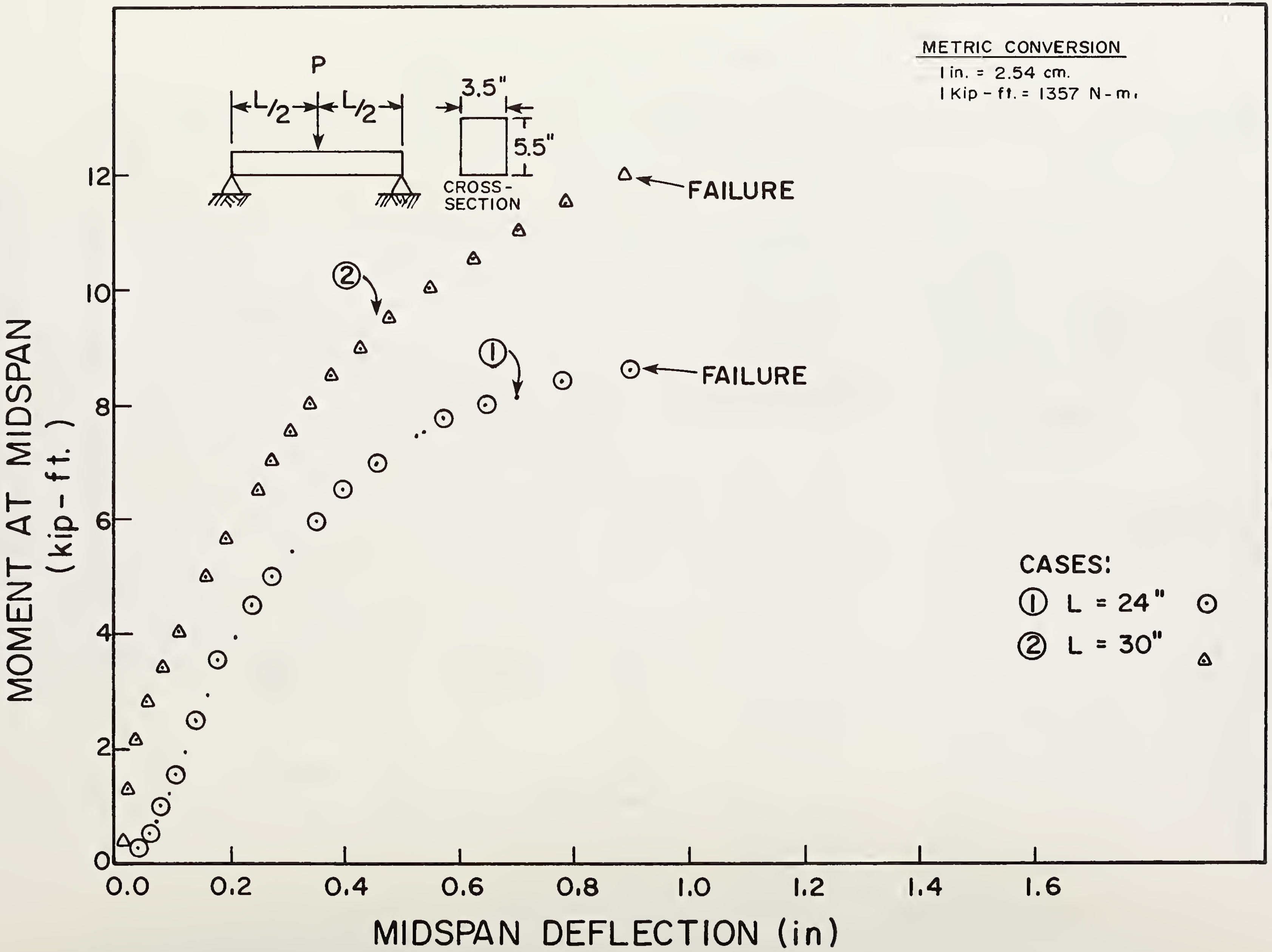


Figure 167. Moment vs. deflection, wood post used in test 12.

APPENDIX C. SOIL PROPERTIES AT TEST SITE

C. SOIL PROPERTIES AT TEST SITE

Two criteria are recommended for soil used to embed crash test articles (3). These include the plasticity index and particle size distribution. The soil used for this series of tests was evaluated, and the findings are reported here.

The recommended maximum plastic index is 5%. The embedment soil fell below this, with a plastic index of 3%. Suggested limits of particle size distribution are shown in Figure 168. The distribution of sizes in this soil is also indicated on the figure.

In addition to these procedures, the relationship of soil density and moisture content was investigated using AASHTO T99-70, Method C. The maximum soil density is 142 lb/ft^3 (2272 kg/m^3) at a moisture content of 7.8%. The moisture density curve can be seen in Figure 169. The soil can be seen in the photos of Figure 6, Appendix A.

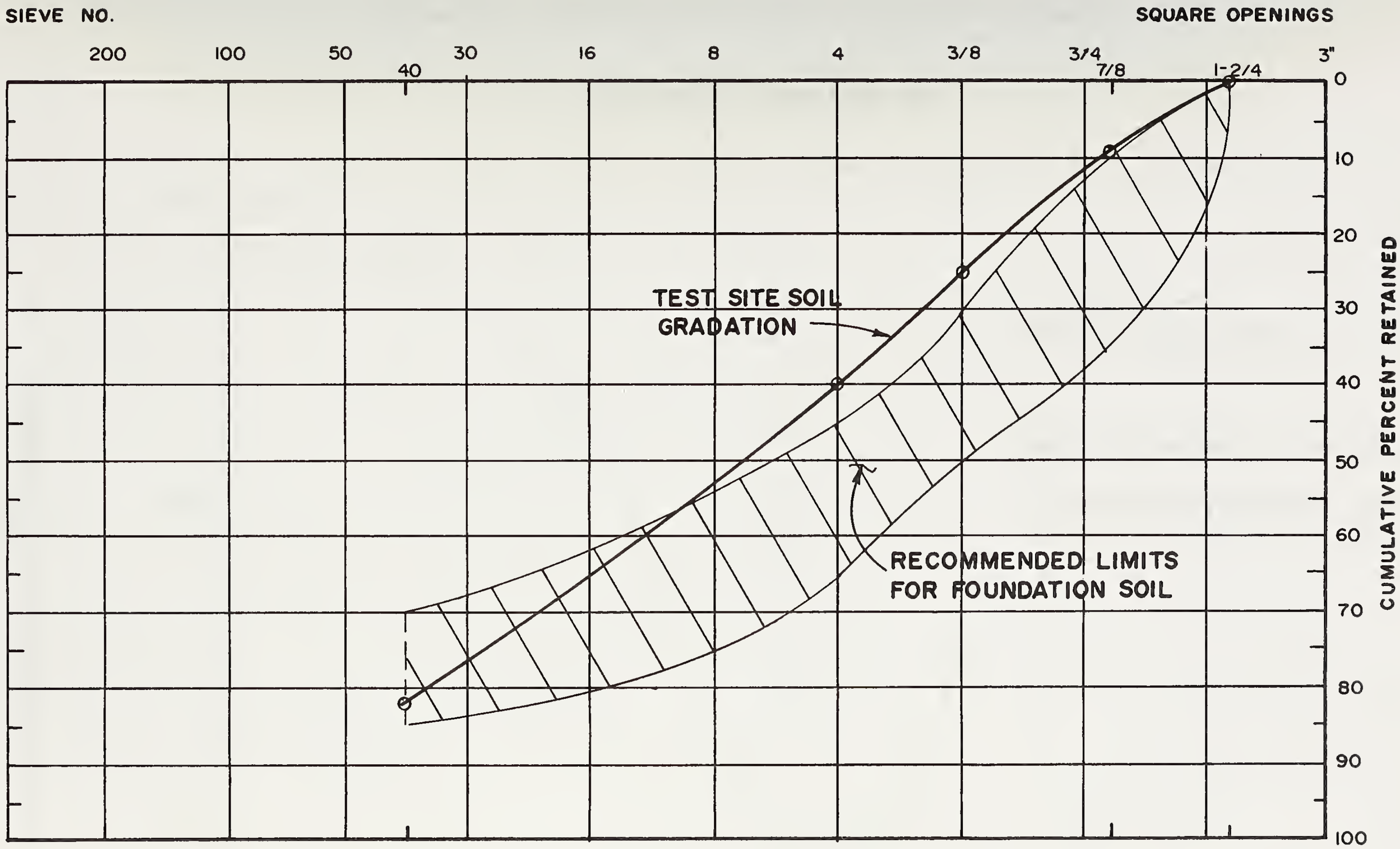


Figure 168. Aggregate gradation, test site embedment soil.

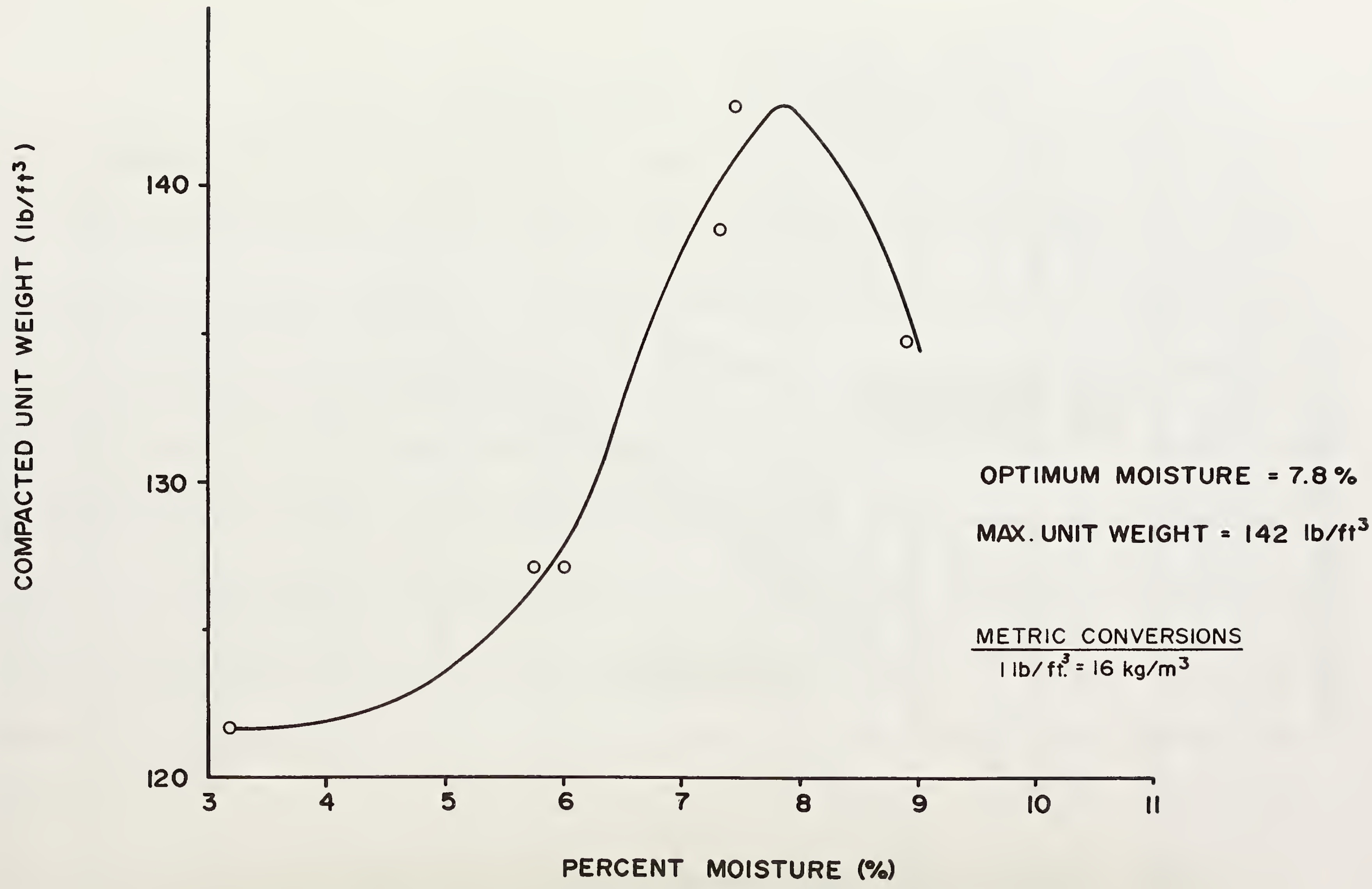


Figure 169. Compacted unit weight vs. moisture content.

APPENDIX D. DATA ACQUISITION SYSTEMS

D. DATA ACQUISITION SYSTEMS

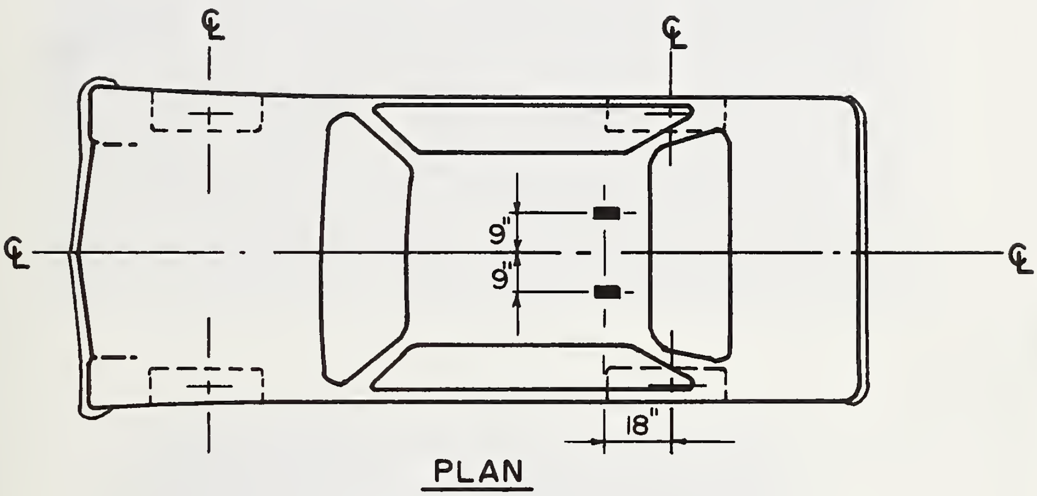
D-1. Deceleration Measurements

Vehicle deceleration measurements were made by means of two longitudinally oriented strain gage linear accelerometers attached to the frame members. Lateral position of each accelerometer was as shown in Figure 170, and the vertical position was approximately 12 in. (30.5 cm) above ground. These accelerometers incorporate a balanced, fully active strain gage bridge which features rugged construction, low response to transverse accelerations and high overload capacity. The particular units used had a measurement range of ±50 g's with a bandwidth of 0 to 250 HZ. The nonlinearity and hysteresis is less than ±1% full scale with infinite resolution.

The accelerometers were physically calibrated by means of a Genisco 1074 precision centrifuge at various input levels. These calibration values were used to establish an 'R' cal value which was transmitted just prior to a test as required in final data reduction. Signals from the accelerometers were transmitted via a telemetry system to the base station for recording on analog tape.

D-2. High-Speed Cine

Three high-speed, ground mounted cameras were used to record the impact behavior of the test article and the vehicle. A fourth movie camera was used for documentary purposes, such as pre and postimpact scenes. Details of these cameras are given in Figure 171 and Table 55. Photos of the high-speed cameras are given in Figure 172.



NOTE: SEE FIGURE A-2 FOR DIMENSIONS OF TEST VEHICLE.

Figure 170. Accelerometer positions.

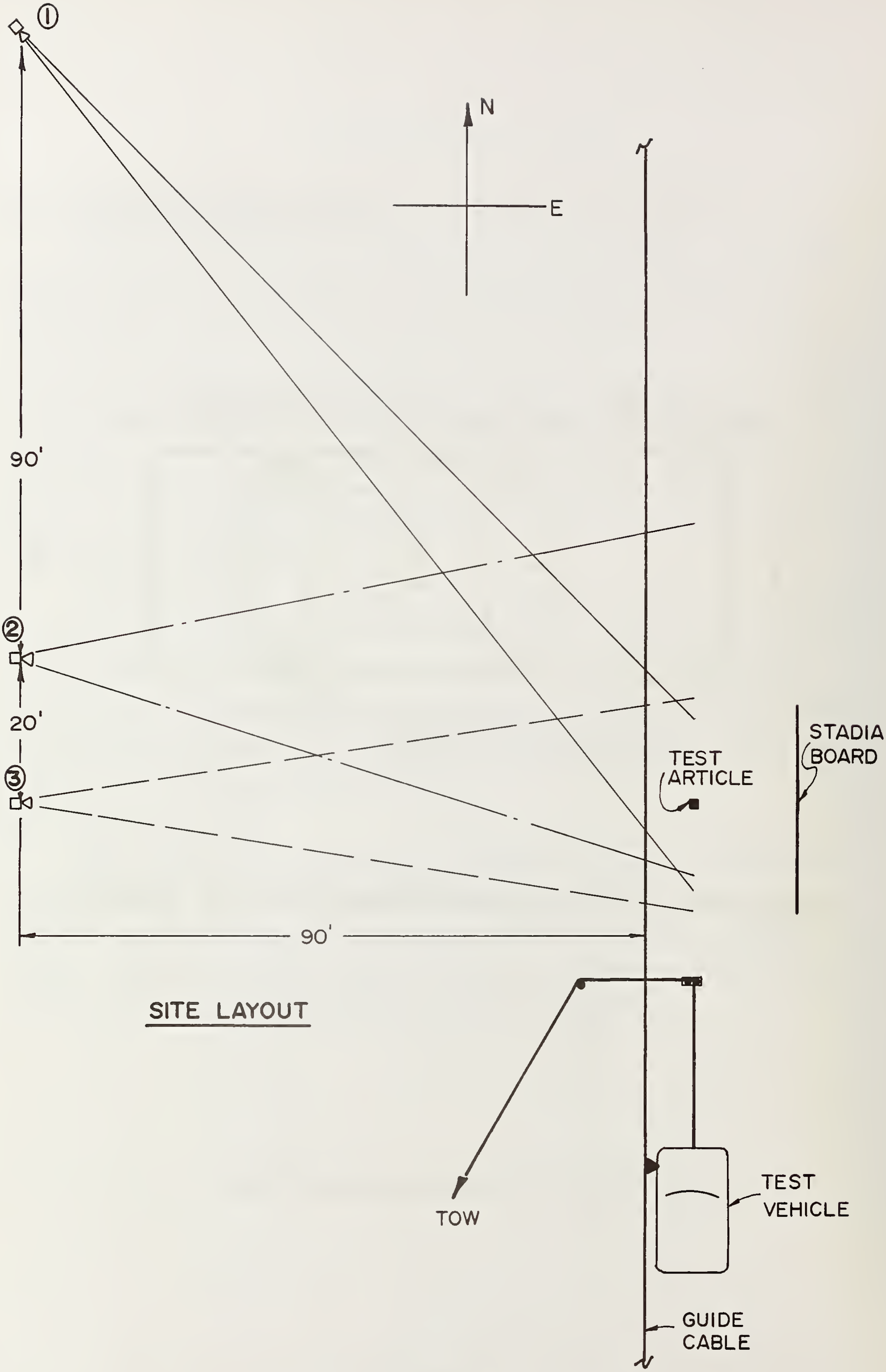
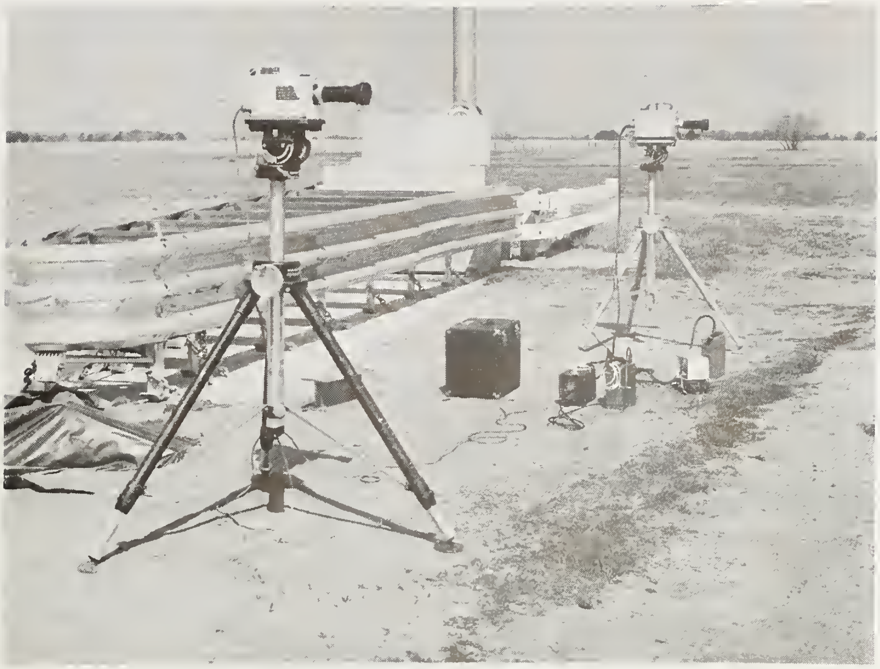
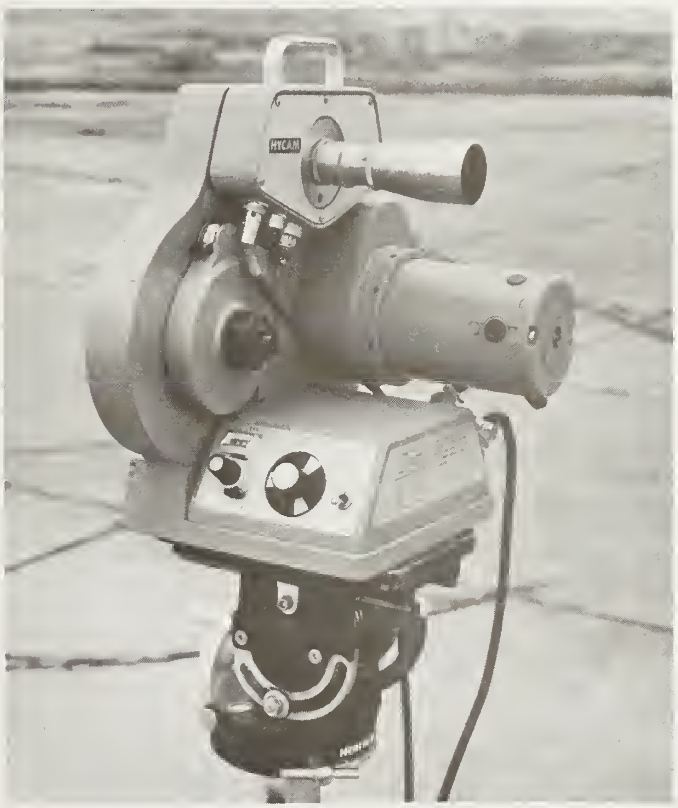


Figure 171. Camera positions.



(a) REDLAKES LOCAM AND PHOTOSONICS



(b) REDLAKES HYCAM

Figure 172. High-speed cameras.

Table 55. Camera details.

CAMERA NO.[a]	TYPE	TYPICAL SPEED (Frames/sec)	BOUNDARIES OF SCENE	LENS
1	Redlakes Hycam	1000	12 ft before and after impact	74 mm Wollensak
2	Redlakes Locam	500	10 ft before and 40 ft after impact	12-120 mm Zoom Angeneaux
3	Photosonics 1P	500	15 ft before and after impact	12-120 mm Zoom Angeneaux
4	Arriflex-M	24	Documentary	17-70 mm Zoom Angeneaux

[a]See Figure 171.

APPENDIX E. REFERENCES

E. REFERENCES

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☆U.S. GOVERNMENT PRINTING OFFICE: 1980-311-586/102

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

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

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