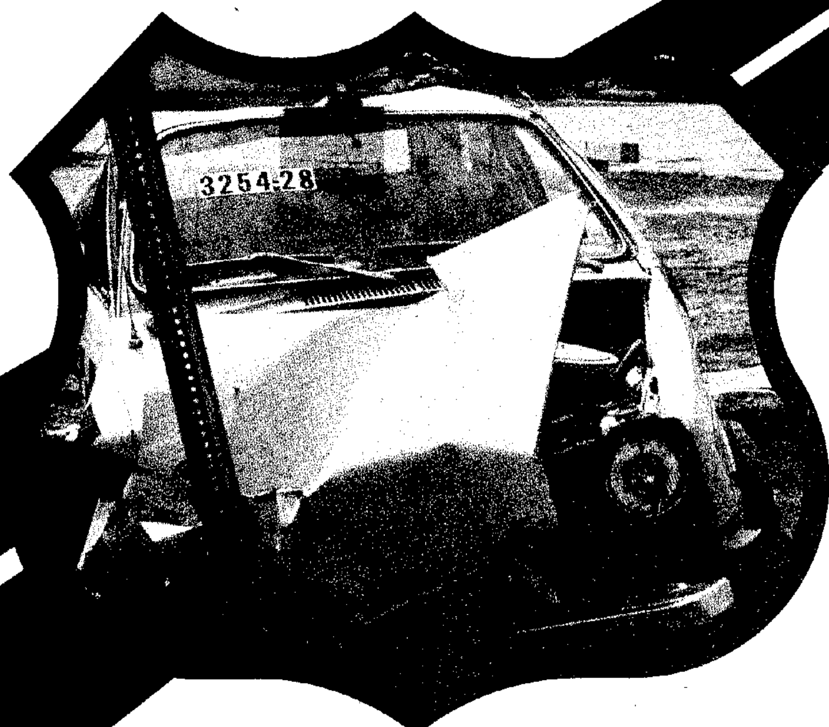
Report No. FHWA/RD-80/503

CRASH TESTS OF SINGLE POST SIGN INSTALLATIONS USING SUBCOMPACT AUTOMOBILES

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 the evaluation of the crashworthiness of widely used support systems and promising new systems.

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 Tests of Small Highway Sign Supports	FHWA/RD-80/502
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
Office of Development

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

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FHWA/RD-80/503		

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CRASH TESTS OF SINGLE POST SIGN INSTALLATIONS USING SUBCOMPACT AUTOMOBILES	5. Report Date: May 1980 6. Performing Organization Code:
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9. Performing Organization Name and Address: Texas Transportation Institute, Texas A&M University, College Station, Texas 77843	10. Work Unit No.: 31Z914 11. Contract or Grant No.: DOT-FH-11-8821
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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

Three full-scale crash tests were conducted to evaluate impact behavior of a subcompact vehicle following impact with widely used signpost designs. Each test vehicle weighed 1940 lb (863 kg) and impact speed was approximately 60 mph (96.5 km/h) in each test. Two tests involved impact with a 3 lb/ft (4.5 kg/m) steel U-post and the other test involved 3 lb/ft (4.5 kg/m) steel U-posts bolted together to form a 6 lb/ft (8.9 kg/m) back-to-back section.

Impact with the 3 lb/ft post in a dry soil resulted in a vehicle change in velocity above the limiting value. Impact with the same post in a wet soil resulted in an acceptable vehicle velocity change since the post was pulled out of the ground. Impact with the 6 lb/ft post resulted in a vehicle change in velocity that greatly exceeded the limiting value. After impact the vehicle rolled over and was a total loss.

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

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Grateful acknowledgment is extended to the technical support personnel of the Texas Transportation Institute who assisted in the preparation, execution, and analysis of the crash tests. Thanks are also extended to Sylvia Velasco for typing the report and Michael Byrd for drafting the figures.

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 September 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 crash test evaluation of rural mailboxes, crash test evaluation of selected small sign supports using subcompact automobiles, and static load tests of a signpost in soil. Results of this work are published in three reports:

6. "Crash Tests of Rural Mailbox Installation", 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.

8. "Pull-out Capacity of a Yielding Signpost as Related to Soil Moisture", Ross, Hayes E., Jr., and Dolf, Timothy J., Research Report 3254-8, Texas A & M Research Foundation, Texas Transportation Institute, Texas A&M University, August, 1979.

A narrated, documentary 16 mm movie presenting a summary of the contract was also developed. Copies of the movie, entitled "Small Sign Supports", can be obtained from the

Office of Development
Implementation Division (HDV-21)
Federal Highway Administration
Washington, D.C. 20590

TABLE OF CONTENTS

I. INTRODUCTION

In a recent crash test program (1), impact behavior of a wide variety of single post sign installations was determined. Each test involved impact by a 2250 lb (1022 kg) automobile, the automobile size recommended for test of sign supports (2). Results of these tests showed that the impact behavior of some of the widely used support systems was marginal in terms of AASHTO safety performance specifications (3).

The trend toward subcompact and mini-sized vehicles continues in the United States. The question then arises -- if a support is marginal for a 2250 lb (1022 kg) automobile, how will it behave when impacted by a vehicle in the 1600-1900 lb (726-863 kg) weight range? To answer this question the Federal Highway Administration elected to conduct the tests reported herein.

II. TEST DETAILS

Three full-scale crash tests were conducted, details of which are summarized in Table 1. Note that each test was conducted at approximately 60 mph (97 km/h). Previous tests had shown that a high-speed impact with a yielding or base-bending signpost was more critical (in terms of change in vehicle velocity) than a low-speed impact.

With the exception of vehicle size, recommended test procedures (2) were followed. Soil at the test site approximated that recommended in the test procedures (2). Properties of the test site soil are given in Appendix C of reference 1.

II-A. Test Article Details

Details of the as-tested configurations can be seen in Figures 1 and 2, and completed installations are shown in Figure 3. Steel U-posts were used in each test. In tests 27 and 29, a single 3.0 lb/ft (4.5 kg/m) post was driven 42 in. (106.7 cm) into the ground. A 24 in. x 30 in. x 0.1 in. (60.7 cm x 76.2 cm x 0.25 cm) aluminum "keep right" sign panel was mounted with two grade 5 3/8 in. x 3 in. (0.95 cm x 7.63 cm) steel bolts with two washers. Test 28 used two 3.0 lb/ft (4.5 kg/m) steel U-posts bolted back-to-back with grade 5, 5/16 in. x 1 in. (0.79 cm x 2.54 cm) steel bolts and two washers. Bolt pattern was as shown in Figure 1. Three grade 5, 3/8 in. x 3 1/2 in. (0.95 cm x 8.89 cm) steel bolts with two washers were used to mount a 36 in. x 48 in. x 0.1 in. (91.4 cm x 122 cm x 0.25 cm) aluminum "keep right sign panel.

Posts in tests 27 and 29 were hot rolled from billet steel, and are known as "rib-back" posts. Posts in test 28 were hot rolled from rail steel. Mechanical, chemical, and Charpy impact data for the post material are given in Appendix A.

II-B. Test Vehicles

Chevrolet Chevettes were used as test vehicles. All were 1976 models. Pictures of one of the test vehicles are shown in Figure 4. Typical dimensions of a 1976 Chevette are shown in Figure 5.

Table 1. Summary of tests.

TEST NO.[a]	VEHICLE DATA		SIGNPOST DATA			PANEL SIZE	INSTALLATION CONFIGURATION[b]
				EMBEDMENT			
	WEIGHT (lb)	IMPACT SPEED (mph)	SIZE (lb/ft)	DEPTH (ft)	METHOD		
27	1940	60.2	3.0	3.5	Driven	2 x 2.5 ft	1
28	1940	65.2	6.0	4.0	Drill & Backfill	3 x 4 ft	2
29	1940	59.9	3.0	3.5	Driven	2 x 2.5 ft	1

[a]Test numbers follow in sequence from previous reports done on this project. Test 27 was first, followed by tests 28 and 29.

[b]See Figure 1 for details.

Metric Conversions

1 ft = 0.305 m
1 mph = 0.447 m/s
1 lb_m = 0.454 kg

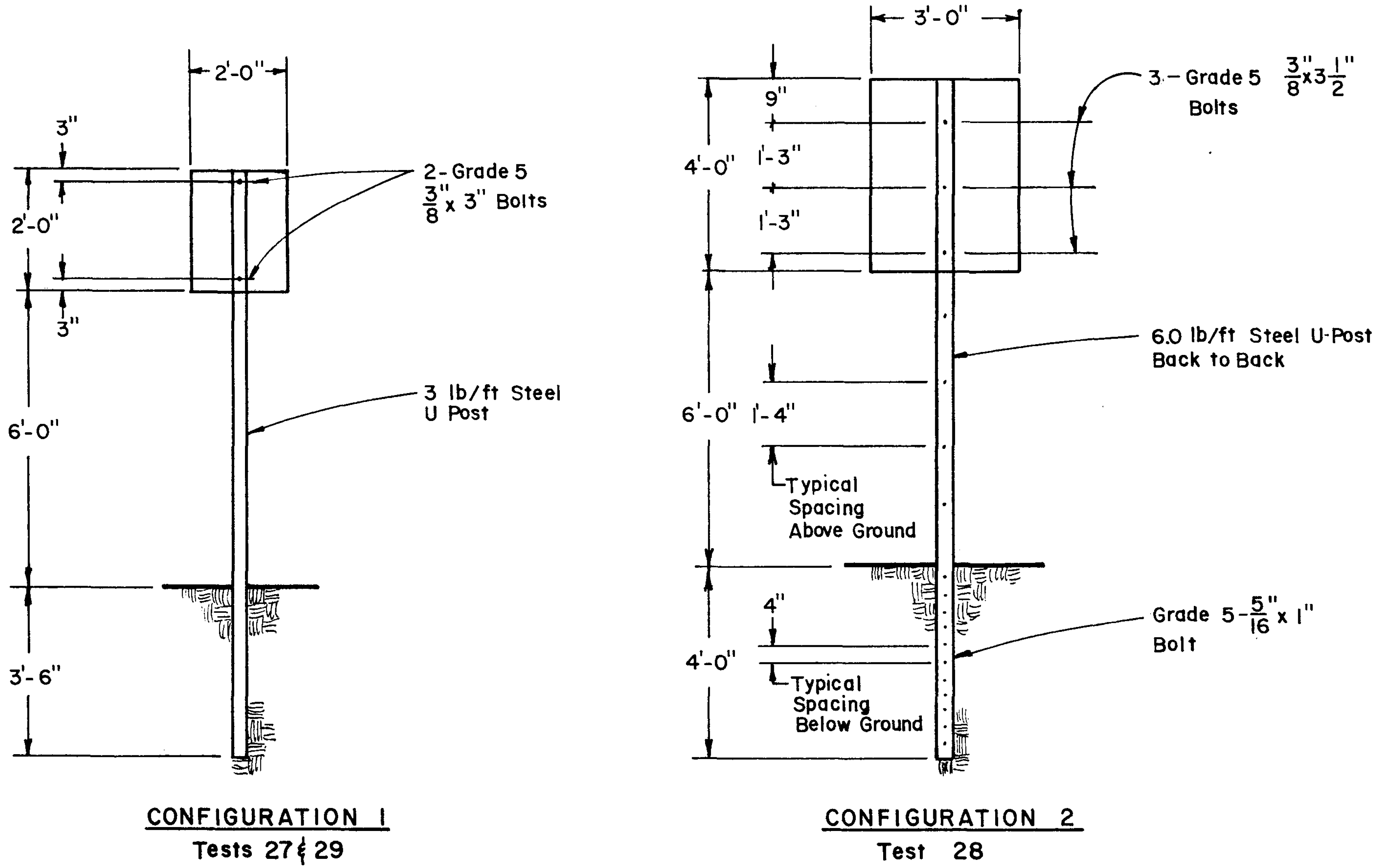
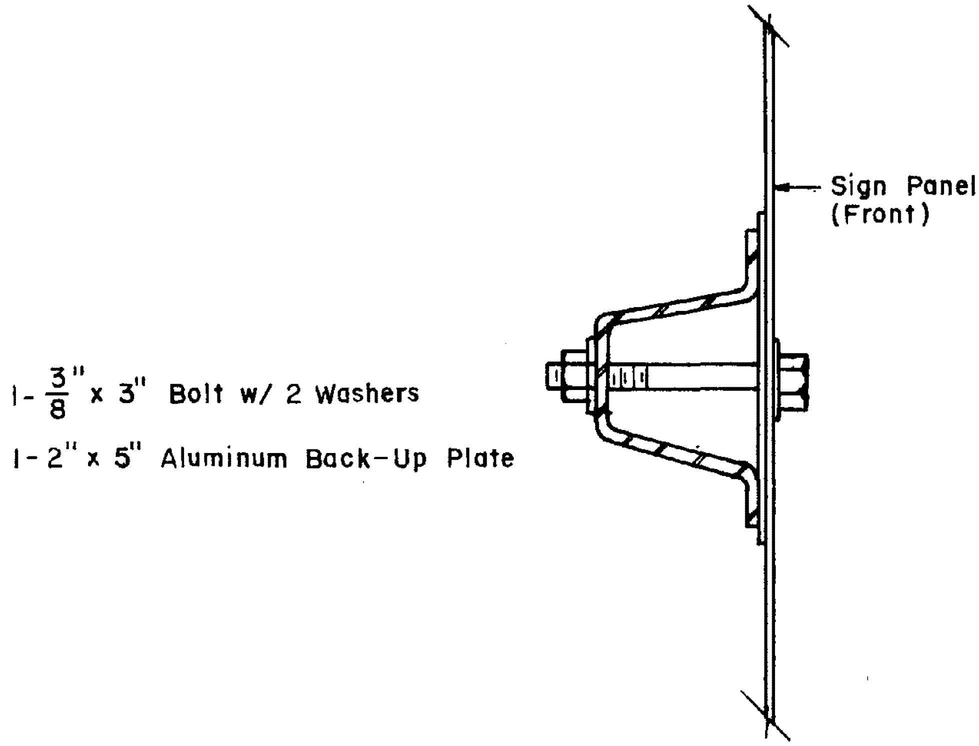
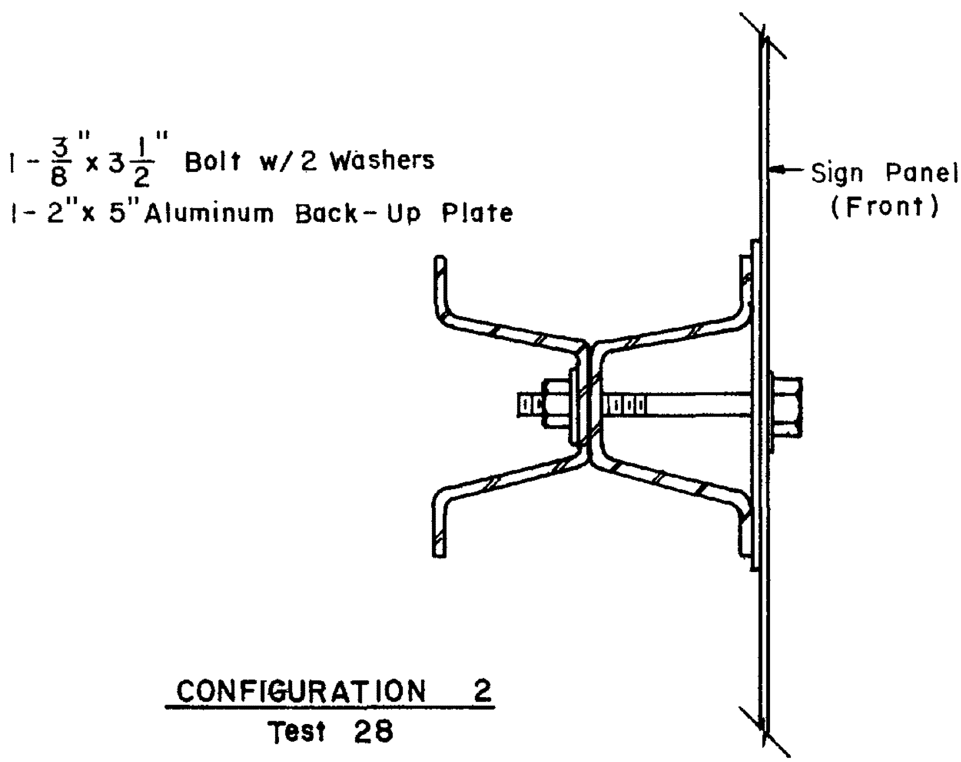


Figure 1. Installation details.



CONFIGURATION 1
Tests 27 & 29



CONFIGURATION 2
Test 28

Figure 2. Post-to-panel connection details.

a) Tests 27 and 29.

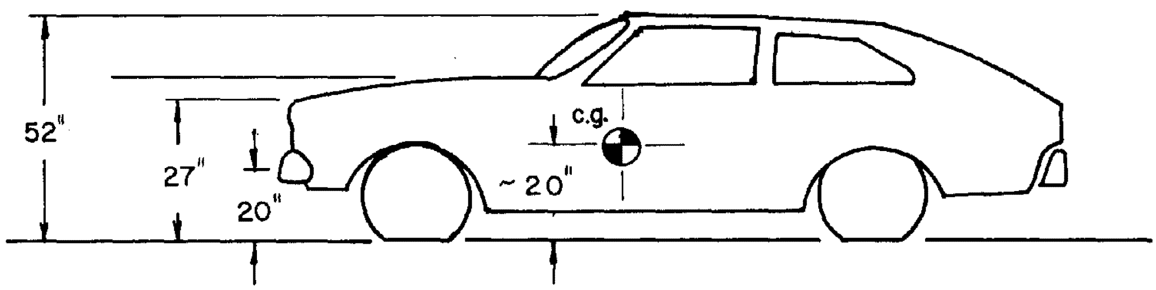
b) Test 28.

Figure 3. Completed installations.

a) Top view

b) Front view

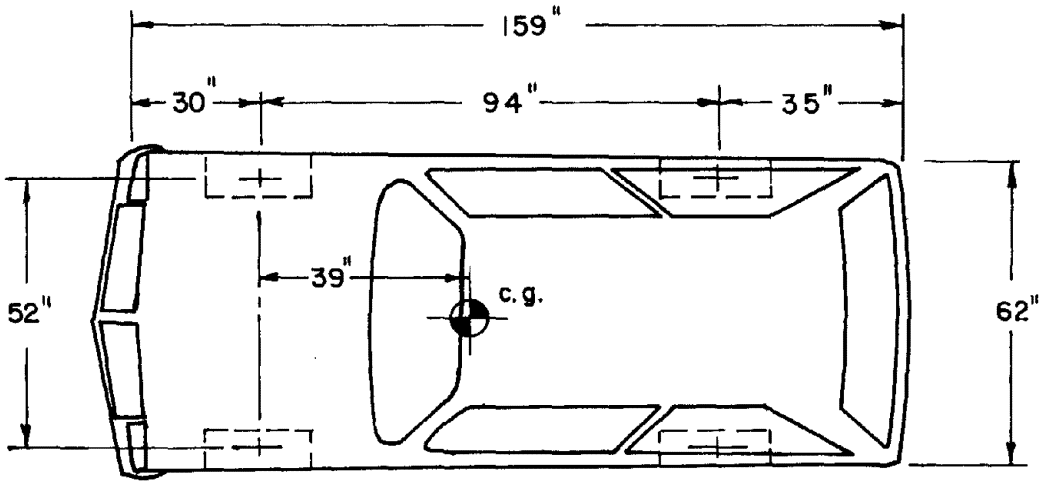
Figure 4. Chevrolet Chevette, 1976 model.



ELEVATION

Metric Conversion:

1 in. = 2.54 cm



PLAN

Figure 5. Typical dimensions of 1976 Chevrolet Chevette.

The vehicle was accelerated to test speed with a reverse tow system and kept on line with the test article by cable guidance. Each test was a head-on impact with the signpost, and the impact point was located 14 in. (35.6 cm) to the right of center in tests 27 and 28 and 14 in. (35.6 cm) to the left of center in test 29.

II-C. Data Acquisition Systems

II-C-1. Electronic Instrumentation

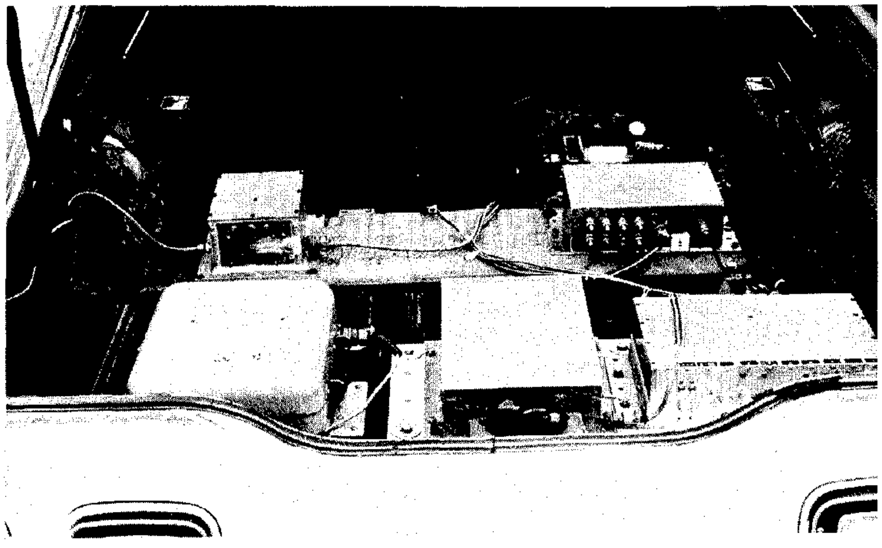
A strain gage accelerometer was placed on both frame members to measure accelerations in the longitudinal direction. The signals from the accelerometers were telemetered to a base receiver station and recorded on magnetic tape for permanent record. The signals were passed through a 100 Hz max flat filter to produce analog traces for analysis. Figure 6 shows the on-board instrumentation.

II-C-2. Photographic Instrumentation

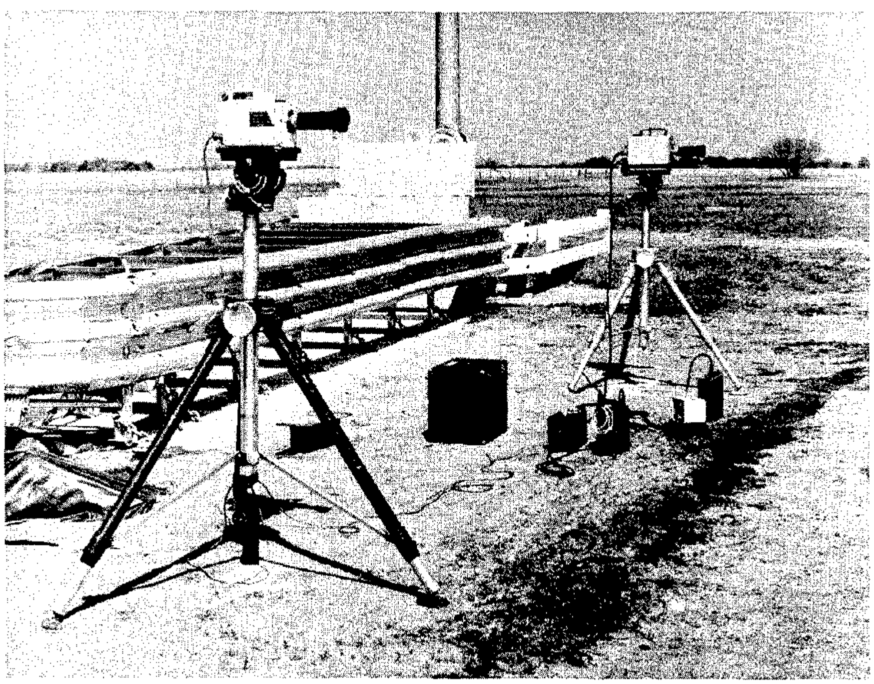
Four cameras were used to record each test; three of these were high-speed cameras.

The first camera was positioned perpendicular to the direction of impact and had a field of view 15 ft (4.6 m) on each side of the signpost. The second camera was also perpendicular to the direction of impact, but had a field of view 10 ft (3.1 m) before impact and 40 ft (12.2 m) past impact. These cameras are shown in Figure 6. A third camera was positioned 45 degrees to the rear of the signpost, and was fitted with a long focal lens to take a closeup view. The final camera was used to make a documentary film.

Further details of the data acquisition systems are given in Appendix D, reference 1.



a) Vehicle instrumentation



b) High-speed cameras

Figure 6. Data acquisition systems.

III. EVALUATION CRITERIA AND TEST RESULTS

III-A. AASHTO Performance Specifications (3)

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.

Stated another way, the AASHTO change-in-momentum limits imply that the change in velocity of a 2250 lb (1020 kg) vehicle striking a signpost(s) should not exceed 10.7 mph (17.3 km/h), but desirably does not exceed 7.3 mph (11.8 km/h). When compared with change in momentum, change in velocity is more meaningful and indicative of the potential for injury of an impact. Change in velocity limits are independent of vehicle size, whereas change in momentum limits are directly related to vehicle mass. Applying the above change-in-velocity limits means that the change in momentum of a 1900 lb (863 kg) vehicle should not exceed 929 lb-sec (4132 N-sec), but desirably should not exceed 633 lb-sec (2817 N-sec). For further comments on AASHTO specifications the reader should refer to Section V-A of Reference 1.

III-B. Vehicle Damage

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) (4) and the Collision

Deformation Classification recommended by the Society of Automotive Engineers (SAE) (5).

III-C. Test Results

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 filtered accelerometer signals. 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. Guidelines for determining this duration are given in Reference 2.

III-C-1. Test No. 27

A summary of test 27 is given in Table 2. Figure 7 shows the sequential photos taken from high-speed filming of the impact, and the corresponding time displacement event summary is given in Table 3. Upon impact, the post first wrapped around the bumper and the sign panel, then struck the hood. As the interaction continued, the signpost was pulled from the ground and traveled with the vehicle for 100 ft (30.5 m). Pull-out of the post was attributed to high moisture content in the soil. The test soil had been saturated by rain the day before the test. Impact with the same size post with a 2250 lb (1022 kg) vehicle at 60 mph (96.5 km/h) and dry soil conditions did not pull the post out of the ground (see Section A-3-4 of Reference 1). Test 29 was a repeat of test 27 with dry soil, and as discussed later the post did not pull out of the ground. Subsequent to the tests reported herein, a static load test program was conducted to evaluate effects of soil moisture content

TABLE 2. SUMMARY OF RESULTS, TEST 3254-27

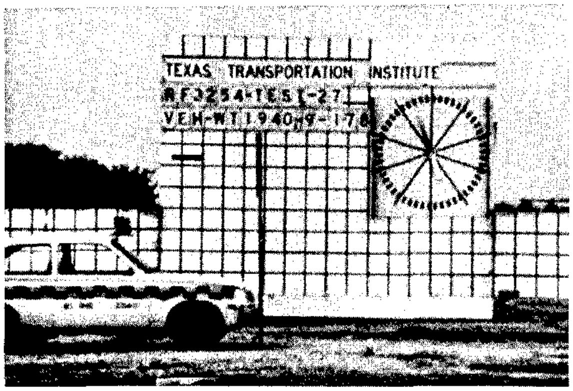
Impact Velocity = 60.2 mph

POST DATA			
Type	Steel U-Post** (Billet Steel)		
Size	3.0 lb/ft		
Embedment Method	Driven		
Embedment Depth (ft)	3.5		
VEHICLE DATA			
Make	Chevrolet		
Model	Chevette		
Year	1976		
Weight (lb)	1940		
Impact Point	15 in. to right of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		610	654
Duration of Event (sec)*		0.161	
Peak Deceleration (G's)		11.33	12.03
Maximum 0.050 Sec Average Deceleration (G's)		3.43	3.92
VEHICLE DAMAGE CLASSIFICATION			
TAD	FR-1		
SAE	12FREN-1		
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



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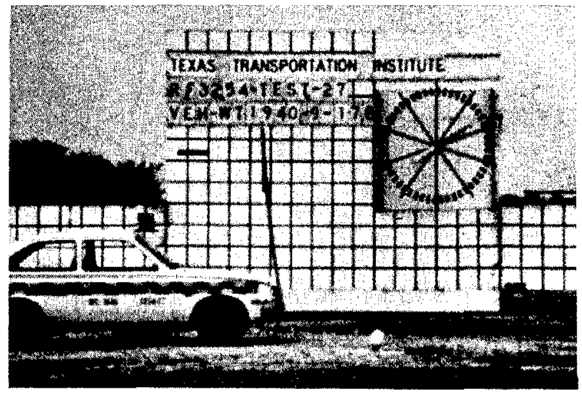

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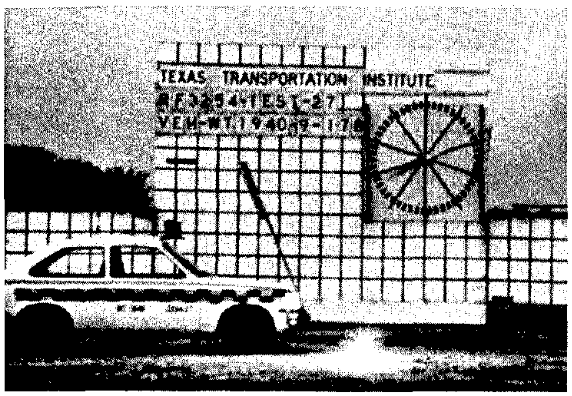

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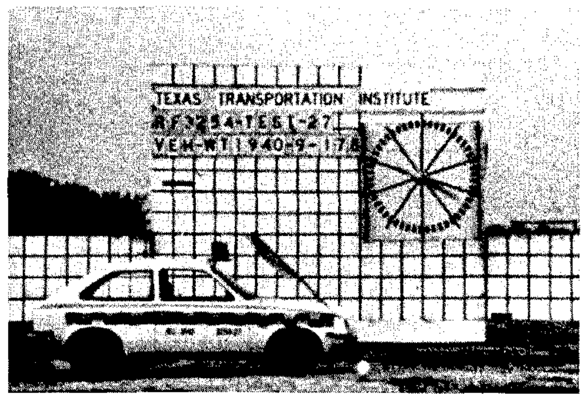

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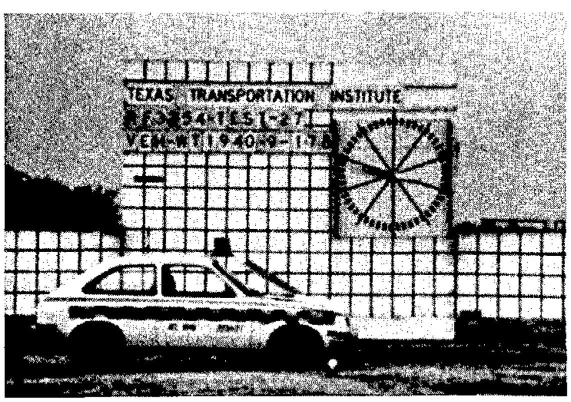

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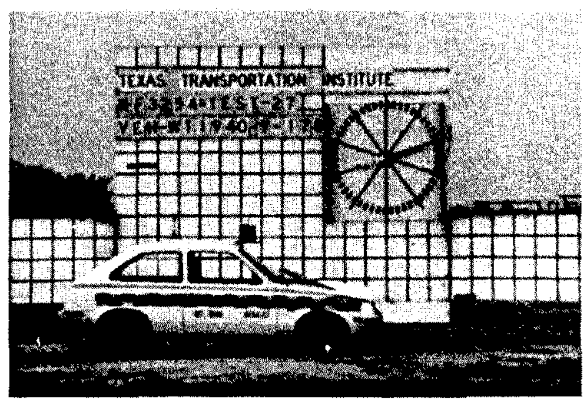

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Figure 7. Sequential photos, test 27.

Table 3. Time displacement event summary for test 27.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.008	0.66	Signpost begins bending
0.026	2.24	Post wrapping around bumper
0.050	4.20	Signpost pulling out of ground
0.066	5.46	Maximum hood deformation
0.081	6.69	Sign panel strikes hood

Metric Conversion:

1 ft = 0.305 m

in the pull-out capacity of the 3.0 lb/ft (4.5 kg/m) steel U-post (6).

Deceleration, change in momentum, and free missile travel versus time data are plotted in Figures 8, 9, and 10. Damage to the installation would only require replacement of the signpost, since the sign panel and mounting hardware were undamaged. The disturbed soil at the point the post pulled out can be seen in Figure 11. Figure 11 also shows the damage to the signpost and panel assembly.

The vehicle sustained minor damage in the test and was operable after impact. Only the hood and right headlight were damaged as shown in Figure 12. The damage was classified according to TAD and SAE scales, and the results are given in Table 2.

III-C-2. Test No. 28

Table 4 summarizes the results of test 28. Sequential photos were taken from high-speed film of the impact, and are shown in Figure 13. Table 5 gives the time displacement event summary. Upon impact, the signpost began to rotate into the vehicle. At the same time, the post forced the bumper down as it wrapped around the hood. This caused the vehicle to spin out and then forced it into a rollover. The vehicle returned to an upright position after rolling. Part of the installation remained in the ground; one U-post was wrapped around the vehicle and part of it broke free of the base.

Figures 14, 15, and 16 show deceleration, change in momentum, and free missile travel versus time data. Damage to the signpost can be seen in Figure 17. (Part of the signpost remained with the vehicle and can be seen in Figure 18.)

The vehicle was extensively damaged due in part to the rollover. The front of the car was crushed approximately 2 ft (0.61 m) and the roof was flattened. The damage can be seen in Figure 18. Table 4 gives the TAD and SAE damage ratings.

III-C-3. Test No. 29

Test 29, which was a repeat of test 27 except with dry soil, is summarized in Table 6. Sequential photos are shown in Figure 19. Table 7 gives a time-displacement event summary. As the vehicle moved

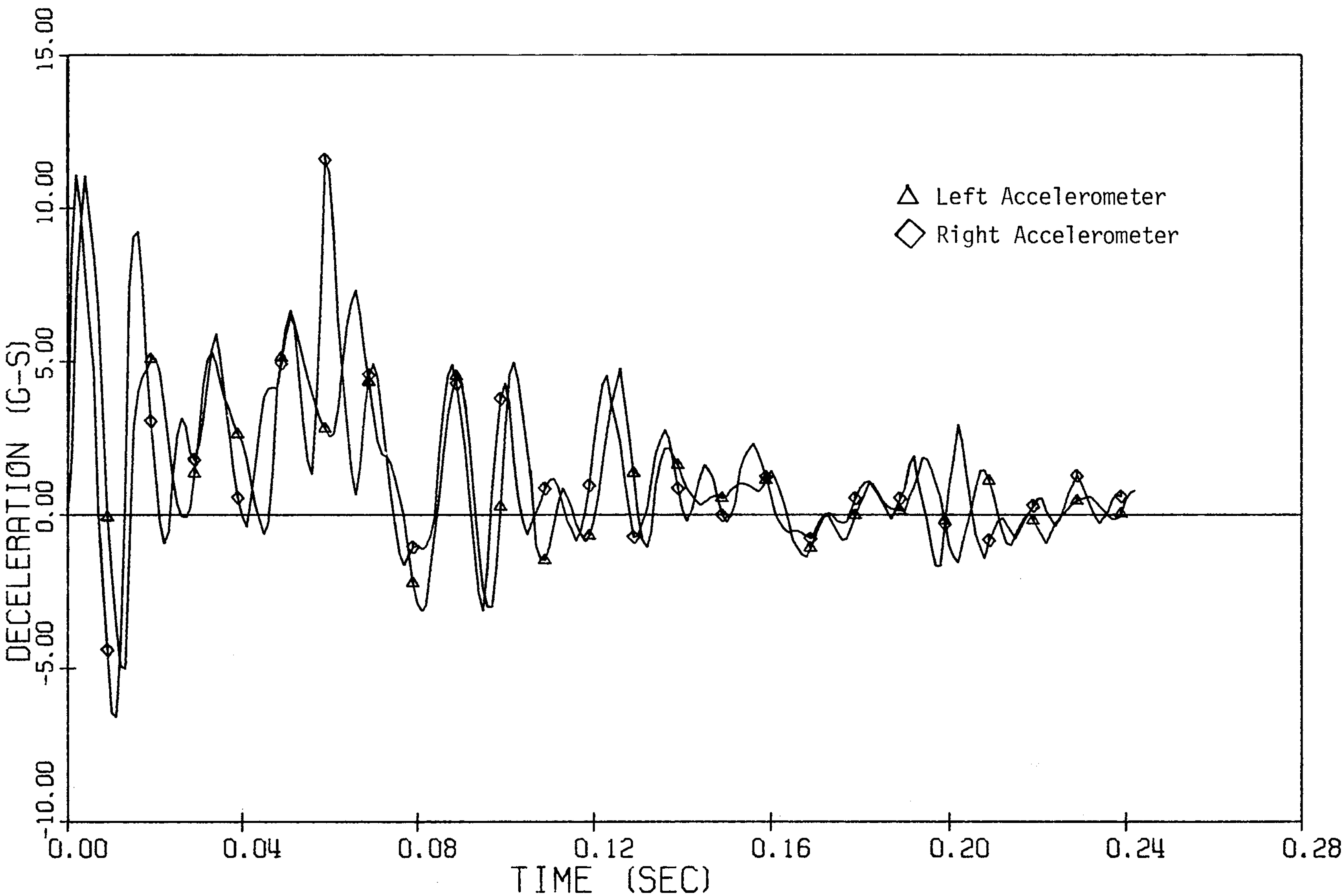


Figure 8. Deceleration versus time, test 27.

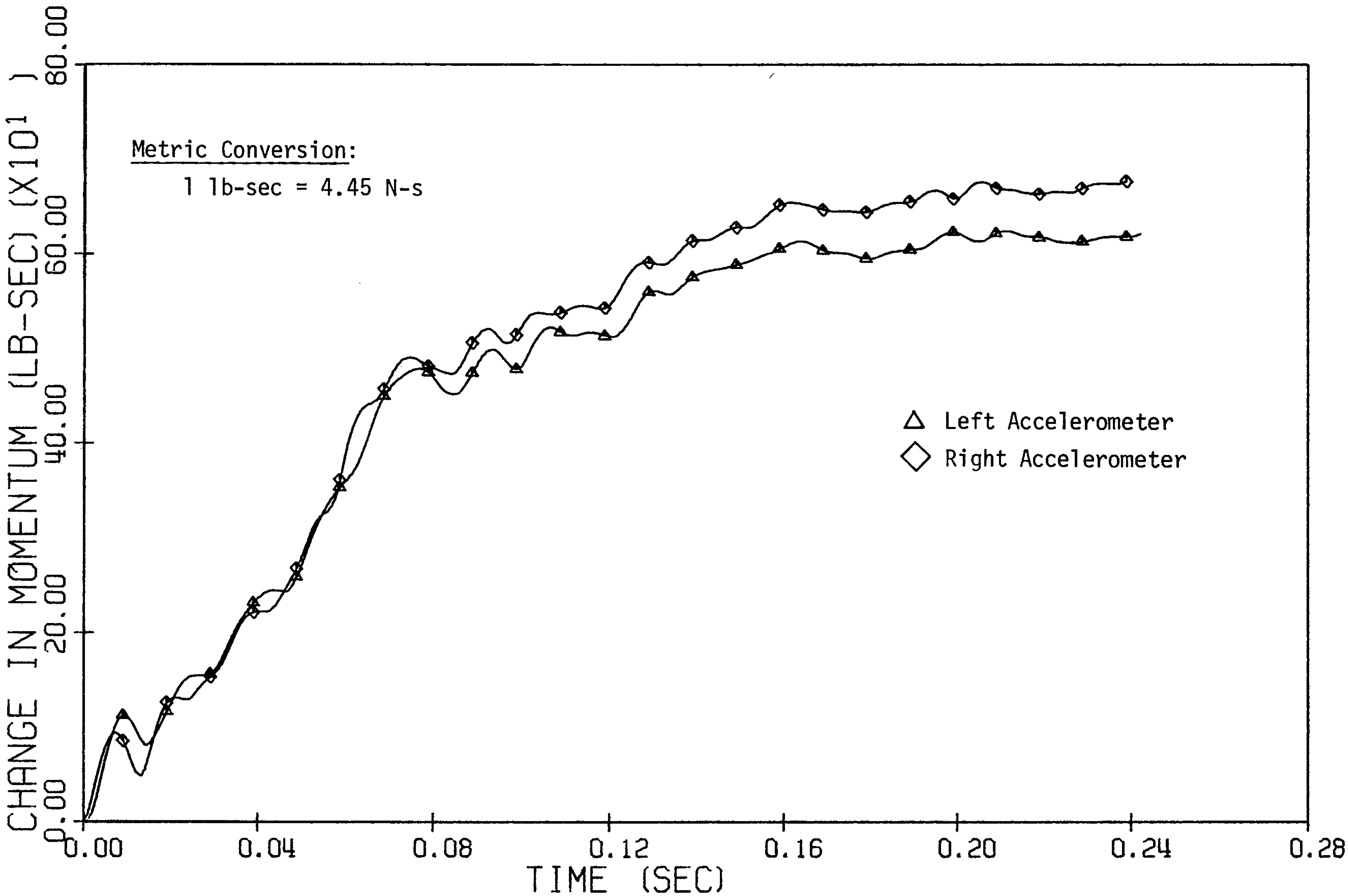


Figure 9. Change in momentum versus time, test 27.

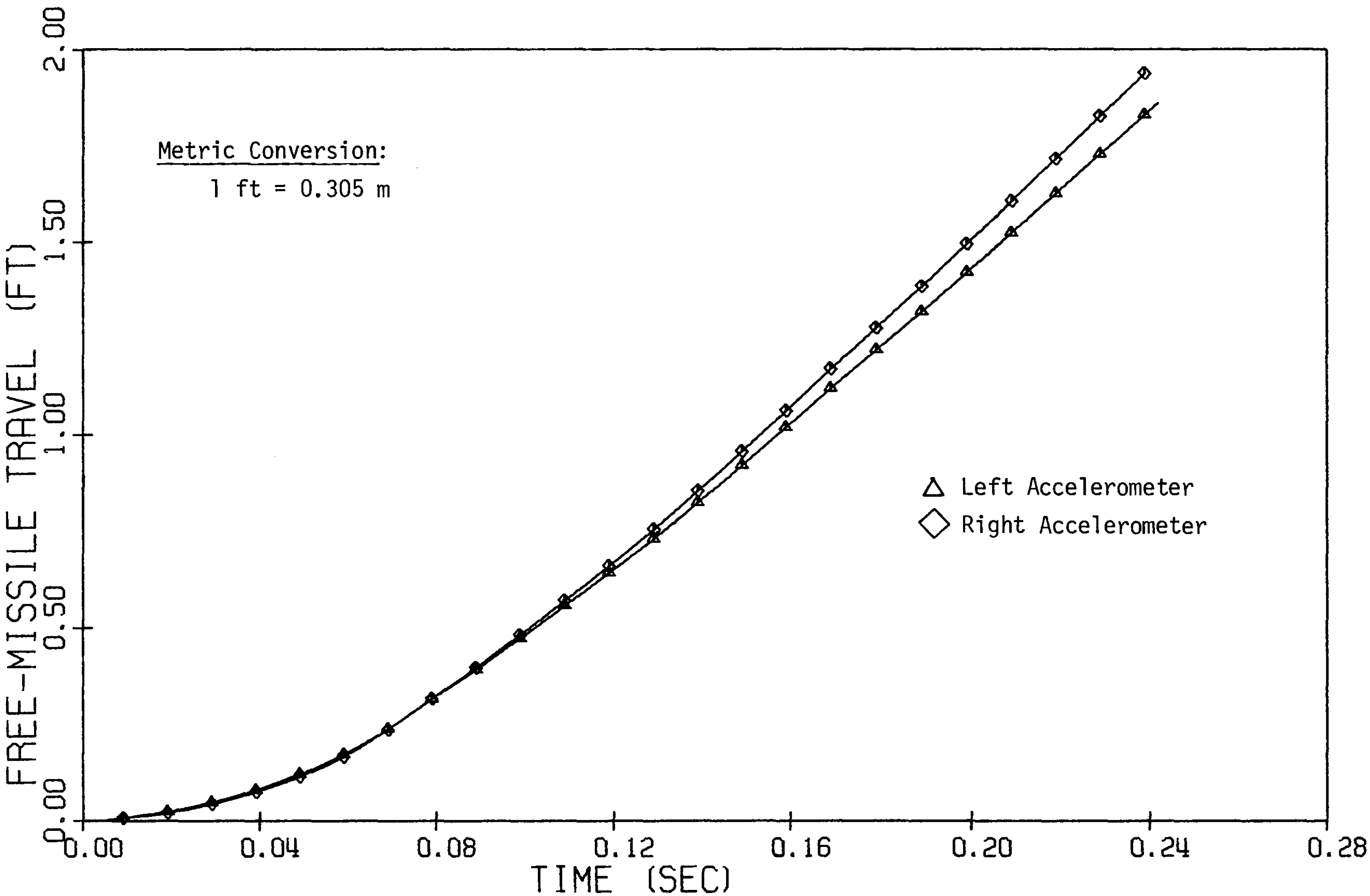
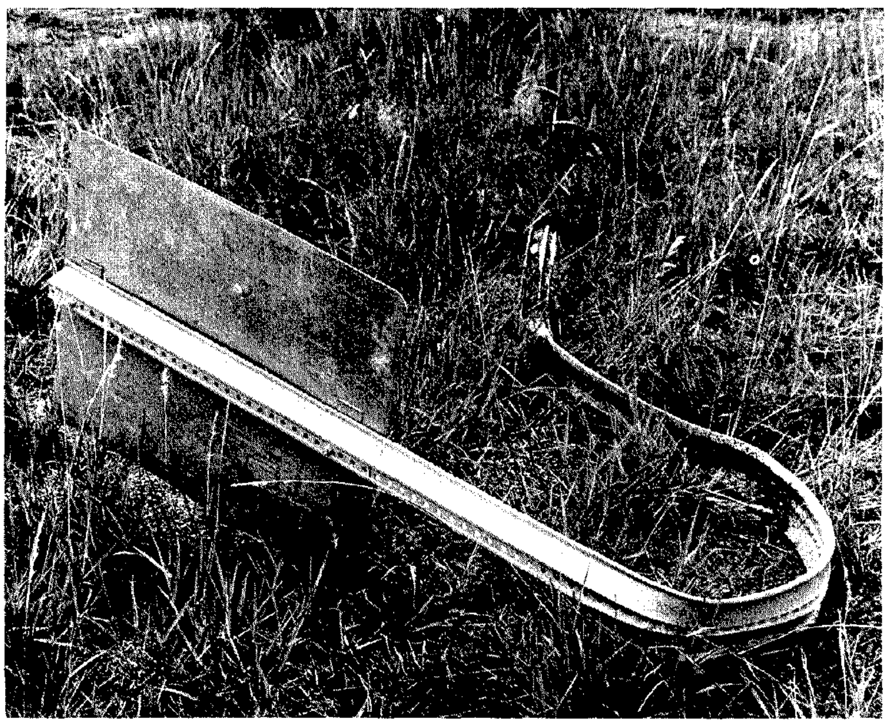


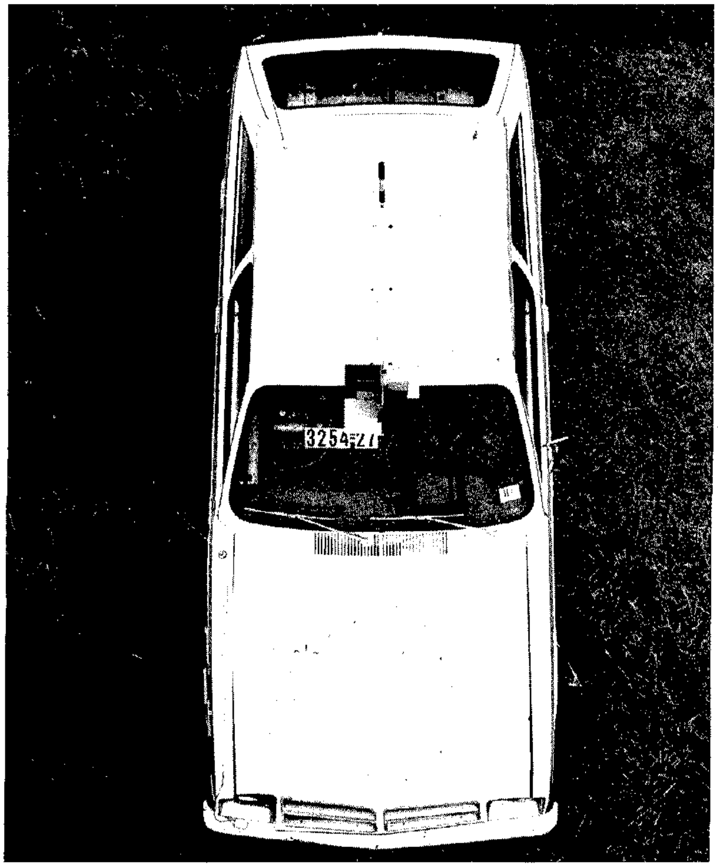
Figure 10. Free missile travel versus time, test 27.

a) Disturbed soil after test 27

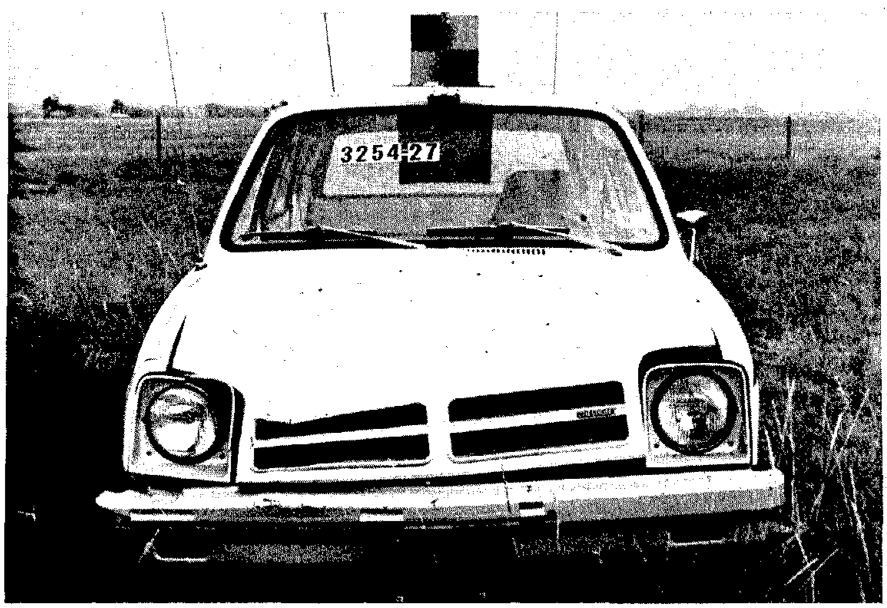


b) Damage to assembly

Figure 11. Installation damage, test 27.



a) Top view



b) Front view

Figure 12. Vehicle damage, test 27.

TABLE 4. SUMMARY OF RESULTS, TEST 3254-28

Impact Velocity = 65.2 mph

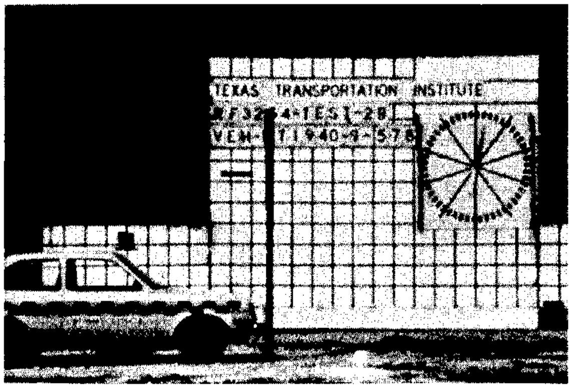
POST DATA		
Type	Steel U-Post**	
Size	6.0 lb/ft Back-to-Back	
Embedment Method	Drill and Backfill	
Embedment Depth (ft)	4.0	
VEHICLE DATA		
Make	Chevrolet	
Model	Chevette	
Year	1976	
Weight (lb)	1940	
Impact Point	15 in. to right of center	
ACCELEROMETER DATA	**Left**	**Right**
Change in Momentum (lb-sec)	2195	2322
Duration of Event (sec)*	0.138	
Peak Deceleration (G's)	19.21	24.16
Maximum 0.050 Sec Average Deceleration (G's)	12.10	13.52
VEHICLE DAMAGE CLASSIFICATION		
TAD	FR-6	
SAE	12FREN-5	
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

*Free Missile Travel Time

**Franklin Steel post (rail steel)



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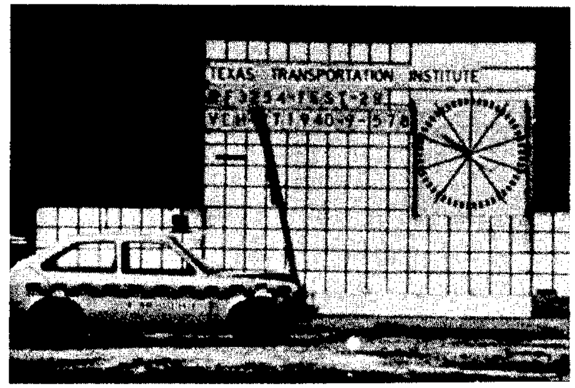

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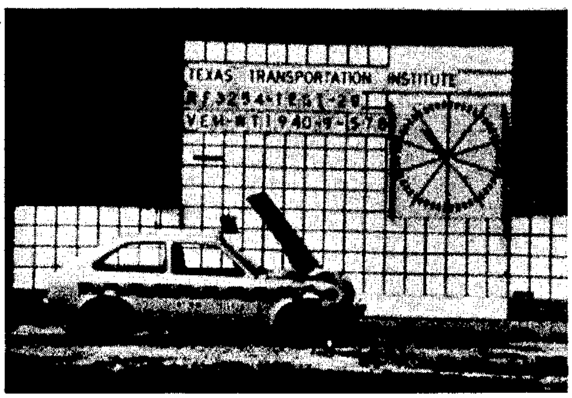

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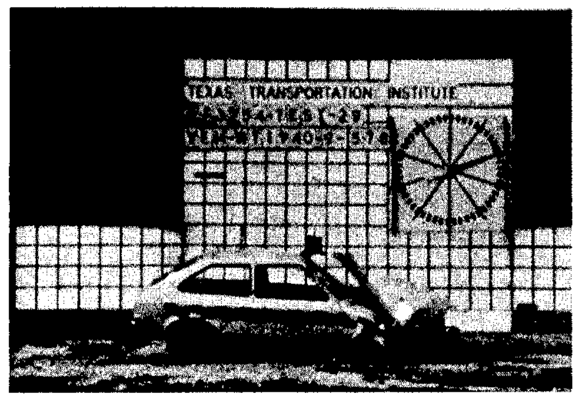

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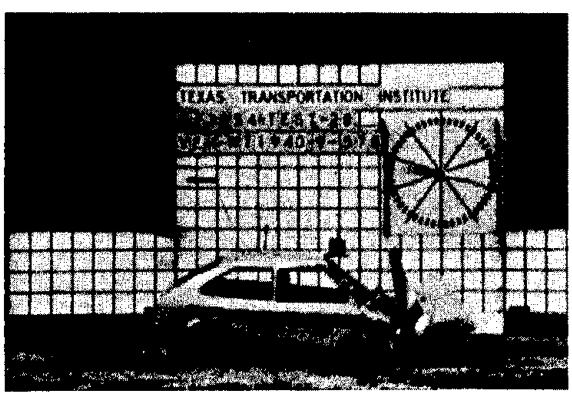

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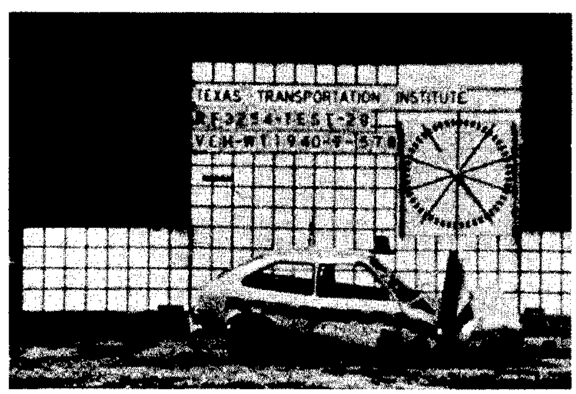


0.155 sec

Figure 13. Sequential photos, test 28.

Table 5. Time displacement event summary for test 28.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.029	2.41	Fender strikes wheel
0.065	5.27	One signpost breaks away
0.112	8.62	Front fender hits ground
0.133	9.79	Free missile travel time
0.155	10.86	Both signposts broken

Metric Conversion:

1 ft = 0.305 m

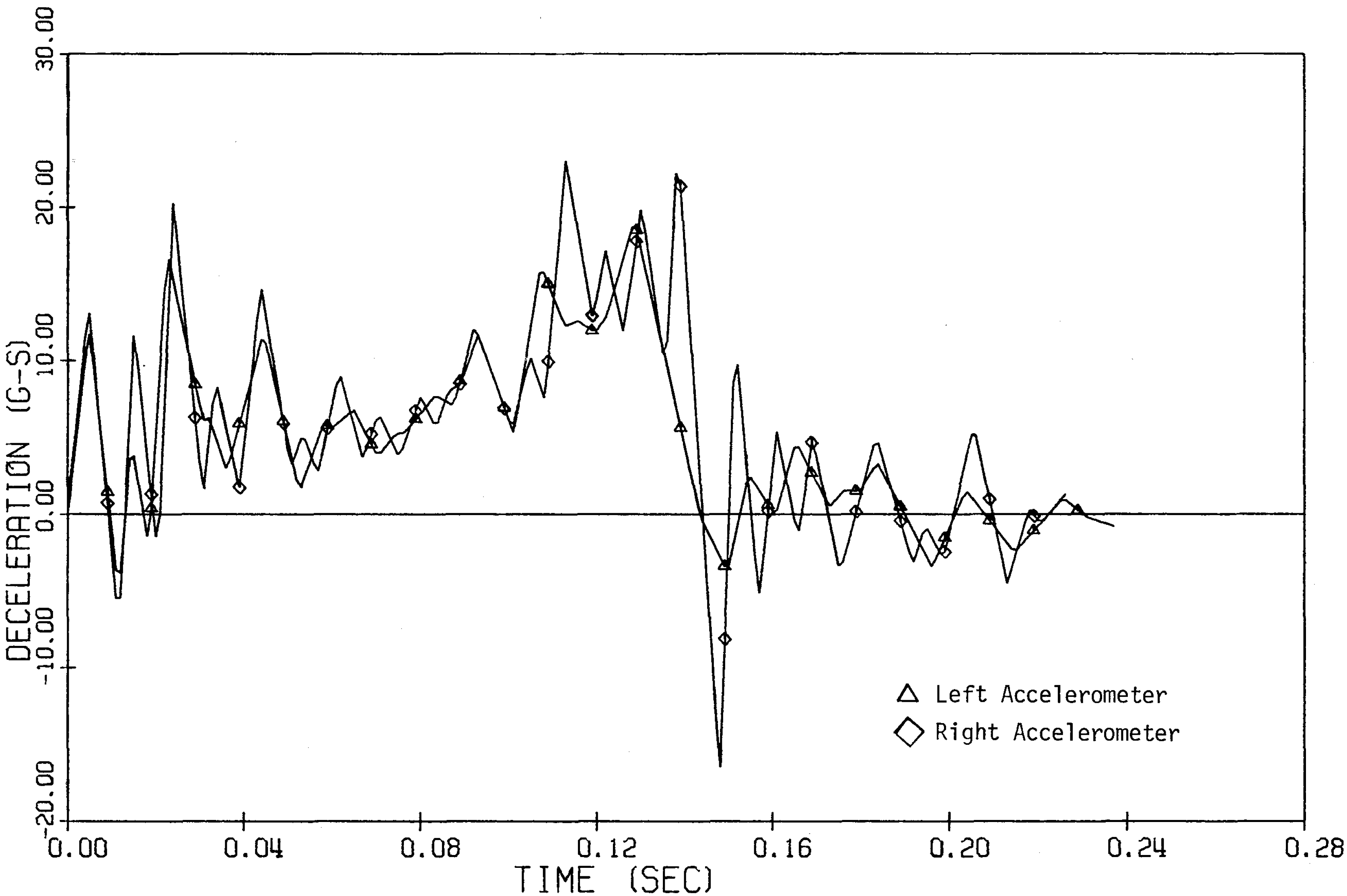


Figure 14. Deceleration versus time, test 28.

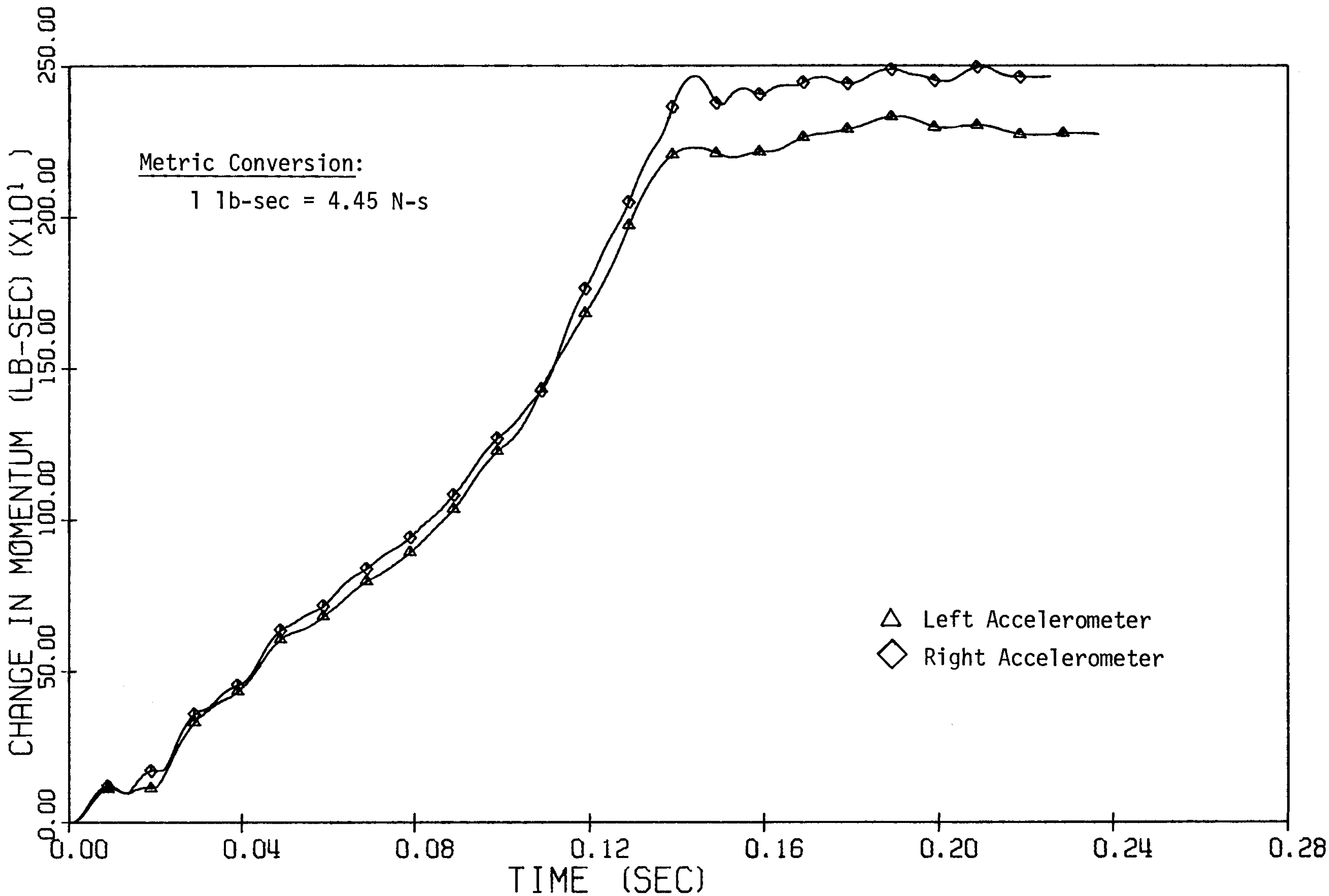


Figure 15. Change in momentum versus time, test 28.

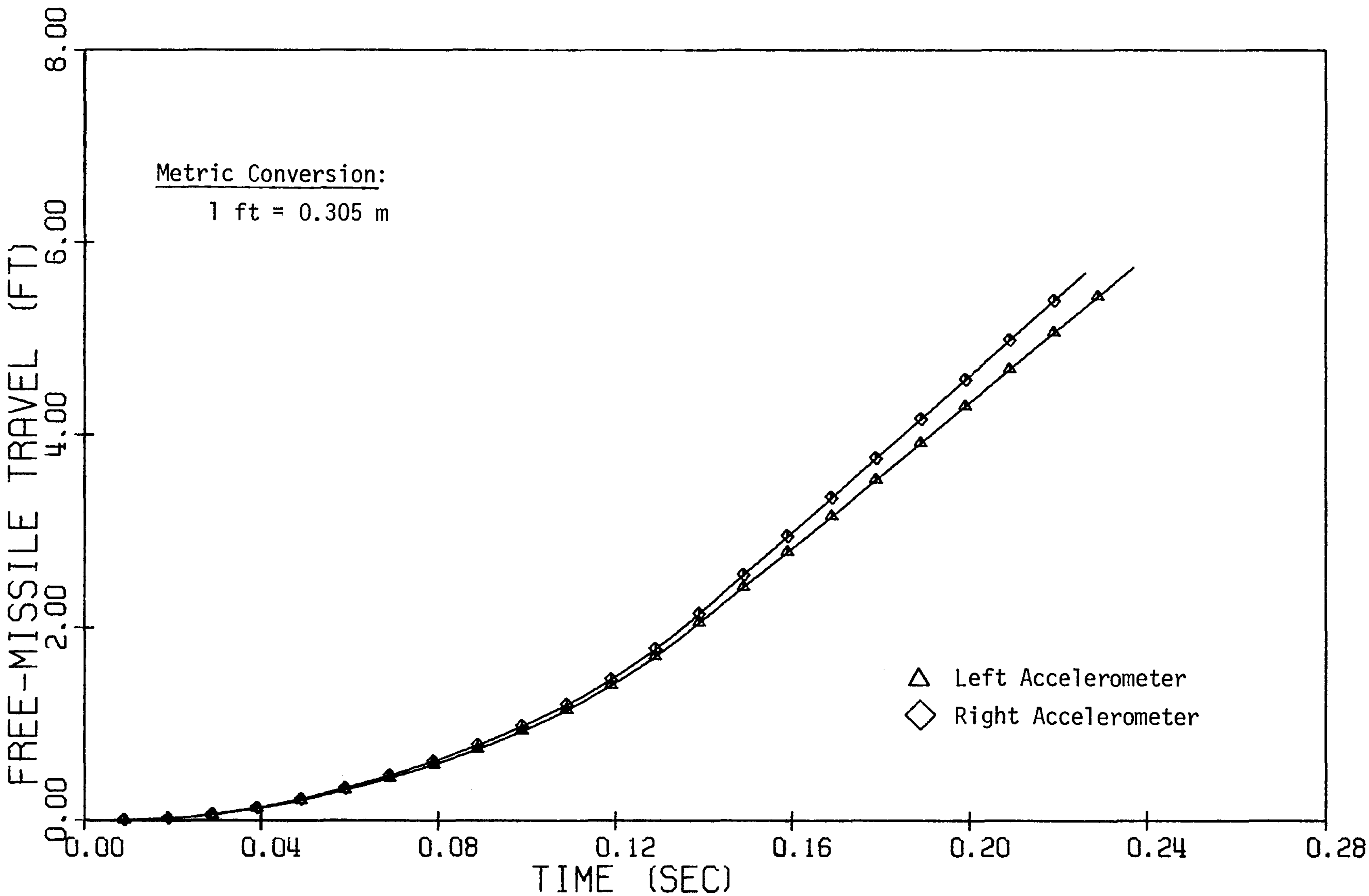
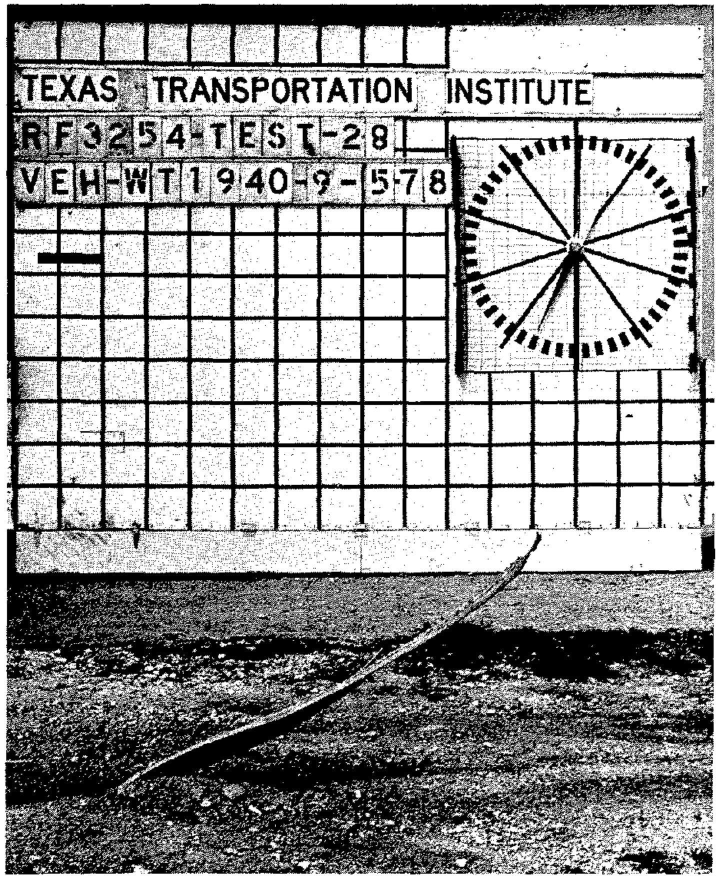
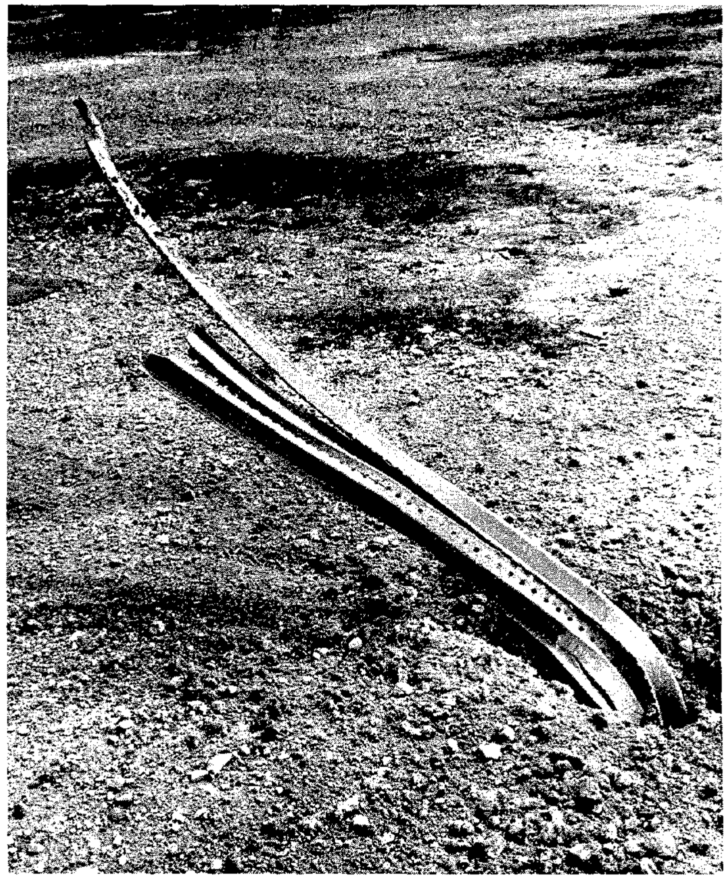


Figure 16. Free missile travel versus time, test 28.



a) Side view



b) Close-up view

Figure 17. Installation damage, test 28.

a) Top view

b) Front view

Figure 18. Vehicle damage, test 28.

TABLE 6. SUMMARY OF RESULTS, TEST 3254-29.

Impact Velocity = 59.9 mph

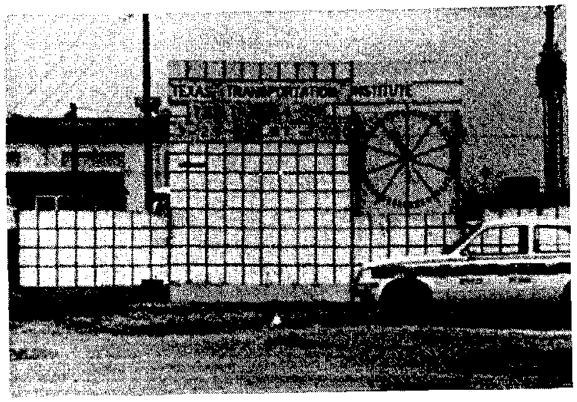
POST DATA			
Type	Steel U-post**		
Size	3.0 lb/ft		
Embedment Method	Driven		
Embedment Depth (ft)	3.5		
VEHICLE DATA			
Make	Chevrolet		
Model	Chevette		
Year	1976		
Weight (lb)	1940		
Impact Point	15 in. to left of center		
ACCELEROMETER DATA		Left	Right
Change in Momentum (lb-sec)		1177	972
Duration of Event (sec)*		0.171	
Peak Deceleration (G's)		14.16	12.39
Maximum 0.050 Sec Average Deceleration (G's)		5.98	4.87
VEHICLE DAMAGE CLASSIFICATION			
TAD	FL-3		
SAE	12FLEN-2		
Did test article penetrate the passenger compartment?	No		
Was windshield broken?	No		

*Free missile travel time

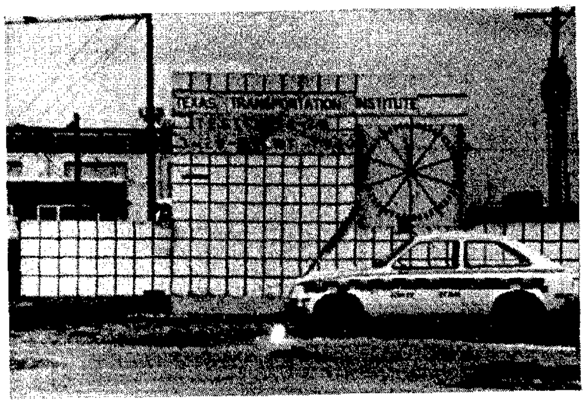
**Armco Steel Corporation Billet Steel Post

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



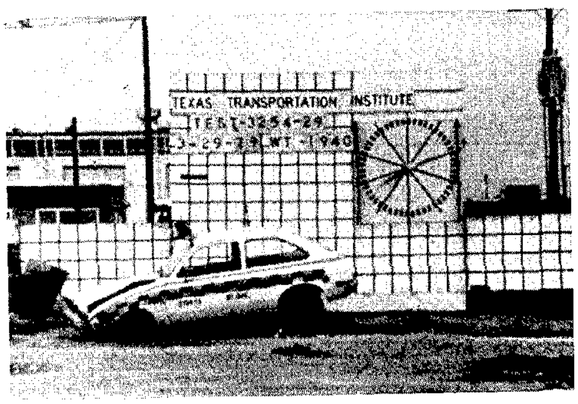
0.000 sec



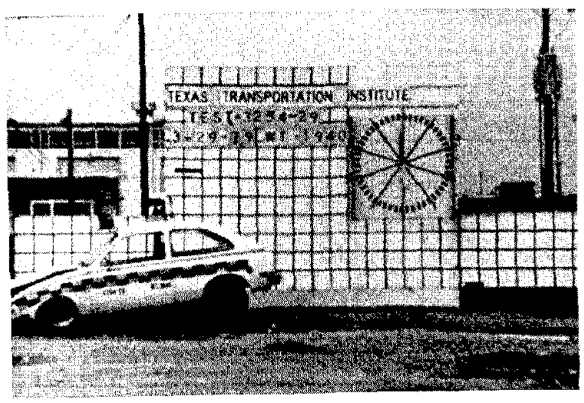
0.027 sec

0.079 sec

0.118 sec



0.167 sec



0.214 sec

Figure 19. Sequential photos, test 29.

Table 7. Time displacement event summary for test 29.

TIME (sec)	NOMINAL VEHICLE DISPLACEMENT (ft)	EVENT
0.000	0.00	Impact
0.037	3.14	Post wrapping around bumper
0.079	6.45	Maximum hood penetration
0.118	9.29	Sign panel hits ground
0.167	12.69	Free missile travel time
0.214	15.81	Rear wheels off ground

Metric Conversion:

1 ft = 0.305 m

through the impact the signpost rotated down into the top of the hood and hooked around the front of the bumper. As the interaction continued, the vehicle pitched forward noticeably and the rear wheels lifted off the ground. The vehicle's momentum carried it through the impact. The sign panel fell away, and the signpost was straightened out by the overriding vehicle. The entire signpost remained in the ground.

Figures 20, 21, and 22 show deceleration, change in momentum, and free missile travel versus time data. Installation damage is given in Figure 23. The entire installation would require replacement.

Vehicle damage was extensive, as shown in Figure 24. The hood, grille, left fender, and bumper were severely bent or crushed. The left headlight was knocked off, and the front left wheel well was nearly separated from the fender. This would have to be replaced, and the right fender would need some repair work. Table 6 gives TAD and SAE damage ratings for test 29.

III-D. Discussion of Results

A summary of results of the three tests reported herein is shown in Table 8 together with results of related tests from reference 1. Post properties are given in Table 9. Tests 4 and 29 show the effect of vehicle weight for impact with the 3 lb/ft (4.5 kg/m) post, since all other parameters were essentially the same. The smaller vehicle experienced a 13 percent increase in change in momentum and a 33 percent increase in change in velocity. The weight of the smaller vehicle was approximately 15 percent less than the larger vehicle. Note that the change in momentum in test 29 is below the 1100 lb-sec (4893 N-s) AASHTO (3) limit for a 2250 lb (1020 kg) vehicle vehicle, but the change in velocity exceeds the 10.7 mph (17.3 km/h) limit implied in the AASHTO specifications. Comparison of tests 27 and 29 shows the effect of soil moisture on impact severity. Clearly, the wet soil conditions had a large effect on the pull-out capacity and hence the impact severity. Static pull-out tests of 3 lb/ft (4.5 kg/m) were conducted subsequent to the crash tests reported herein to quantify effects of soil moisture (6).

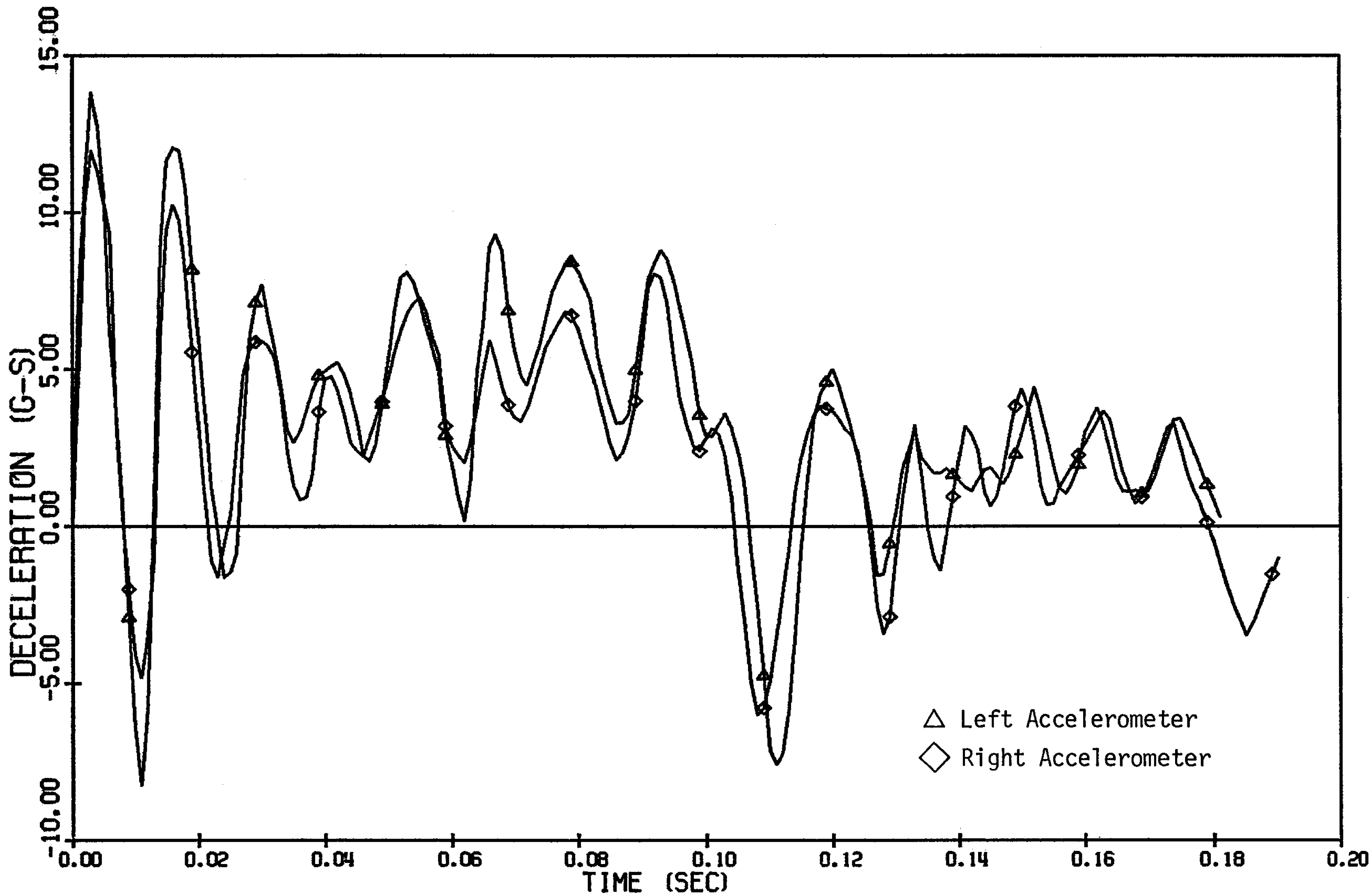


Figure 20. Deceleration versus time, test 29.

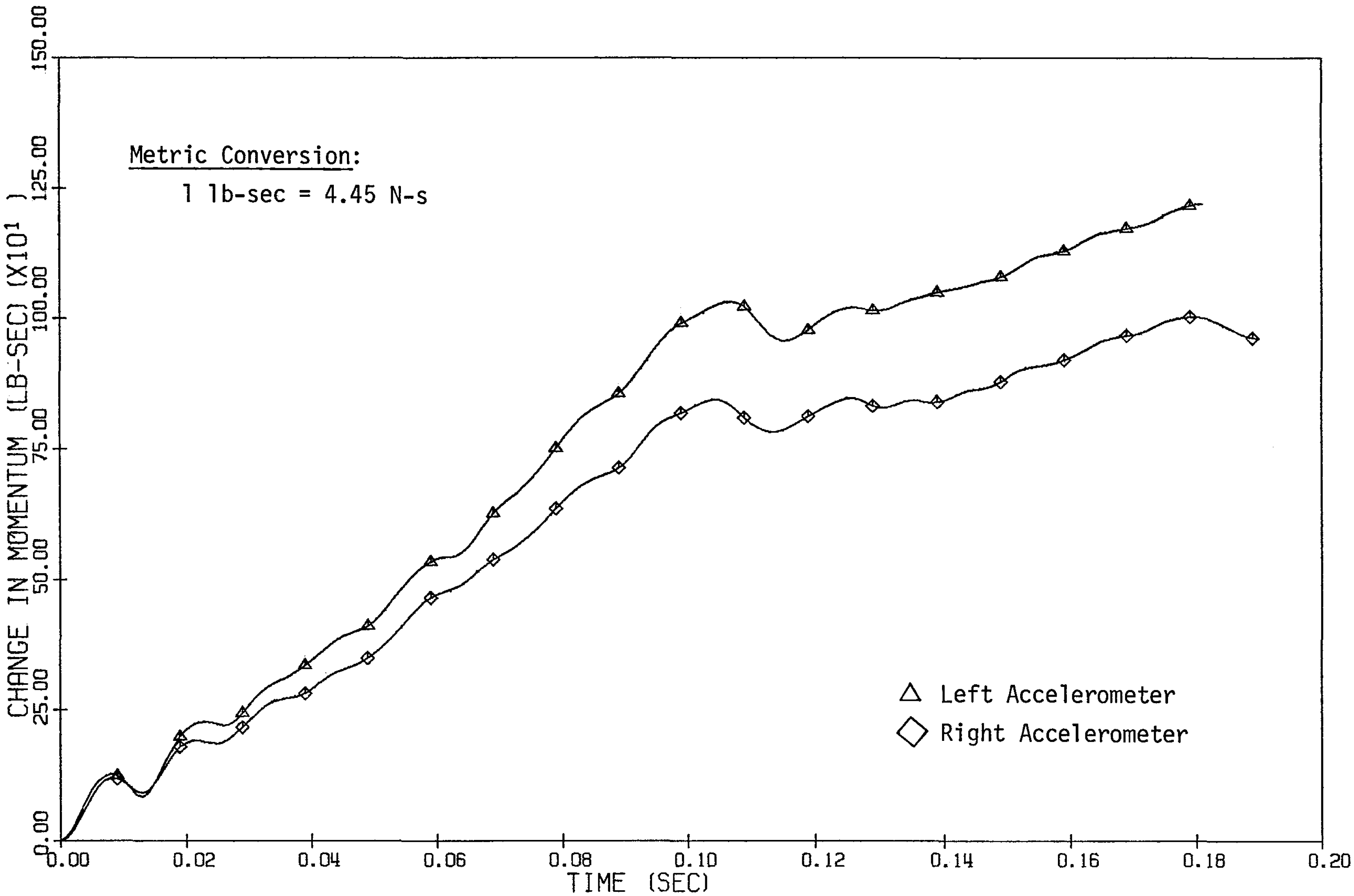


Figure 21. Change in momentum versus time, test 29.

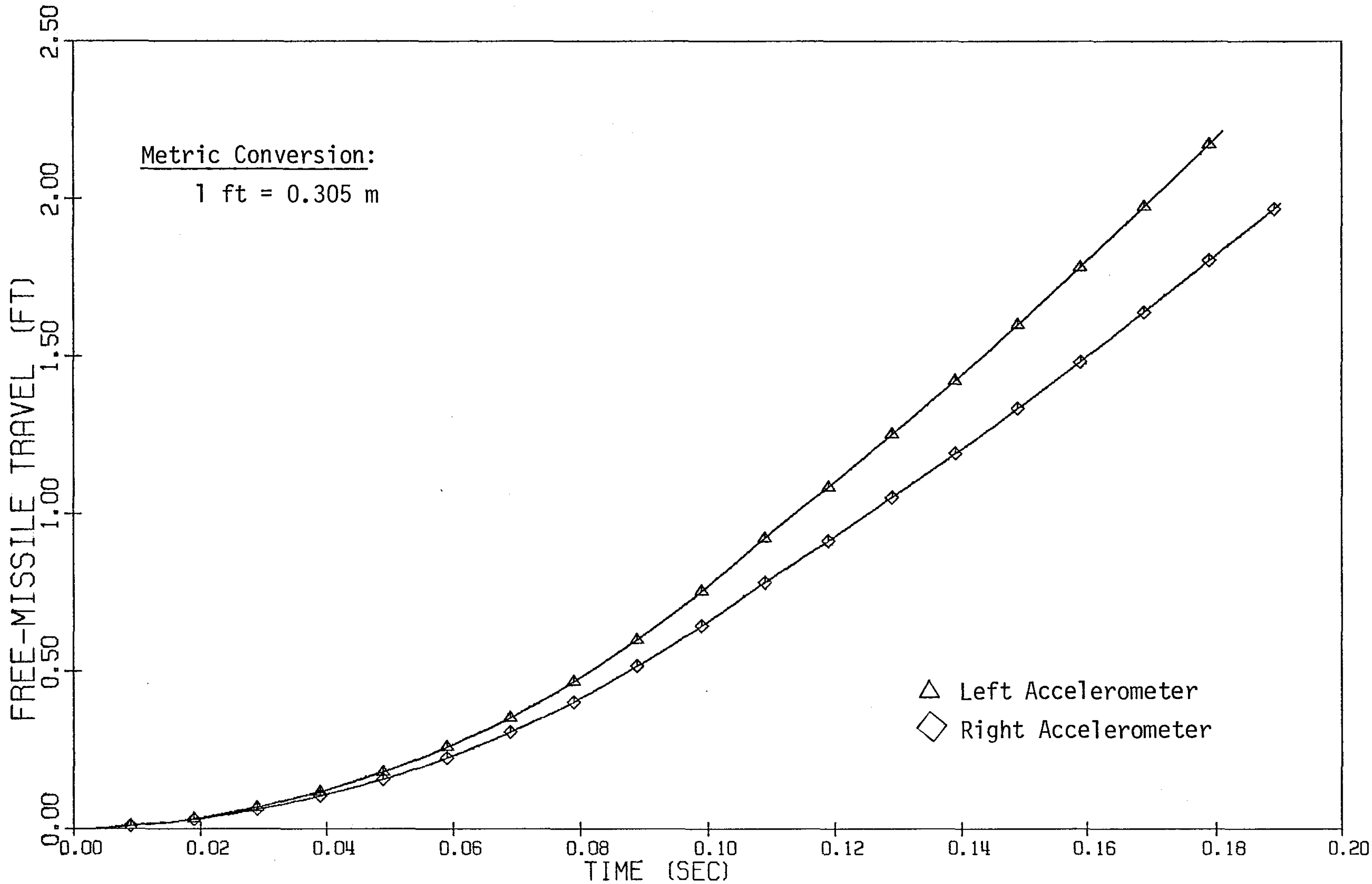
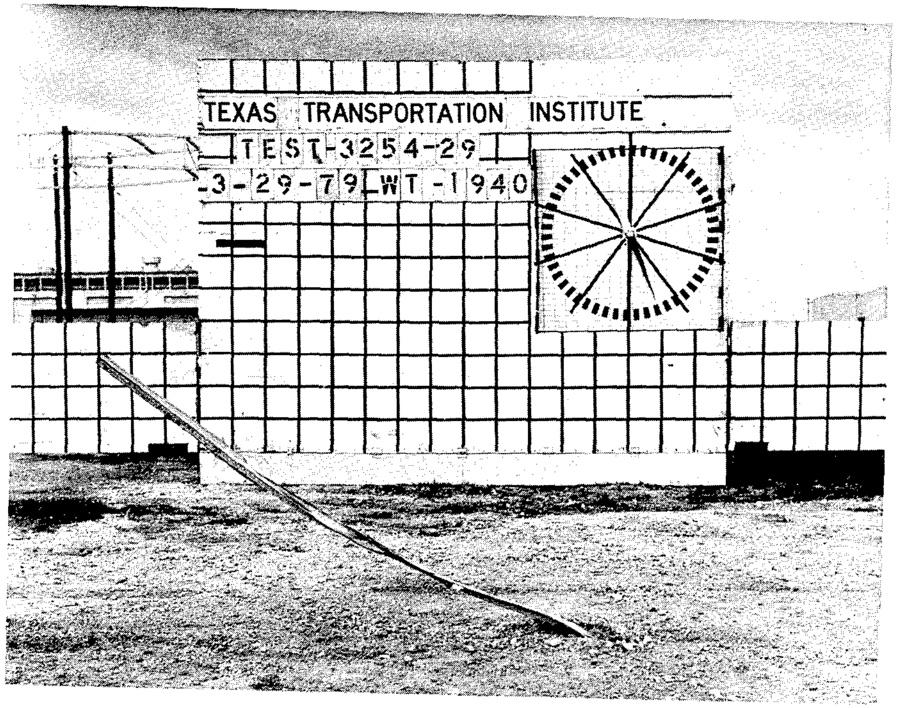
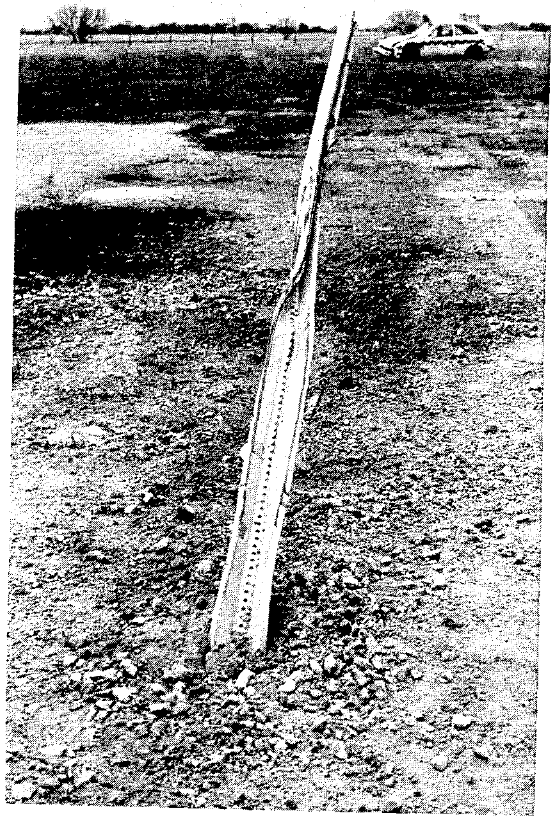


Figure 22. Free missile travel versus time, test 29.

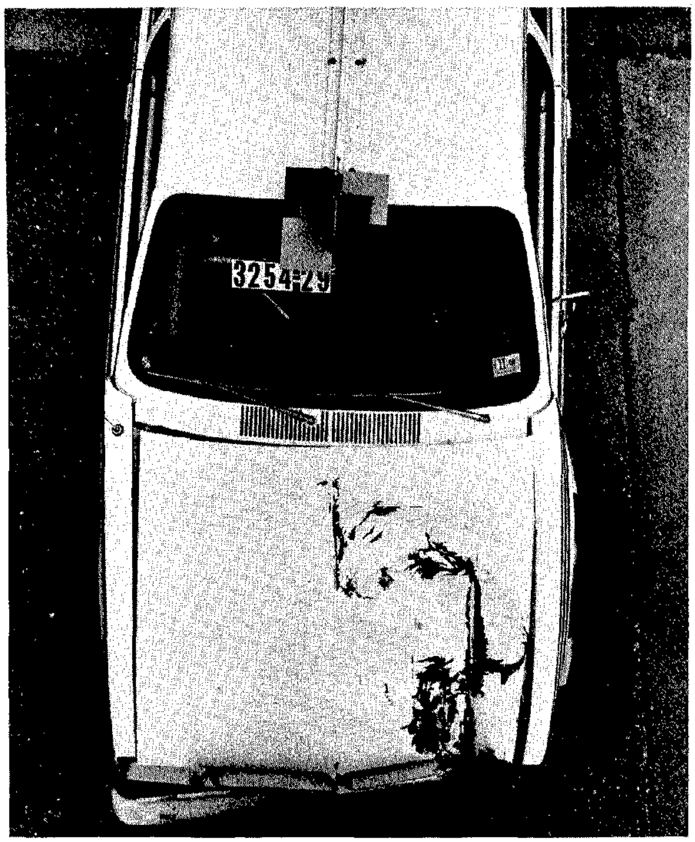


a) Side view



b) Close-up view

Figure 23. Installation damage, test 29.



a) Top view

b) Front view

Figure 24. Vehicle damage, test 29.

Table 8. Comparison of test results.

SIGNPOST	TEST NO.	VEHICLE DATA		SOIL CONDITION	IMPACT DATA	
		WEIGHT (lb)	IMPACT SPEED (mph)		CHANGE IN MOMENTUM (lb-sec)[c]	CHANGE IN VELOCITY (mph)
3 lb/ft billet steel U-post[d]	4[a]	2270	61.2	Dry	950	9.2
	27[b]	1940	60.2	Wet	632	7.2
	29	1940	59.9	Dry	1075	12.2
Two 3 lb/ft steel U-post back-to-back[d]	20A[a]	2270	62.9	Dry	669	6.5
	21[a]	2270	57.9	Dry	430	4.2
	28	1940	65.2	Dry	2259	25.6

[a]From reference 1.

[b]Post pulled out of ground due to high soil moisture content.

[c]Average of left and right accelerometer data.

[d]See Table 9 for post properties.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.609 kg/h
1 lb-sec = 4.45 N-s

Table 9. Post properties.

SIGNPOST	TEST NO.	YIELD STRENGTH (psi)	ULTIMATE STRENGTH (psi)	PERCENT ELONGATION (%)	CHARPY FRACTURE ENERGY[a] (in.-lb/in.^{2})
3 lb/ft billet steel U-post[b]	4	68,000	104,500	13.0	2766
	27	68,000	104,500	13.0	2540
	29	68,000	108,900	14.5	3054
Two 3 lb/ft steel U-post back-to-back	20A[c]	81,670[e]	145,300[e]	11.5[e]	682[e]
	21[d]	104,000[e]	157,000[e]	5.0[e]	694[e]
	28[c]	83,667[e]	143,000[e]	8.5[e]	928[e]

[a]Specimen at 150°F.

[b]All posts were hot rolled from billet steel by Armco Steel Corporation.

[c]Post hot rolled from rail steel by Franklin Steel Company.

[d]Post hot rolled from "experimental" billet steel by Armco Steel Corporation.

[e]Average value of both posts.

Metric Conversions:

1 psi = 6,895 Pa
1 in.-lb/in.^{2} = 1.75 cm-N/cm^2

Tests 20A and 21 both involved impacts by 2270 lb (1031 kg) vehicles with relatively high strength, low ductility, brittle steel posts. Test 28 involved impact by a 1940 lb (881 kg) vehicle with a post very similar in properties to those of tests 20A and 21. A comparison of these tests shows the smaller vehicle experienced much higher impact forces, with momentum and velocity changes greatly exceeding limiting values. After impact the vehicle rolled over and was a total loss. Although a larger velocity change was anticipated the actual magnitude far exceeded what one would predict based on (1) relative weights of the two vehicles and (2) results observed in tests 4 and 29. Note that the Charpy fracture energy of the post in test 28 was not significantly different from the posts in tests 20A and 21. Analysis of previous tests and test specimens (1) showed that a metal post would fracture during a high-speed impact, without excessive impact forces, if its Charpy fracture energy was less than 2000 in.-lb/in.^{2} (3540 cm-N/cm^2) and, provided the post size did not exceed a limiting value. As shown in Table 8 change in momentum values in tests 20A and 21 for the two 3 lb/ft (4.5 kg/m) posts were below limiting values. Other than vehicle size there is no apparent reason for the differences in the results of tests 20A (or 21) and 28. It is noted that the bumper on the vehicle in test 28 met current standards for low-speed impacts, and as a consequence, it was much stiffer and stronger overall than the bumper on the vehicles used in tests 20A and 21. A stiff bumper should initiate a fracture of a frangible post more readily than a less stiff bumper due to higher load and strain rates.

IV. CONCLUSIONS

1. In high speed impacts (approximately 60 mph (96.5 km/h)) with a 3 lb/ft (4.5 kg/m) steel U-post, a 1940 lb (881 kg) sub-compact vehicle sustained a change in momentum 13 percent higher than a 2270 lb (1031 kg) compact vehicle. It is important to note that change in velocity of the smaller vehicle was 33 percent higher than the larger vehicle. While the change in momentum in both cases was below AASHTO limits (3), change in velocity was above what is believed to be a safe limit, i.e., about 11 mph (17.k km/h), in the sub-compact vehicle.
2. Impact behavior of a yielding metal signpost is dependent on soil moisture content. In a high-speed test, a 3 lb/ft (4.5 kg/m) steel U-post, embedded in a standard soil (2), hooked on the vehicle and was pulled from the ground when the soil was wet. When embedded in a dry soil the post hooked on the vehicle but was then ridden down without being pulled out of the ground. Change in velocity during impact with the post in the dry soil was approximately 70 percent higher than when the post was in a wet soil. Static load tests have been conducted to quantify effects of soil moisture content on pull-out capacity of a 3 lb/ft (4.5 kg/m) post (6).
3. Impact of two 3 lb/ft (4.5 kg/m) steel U-posts (bolted together to form a back-to-back design) with a sub-compact vehicle weighing 1940 lb (881 kg) produced a change in momentum that greatly exceeded AASHTO limits (3). The vehicle rolled over and was a total loss. Two tests of the same design with compact vehicles weighing 2270 lb (1031 kg) did not result in excessive changes in momentum. Other than vehicle size, there were no appreciable differences in the sign installations or test conditions.

V. RECOMMENDATIONS

1. Strong consideration should be given to the use of sub-compact vehicles in crash test evaluation of sign structures and other safety appurtenances. Present AASHTO specifications and testing procedures require compact vehicles weighing approximately 2250 lb (1022 kg) to be used in evaluation of sign structures. Tests of signs reported herein with vehicles weighing 1940 lb (881 kg) exhibited important differences from similar tests involving 2250 lb (1022 kg) vehicles. Current downsizing trends in automobiles strongly suggest that sub-compact vehicles will be a major portion of the vehicle population in the near future.
2. Impact performance specifications for sign structures (and luminaire supports) should be stated in terms of change in vehicle velocity limits rather than the present change in vehicle momentum limits. Current AASHTO specifications imply that change in vehicle velocity during impact should not exceed approximately 11 mph (17.7 km/h). The authors are not in a position to suggest that this limit be changed. However, the following points should be considered in developing a limiting value.

   The 11 mph (17.7 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 11 mph (17.7 km/h) could be expected to sustain disabling injuries. These data were developed over ten years ago 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. In addition, increased bumper stiffness of current automobile should enhance the breakaway and/or fracture of many sign and luminaire support designs. On the negative side, 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, velocity change can be expected to increase as the vehicle weight decreases. One must also consider the stability factor of the smaller vehicles. For a given size post and impact speed, the potential for spinout and rollover may increase as the wheel base and inertia properties decrease.

The problem should also be viewed from an energy management standpoint. As an example, if a vehicle impacts an object at 20 mph (32.2 km/h) and at 60 mph (96.5 km/h) and in both cases experiences a 10 mph (16.1 km/h) velocity change, 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 therefore desirable.

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

APPENDIX A
SIGNPOST MATERIAL PROPERTIES

Mechanical and chemical properties of the steel U-posts used in tests 27, 28, and 29 are given in Table 10 as given by the manufacturers of the posts. Figures 25 and 26 give the cross-sectional properties of the posts.

In previous testing of base bending signposts, an attempt was made to correlate full-scale crash test results with Charpy impact tests (2). As before, the specimens were cut from the tested posts and simple beam tests were conducted in accordance with ASTM E23-72 specifications. Tests were conducted at the ambient temperature at the time of testing and at 150°F (65.6°C). Table 11 summarizes the results of the Charpy impact tests.

Table 10. Mechanical and chemical properties of signposts.

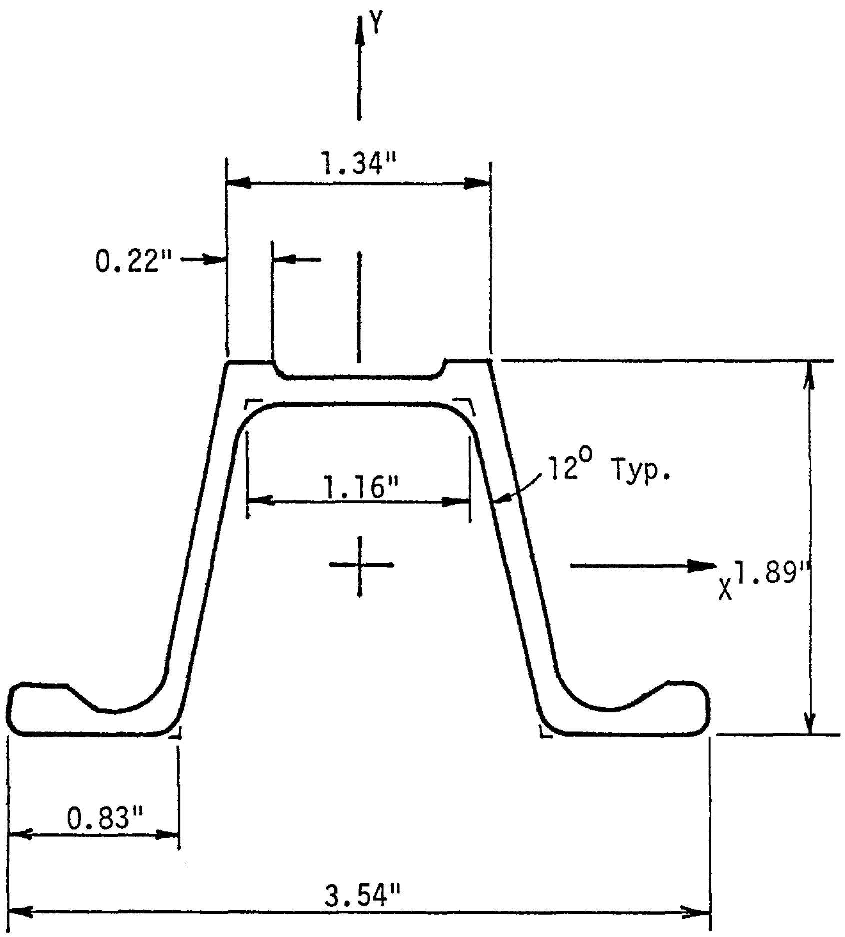
Test No.	Post Type and Size	No. of Specimen	Mechanical Properties: Yield Strength (psi)	Ultimate Strength (psi)	Elongation (%)	Chemical Analysis: C	Mn	P	S	Si	Ni	Cr	Mo	Cu
27	Billet Steel U-Post[a] 3.0 lb/ft	1	68,000	104,500	13.0	.38	.76	.023	.028	-	-	-	-	-
28	Rail Steel U-Post[b] Two 3.0 lb/ft Back-to-Back	1 2	82,000 85,333	144,666 141,333	8.0 9.0	.76 .78	.82 .93	.012 .018	.019 .034	.19 .23				
29	Billet Steel U-Post[a] 3.0 lb/ft	1	68,800	108,900	14.5	.45	.76	.030	.028	.23	.08	.14	.02	.30

[a]Properties provided by Armco Steel Corporation.

[b]Properties provided by Franklin Steel Company.

Metric Conversions:

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



$I_{xx} = 0.430 \text{ in.}^4$
$S_x = 0.409 \text{ in.}^3$
$I_{yy} = 0.920 \text{ in.}^4$
$S_y = 0.519 \text{ in.}^3$

Metric Conversions:

1 in. = 2.54 cm
$1 \text{ in.}^3 = 16.4 \text{ cm}^3$
$1 \text{ in.}^4 = 41.6 \text{ cm}^4$

Figure 25. Properties of 3 lb/ft steel U-post used in tests 27 and 29.

I_{xx} = 0.372 in.^{4}
S_x = 0.403 in.^{3}
I_{yy} = 0.870 in.^{4}
S_y = 0.497 in.^{3}

<u>Metric Conversions:</u>

1 in. = 2.54 cm
1 in.^{3} = 16.4 cm^3
1 in.^{4} = 41.6 cm^3

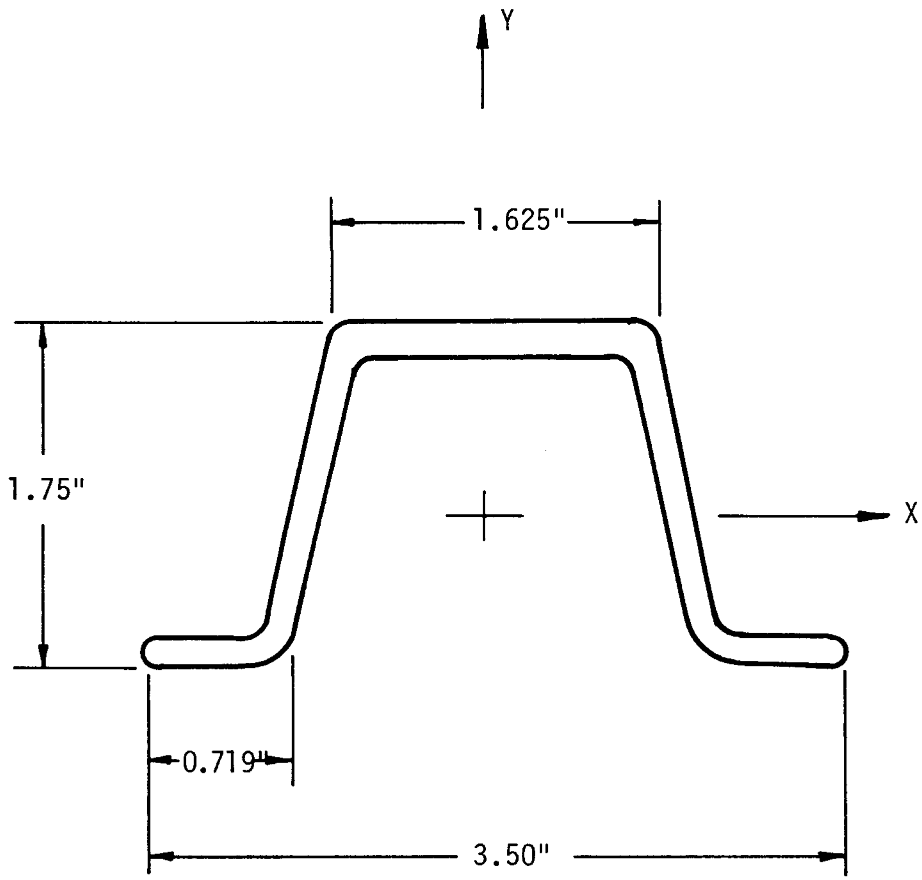


Figure 26. Properties of 3 lb/ft steel U-post used in test 28.

Table 11. Charpy test data.

Test No.	Steel Type	Specimen Thickness (in.)	Specimen Temperature (°F)	Charpy Fracture Energy (in.-lb/in.^{2})	Fracture in Crash Test?
27	Billet[a]	.137 .137 .137 .137	83 83 150 150	2092 1813 2606 2474	No[c]
28 Post 1 (Impact Side)	Rail[b]	.118 .118 .118 .118	85 85 150 150	646 646 969 1291	Yes[d]
28 Post 2 (Back Side)	Rail[b]	.118 .118 .118 .118	85 85 150 150	646 646 807 646	Yes[d]
29	Billet[a]	.131 .131 .131 .131	75 75 150 150	2326 2326 3199 2908	No

[a]Post manufactured by Armco Steel Corporation.

[b]Post manufactured by Franklin Steel Company.

[c]Post pulled from ground due to wet soil.

[d]Although post fractured, impact forces were excessive.

Metric Conversions:

1 in. = 2.54 cm

1 in.-lb/in.^{2} = 1.77 cm-N/cm^2

$t_f^o = 1.8\ t_c^o + 32$

REFERENCES

1. Ross, H. E., Jr., Walker, K. C., and Effenberger, M. J., "Crash Tests of Small Highway Sign Supports", Research Report 3254-3, Contract DOT-FH-11-8821, Texas Transportation Institute, Texas A&M University, September, 1978.

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

3. "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals", American Association of State Highway and Transportation Officials, 1975.

4. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project Bulletin No. 1, National Safety Council, 1971.

5. "Collision Deformation Classification, Recommended Practice J224a", Society of Automotive Engineers, New York, 1973.

6. Ross, H. E., Jr., and Dolf, Timothy J., "Pull-out Capacity of a Yielding Signpost as Related to Soil Moisture", Research Report 3254-8, Contract DOT-FH-11-8821, Texas Transportation Institute, Texas A&M University, August, 1979.

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