Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-01/1458-3		

4. Title and Subtitle	5. Report Date
TESTING AND EVALUATION OF RECYCLED MATERIALS IN ROADSIDE SAFETY DEVICES	October 2000 Resubmitted: April 2001
	6. Performing Organization Code
7. Author(s) Roger P. Bligh, Wanda L. Menges, and Dean C. Alberson	8. Performing Organization Report No. Report 1458-3
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-1458
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Research: August 1997 - August 1999 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: Recycled Materials in Roadside Safety Devices

16. Abstract

This report summarizes the third phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. In the first phase of the study, information regarding recycled material manufacturers and their products was acquired through a literature review. The information received was categorized into two areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having the possibility of use in such applications.

In the second phase of this study, researchers used a series of static and dynamic laboratory tests to further evaluate those products lacking the desired data to make conclusive decisions regarding their suitability for implementation. Tests of conventional materials commonly used in nationally approved roadside safety devices provided baseline performance data. For those products displaying inadequate performance when compared to baseline performance, necessary improvements were made. The Phase II test data were used to prioritize and select the most promising recycled materials and products for further investigation of their impact performance under Phase III of this study.

Phase III consists of full-scale crash testing of selected products to validate laboratory results and verify their crashworthiness. The research team evaluated three products for use as temporary sign supports. Another product was evaluated for use as guardrail posts and offset blocks in strong post W-beam guardrail systems. Descriptions of the test installations, results of the full-scale crash tests, and conclusions regarding impact performance are summarized in this report.

17. Key Words	18. Distribution Statement
Signs, Guardrail, Post, Block-Out, Recycled Materials, Crash Testing, Roadside Safety	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	164	

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

TESTING AND EVALUATION OF RECYCLED MATERIALS IN ROADSIDE SAFETY DEVICES

by

Roger P. Bligh
Assistant Research Engineer
Texas Transportation Institute

Wanda L. Menges
Associate Research Specialist
Texas Transportation Institute

and

Dean C. Alberson
Associate Research Engineer
Texas Transportation Institute

Report 1458-3
Project Number 0-1458
Research Project Title: Recycled Materials in Roadside Safety Devices

Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

October 2000
Resubmitted: April 2001

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

The contents of this report reflect the views of the authors, who are solely responsible for the facts and accuracy of the data, and the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, the Texas Department of Transportation, the Texas A&M University System, or Texas Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers. The engineer in charge of the project was Mr. Roger P. Bligh, P.E. #78550.

ACKNOWLEDGMENTS

This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the U.S. Department of Transportation, Federal Highway Administration. Mr. Thomas Elliot, Mr. Chris Pankey, and Mr. Tom Yarbrough were the TxDOT project directors over the duration of the project. Their assistance and guidance are acknowledged. The guidance of the project advisory panel, which consisted of Ms. Rebecca Davio, Ms. Kathleen Jones, Ms. Claudia Kern, Ms. Cathy Wood, and Mr. Greg Brinkmeyer, is also acknowledged and appreciated.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

Figure	Page

LIST OF FIGURES (continued)

Figure Page

LIST OF TABLES

Table Page

I. INTRODUCTION

This report summarizes the third phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. In the first phase of this study, information regarding recycled material manufacturers and their products was acquired through an extensive literature review and survey of research organizations, various state and federal transportation agencies, professional and trade societies, and manufacturers. The information received was categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having the possibility of use in such applications.

In the second phase of this study, those products lacking the desired data to make conclusive decisions regarding their suitability for implementation were further evaluated through a series of static and dynamic laboratory tests. Basic physical and mechanical properties of the recycled products were determined through static laboratory tests such as flexure, compression, creep, and density. Response to environmental variables such as temperature, moisture, and freeze/thaw were investigated through exposure tests. The dynamic impact behavior of the materials was examined using pendulum tests. A unique test matrix was established for each application area. Conventional materials commonly used in nationally approved roadside safety devices were also tested in order to provide baseline performance data. Laboratory tests were used to verify a material met basic service requirements prior to running dynamic pendulum tests. For those products displaying inadequate performance when compared to baseline performance, necessary improvements were made in collaboration with the manufacturer. In response, the manufacturers submitted several second and third generation products for further testing and evaluation. Researchers used the Phase II test data to prioritize and select the most promising recycled materials and products for further investigation of their impact performance under Phase III of this study.

Phase III consists of full-scale crash testing of selected products to validate laboratory results and verify their crashworthiness. Researchers evaluated three products for use as temporary sign supports. Another product was evaluated for use as guardrail posts and offset blocks in strong post W-beam guardrail systems. Performance specifications were prepared for those applications for which suitable alternatives have been identified.

Descriptions of the test installations, results of the full-scale crash tests, and conclusions regarding impact performance are summarized in this report.

II. TEMPORARY SIGN SUPPORTS WITH RECYCLED POSTS

TEST ARTICLES

Researchers used results from the Phase II laboratory and dynamic pendulum tests to evaluate and prioritize the recycled sign support candidates. The project advisory panel selected three products from the prioritized list for further evaluation through full-scale crash testing. The purpose of the full-scale crash tests was to investigate the crashworthiness and breakaway performance of the supports. A description of each test article is provided below.

Sign Support Candidate 1

The recycled plastic post designated as product 17.D.1 was selected for testing and evaluation as a temporary single sign support. This is an extruded product comprised of high density polyethylene (HDPE). The test installation consisted of a 90 mm × 90 mm × 3810 mm post embedded 762 mm in standard soil as defined within National Cooperative Highway Research Program *(NCHRP) Report 350* [(1)]. A rigid plywood sign panel, measuring 1219 mm × 914 mm × 16 mm thick was attached to the recycled post with two 11 mm diameter × 127 mm long American Society for Testing and Materials (ASTM) A307 carriage bolts. The top of the sign panel was mounted even with the top of the support post, and the panel was oriented with the larger dimension parallel to the ground. The base of the sign panel was located 2134 mm above ground level. There were no splices or modifications made to the posts. The test article details are shown in figure 1.

Sign Support Candidate 2

The recycled plastic post designated as product 3.D.1 was the second product selected for testing and evaluation as a temporary single sign support. This is a molded product comprised of a blend of polyethylene plastics. The test installation consisted of an 86 mm × 86 mm × 3658 mm post embedded 686 mm in *NCHRP Report 350* designated standard soil. A rigid plywood sign panel, measuring 1219 mm × 914 mm × 16 mm thick, was attached with two 11 mm diameter × 127 mm long ASTM A307 carriage bolts. The top of the sign panel was mounted 76 mm above the top of the support post and the longer edge of the sign panel was mounted in the horizontal direction. The bottom edge of the sign panel was located 2134 mm above ground level. There were no splices or modifications made to the posts. Details of the test article are shown in figure 2.

Sign Support Candidate 3

The product designated as 17.D.2 was the third product evaluated for application as a temporary single sign support. This recycled plastic post is an extruded HDPE product. The test installation consisted of a 90 mm × 140 mm × 4570 mm long post embedded 916 mm in *NCHRP Report 350* designated standard soil. A rigid plywood sign panel, measuring 1220 mm × 1525 mm × 16 mm thick, was attached with two 8 mm diameter × 203 mm long ASTM A307 hex bolts. The top of the sign panel was mounted even with the top of the support post. The vertical edge of the sign panel was the longer dimension. The base of the sign panel was located 2130 mm above ground level. There were no splices or modifications to the posts at or around ground level. Details of the test article are shown in figure 3.

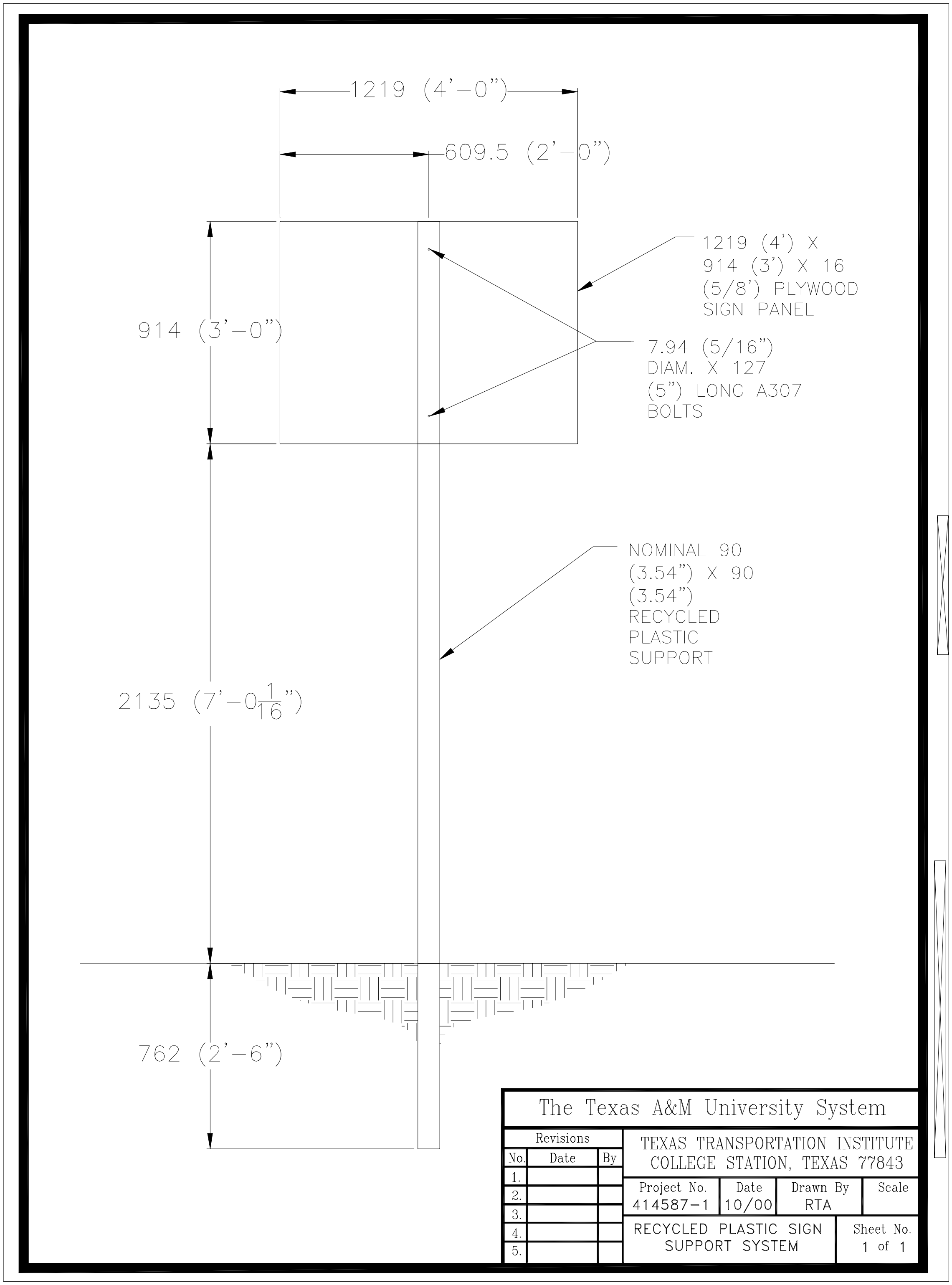


Figure 1. Details of the Recycled Plastic Sign Support Used in Tests 414587-1 and 2.

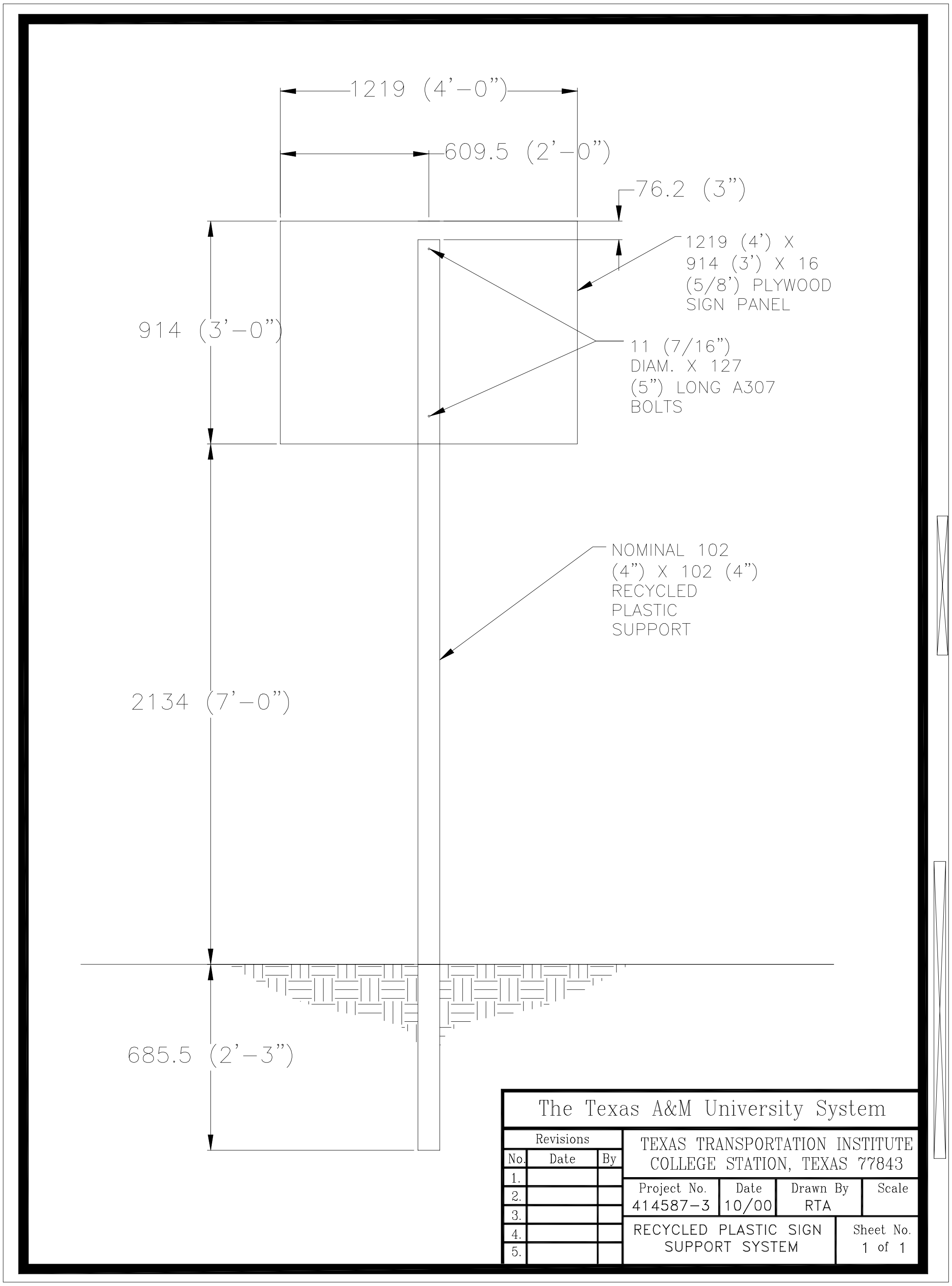


Figure 2. Details of the Recycled Plastic Sign Support Used in Tests 414587-3 and 4.

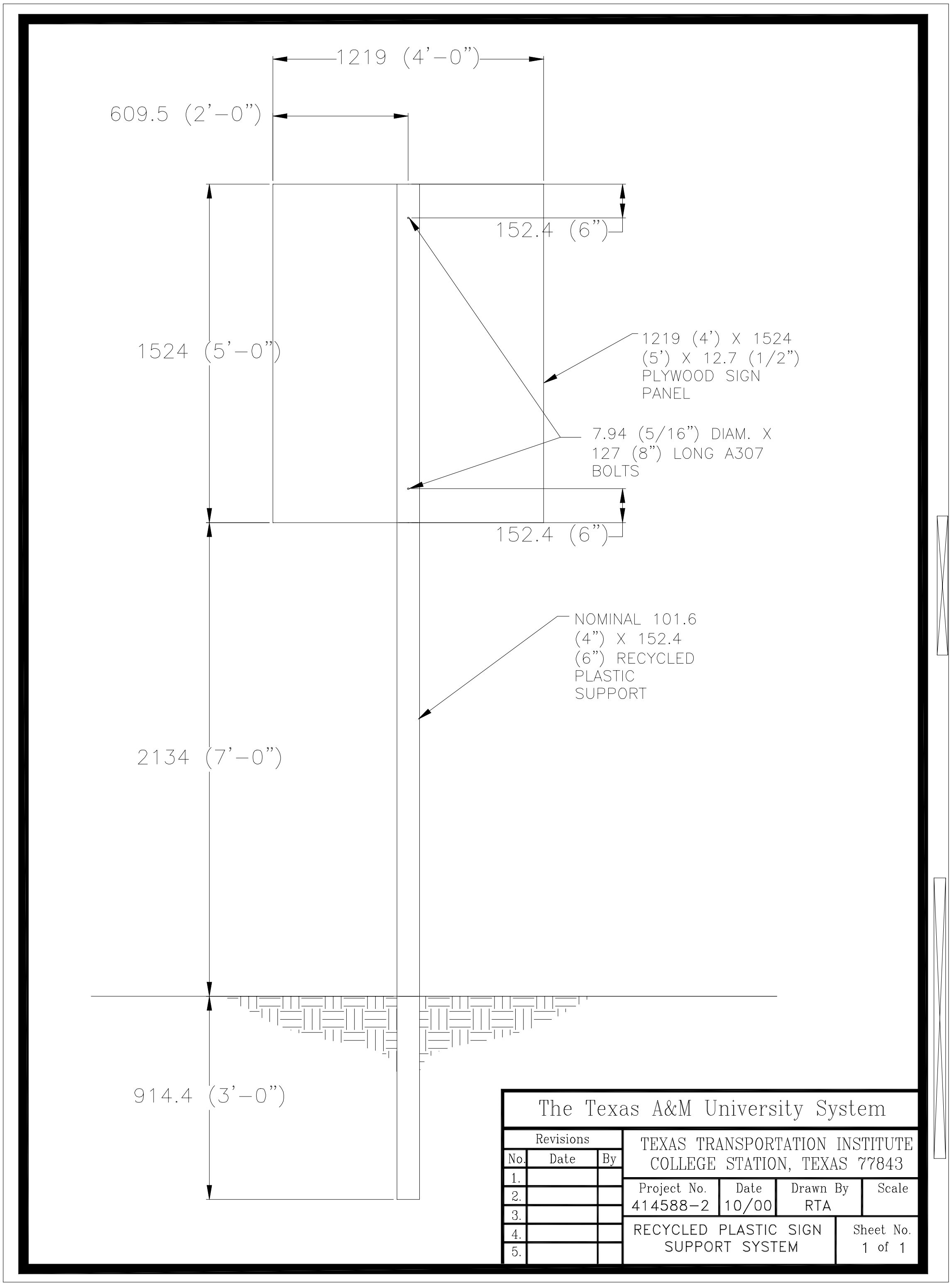


Figure 3. Details of the Recycled Plastic Sign Support Used in Tests 414588-2 and 3.

CRASH TEST CONDITIONS

According to *NCHRP Report 350*, the recommended tests for evaluating the impact performance of breakaway sign support structures at test level three are test designations 3-60 and 3-61 [(1)].

> ***NCHRP Report 350*** **Test Designation 3-60**: This test involves an 820 kg vehicle impacting the sign support head on at a nominal speed of 35 km/h. The purpose of the test is to evaluate structural adequacy, occupant risk, and vehicle trajectory. This test designation was run on each of the three recycled sign support candidates. These tests correspond to test numbers 414587-1, 414587-3, and 414588-2.
>
> ***NCHRP Report 350*** **Test Designation 3-61**: This test involves an 820 kg vehicle impacting the sign support head on at a nominal speed of 100 km/h. The purpose of the test is to evaluate structural adequacy, occupant risk, and vehicle trajectory. This test designation was run on each of the three recycled sign support candidates. These tests correspond to test numbers 414587-2, 414587-4, and 414588-3.

All crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

EVALUATION CRITERIA

The results of the crash tests were evaluated in accordance with the criteria presented in *NCHRP Report 350* [(1)]. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the sign support crash tests reported herein:

- **Structural Adequacy**

  B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

- **Occupant Risk**

  D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.

H. Occupant impact velocities should satisfy the following:

Longitudinal Occupant Impact Velocity - m/s	
Preferred	Maximum
3	5

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations - g's	
Preferred	Maximum
15	20

- **Vehicle Trajectory**

K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

N. Vehicle trajectory behind the test article is acceptable.

In addition, the 1994 American Association of State Highway Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals *(2)* presents the following additional evaluation criterion:

> Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound [817 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h [32 km/h to 97 km/h] does not exceed 16 ft/s [4.87 m/s], but preferably does not exceed 10 ft/s [3.05 m/s] or less.

SIGN SUPPORT CANDIDATE 1

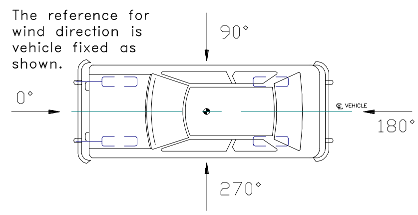
Low-Speed Test (Test 414587-1; *NCHRP Report 350* Test No. 3-60)

Test Vehicle

The recycled plastic sign support was installed, as shown in figure 4. A 1991 Ford Festiva, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 56. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather Conditions

Researchers performed the test the morning of August 28, 1997. Weather conditions at the time of the test were as follows: wind speed: 6 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle traveling in a northerly direction); temperature: 29 °C; and relative humidity: 44 percent.



Test Description

The vehicle, traveling at 33.9 km/h, impacted the sign support at a zero degree angle, with the left quarter point of the vehicle aligned with the centerline of the support. At 0.004 s after impact, the support began to flex, and at 0.034 s the support had pulled out of the ground. At 0.119 s the post was bowed around the bumper of the vehicle in a C-shape with the ends of the support post each bent at a 45-degree angle from vertical toward the vehicle. Post-test examination of the support post showed that it had fractured 203 mm below ground. At 0.243 s the vehicle had slowed to 28.0 km/h. The support, with attached panel, was dragged along as the vehicle continued to travel forward. Brakes on the vehicle were applied at 5.3 s, bringing it to a safe and controlled stop 13.7 m downstream and 1.5 m to the left of the point of impact. The sign support came to rest under the vehicle. Sequential photographs of the impact event are presented in appendix C, figure 59.

Damage to Test Installation

The sign support fractured 203 mm below ground level. The support and sign were dragged under the vehicle until the vehicle came to a stop. The sign support was not reusable. Damage to the sign installation is shown in figures 7 and 8.

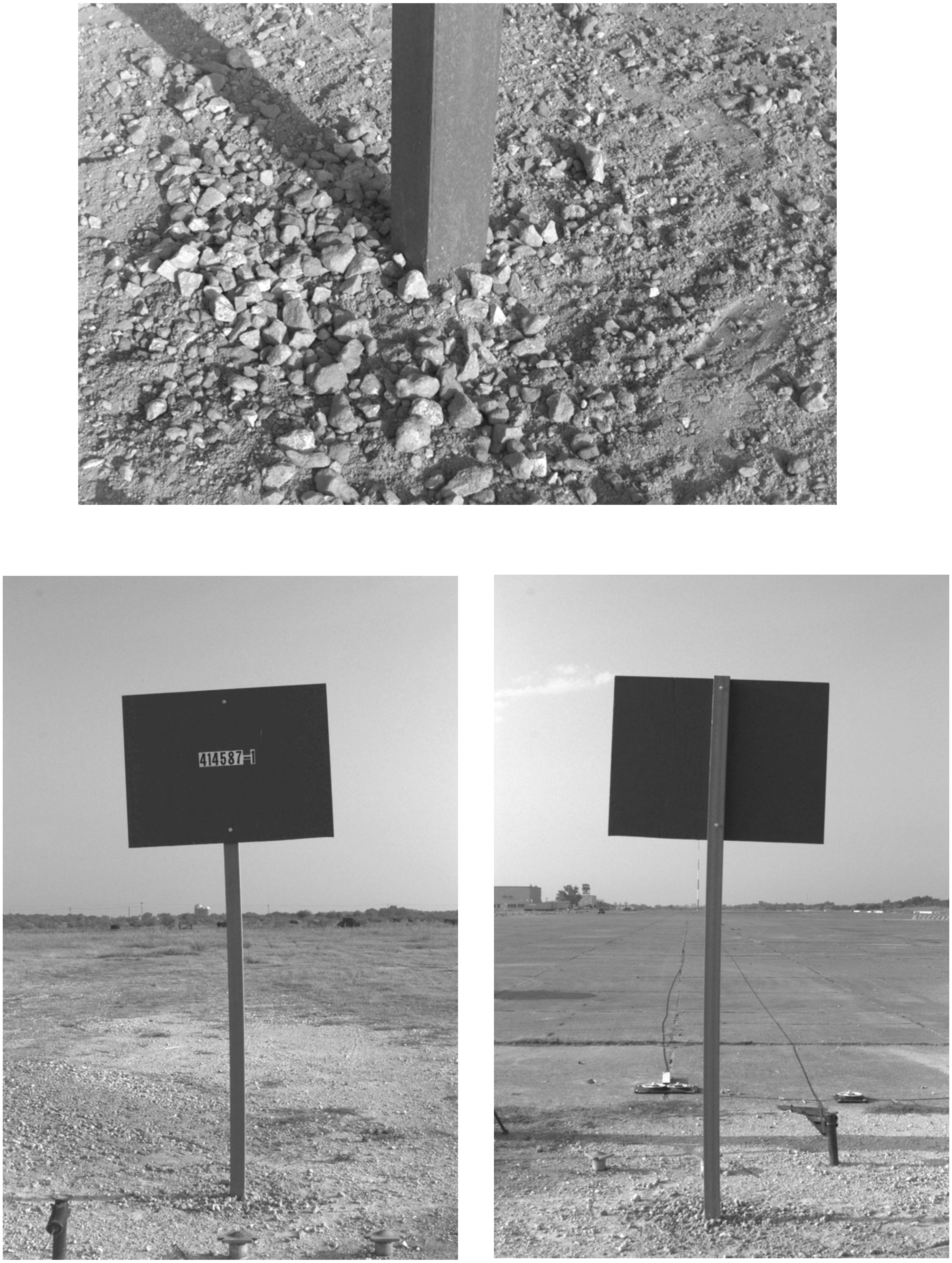


Figure 4. Recycled Plastic Sign Support Before Test 414587-1.

Figure 5. Vehicle/Support Geometrics for Test 414587-1.

Figure 6. Vehicle Before Test 414587-1.

Figure 7. After Impact Trajectory for Test 414587-1.

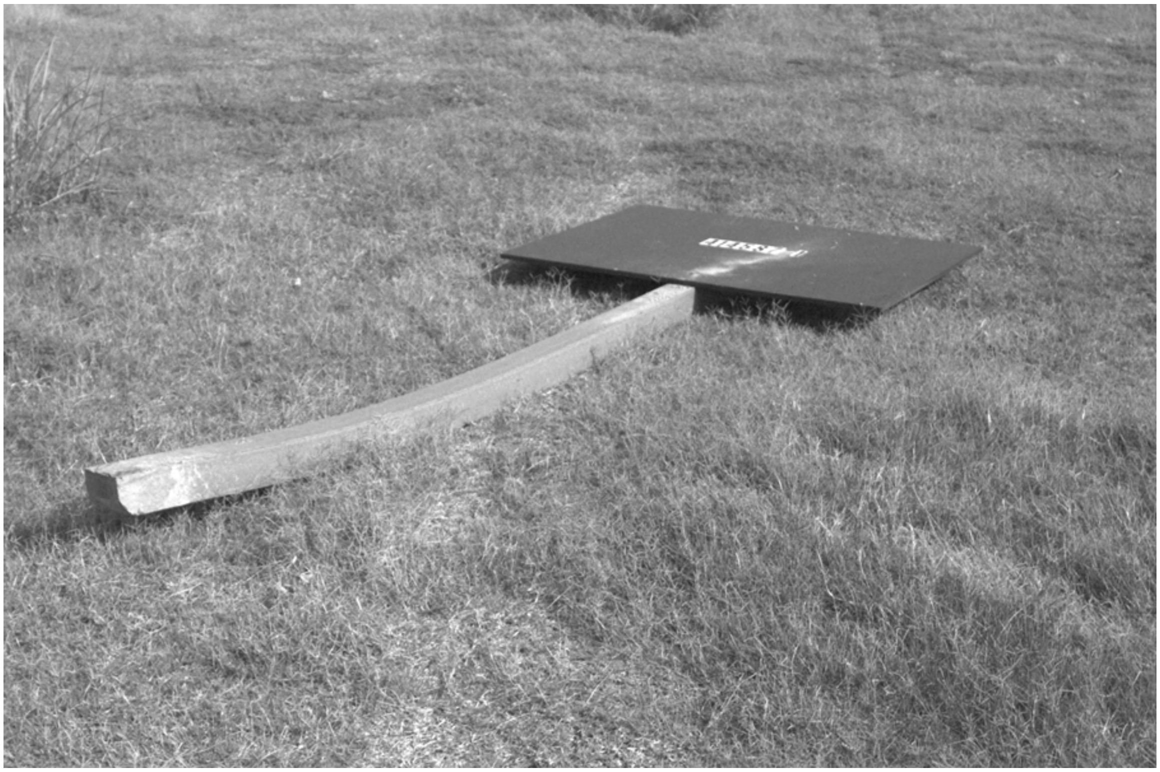


Figure 8. Support After Test 414587-1.

Vehicle Damage

As seen in figure 9, no damage was sustained by the vehicle from its contact with the support. There was no measurable exterior crush, and no deformation or intrusion into the occupant compartment. Subsequent tests re-used the vehicle.

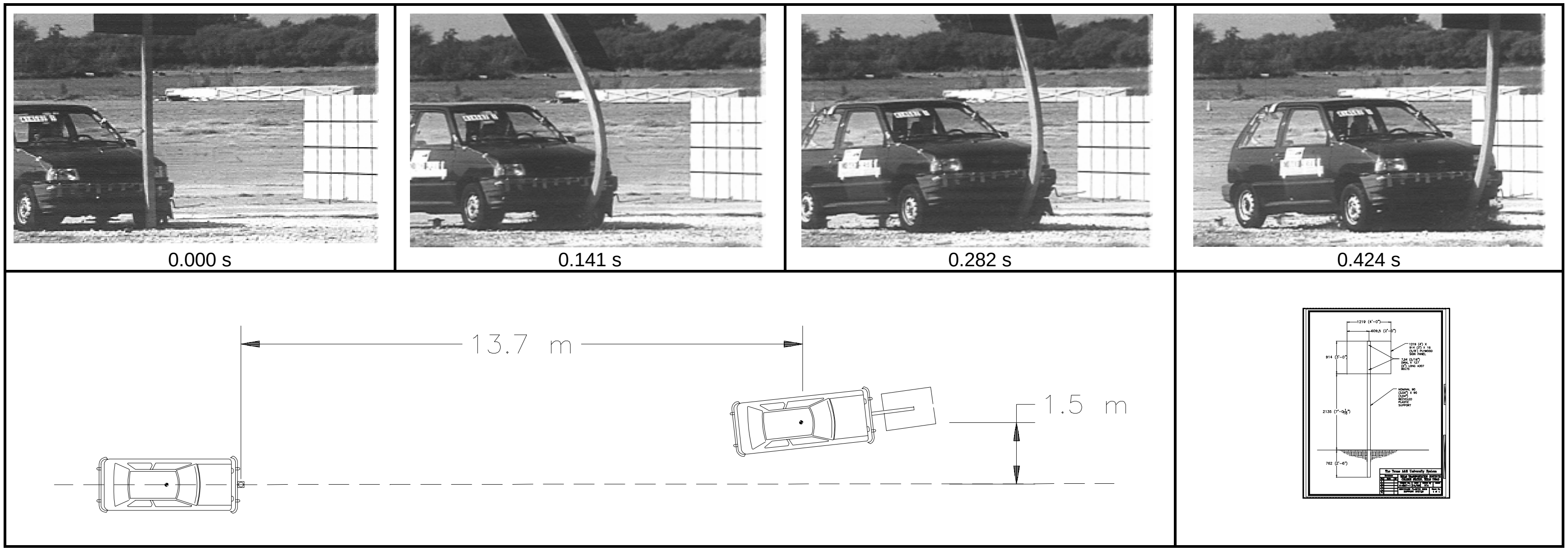
Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 1.8 m/s at 0.482 s, the highest 0.010 s occupant ridedown acceleration was -0.3 g from 0.518 to 0.528 s, and the maximum 0.050 s average acceleration was -1.2 g between 0.001 and 0.051 s. In the lateral direction, the occupant impact velocity was 0.6 m/s at 0.838 s, the highest 0.010 s occupant ridedown acceleration was -0.4 g from 0.600 to 0.610 s, and the maximum 0.050 s average was -0.2 g between 0.252 and 0.302 s. These data and other pertinent information from the test are summarized in figure 10. Vehicle angular displacements are displayed in appendix D, figure 67. Vehicular accelerations versus time traces are presented in appendix D, figures 68 through 70.

Summary of Findings

In the low-speed test on the first support, the recycled plastic sign support fractured below ground level. The fractured support rode along with the vehicle and did not penetrate or show potential for penetrating the occupant compartment, nor did it present undue hazards to others in the area. There was no deformation or intrusion into the occupant compartment. The vehicle remained upright and stable during and after the collision period. Occupant risk factors were within the preferred limits specified in *NCHRP Report 350*. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 2.5 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

Figure 9. Vehicle After Test 414587-1.



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 414587-1
- Date 08/28/97

Test Article
- Type .... Sign Support
- Name .... Recycled Plastic Sign Support
- Installation Height (m) 2.14
- Material or Key Elements .... 102 mmx102 mm Recycled Plastic Sign Support

Soil Type and Condition .... Standard Soil, Dry

Test Vehicle
- Type .... Production
- Designation 820C
- Model .... 1991 Ford Festiva
- Mass (kg) Curb 810
  - Test Inertial 820
  - Dummy 76
  - Gross Static 896

Impact Conditions
- Speed (km/h) 33.9
- Angle (deg) 0

Exit Conditions
- Speed (km/h) 24.7
- Angle (deg) 0

Change in Velocity .... 2.5 m/s

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 1.8
  - y-direction 0.6
- Ridedown Accelerations (g's)
  - x-direction .... -0.3
  - y-direction .... -0.4
- Max. 0.050 s Average (g's)
  - x-direction .... -1.2
  - y-direction .... -0.2
  - z-direction .... -0.7

Test Article Debris pattern (m)
- Longitudinal 13.7
- Lateral 1.5

Vehicle Damage
- Exterior
  - VDS 12FL1
  - CDC 12FLLN1
- Maximum Exterior
  - Vehicle Crush (mm) ...... nil
- Interior
  - OCDI LF0000000
- Max. Occ. Compart.
  - Deformation (mm) 0

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) ...... -3
- Max. Pitch Angle (deg) 3
- Max. Roll Angle (deg) 2

Figure 10. Summary of Results for Test 414587-1.

Table 1. Performance Evaluation Summary for Test 414587-1, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 414587-1 | Test Date: 08/28/97

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled plastic sign support fractured below ground level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The fractured support rode along with the vehicle and did not penetrate or show potential for penetrating the occupant compartment, nor did it present undue hazards to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
</table></td><td>Longitudinal occupant impact velocity was 1.79 m/s.
Lateral occupant impact velocity was 0.62 m/s.</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration was -0.26 g.
Lateral ridedown acceleration was -0.37 g.</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

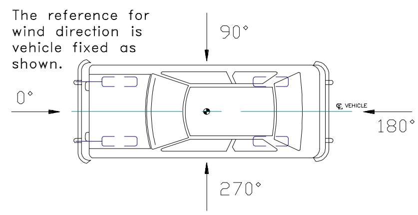
High-Speed Test (Test 414587-2; *NCHRP Report 350* Test No. 3-61)

Test Vehicle

For the second test of sign support candidate 1, another recycled plastic sign support was installed as shown in figure 11. The same 1991 Ford Festiva used in the previous crash test (shown in figures 12 and 13), was also used for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 56. The vehicle was directed into the support using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather Conditions

Researchers performed the test the afternoon of August 28, 1997. Weather conditions at the time of the test were as follows: wind speed: 6 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle traveling in a northerly direction); temperature: 32 °C; and relative humidity: 44 percent.



Test Description

The vehicle, traveling at 99.9 km/h, impacted the recycled plastic sign support at a zero degree angle with the right quarter point of the vehicle aligned with the centerline of the support. Shortly following impact, the support moved and began to fracture at bumper height. At 0.009 s the support simultaneously fractured into three pieces. The support began to separate from the bottom portion of the sign panel at 0.029 s and became completely detached at 0.031 s. The detached sign panel was suspended in midair momentarily before it came to rest to the right of the point of impact. By 0.044 s, the lower end of the middle section of the support, which measured 1.8 m, was impacted by the vehicle's hood and grill, causing it to rotate above the vehicle. Vehicle speed at this time was 98.7 km/h. The lower section of the support, measuring 0.3–0.6 m, became caught underneath the vehicle and traveled with the vehicle a distance of 15.2 m. At 0.095 s the upper end of the middle section of the support contacted the front section of the vehicle's roof, rebounded off at 0.132 s, and came to rest 33 m downstream from and 1.5 m to the right of the initial point of impact. The vehicle at this time was traveling at 98.0 km/h. Brakes on the vehicle were applied at 1.5 s, bringing it to a safe and controlled stop 98 m downstream from and 3.6 m to the left of the point of impact. Sequential photographs of the test period are presented in appendix C, figure 60.

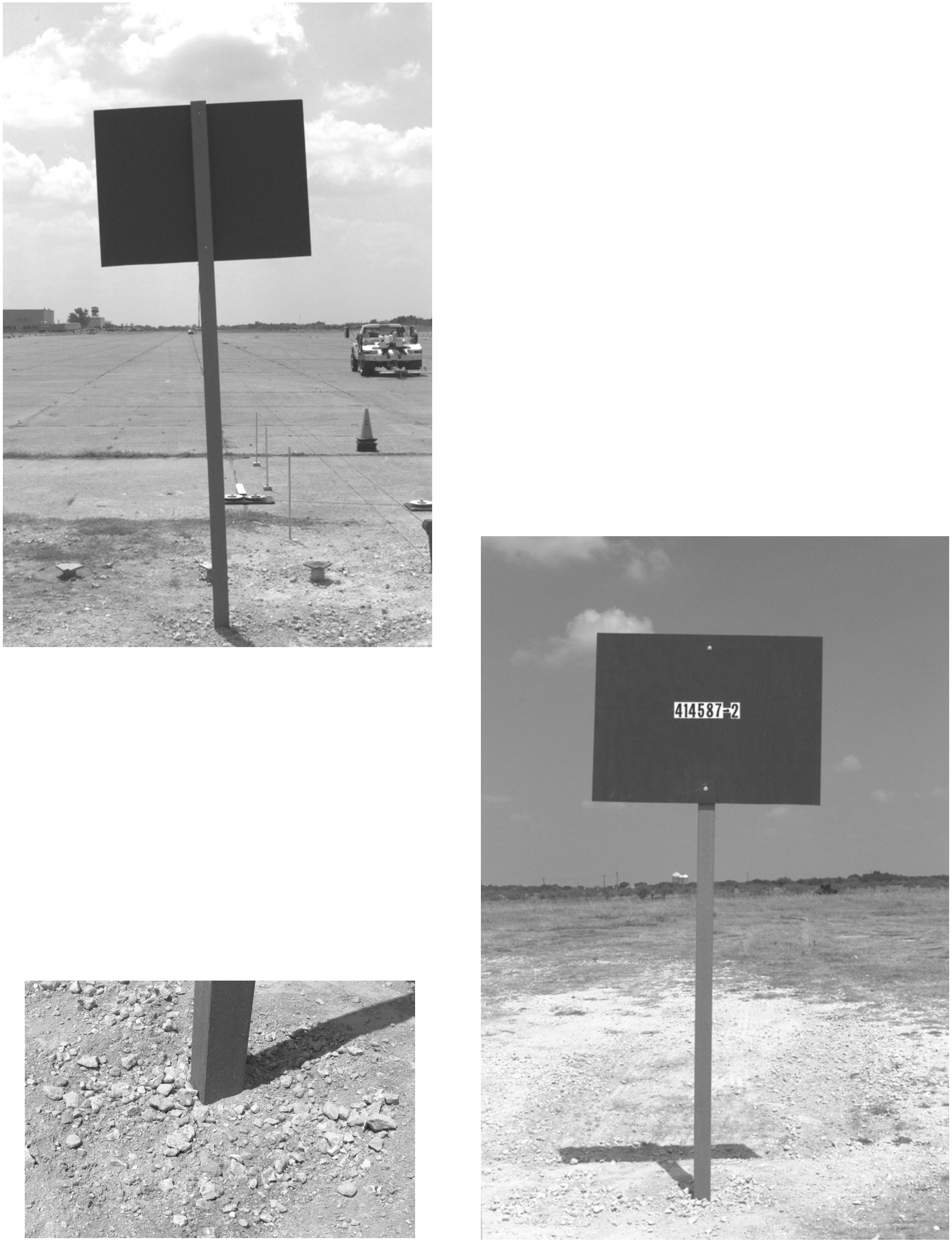


Figure 11. Recycled Plastic Sign Support Before Test 414587-2.

Figure 12. Vehicle/Support Geometrics for Test 414587-2.

Figure 13. Vehicle Before Test 414587-2.

Damage to Test Installation

The sign support fractured near ground level, as shown in figures 14 and 15, and then into three sections. The base of the support fractured at 10 mm (impact side) and 45 mm (rear side) above ground level. The sign panel and a piece of the support separated during initial impact and came to rest near the impact point. One section of the support was 0.3 to 0.6 m long, and the other was 1.8 m long. The soil around the support was only disturbed. The support was not reusable.

Vehicle Damage

Minor damage was done to the vehicle, as shown in figure 16. The right front bumper was dented in 15 mm. The roof was dented 25 mm deep in an area 700 mm in length by 900 mm wide. A scuff mark from contact with the panel was noted within the roof indentation. Maximum occupant compartment deformation was 7 mm in the rear occupant roof area.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. There was no occupant impact in either the longitudinal direction or in the lateral direction. The maximum 0.050 s average acceleration in the longitudinal direction was 0.9 g between 0.008 and 0.058 s. In the lateral direction, the maximum 0.050 s average was -0.6 g between 0.164 and 0.214 s. These data and other pertinent information from the test are summarized in figure 17. Vehicle angular displacements are displayed in appendix D, figure 71. Vehicular accelerations versus time traces are presented in appendix D, figures 72 through 74.

Summary of Findings

The recycled plastic support fractured just above ground level and then into three sections during the high-speed test. The fragments of the sign support did not penetrate or show potential for penetrating the occupant compartment, nor did it present undue hazards to others in the area. Maximum occupant compartment deformation was 7 mm in the rear passenger roof area and was judged to not cause serious injury. The vehicle remained upright and relatively stable during and after the collision period. There was no occupant contact in either the longitudinal or lateral direction during impact. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 0.5 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

Figure 14. After Impact Trajectory for Test 414587-2.

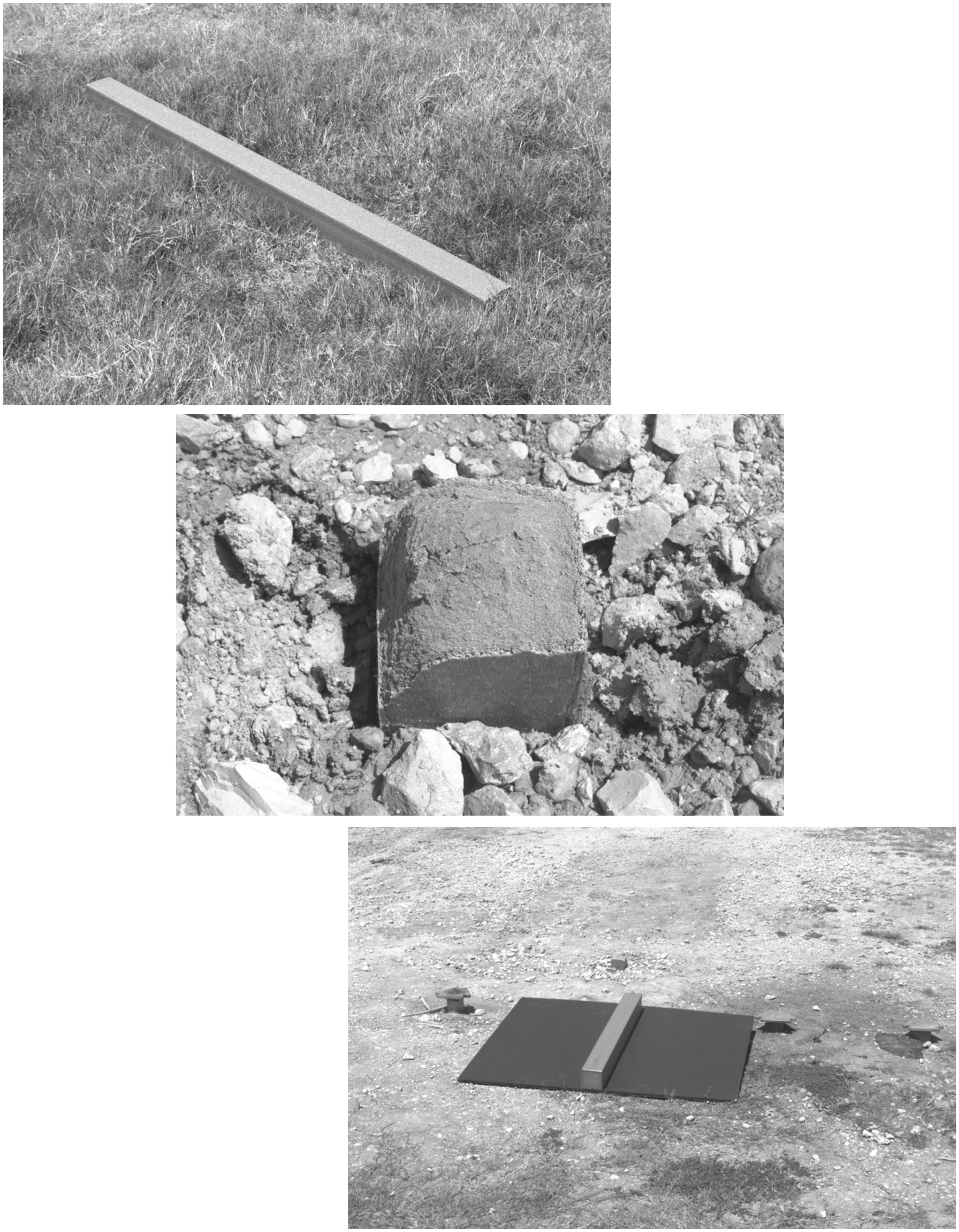


Figure 15. Support After Test 414587-2.

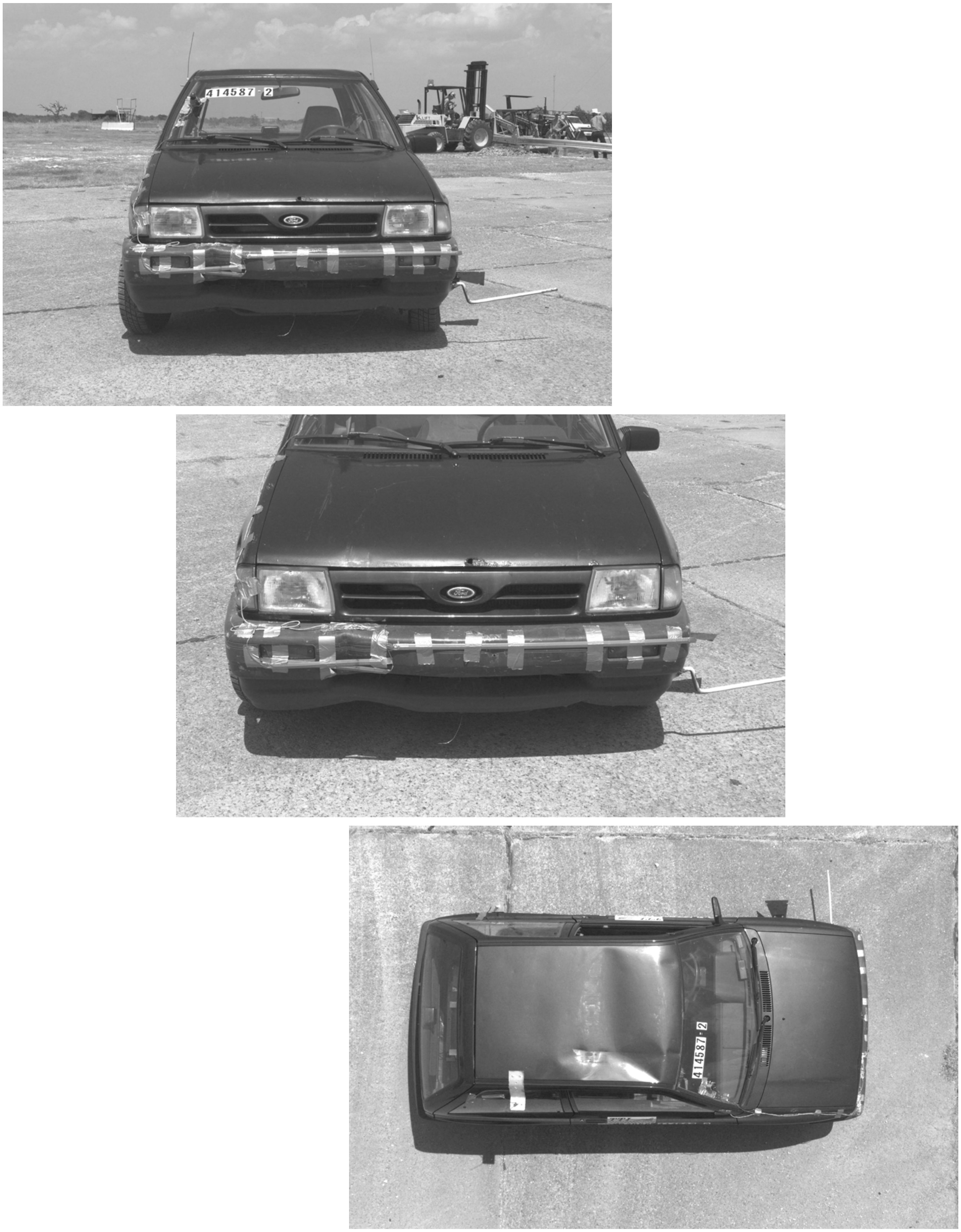


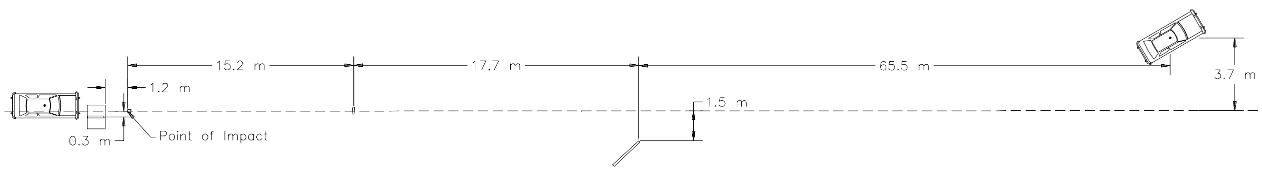
Figure 16. Vehicle After Test 414587-2.

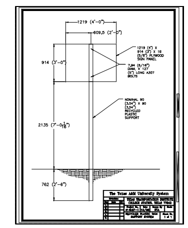
0.000 s

0.058 s

0.117 s

0.176 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	414587-2
Date	08/28/97
Test Article	
Type	Sign Support
Name	Recycled Plastic Sign Support
Installation Height (m)	2.14
Material or Key Elements	102 mmx102 mm Recycled Plastic Sign Support
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	99.9
Angle (deg)	0
Exit Conditions	
Speed (km/h)	98.0
Angle (deg)	0
Change in Velocity	0.5 m/s
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	No Contact
y-direction	No Contact
Ridedown Accelerations (g's)	
x-direction	N/A
y-direction	N/A
Max. 0.050 s Average (g's)	
x-direction	0.9
y-direction	-0.6
z-direction	-2.8

Test Article Debris pattern (m)	
Longitudinal	32.9
Lateral	1.5
Vehicle Damage	
Exterior	
VDS	12FR1
CDC	12FRLN1
Maximum Exterior Vehicle Crush (mm)	15
Interior	
OCDI	RF0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	11
Max. Pitch Angle (deg)	10
Max. Roll Angle (deg)	-4

Figure 17. Summary of Results for Test 414587-2.

Table 2. Performance Evaluation Summary for Test 414587-2, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 414587-2 | Test Date: 08/28/97

<table>
<tr><th colspan="4">NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="4"><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled plastic support fractured just above ground level and then into three sections.</td><td>Pass</td></tr>
<tr><td colspan="4"><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The fragments of the sign support did not penetrate nor show potential for penetrating the occupant compartment, nor did they present undue hazard to others in the area. Maximum occupant compartment deformation was 7 mm in the rear passenger roof area and judged to not cause serious injury.</td><td>Pass</td></tr>
<tr><td colspan="4">F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and relatively stable during and after the collision period.</td><td>Pass</td></tr>
<tr><td colspan="4">H. Occupant impact velocities should satisfy the following:</td><td rowspan="4">There was no occupant contact in either the longitudinal or lateral direction during impact.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal</td><td>3</td><td>5</td></tr>
<tr><td colspan="4">I. Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">There was no occupant contact.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="4"><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td colspan="4">N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

SIGN SUPPORT CANDIDATE 2

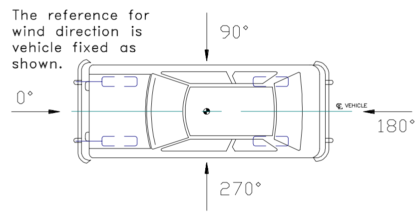
Low-Speed Test (Test 414587-3; *NCHRP Report 350* Test No. 3-60)

Test Vehicle

The installation for the low-speed test of the second recycled plastic sign support candidate is shown in figure 18. The 1991 Ford Festiva, shown in figures 19 and 20, was repaired from the previous test and used for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 56. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather Conditions

Researchers performed the test the morning of August 29, 1997. Weather conditions at the time of the test were as follows: wind speed: 9 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle traveling in a northerly direction); temperature: 26 °C; and relative humidity: 81 percent.



Test Description

The vehicle, traveling at 34.7 km/h, impacted the recycled plastic sign support at a zero degree angle, with the left quarter point of the vehicle aligned with the centerline of the support. Shortly after impact, the support began to deform back without fracturing at the ground. As the vehicle continued forward it rode up the deflecting sign support causing the left tire to leave the ground at 0.150 s, followed by the right tire at 0.283 s. The sign support continued to deform back without fracturing and impacted the ground at 0.300 s. The vehicle traveled over the sign panel and fractured the plywood panel in half from top to bottom. The fractured panel came to rest 0.9 m down from point of impact. The vehicle's right front tire returned to the ground at 0.350 s, followed by the left tire at 0.433 s. The support, with half of the panel still attached, returned to a near upright position. Brakes were applied at 3.35 s, bringing the vehicle to a safe and controlled stop 20.4 m down from and 0.9 m to the left of the point of impact. High speed film was not available, but sequential photographs of the test period taken from video are presented in appendix C, figure 61.

Damage to Test Installation

Damage to the sign support is shown in figures 21 and 22. The support had been pushed back 185 mm during the test (measured at ground level) and had a permanent displacement of

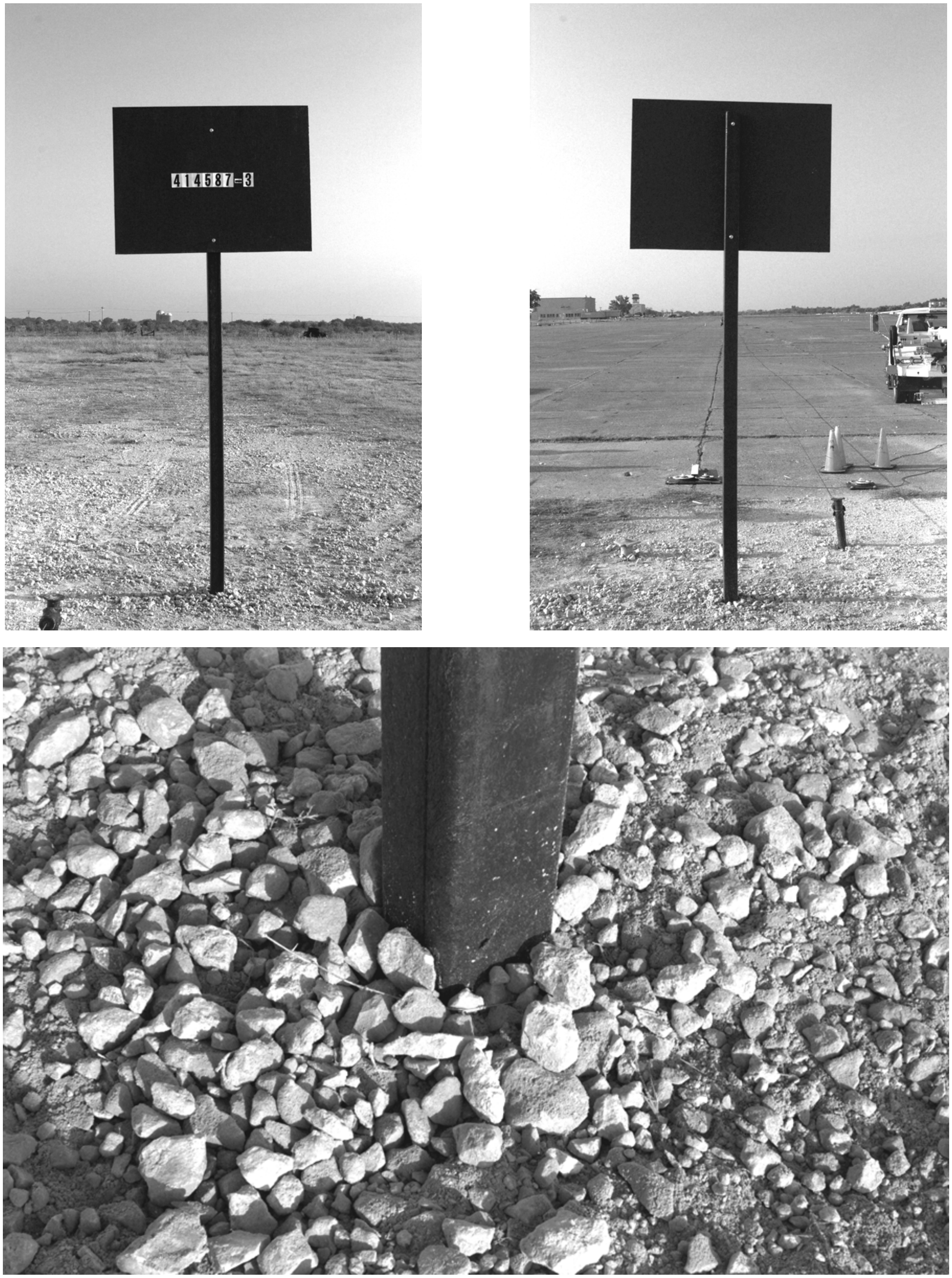


Figure 18. Recycled Plastic Sign Support Before Test 414587-3.

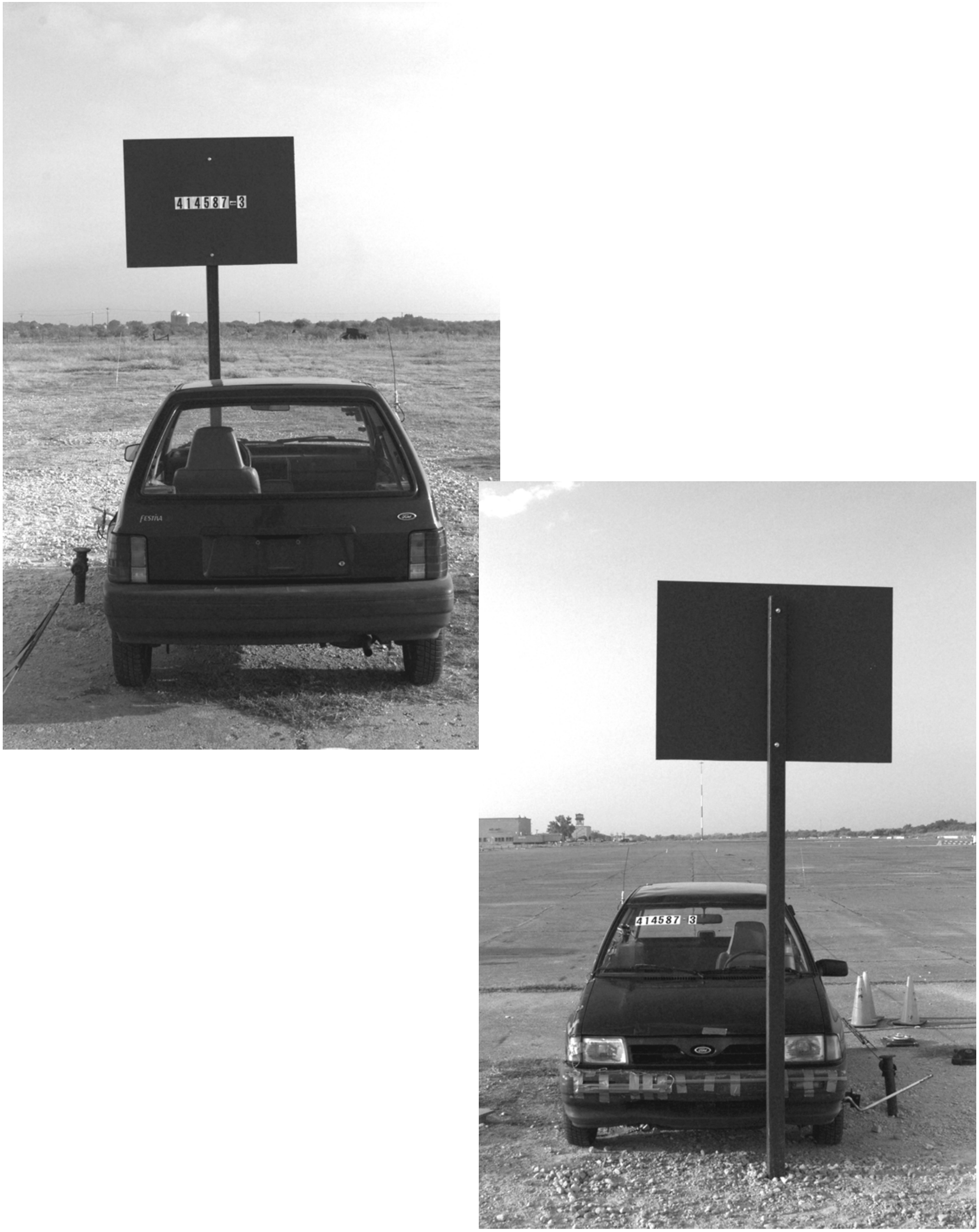


Figure 19. Vehicle/Support Geometrics for Test 414587-3.

Figure 20. Vehicle Before Test 414587-3.

Figure 21. After Impact Trajectory for Test 414587-3.

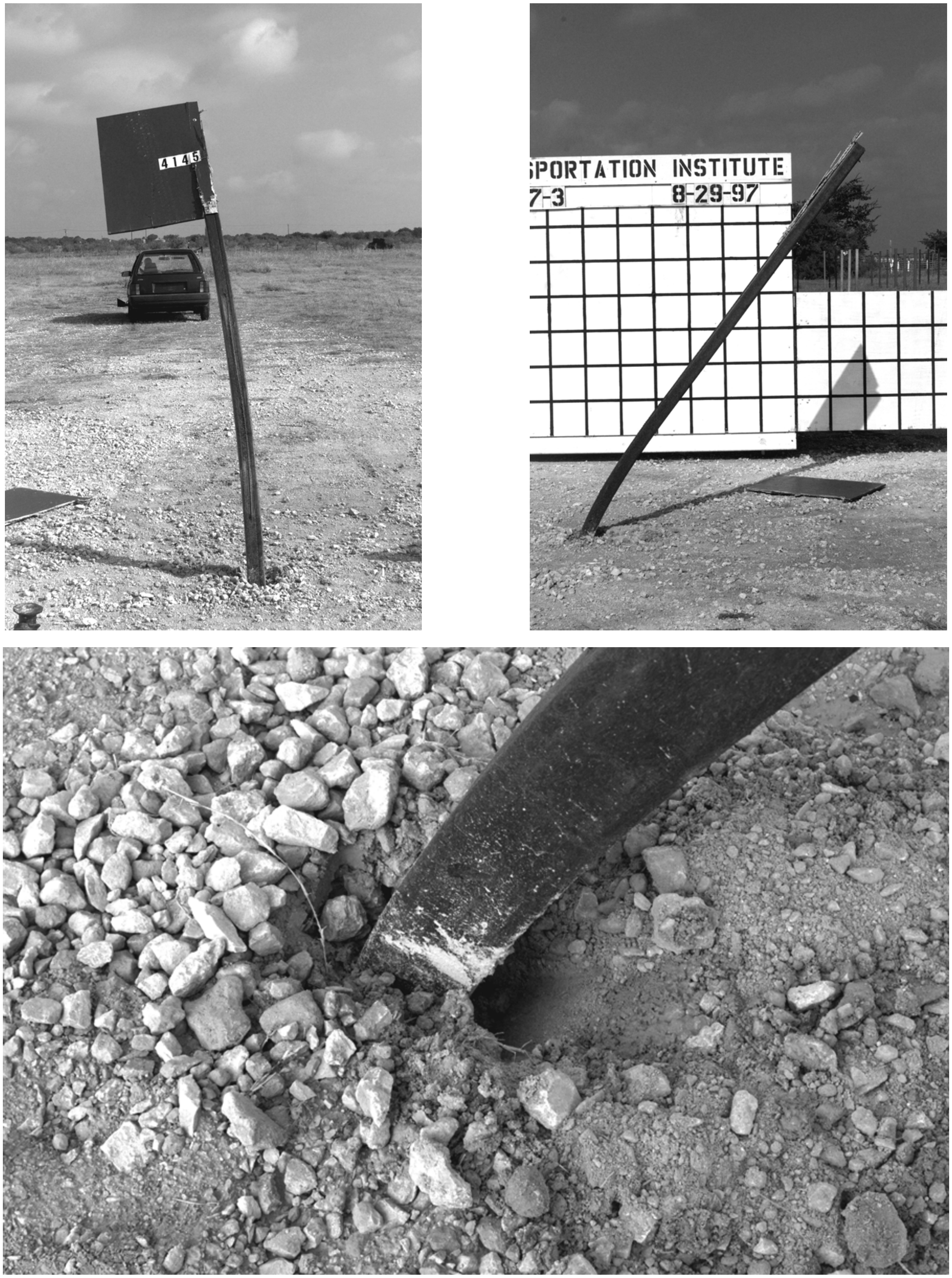


Figure 22. Support After Test 414587-3.

75 mm after the test (measured at ground level). The support did not rotate in the soil, but was leaning back at about a 60 degree angle. The plywood sign panel was split with one half remaining attached to the support and the other half coming to rest near the impact point.

Vehicle Damage

Damage received by the vehicle was minor, as shown in figure 23. The left front bumper showed no damage from contact with the support. A dent was noted on the lower left air deflector. No deformation or intrusion into the occupant compartment occurred. The vehicle was re-used in the next test.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 3.1 m/s at 0.308 s, the highest 0.010 s occupant ridedown acceleration was -1.06 g from 0.468 to 0.478 s, and the maximum 0.050 s average acceleration was -2.0 g between 0.021 and 0.071 s. In the lateral direction, the occupant impact velocity was 1.1 m/s at 0.0645 s, the highest 0.010 s occupant ridedown acceleration was -2.1 g from 0.402 to 0.412 s, and the maximum 0.050 s average was -0.5 g between 0.402 and 0.452 s. These data and other pertinent information from the test are summarized in figure 24. Vehicle angular displacements are displayed in appendix D, figure 75. Vehicular accelerations versus time traces are presented in appendix D, figures 76 through 78.

Summary of Findings

In the low-speed test on the second support, the recycled plastic support yielded to the vehicle. The support partially righted itself after the vehicle passed over it. The sign panel fractured and separated from the support but did not penetrate or show potential for penetrating the occupant compartment, nor did it present undue hazards to others in the area. There was no deformation or intrusion into the occupant compartment. The vehicle remained upright and stable during and after the collision period. Occupant risk factors were just over the preferred but within the maximum limits specified in *NCHRP Report 350*. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 3.1 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

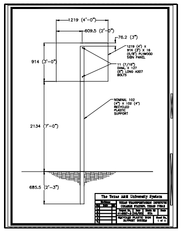
Figure 23. Vehicle After Test 414587-3.


0.000 s


0.083 s


0.200 s


0.416 s



General Information	
Test Agency	Texas Transportation Institute
Test No.	414587-3
Date	08/29/97
Test Article	
Type	Sign Support
Name	Recycled Plastic Sign Support
Installation Height (m)	2.14
Material or Key Elements	102 mmx102 mm Recycled Plastic Sign Support
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	34.7
Angle (deg)	0
Exit Conditions	
Speed (km/h)	23.6
Angle (deg)	0
Change in Velocity	3.1 m/s
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.1
y-direction	1.1
Ridedown Accelerations (g's)	
x-direction	-1.0
y-direction	-2.1
Max. 0.050-s Average (g's)	
x-direction	-2.0
y-direction	-0.5
z-direction	0.9

Test Article Debris pattern (m)	
Longitudinal	0.9
Lateral	1.5
Vehicle Damage	
Exterior	
VDS	12FL1
CDC	12FLLN1
Maximum Exterior Vehicle Crush (mm)	nil
Interior	
OCDI	LF0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-9
Max. Pitch Angle (deg)	5
Max. Roll Angle (deg)	8

Figure 24. Summary of Results for Test 414587-3.

Table 3. Performance Evaluation Summary for Test 414587-3, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 414587-3 | Test Date: 08/29/97

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled plastic support yielded to the vehicle. The support partially righted itself after the vehicle passed over it.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The sign panel fractured and separated from the support but did not penetrate nor show potential for penetrating the occupant compartment, nor did it present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
</table></td><td>Longitudinal occupant impact velocity was 3.12 m/s.
Lateral occupant impact velocity was 1.10 m/s.</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration was -0.96 g.
Lateral ridedown acceleration was -2.14 g.</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

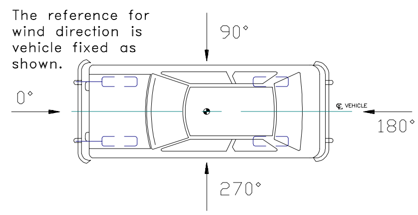
High-Speed Test (Test 414587-4; *NCHRP Report 350* Test No. 3-61)

Test Vehicle

Another recycled plastic sign support was installed for the high-speed test of the second sign support candidate as shown in figure 25. The 1991 Ford Festiva used in the previous crash tests and shown in figures 26 and 27, was repaired and re-used for this test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 56. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather Conditions

Researchers performed the test the afternoon of August 29, 1997. Weather conditions at the time of the test were as follows: wind speed: 9 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle traveling in a northerly direction); temperature: 34 °C; and relative humidity: 84 percent.



Test Description

The vehicle, traveling at 100.2 km/h, impacted the sign support at zero degrees, with the right quarter point of the vehicle aligned with the centerline of the support. Shortly following impact, the support began to deform at bumper height. At 0.017 s the support began to pull out of the ground and was clear of the ground at 0.033 s. The sign panel separated from the support at 0.050 s. At 0.066 s the bottom of the sign panel contacted the front section of the vehicle’s roof approximately 25–50 mm from the top of the windshield. The sign panel was flat on top of the roof at 0.083 s and snagged the hinges of the hatchback door, causing damage to that area of the vehicle. As the panel tore free, it rotated parallel to the ground and came to rest 22.8 m down from and 6 m to the right of point of impact. By 0.117 s the upper section of plastic support that was connected to the sign panel lost contact with the vehicle. The support itself did not come in contact with the vehicle’s roof or windshield and came to rest 42 m down from and 1.5 m to the right of the point of impact. At 2.0 s, brakes on the vehicle were applied, bringing it to a safe and controlled stop 64.8 m down from the point of impact. High speed film was not available, but sequential photographs of the test period taken from video are presented in appendix C, figure 62.

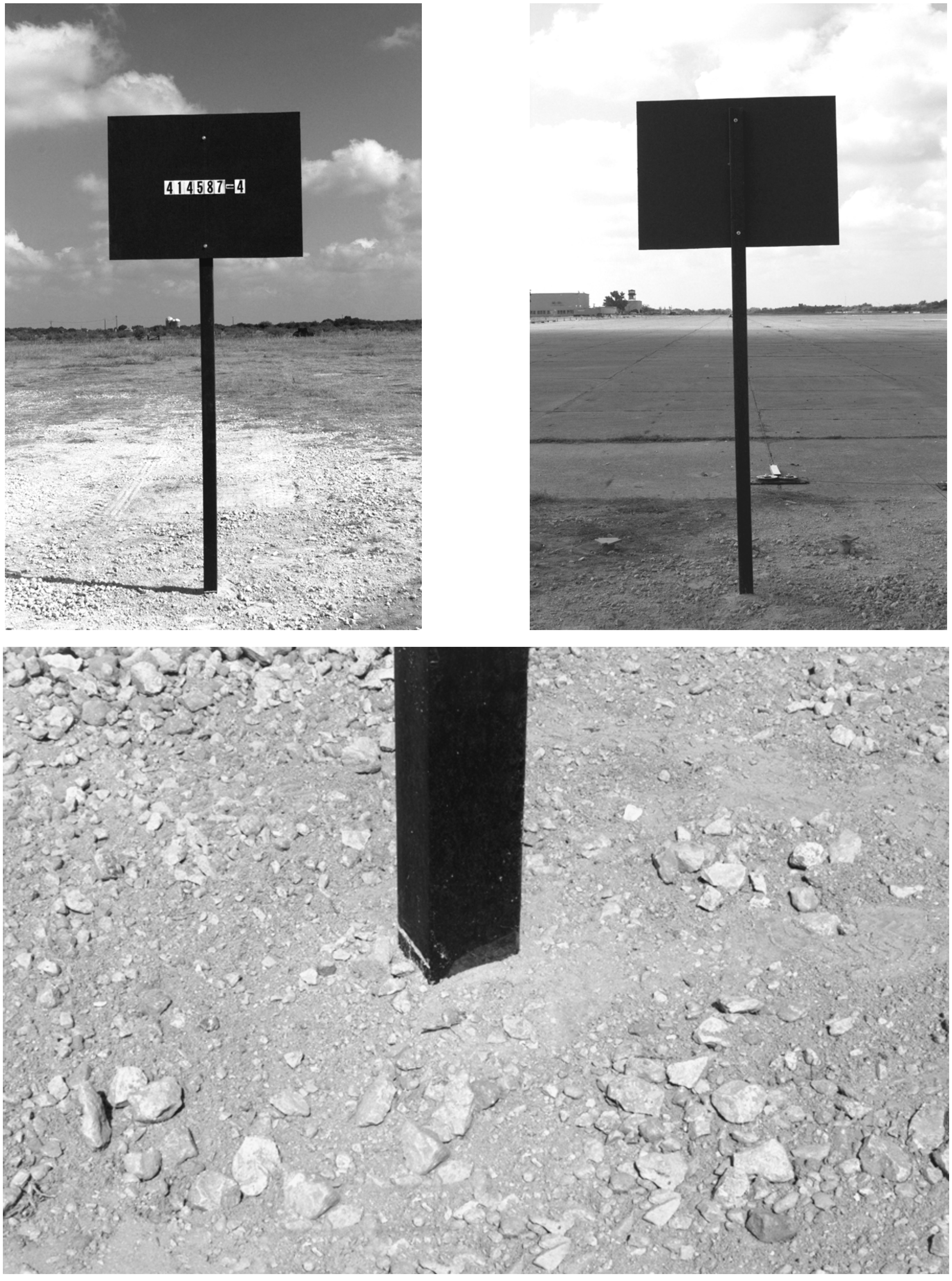


Figure 25. Recycled Plastic Sign Support Before Test 414587-4.

Figure 26. Vehicle/Support Geometrics for Test 414587-4.

Figure 27. Vehicle Before Test 414587-4.

Damage to Test Installation

As can be seen in figures 28 and 29, the support pulled out of the ground without fracturing. The support was deformed from ground level to just above bumper height. The sign panel was split and separated from the support.

Vehicle Damage

Figure 30 shows the moderate damage sustained by the vehicle. The right front bumper was dented 30 mm, and the right front headlight was broken. The hood was slightly dented. A dent in the roof measuring 960 mm long by 960 mm wide by 17 mm deep was noted. The rear hatch was damaged on the right side with a gap between the body and the hatch of 120 mm. Maximum exterior crush to the right side of the vehicle was 30 mm at the bumper. Maximum occupant compartment deformation was 37 mm in the roof toward the rear of the occupant compartment. Exterior crush and occupant compartment measurements are shown in appendix B, tables 11 and 12.

Occupant Risk Values

Operators digitized data from the accelerometer located at the vehicle center of gravity for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 2.0 m/s at 0.413 s, the highest 0.010 s occupant ridedown acceleration was -0.5 g from 0.482 to 0.492 s, and the maximum 0.050 s average acceleration was -2.3 g between 0.004 and 0.054 s. In the lateral direction, the occupant impact velocity was -1.3 m/s at 0.672 s, the highest 0.010 s occupant ridedown acceleration was 0.9 g from 0.848 to 0.858 s, and the maximum 0.050 s average was 0.6 g between 0.267 and 0.317 s. These data and other pertinent information from the test are summarized in figure 31. Vehicle angular displacements are displayed in appendix D, figure 79. Vehicular accelerations versus time traces are presented in appendix D, figures 80 through 82.

Summary of Findings

The recycled sign support pulled out of the ground in the high-speed test on the second support. The support pulled out of the ground, and the sign panel separated from the support but did not penetrate the occupant compartment, nor did it show potential for penetrating the occupant compartment. Hazards to others in the area would be minimal. There was 35 mm deformation into the rear passenger roof area and was judged to not cause serious injury. The vehicle remained upright and relatively stable during and after the collision period. Occupant risk factors were within the preferred limits specified in *NCHRP Report 350*. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 2.3 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

Figure 28. After Impact Trajectory for Test 414587-4

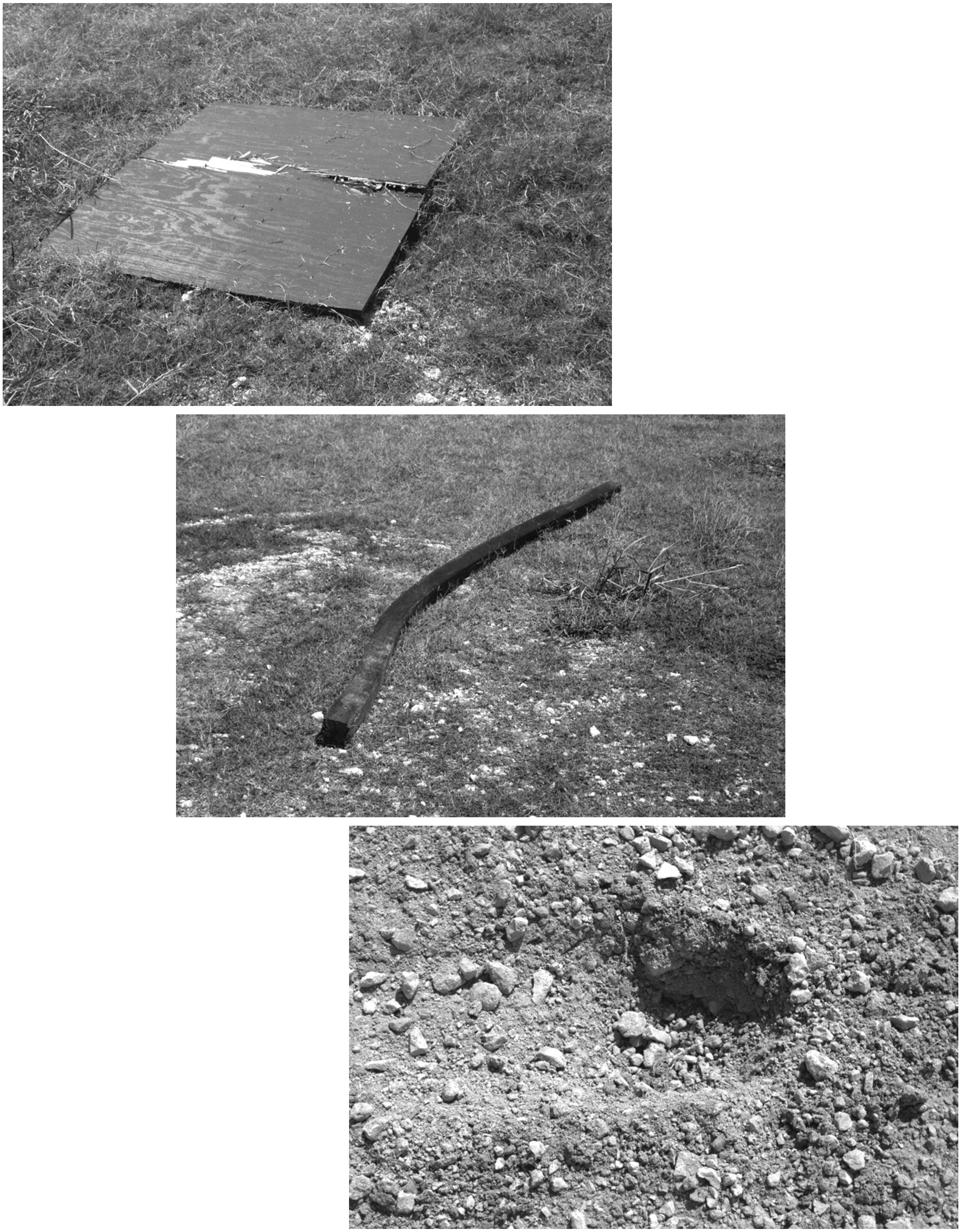


Figure 29. Support After Test 414587-4.

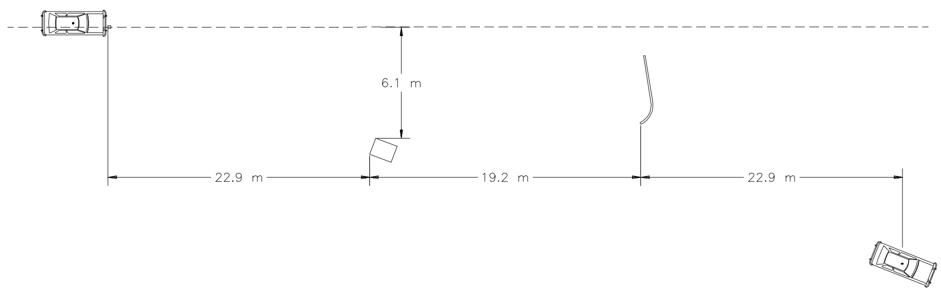
Figure 30. Vehicle After Test 414587-4.

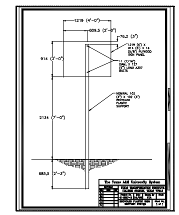

0.000 s


0.033 s


0.083 s


0.150 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	414587-4
Date	08/29/97
Test Article	
Type	Sign Support
Name	Recycled Plastic Sign Support
Installation Height (m)	2.14
Material or Key Elements	102 mmx102 mm Recycled Plastic Sign Support
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	100.3
Angle (deg)	0
Exit Conditions	
Speed (km/h)	92.0
Angle (deg)	0
Change in Velocity	2.3 m/s
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.0
y-direction	1.3
Ridedown Accelerations (g's)	
x-direction	-0.5
y-direction	0.9
Max. 0.050 s Average (g's)	
x-direction	-2.3
y-direction	0.6
z-direction	-2.1

Test Article Debris pattern (m)	
Longitudinal	42.1
Lateral	6.1
Vehicle Damage	
Exterior	
VDS	12FR1
CDC	12FRLN1
Maximum Exterior Vehicle Crush (mm)	30
Interior	
OCDI	LF0000000
Max. Occ. Compart. Deformation (mm)	37
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	10
Max. Pitch Angle (deg)	8
Max. Roll Angle (deg)	-4

Figure 31. Summary of Results for Test 414587-4.

Table 4. Performance Evaluation Summary for Test 414587-4, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 414587-4 | Test Date: 08/29/97

<table>
<tr><th colspan="4">NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="4"><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled sign support pulled out of the ground.</td><td>Pass</td></tr>
<tr><td colspan="4"><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The support pulled out of the ground and the sign panel separated from the support but did not penetrate the occupant compartment, nor show potential for penetrating the occupant compartment. Hazards to others in the area would be minimal. There was 35 mm deformation into the rear passenger roof area and was judged to not cause serious injury.</td><td>Pass</td></tr>
<tr><td colspan="4">F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and relatively stable during and after the collision period.</td><td>Pass</td></tr>
<tr><td colspan="4">H. Occupant impact velocities should satisfy the following:</td><td rowspan="4">Longitudinal occupant impact velocity was 1.95 m/s.
Lateral occupant impact velocity was -1.32 m/s.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal</td><td>3</td><td>5</td></tr>
<tr><td colspan="4">I. Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">Longitudinal ridedown acceleration was -0.52 g.
Lateral ridedown acceleration was 0.91 g.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="4"><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td colspan="4">N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

SIGN SUPPORT CANDIDATE 3

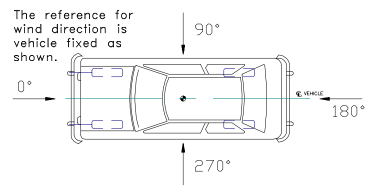
Low-Speed Test (Test 414588-2; *NCHRP Report 350* Test No. 3-60)

Test Vehicle

The third recycled plastic sign support candidate was installed for the low-speed test as shown in figure 32. A 1994 Geo Metro, shown in figures 33 and 34, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 895 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 57. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather and Soil Conditions

Researchers performed the test the morning of May 29, 1998. No rain occurred during the 10 days prior to the test. Moisture content of the *NCHRP Report 350* standard soil used for the test was 7.4 percent. Weather conditions during the time of the test were as follows: wind speed: 14 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 27 °C; relative humidity: 75 percent.



Test Description

The vehicle, traveling at 34.7 km/h, impacted the recycled plastic support with the right quarter point at zero degree. At 0.041 s the support fractured just below ground level and began to rotate toward the vehicle. The top and bottom brackets on the sign panel sheared at 0.080 s and 0.082 s, respectively, releasing the sign panel from the support. At 0.156 s the vehicle began to ride up the support, and the left front wheel momentarily left the ground followed by the right. The vehicle lost contact with the support at 0.329 s while traveling at a speed of 22.9 km/h. As the vehicle continued forward, the corner of the plywood sign panel contacted the hood at 0.388 s and then the windshield at 0.393 s. The sign panel bounced off the vehicle at 0.440 s. At 0.536 s the left front wheel returned to the ground. At 0.704 s the sign panel lightly grazed the vehicle on the passenger door as it fell to the ground 3.6 m down from and 2.6 m to the right of the point of impact. The support traveled along with the vehicle and came to rest in front of the vehicle 30.0 m down from the point of impact. Brakes on the vehicle were not applied. The vehicle came to a safe and controlled stop on its own 26.0 m down from the point of impact. Sequential photographs of the test period are shown in appendix C, figure 63.

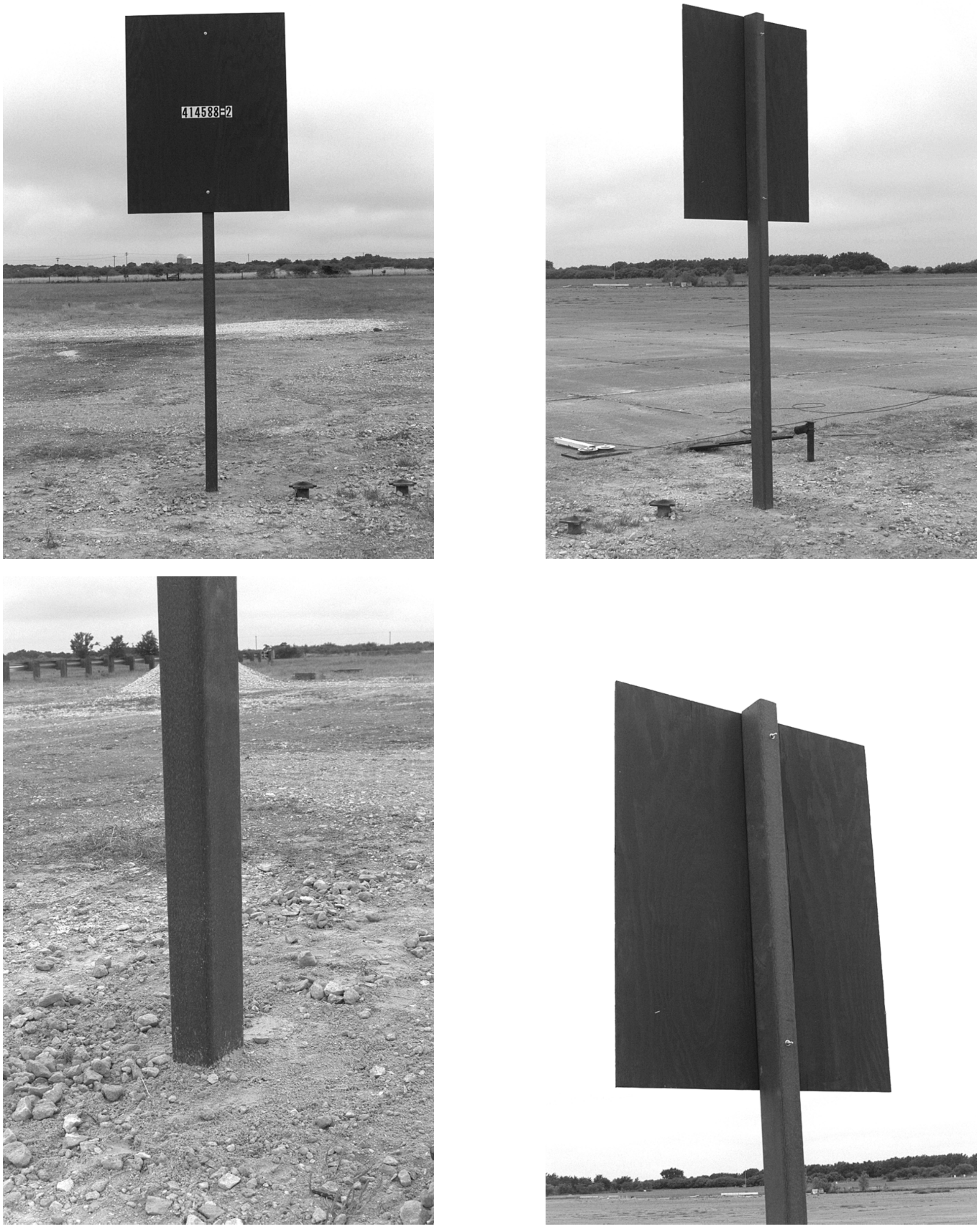


Figure 32. Recycled Plastic Sign Support Before Test 414588-2.

Figure 33. Vehicle/Support Geometrics for Test 414588-2.

Figure 34. Vehicle Before Test 414588-2.

Damage to Test Installation

As can be seen in figures 35 and 36, the support fractured just below ground level leaving 788 mm below the ground. The sign panel was separated from the support.

Vehicle Damage

As can be seen in figure 37, minimal damage was received by the vehicle. There was a small indentation in the bumper, and the hood, windshield, and passenger door were scuffed. No measurable crush occurred to the exterior of the vehicle, and no deformation of the occupant compartment occurred. Occupant compartment measurements are shown in appendix B, table 13.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 2.7 m/s at 0.297 s, the highest 0.010 s occupant ridedown acceleration was 0.5 g from 0.331 to 0.341 s, and the maximum 0.050 s average acceleration was -2.9 g between 0.011 and 0.061 s. In the lateral direction, the occupant impact velocity was 0.8 m/s at 0.784 s, the highest 0.010 s occupant ridedown acceleration was 0.6 g from 0.306 to 0.316 s, and the maximum 0.050 s average was 0.4 g between 0.034 and 0.084 s. These data and other pertinent information from the test are summarized in figure 38. Vehicle angular displacements are displayed in appendix D, figure 83. Vehicular accelerations versus time traces are presented in appendix D, figures 84 through 86.

Summary of Findings

In test 414588-2, the recycled plastic support fractured just below ground level. The support fragment and sign panel did not penetrate nor show potential for penetrating the occupant compartment, nor did it present undue hazards to others in the area. No deformation or intrusion of the occupant compartment occurred. The vehicle remained upright during and after the collision period. Occupant risk factors were within the limits specified in *NCHRP Report 350*. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 3.2 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

Figure 35. After Impact Trajectory for Test 414588-2.

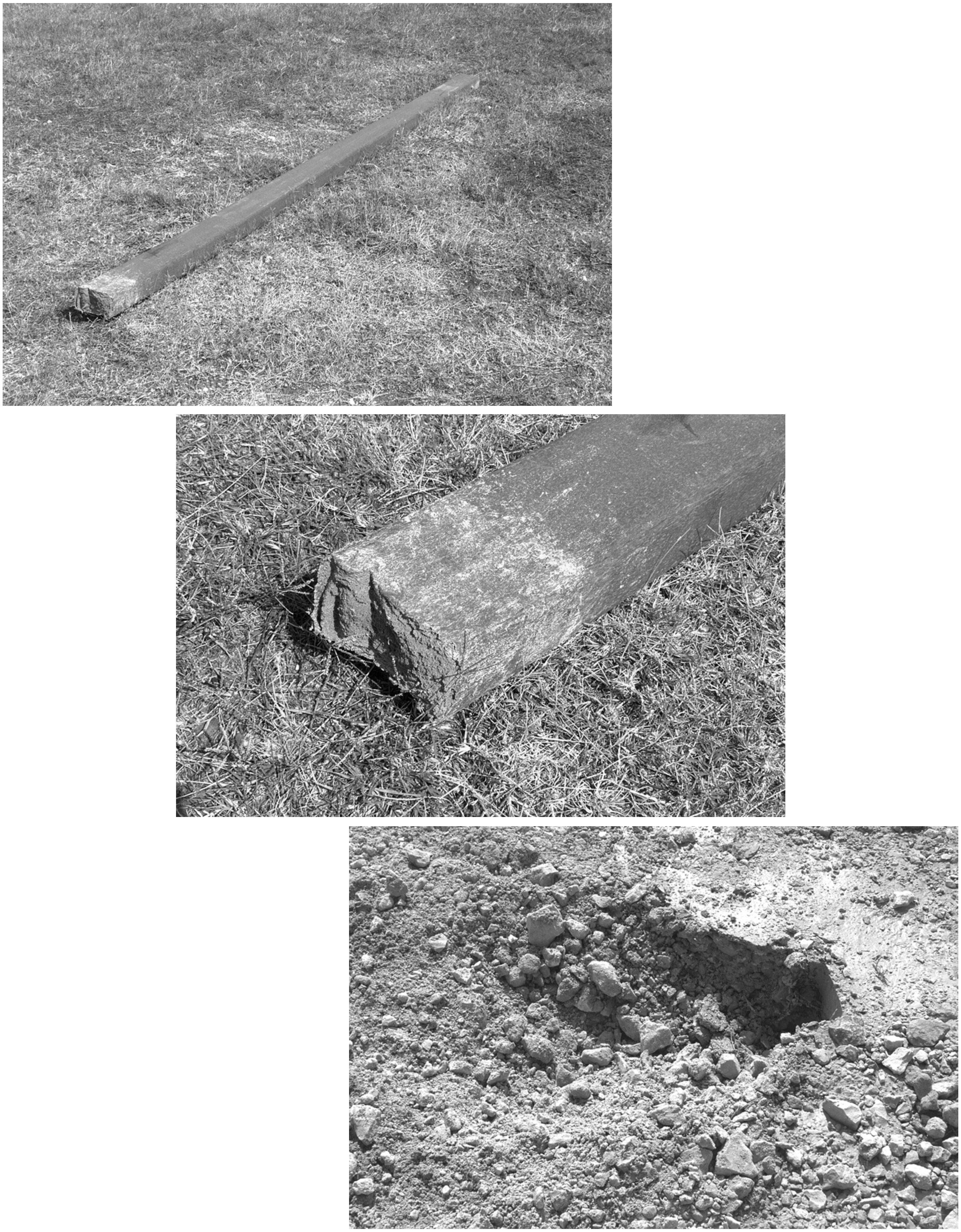
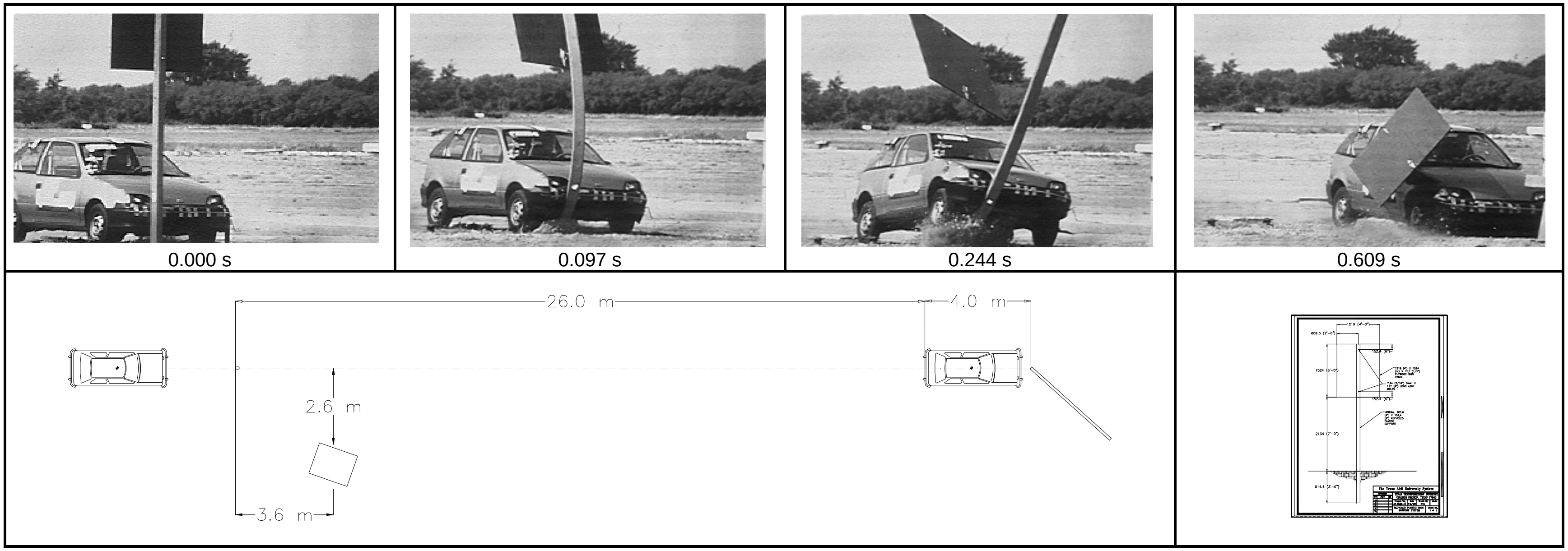


Figure 36. Support After Test 414588-2.

Figure 37. Vehicle After Test 414588-2.



General Information	
Test Agency	Texas Transportation Institute
Test No.	414588-2
Date	05/29/98
Test Article	
Type	Sign Support
Name	Recycled Plastic Sign Support
Installation Height (m)	2.13
Material or Key Elements	90 mmx140 mm Recycled Plastic Sign Support
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (kg) Curb	750
Test Inertial	820
Dummy	75
Gross Static	895

Impact Conditions	
Speed (km/h)	34.7
Angle (deg)	0
Exit Conditions	
Speed (km/h)	22.9
Angle (deg)	0
Change in Velocity	3.2 m/s
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.7
y-direction	0.6
Ridedown Accelerations (g's)	
x-direction	0.5
y-direction	0.6
Max. 0.050 s Average (g's)	
x-direction	-2.9
y-direction	0.4
z-direction	-1.6

Test Article Debris pattern (m)	
Longitudinal	30.0
Lateral	2.7
Vehicle Damage	
Exterior	
VDS	12FR1
CDC	12FRLN1
Maximum Exterior Vehicle Crush (mm)	nil
Interior	
OCDI	RF0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	7
Max. Pitch Angle (deg)	5
Max. Roll Angle (deg)	-8

Figure 38. Summary of Results for Test 414588-2.

Table 5. Performance Evaluation Summary for Test 414588-2, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 414588-2 | Test Date: 05/29/98

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled plastic support fractured just below ground level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The support fragment and sign panel did not penetrate nor show potential for penetrating the occupant compartment, nor did they present undue hazards to others in the area. No deformation or intrusion of the occupant compartment occurred.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright during and after the collision period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal</td><td>3</td><td>5</td></tr></table></td><td>Longitudinal occupant impact velocity was 2.7 m/s.
Lateral occupant impact velocity was 0.8 m/s.</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal ridedown acceleration was 0.5 g.
Lateral ridedown acceleration was 0.6 g.</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

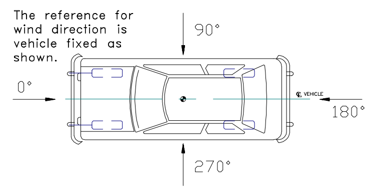
High-Speed Test (Test 414588-3; *NCHRP Report 350* Test No. 3-61)

Test Vehicle

Another recycled plastic sign support was installed for the high-speed test of the third sign support candidate as shown in figure 39. The vehicle used in the previous test, a 1994 Geo Metro, shown in figures 40 and 41, was re-used for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 895 kg. Additional dimensions and information on the vehicle are given in appendix B, figure 57. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Weather and Soil Conditions

Researchers performed the test the afternoon of May 29, 1998. No rain occurred during the 10 days prior to the test. Moisture content of the *NCHRP Report 350* standard soil used for the test was 7.4 percent. Weather conditions during the time of the test were as follows: wind speed: 10 km/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 31 °C; relative humidity: 62 percent.



Test Description

The vehicle, traveling at 102.3 km/h, impacted the recycled plastic support with the left quarter point at zero degree. Immediately upon impact the support moved, and by 0.019 s the support had pushed through the soil at ground level. At 0.024 s the support fractured near hood height of the vehicle, and the lower bracket attaching the sign panel to the support failed. The support fractured at a second location below ground level at 0.032 s. At 0.046 s the lower segment of the fractured post, which was 920 mm long, contacted the ground and bounced in front of the vehicle. The vehicle lost contact with the support while traveling at a speed of 95.5 km/h. At 0.112 s the upper bracket of the sign panel failed, causing the plywood panel to separate from the support. The upper fragment of the support was parallel over the roof of the vehicle at 0.136 s. This fragment was 2920 mm long and eventually came to rest 10.5 m down from and 2.2 m to the left of the point of impact. The smaller fragment traveled along with the vehicle and came to rest 13.0 m down from and 1.7 m to the right of the point of impact. Brakes on the vehicle were applied at 1.75 s after impact as the vehicle exited the test site. The vehicle subsequently came to a safe, controlled stop 86.5 m down from and 7.0 m to the left of the point of impact. Sequential photographs of the test period are shown in appendix C, figure 64.

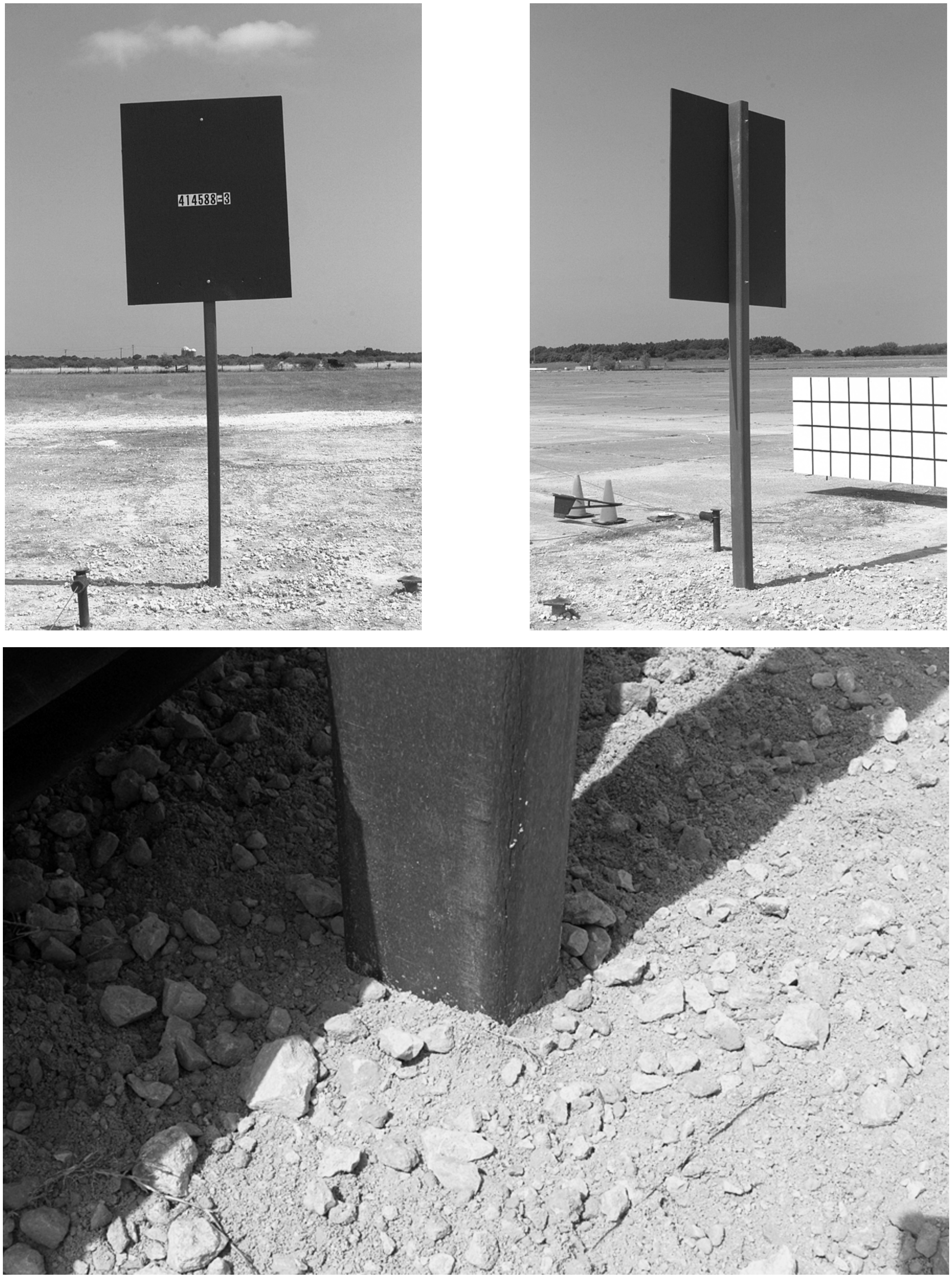


Figure 39. Recycled Plastic Sign Support Before Test 414588-3.

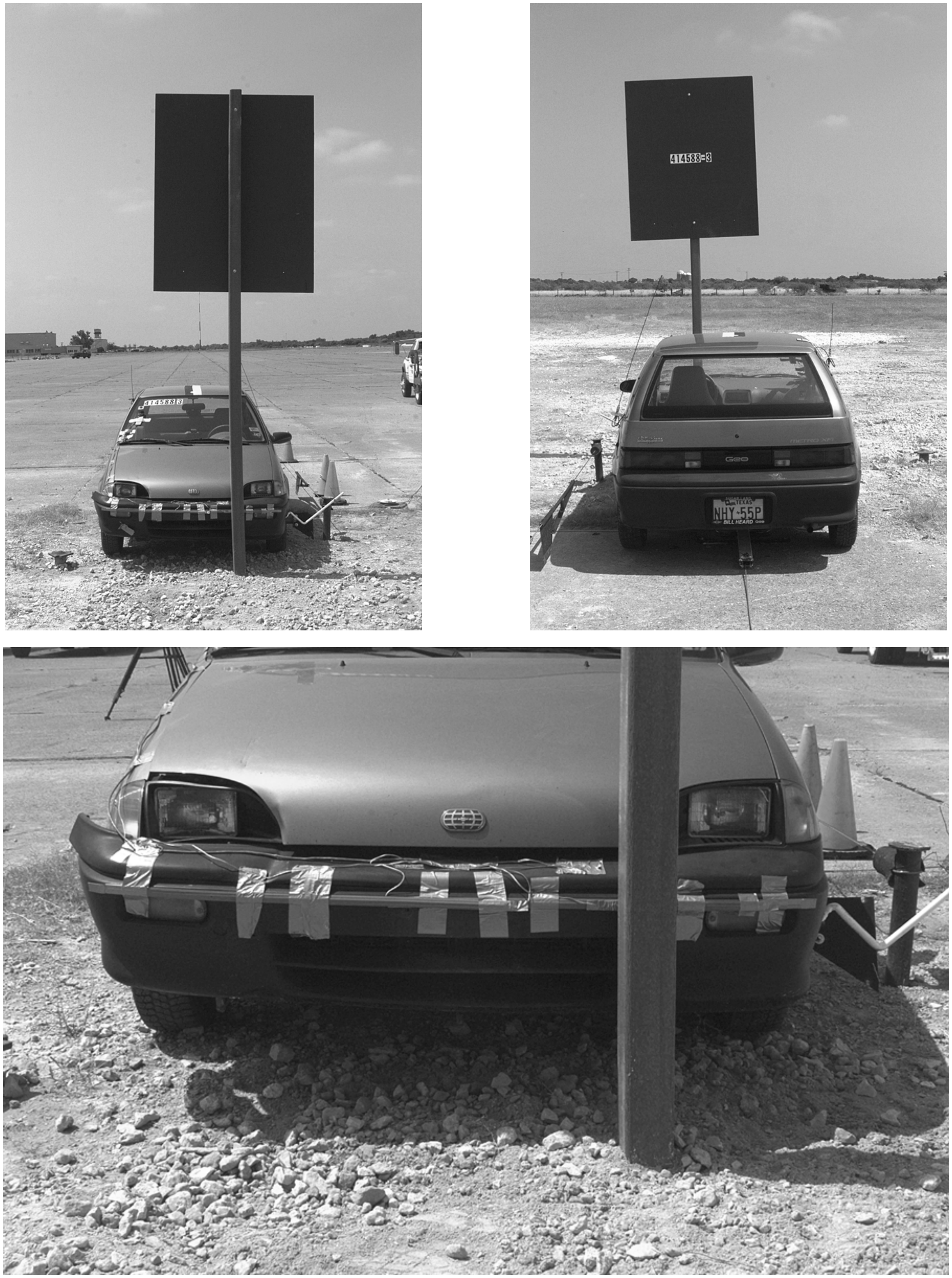


Figure 40. Vehicle/Support Geometrics for Test 414588-3.

Figure 41. Vehicle Before Test 414588-3.

Damage to Test Installation

As can be seen in figures 42 and 43, the support fractured into three pieces. A piece 680 mm long remained below ground. The other fragments were 920 mm long and 2920 mm long. The sign panel was separated from the support.

Vehicle Damage

As can be seen in figure 44, minimal damage was received by the vehicle. The front bumper, inner bumper, hood, and radiator support were deformed. Maximum exterior crush to the vehicle was 120 mm occurring at the left quarter point at bumper height. No deformation or intrusion of the occupant compartment occurred. Exterior crush measurements are shown in table 15.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 1.9 m/s at 0.415 s, the highest 0.010 s occupant ridedown acceleration was -1.0 g from 0.415 to 0.425 s, and the maximum 0.050 s average acceleration was -2.8 g between 0.003 and 0.053 s. In the lateral direction, the occupant impact velocity was 1.4 m/s at 0.499 s, the highest 0.010 s occupant ridedown acceleration was -1.5 g from 0.680 to 0.690 s, and the maximum 0.050 s average was -0.7 g between 0.311 and 0.361 s. These data and other pertinent information from the test are summarized in figure 45. Vehicle angular displacements are displayed in appendix D, figure 87. Vehicular accelerations versus time traces are presented in appendix D, figures 88 through 90.

Summary of Findings

The recycled plastic support fractured into three pieces during test 414588-3. The fractured support and sign panel did not penetrate nor show potential for penetrating the occupant compartment, nor did they show potential for undue hazards to others in the area. No deformation or intrusion of the occupant compartment occurred. The vehicle remained upright during and after the collision event. Occupant risk factors were within the limits specified in *NCHRP Report 350*. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The change in velocity was 1.9 m/s, which is within the preferred limit set forth in the AASHTO Specifications.

Figure 42. After Impact Trajectory for Test 414588-3.

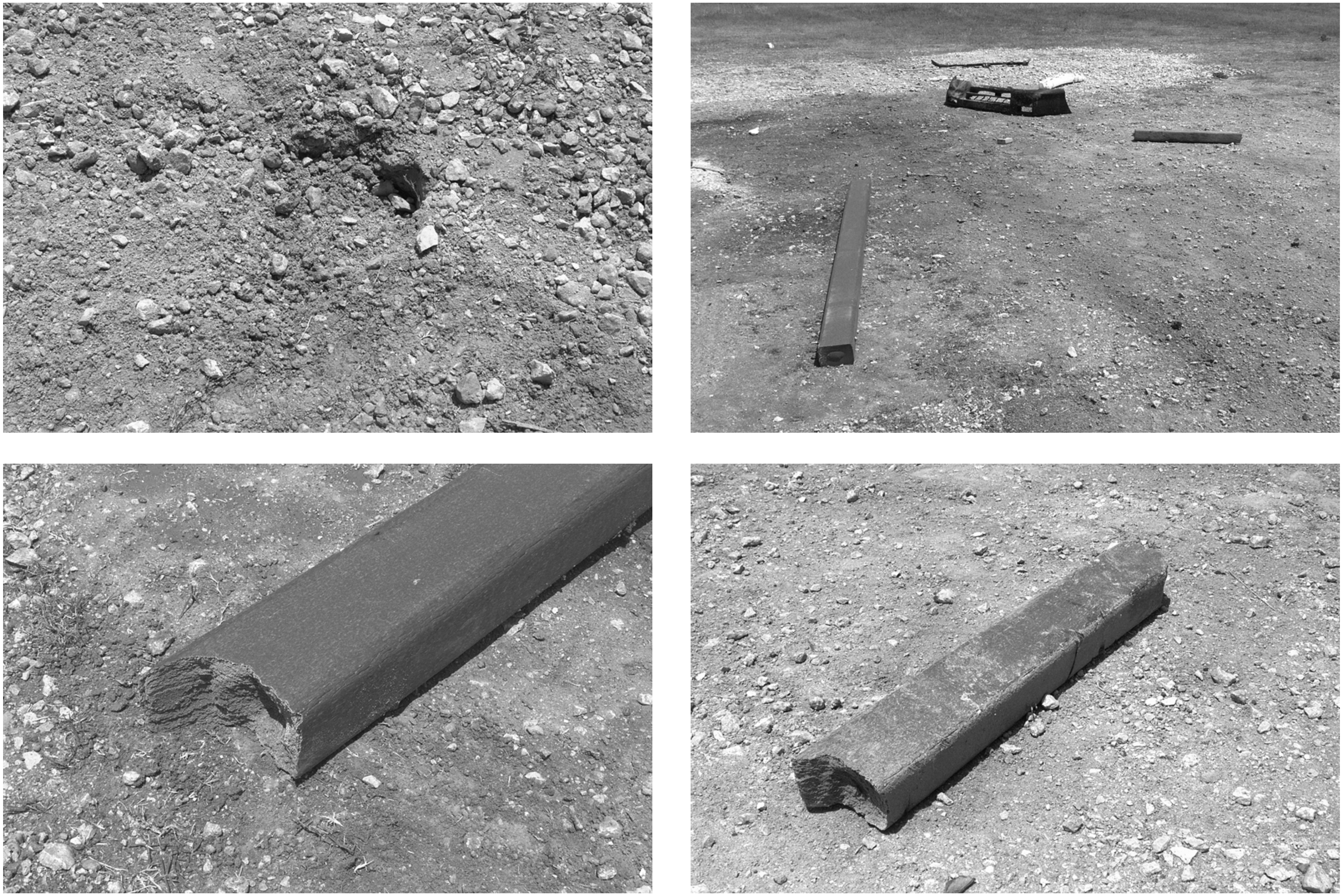
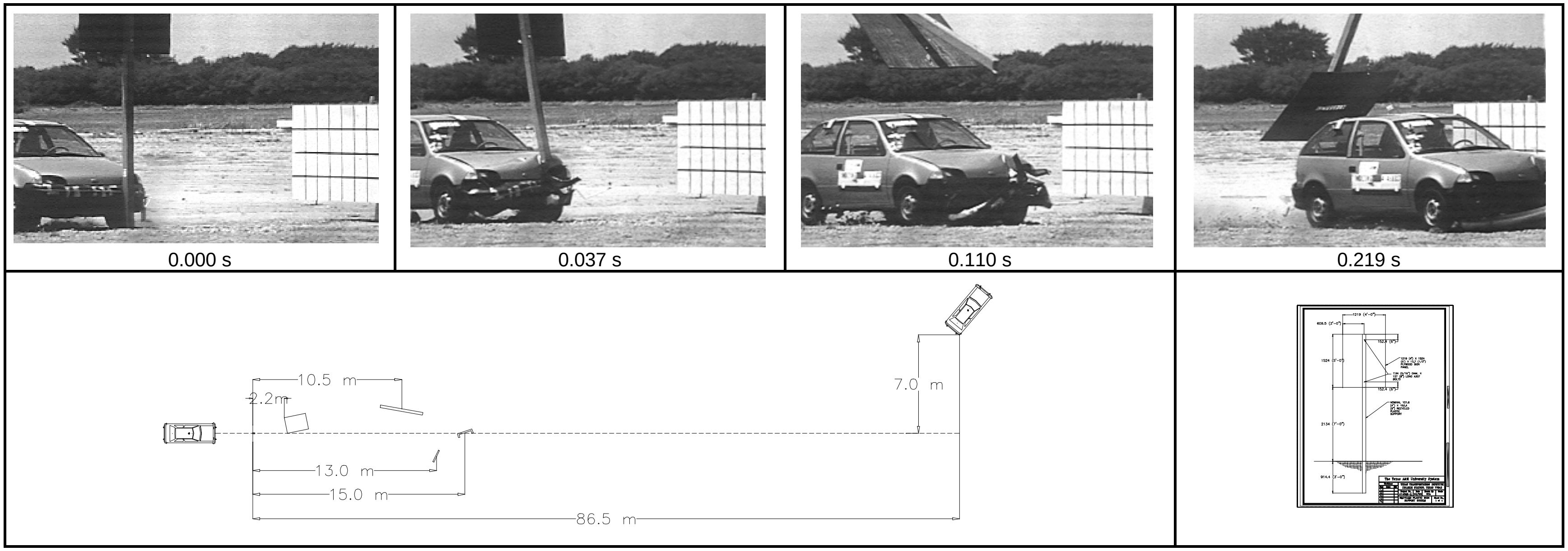


Figure 43. Support After Test 414588-3.

Figure 44. Vehicle After Test 414588-3.



General Information	
Test Agency	Texas Transportation Institute
Test No.	414588-3
Date	05/29/98
Test Article	
Type	Sign Support
Name	Recycled Plastic Sign Support
Installation Height (m)	2.13
Material or Key Elements	90 mmx140 mm Recycled Plastic Sign Support
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (kg) Curb	750
Test Inertial	820
Dummy	75
Gross Static	895

Impact Conditions	
Speed (km/h)	102.3
Angle (deg)	0
Exit Conditions	
Speed (km/h)	95.5
Angle (deg)	0
Change in Velocity	1.9 m/s
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.9
y-direction	1.4
Ridedown Accelerations (g's)	
x-direction	-1.0
y-direction	-1.5
Max. 0.050-s Average (g's)	
x-direction	-2.8
y-direction	-0.7
z-direction	-1.4

Test Article Debris pattern (m)	
Longitudinal	12.0
Lateral	1.7
Vehicle Damage	
Exterior	
VDS	12FL3
CDC	12FLLN2
Maximum Exterior Vehicle Crush (mm)	120
Interior	
OCDI	LF0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-13
Max. Pitch Angle (deg)	5
Max. Roll Angle (deg)	4

Figure 45. Summary of Results for Test 414588-3.

Table 6. Performance Evaluation Summary for Test 414588-3, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 414588-3 | Test Date: 05/29/98

<table>
<tr><th colspan="3">NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="3"><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The recycled plastic support fractured into three pieces.</td><td>Pass</td></tr>
<tr><td colspan="3"><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The fractured support and sign panel did not penetrate nor show potential for penetrating the occupant compartment, nor show undue hazards to others in the area. No deformation or intrusion of the occupant compartment occurred.</td><td>Pass</td></tr>
<tr><td colspan="3">F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright during and after the collision event.</td><td>Pass</td></tr>
<tr><td colspan="3">H. Occupant impact velocities should satisfy the following:</td><td rowspan="4">Longitudinal occupant impact velocity was 8.6 m/s.
Lateral occupant impact velocity was 1.4 m/s.</td><td rowspan="4">Pass</td></tr>
<tr><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
<tr><td colspan="3">I. Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">Longitudinal ridedown acceleration was -1.0 g.
Lateral occupant ridedown acceleration was -1.5 g.</td><td rowspan="4">Pass</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="3"><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td colspan="3">N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the installation.</td><td>Pass</td></tr>
</table>

III. W-BEAM GUARDRAIL WITH RECYCLED POSTS AND OFFSET BLOCKS

TEST ARTICLE

Previous research and testing under Phase II of this project indicated product 3.C.3 had desirable characteristics for use as a guardrail post and offset block in guardrail applications. A strong post W-beam guardrail system, G4-2W, was chosen due to similarities between the conventional wood products and the recycled plastic product selected. Overall nominal dimensions of the selected recycled plastic are similar to the wood counterparts.

The nominal cross-section dimensions for the recycled posts and offset blocks were 150 mm × 200 mm. The overall post length was 1829 mm and 1118 mm was embedded in *NCHRP Report 350* standard soil. Anchorage of the guardrail system was accomplished with LETs on each end of a 30.48 m length-of-need section. The total length of the installation was 53.34 m. Recycled plastic posts and blockouts were used in the entire length-of-need section. Posts were spaced 1.905 m on center throughout the installation. Detailed drawings are shown in figures 46 and 47. Photographs of the installation are shown in figure 48.

Figure 46. Details of the Plastic Post W-Beam Guardrail Installation.

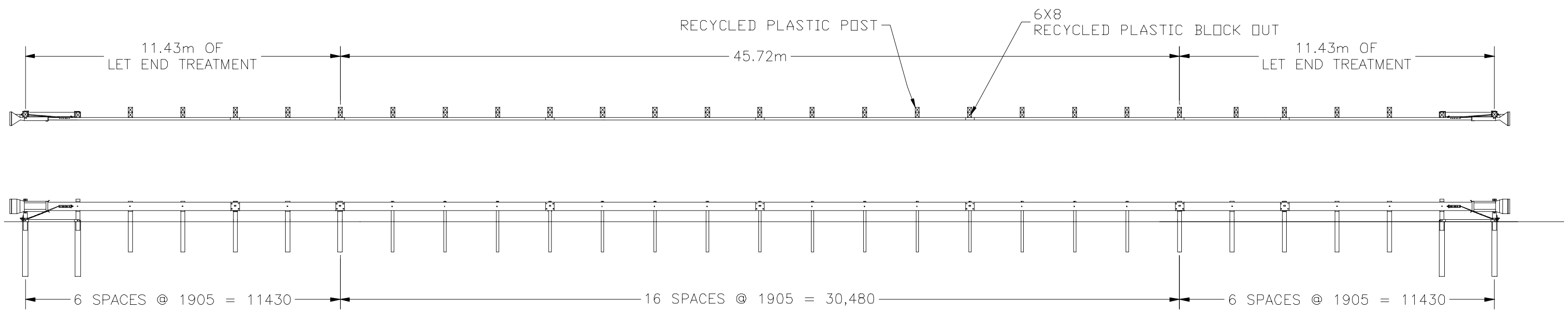


Figure 47. Layout of the Plastic Post W-Beam Guardrail Installation for Test 414588-1.

Figure 48. Plastic Post W-Beam Guardrail Installation Before Test 414588-1.

CRASH TEST CONDITIONS

According to *NCHRP Report 350*, two crash tests are required for the evaluation of longitudinal barriers at test level 3 (TL-3):

> ***NCHRP Report 350*** **Test Designation 3-10**: An 820 kg passenger vehicle impacting the critical impact point (CIP) of the length of need (LON) at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section in general and occupant risks in particular.
>
> ***NCHRP Report 350*** **Test Designation 3-11**: A 2000 kg pickup truck impacting the CIP of the LON at a nominal speed and angle of 100 km/h and 25 degrees. This test is intended to evaluate strength of the section in containing and redirecting the pickup truck.

The W-beam guardrail test reported herein (test no. 414588-1) corresponds to *NCHRP Report 350* test designation 3-11.

All crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350.* Brief descriptions of these procedures are presented in appendix A.

EVALUATION CRITERIA

The crash test performed was evaluated in accordance with the criteria presented in *NCHRP Report 350.* As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the guardrail crash test with recycled posts and offset blocks reported herein:

- **Structural Adequacy**

  A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

- **Occupant Risk**

  D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

- **Vehicle Trajectory**

  K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

  L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s, and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.

  M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.

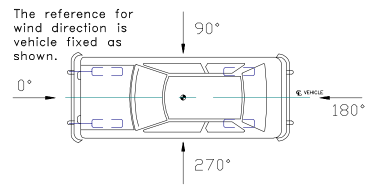
High-Speed Test (Test 414588-1; *NCHRP Report 350* Test No. 3-11)

Test Vehicle

A 1993 Chevrolet 2500 pickup truck, shown in figures 49 and 50, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The bumper height of the vehicle ranged from 415–640 mm from its lower to upper edge, respectively. Additional dimensions and information on the vehicle are given in figure 58. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Weather and Soil Conditions

Researchers performed the test the morning of May 27, 1998. No rain occurred during the 10 days prior to the test. Moisture content of the *NCHRP Report 350* standard soil in which the guardrail was installed was 5.7 percent, 6.0 percent, and 5.5 percent at posts 12, 14, and 16, respectively. Weather conditions during the time of the test were as follows: wind speed: 8 km/h; wind direction: zero degrees with respect to the vehicle (vehicle was traveling in a south/southwest direction); temperature: 32 °C; relative humidity: 69 percent.



Test Description

The vehicle, traveling at 100.6 km/h, impacted the guardrail at 26.5 degrees. Initial contact was 330 mm upstream of post 13. Upon impact the rail element moved as posts 12 and 13 began to deflect. At 0.020 s the front of the vehicle contacted and fractured post 13. The vehicle began to redirect at 0.047 s. At 0.079 s post 14 fractured in advance of the vehicle. Post 15 and post 16 both fractured in advance of the vehicle at 0.114 s and 0.143 s, respectively. Post 17 fractured at 0.177 s. At 0.206 s the rail ruptured at a splice at the location of post 15. Post 18 fractured 940 mm from the top about its strong axis but remained upright, supported by the rail. At 0.288 s an elbow formed as the ruptured rail bent around post 18. At 0.539 s the ruptured rail and the vehicle contacted post 19 and fractured the post about its weak axis. The vehicle contacted post 20 at 0.692 s, causing the post to fracture about its weak axis. At 0.866 s the separated rail section swung over the posts. The vehicle continued traveling through the guardrail system behind the test installation. Brakes on the impacting vehicle were applied at 5.4 s. The vehicle remained upright and subsequently came to rest 45.7 m down from impact and 13.7 m behind the installation. Sequential photographs of the test period are shown in appendix C, figures 65 and 66.

Figure 49. Vehicle/Installation Geometrics for Test 414588-1.

Figure 50. Vehicle Before Test 414588-1.

Damage to Test Installation

The W-beam guardrail with plastic posts and blockouts sustained substantial damage as shown in figures 51 and 52. The W-beam rail element ruptured at the lower bolt holes of the connection splice at post 15. Posts 1 through 6 were disturbed, post 7 was pulled laterally 5 mm, and posts 8 through 10 were disturbed. Post 11 was displaced 10 mm in both the lateral and longitudinal directions and post 12 was displaced 20 mm longitudinally. Posts 13 through 20 were fractured. Post 21 was pulled laterally 20 mm, post 22 was pulled back 15 mm, and the blockout was rotated. The post to rail connection bolt was pulled from the rail at posts 21 and 22. Posts 23 through 29 were disturbed, and the end anchors were each pulled inward 5 mm.

Vehicle Damage

The vehicle sustained moderate damage as shown in figure 53. Structural damage included the left outer tie rod and left lower A-arm. The left front tire was flat and the rim bent. The left and right front quarter panels, grill, and bumper were damaged. A dent was noted in the left corner of the cab. Scuff marks and dents were found on the left door. Maximum crush to the vehicle was 360 mm at the left front corner of the front bumper. No intrusion into the occupant compartment occurred, as shown in figure 54. Details of the vehicle damage are given in tables 16 and 17 of appendix B.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 6.3 m/s at 0.223 s, the highest 0.010 s occupant ridedown acceleration was -8.6 g from 0.452 to 0.462 s, and the maximum 0.050 s average acceleration -4.6 g between 0.103 and 0.153 s. In the lateral direction, the occupant impact velocity was 4.4 m/s at 0.169 s, the highest 0.010 s occupant ridedown acceleration was -7.5 g from 0.860 to 0.870 s, and the maximum 0.050 s average was 4.4 g between 0.131 and 0.181 s. These data and other pertinent information from the test are summarized in figure 55. Vehicle angular displacements are displayed in appendix D, figure 91. Vehicular accelerations versus time traces are presented in appendix D, figures 92 through 94.

Figure 51. After Impact Trajectory for Test 414588-1.

Figure 52. Installation After Test 414588-1.

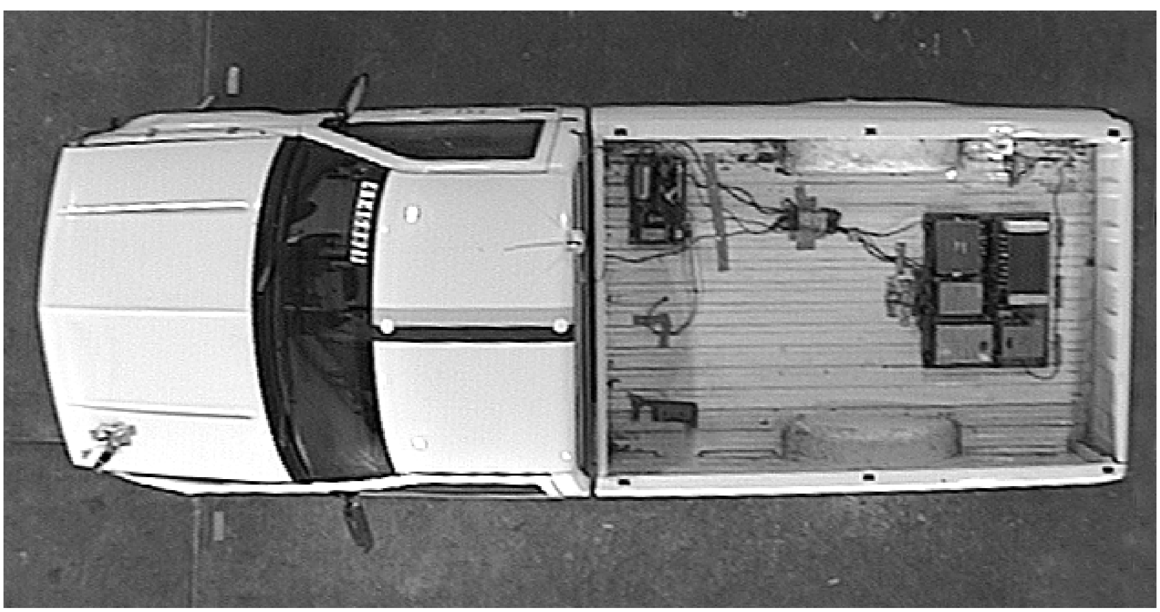
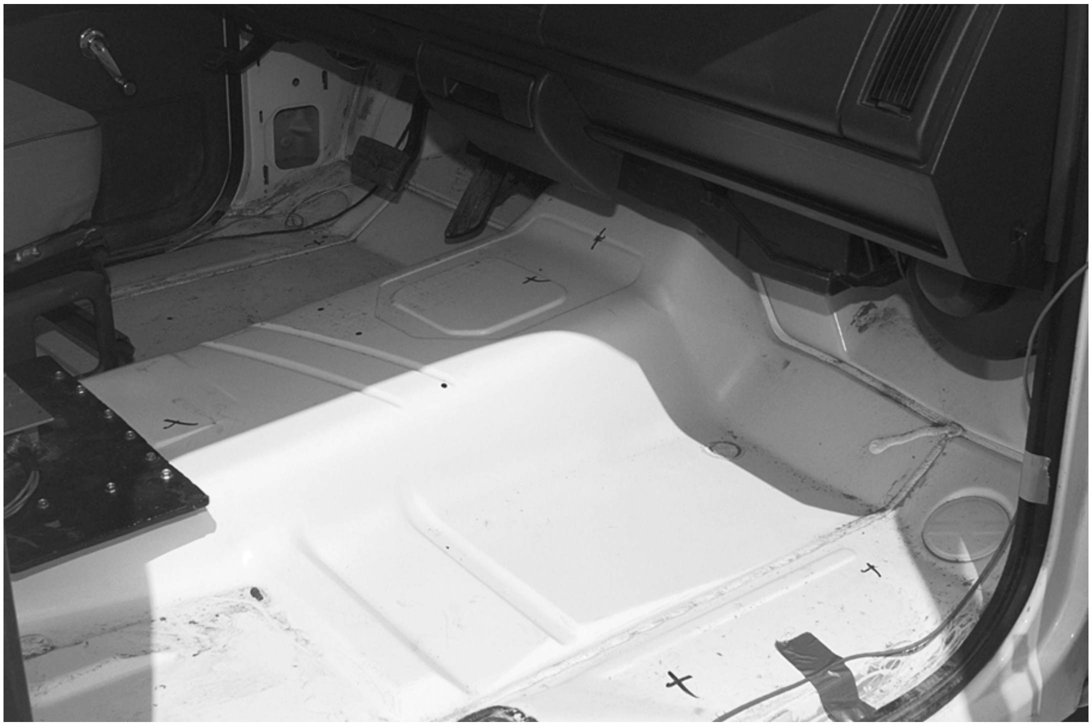


Figure 53. Vehicle After Test 414588-1.



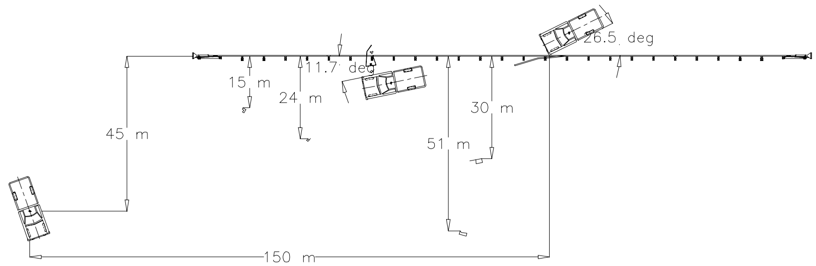
Before
test

After
test

Figure 54. Interior of Vehicle for Test 414588-1.

	
0.000 s	0.185 s

	
0.396 s	0.713 s



General Information	
Test Agency	Texas Transportation Institute
Test No.	414588-1
Date	05/27/98
Test Article	
Type	Guardrail
Name	W-beam Guardrail w/Recycled Posts
Installation Length (m)	53.3
Material or Key Elements	W-beam Guardrail with Recycled Plastic Posts and Blockouts
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1993 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	1877
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	100.6
Angle (deg)	26.5
Exit Conditions	
Speed (km/h)	78.9
Angle (deg)	11.7
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3
y-direction	4.4
THIV (km/h)	21.7
Ridedown Accelerations (g's)	
x-direction	-8.6
y-direction	-7.5
PHD (g's)	10.9
ASI	0.59
Max. 0.050 s Average (g's)	
x-direction	-4.6
y-direction	4.4
z-direction	2.3

Test Article Deflections (m)	
Dynamic	Ruptured
Permanent	Ruptured
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11LYEW2
Maximum Exterior Vehicle Crush (mm)	360
Interior	
OCDI	LS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	59
Max. Pitch Angle (deg)	-2
Max. Roll Angle (deg)	-12

Figure 55. Summary of Results for Test 414588-1.

Summary of Findings

The W-beam guardrail with recycled posts and blockouts did not contain and redirect the vehicle. The vehicle penetrated the installation as the rail element ruptured. Detached posts and ruptured rail elements did not penetrate the occupant nor show potential for penetrating the occupant compartment. Much debris came to rest behind the guardrail installation, which may present minimal hazard to others in the area. No deformation or intrusion of the occupant compartment occurred. The vehicle remained upright during and after the collision period. The vehicle did not intrude into adjacent traffic lanes. Longitudinal occupant impact velocity was 6.3 m/s and longitudinal ridedown acceleration was -8.6 g. Exit angle at loss of contact was 11.7 degrees; however, the vehicle had penetrated the guardrail.

Table 7. Performance Evaluation Summary for Test 414588-1, *NCHRP Report 350* Test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 414588-1 | Test Date: 05/27/98

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The W-beam guardrail with recycled posts and blockouts did not contain and redirect the vehicle. The vehicle penetrated the installation as the rail element ruptured.	Fail
Occupant Risk D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Detached posts and ruptured rail elements did not penetrate the occupant nor show potential for penetrating the occupant compartment. Much debris came to rest behind the guardrail installation, which may present minimal hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.	Marginal
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s, and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity was 6.3 m/s and longitudinal ridedown acceleration was -8.6 g.	Pass
M The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle at loss of contact was 11.7 degrees; however, the vehicle had penetrated the guardrail.	N/A

IV. CONCLUSIONS

All sign supports tested performed acceptably according to the evaluation criteria in NCHRP Report 350. The results of these and other tests conducted by TTI show recycled plastic sign supports have performed acceptably when impacted by an 820 C (small passenger vehicle) at both low and high speeds. Testing conducted in Phase II of this project indicated low modulus of elasticity on most products submitted for evaluation. The low modulus of elasticity allowed significant deflections under load when compared to baseline wood products. Therefore, while ultimate loads were somewhat comparable to baseline wood products, sign panel orientation/deflection may be unacceptable when mounted on similar sized recycled products when again compared to baseline wood products. Acceptable deflections will need to be determined to appropriately size recycled support cross-section dimensions. The desired deflections can also be achieved by limiting the sign panel area for given support sizes.

The guardrail system constructed with recycled plastic posts failed to contain the 2000P test vehicle at 100 km/h and 25 degrees. The vehicle pocketed and subsequently ruptured the W-beam rail. Subsequent to the failed full-scale crash on the strong post guardrail system with recycled guardrail posts, testing of the guardrail posts indicated an approximate 33 percent strength deficiency when compared to the posts tested in Phase II. This large variation dictates close monitoring of the material properties will be needed. Sufficient history and data are not available to accurately predict acceptable performance in full-scale crash tests. Conventional static and dynamic tests may in the future be substituted for full-scale crash tests; however, a level of confidence must be established before this can occur. Therefore, full-scale crash tests are recommended for recycled content guardrail posts.

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report 350, Transportation Research Board, Washington, D.C., 1993.

2. American Association of State Highway Transportation Officials (AASHTO) *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, 1994.

APPENDIX A. CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350.* Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center of gravity to measure longitudinal, lateral, and vertical acceleration levels: and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Researchers actuated pressure sensitive switches on the bumper of the impacting vehicle just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an “event” mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, was received at the data acquisition station and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10 ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50 ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067 s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350,* and there was no dummy used in the tests with the 2000P vehicle.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point, one placed behind the installation at an angle, and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two to one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, researchers released the test vehicle to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

APPENDIX B. VEHICLE PROPERTIES AND INFORMATION

DATE: 8/28-29/97 TEST NO.: 414587-1thru4 VIN NO.: KNJPT05H7M6121564 MAKE: FORD

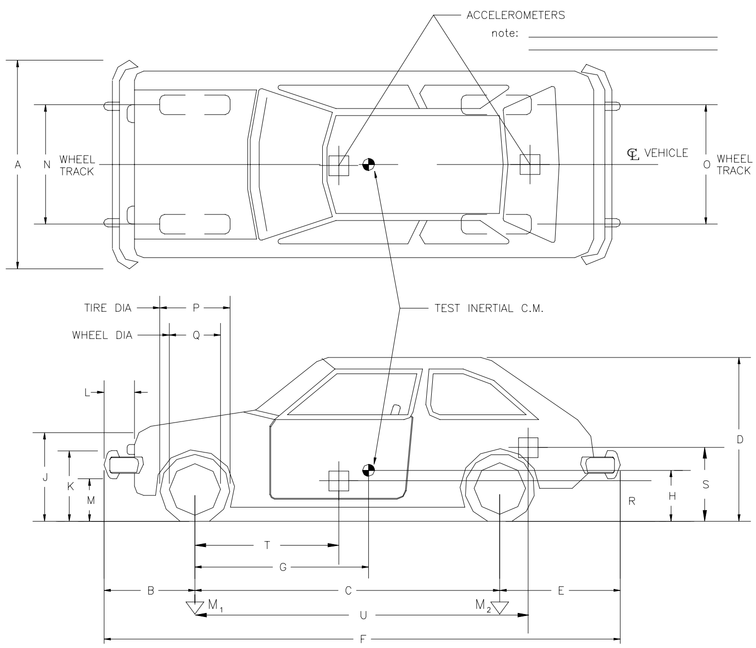
MODEL: FESTIVA YEAR: 1991 ODOMETER: 99019 TIRE SIZE: 155R12

TIRE INFLATION PRESSURE: ______

1st Use: ___ 2nd or More Use: X Minor Damage Charged to Project: ______

MASS DISTRIBUTION (kg) LF 264 RF 251 LR 155 RR 150

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL

ENGINE CID: 1.3L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY - (mm)

A	1500	E	540	J	760	N	1390	R	410
B	650	F	3490	K	590	O	1395	S	515
C	2300	G	855.5	L	120	P	530	T	890
D	1460	H		M	390	Q	330	U	2410

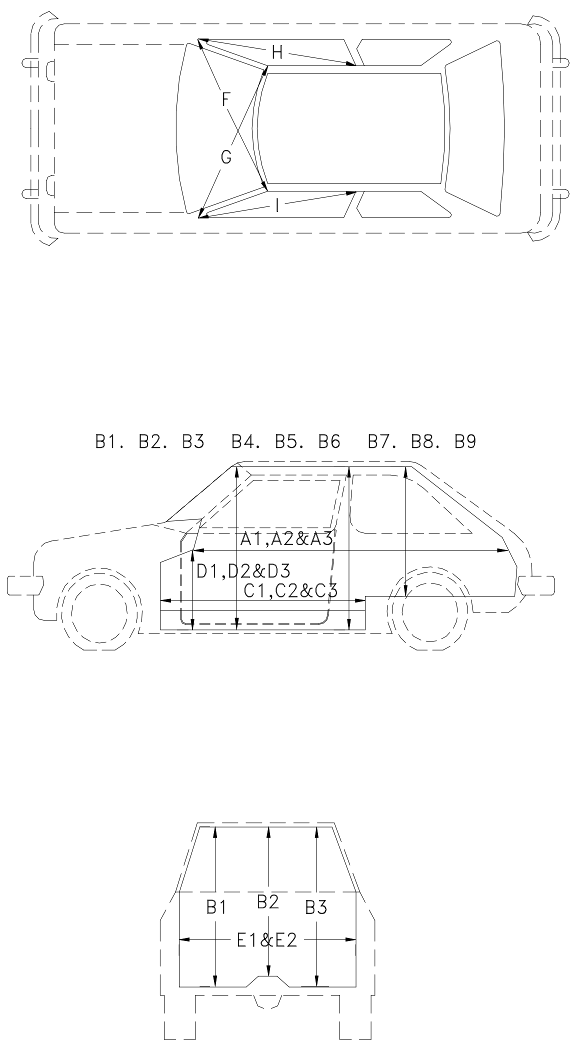
MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	507	515	553
M_2	303	305	343
M_T	810	820	896

Figure 56. Vehicle Properties for Tests 414587-1, 2, 3, and 4.

Table 8. Occupant Compartment Measurements for Test 414587-1.

Small Car

Occupant Compartment Deformation

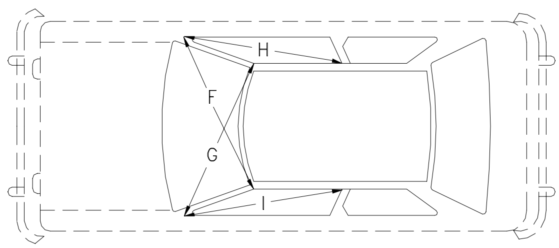


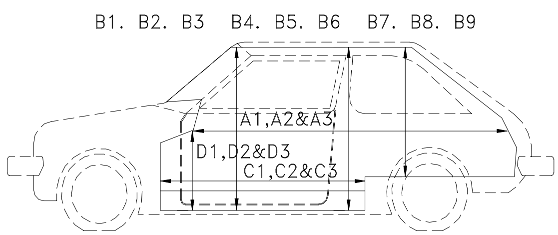
	BEFORE	AFTER
A1	1515	1515
A2	2040	2040
A3	1545	1545
B1	1064	1064
B2	931	931
B3	1064	1064
B4	970	970
B5	972	972
B6	972	972
B7	830	830
B8	840	840
B9	820	820
C1	630	630
C2	630	630
C3	626	626
D1	329	329
D2	225	225
D3	340	340
E1	1253	1253
E2	1246	1246
F	1170	1170
G	1170	1170
H	900	900
I	900	900

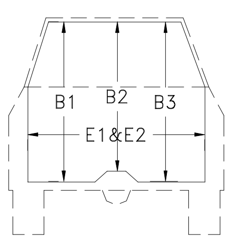
Table 9. Occupant Compartment Measurements for Test 414587-2.

Small Car

Occupant Compartment Deformation





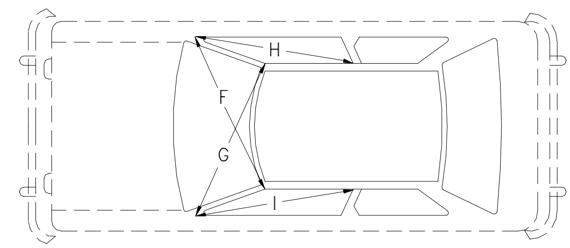


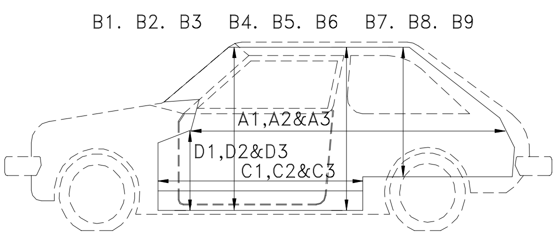
	BEFORE	AFTER
A1	1515	1515
A2	2040	2040
A3	1545	1545
B1	1064	1064
B2	931	931
B3	1064	1064
B4	970	970
B5	972	965
B6	972	965
B7	830	830
B8	840	840
B9	820	820
C1	630	630
C2	630	630
C3	626	626
D1	329	329
D2	225	225
D3	340	340
E1	1253	1253
E2	1246	1246
F	1170	1170
G	1170	1170
H	900	900
I	900	900

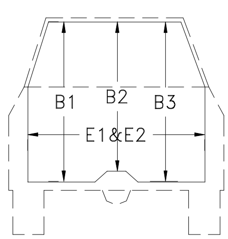
Table 10. Occupant Compartment Measurements for Test 414587-3.

S m a l l C a r

O c c u p a n t C o m p a r t m e n t D e f o r m a t i o n





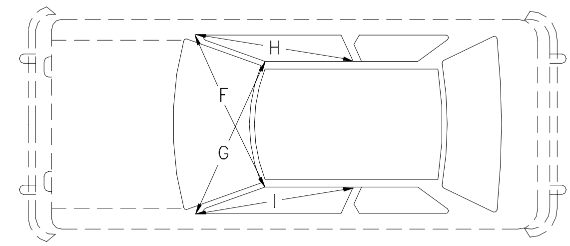


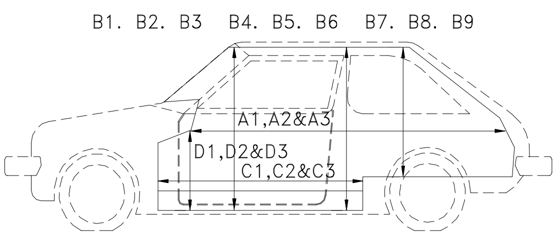
	BEFORE	AFTER
A1	1515	1515
A2	2040	2040
A3	1545	1545
B1	1064	1064
B2	931	931
B3	1064	1064
B4	970	970
B5	972	972
B6	972	972
B7	830	830
B8	840	840
B9	820	820
C1	630	630
C2	630	630
C3	626	626
D1	329	329
D2	225	225
D3	340	340
E1	1253	1253
E2	1246	1246
F	1170	1170
G	1170	1170
H	900	900
I	900	900

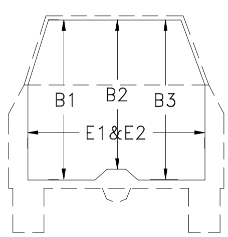
Table 11. Occupant Compartment Measurements for Test 414587-4.

Small Car

Occupant Compartment Deformation







	BEFORE	AFTER
A1	1515	1515
A2	2040	2040
A3	1545	1545
B1	1064	1064
B2	931	931
B3	1064	1064
B4	970	945
B5	972	935
B6	972	951
B7	830	830
B8	840	830
B9	820	815
C1	630	630
C2	630	630
C3	626	626
D1	329	329
D2	225	225
D3	340	340
E1	1253	1253
E2	1246	1246
F	1170	1170
G	1170	1170
H	900	900
I	900	900

Table 12. Exterior Crush Measurements for Test 414587-4.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant $\frac{X1 + X2}{2}$ = _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At bumper	540	30	280	0	15	15	0	N/A	N/A	+340

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

DATE: 5-29-98 TEST NO.: 141588-2&3 VIN NO.: 2C1M52467R6762975

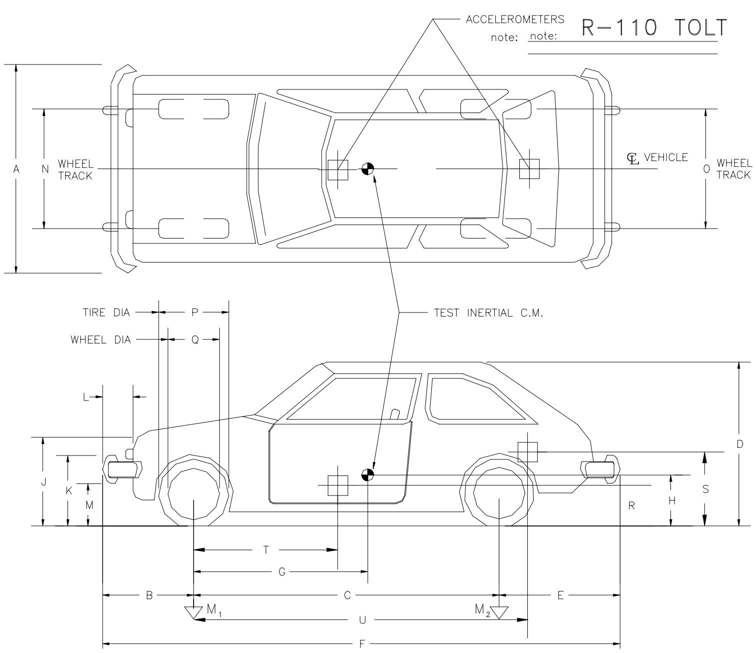
YEAR: 1994 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ______ ODOMETER: 72039 TIRE SIZE: 155R12

1st Use: X 2nd or More Use: ____ Minor Damage Charged to Project: ______

MASS DISTRIBUTION (kg) LF 240 RF 239 LR 172 RR 169

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 CYL

ENGINE CID: 1.0L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1400	E	640	J	650	N	1370	R	370
B	720	F	3635	K	520	O	1355	S	530
C	2275	G	946.1	L	90	P	530	T	900
D	1350	H		M	385	Q	325	U	2425

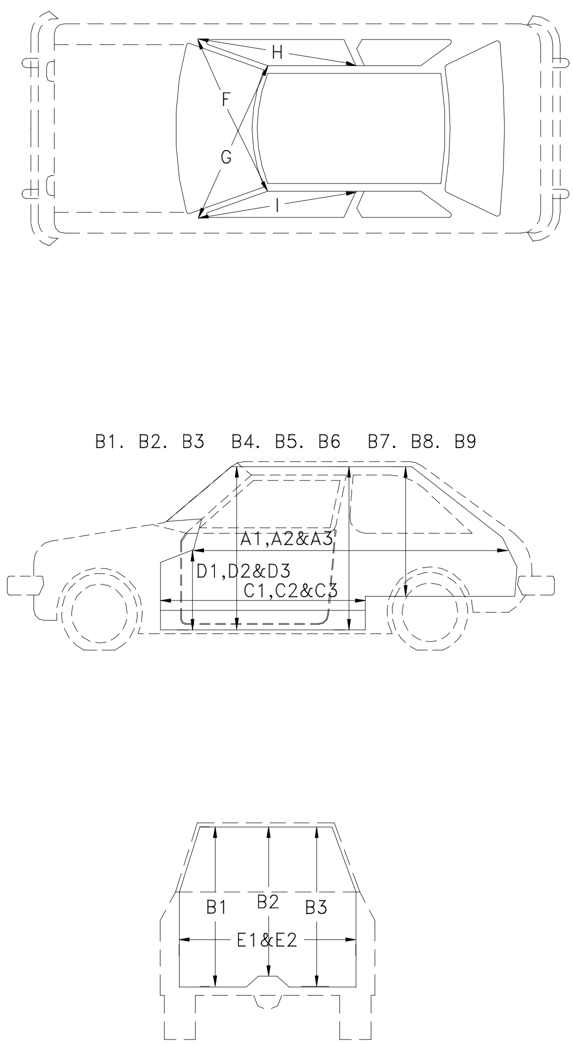
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	452	479	511
M_2	298	341	384
M_T	750	820	895

Figure 57. Vehicle Properties for Tests 414588-2 and 3.

Table 13. Occupant Compartment Measurements for Test 414588-2.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1485	1485
A2	2070	2070
A3	1500	1500
B1	982	982
B2	916	916
B3	974	974
B4	961	961
B5	855	855
B6	945	945
B7	N/A	N/A
B8	N/A	N/A
B9	N/A	N/A
C1	714	714
C2	706	706
C3	707	707
D1	283	283
D2	170	170
D3	300	300
E1	1230	1230
E2	1235	1235
F	1210	1210
G	1210	1210
H	900	900
I	900	900

Table 14. Exterior Crush Measurements for Test 414588-3.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant $\frac{X1 + X2}{2}$ = _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At bumper	570	120	884	-50	30	95	55	20	0	-140

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

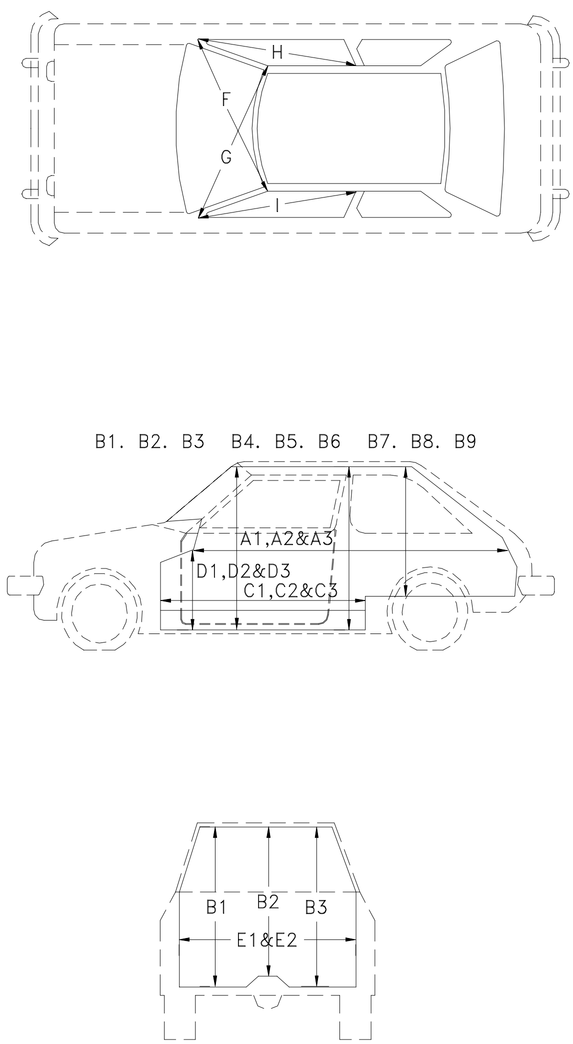
***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table 15. Occupant Compartment Measurements for Test 414588-3.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1485	1485
A2	2070	2070
A3	1500	1500
B1	982	982
B2	916	916
B3	974	974
B4	961	961
B5	855	855
B6	945	945
B7	N/A	N/A
B8	N/A	N/A
B9	N/A	N/A
C1	714	714
C2	706	706
C3	707	707
D1	283	283
D2	170	170
D3	300	300
E1	1230	1230
E2	1235	1235
F	1210	1210
G	1210	1210
H	900	900
I	900	900

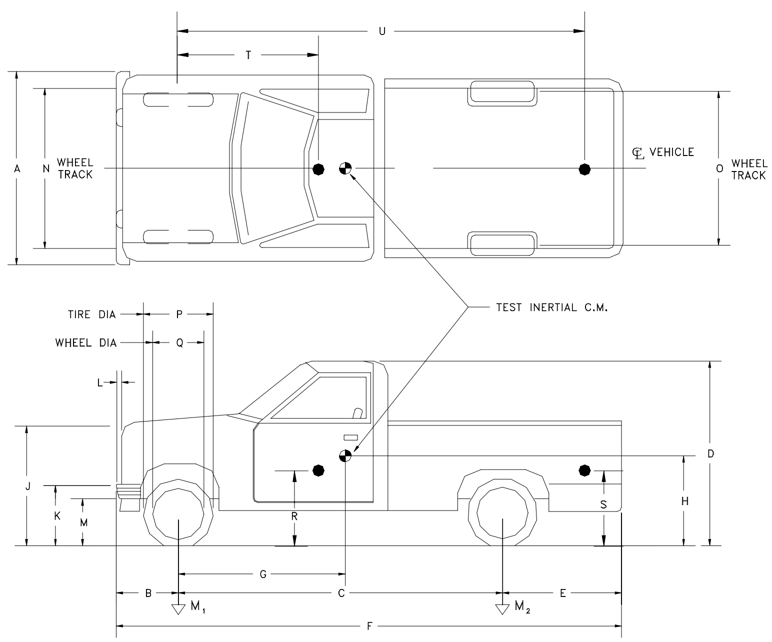
DATE: 5-27-98 TEST NO.: 414588-1 VIN NO.: 1GCFC24K3PZ242781

YEAR: 1993 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 222770 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 557 RF 529 LR 452 RR 462

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1880	E	1270	J	1060	N	1685	R	690
B	760	F		K	640	O	1625	S	890
C	3350	G	1531	L	70	P	770	T	1500
D	1770	H		M	415	Q	445	U	3950

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1102	1086	
M_2	775	914	
M_T	1877	2000	

Figure 58. Vehicle Properties for Test 414588-1.

Table 16. Exterior Crush Measurements for Test 414588-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant $\frac{X1 + X2}{2}$ = _____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
1	At bumper	500	360	1765	360	167	135	85	130	240	0

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

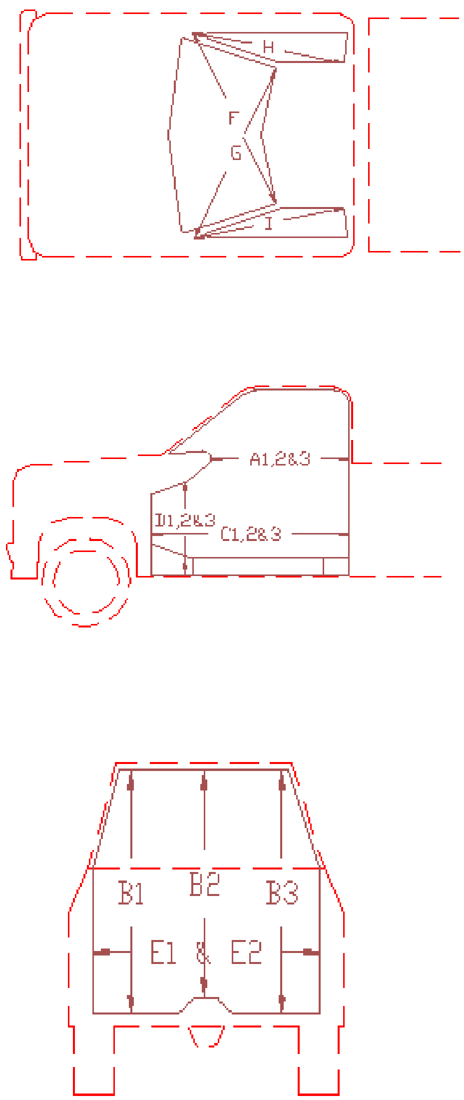
***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table 17. Occupant Compartment Measurements for Test 414588-1.

Truck

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1041	1041
A2	1083	1083
A3	1042	1042
B1	1079	1079
B2	1030	1030
B3	1075	1075
C1	1377	1377
C2	1247	1247
C3	1371	1371
D1	316	316
D2	95	95
D3	312	312
E1	1598	1598
E2	1596	1596
F	1470	1470
G	1470	1470
H	900	900
I	900	900

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

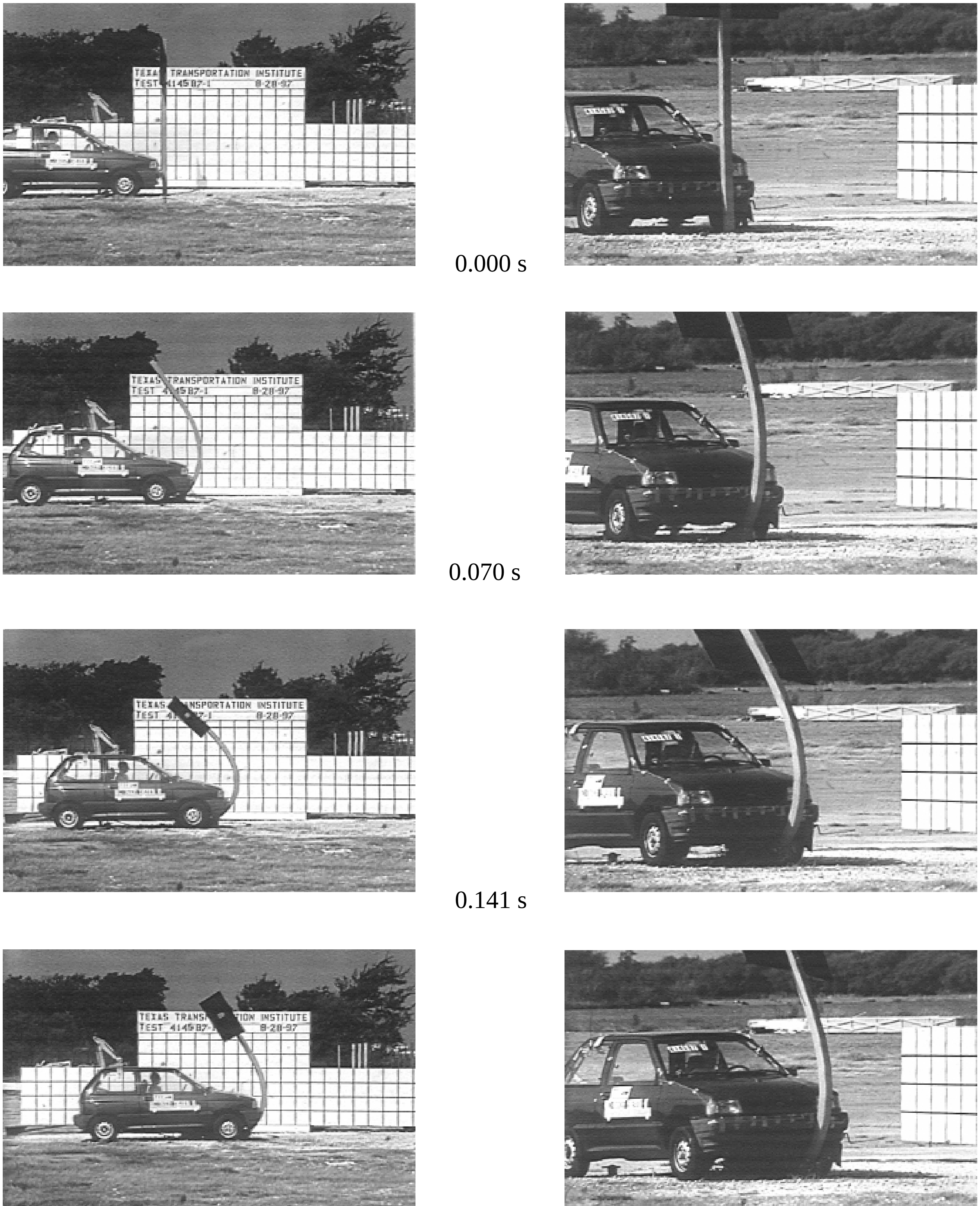
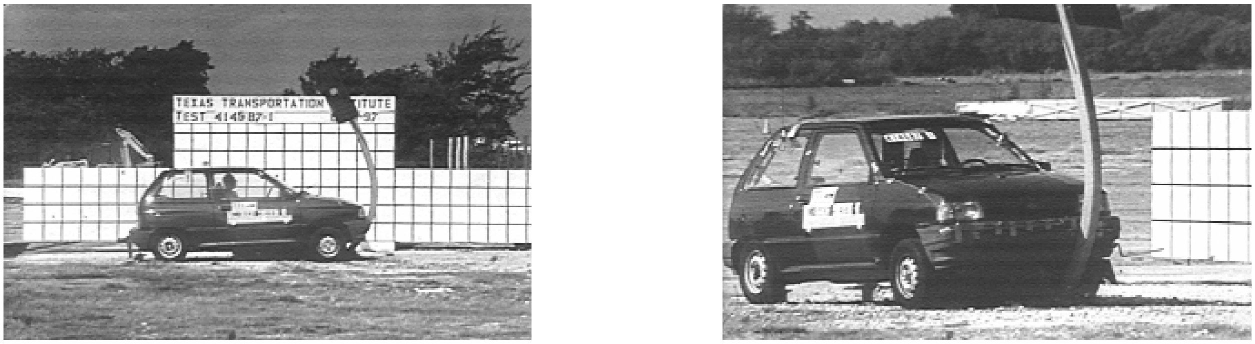


Figure 59. Sequential Photographs for Test 414587-1 (Perpendicular and Oblique Views).



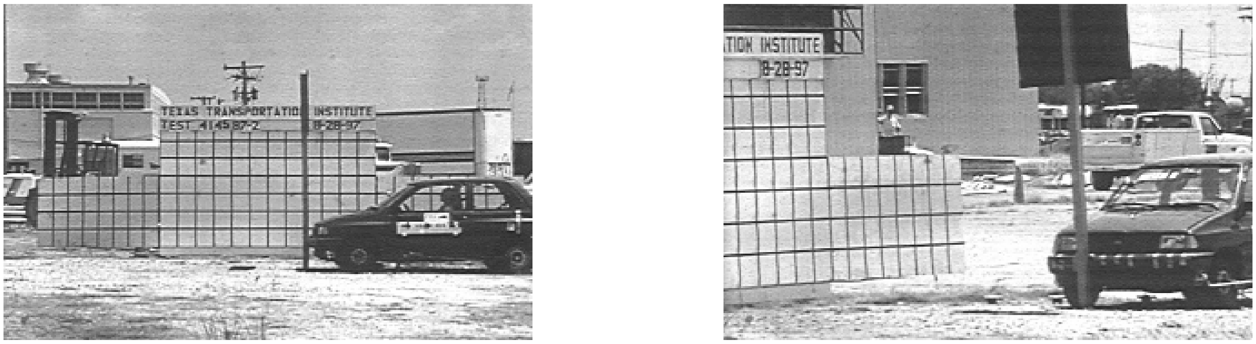
0.282 s

0.353 s

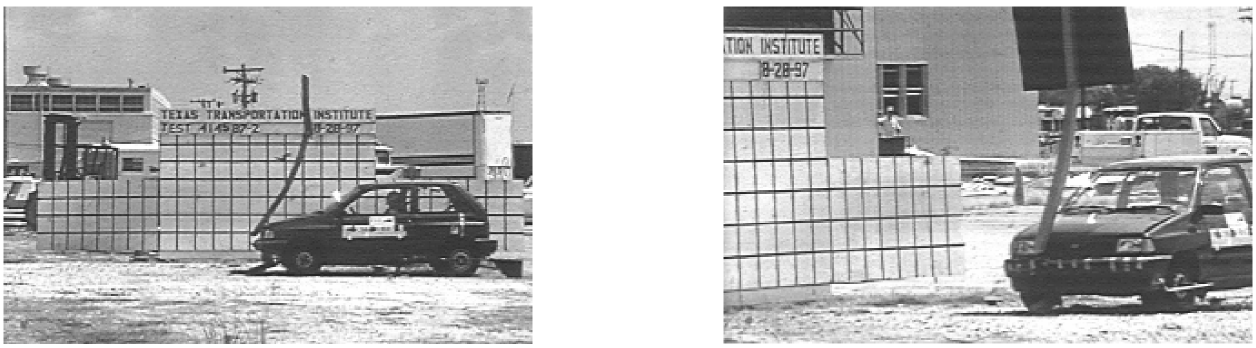
0.424 s

0.495 s

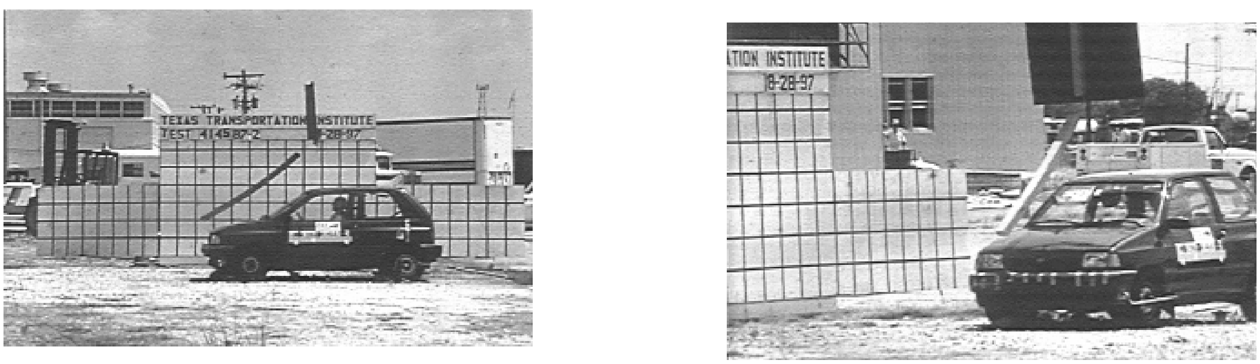
Figure 59. Sequential Photographs for Test 414587-1 (Perpendicular and Oblique Views) (continued).



0.000 s



0.029 s

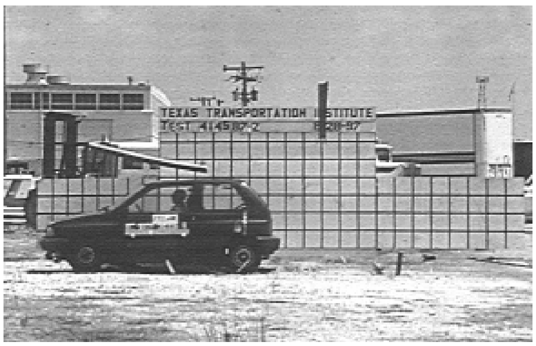


0.058 s

0.088 s

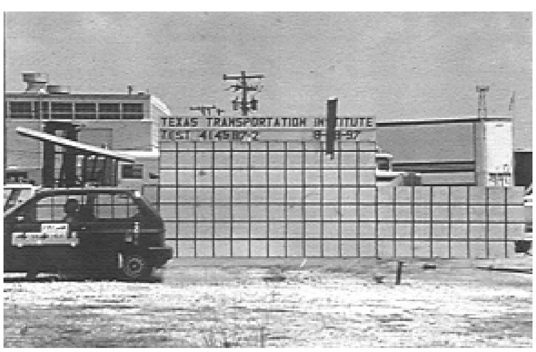
Figure 60. Sequential Photographs for Test 414587-2 (Perpendicular and Oblique Views).


0.282 s




0.353 s


0.176 s



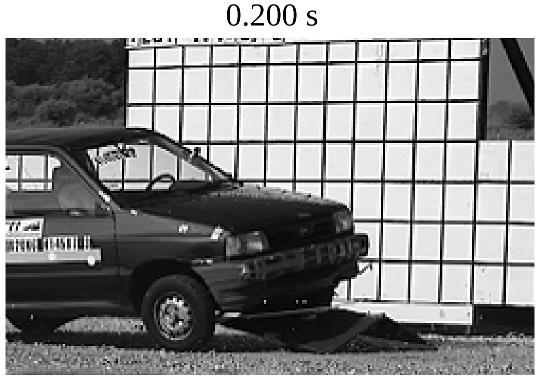

0.205 s

Figure 60. Sequential Photographs for Test 414587-2 (Perpendicular and Oblique Views) (continued).

0.000 s

0.083 s

0.200 s



0.416 s

Figure 61. Sequential Photographs for Test 414587-3 (Oblique View).

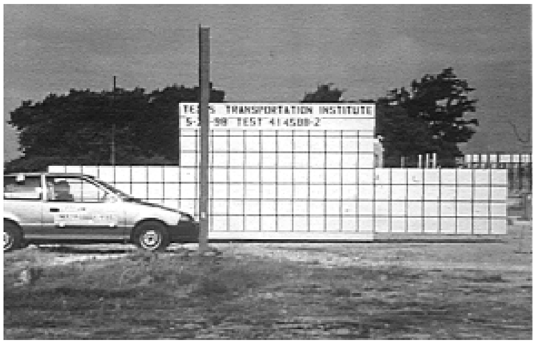
0.000 s

0.033 s

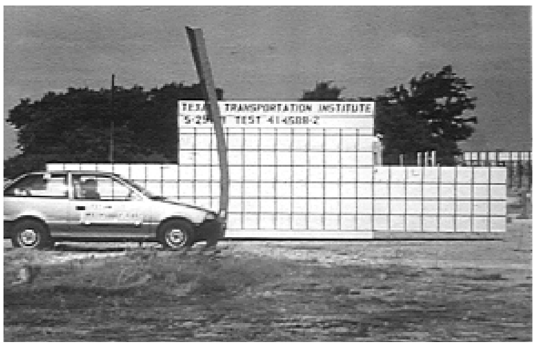
0.083 s

0.150 s

Figure 62. Sequential Photographs for Test 414587-4 (Oblique View).



0.000 s



0.049 s

0.097 s

0.171 s

Figure 63. Sequential Photographs for Test 414588-2 (Perpendicular and Oblique Views).

0.244 s

0.365 s

0.609 s

0.926 s

Figure 63. Sequential Photographs for Test 414588-2 (Perpendicular and Oblique Views) (continued).

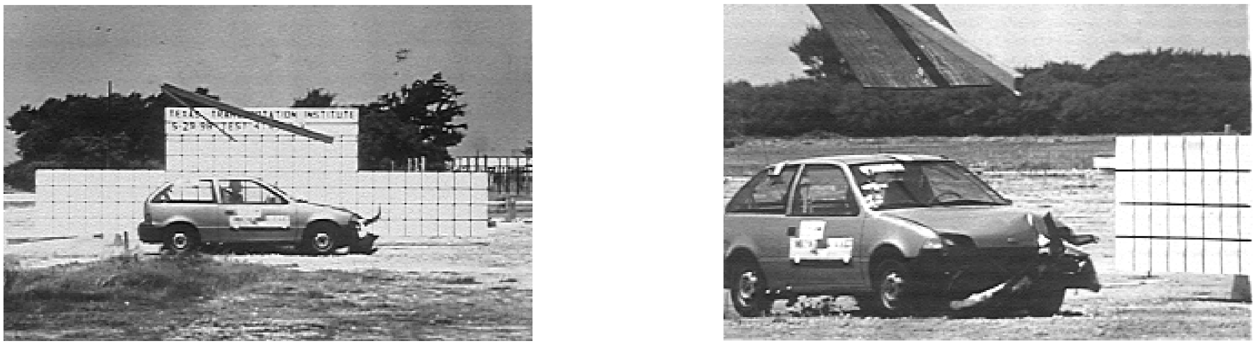
0.000 s

0.012 s

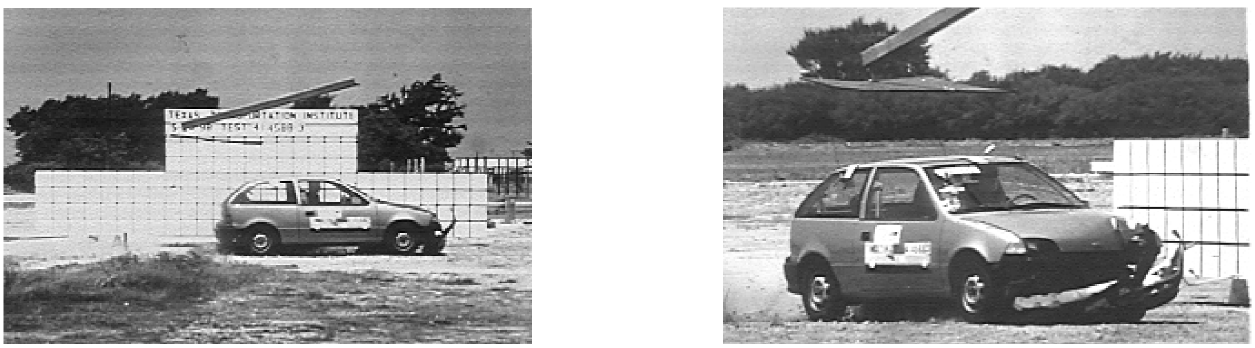
0.037 s

0.074 s

Figure 64. Sequential Photographs for Test 414588-3 (Perpendicular and Oblique Views).



0.110 s



0.158 s

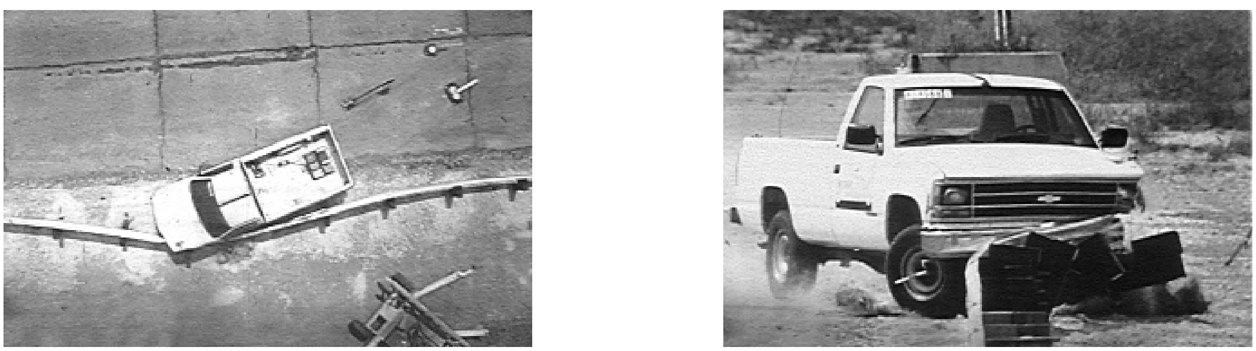
0.219 s

0.292 s

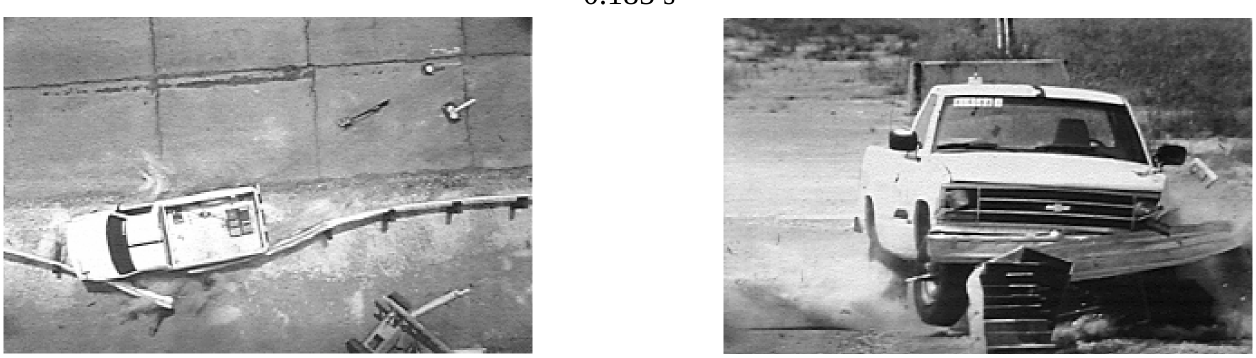
Figure 64. Sequential Photographs for Test 414588-3 (Perpendicular and Oblique Views) (continued).

0.000 s

0.079 s



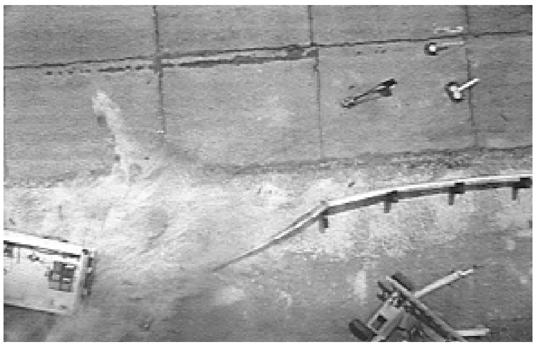
0.185 s



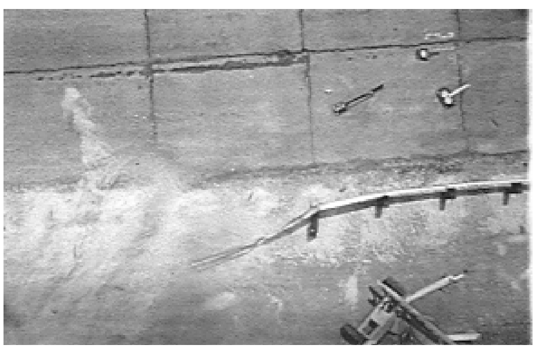
0.290 s

Figure 65. Sequential Photographs for Test 414588-1 (Overhead and Frontal Views).

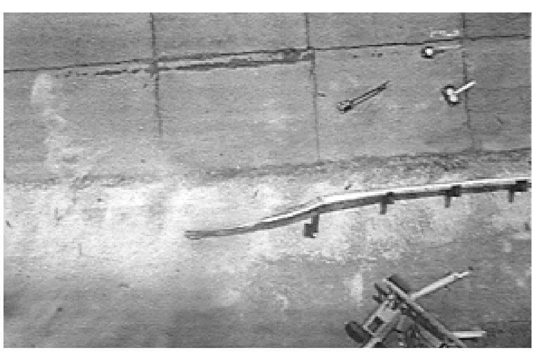
0.396 s

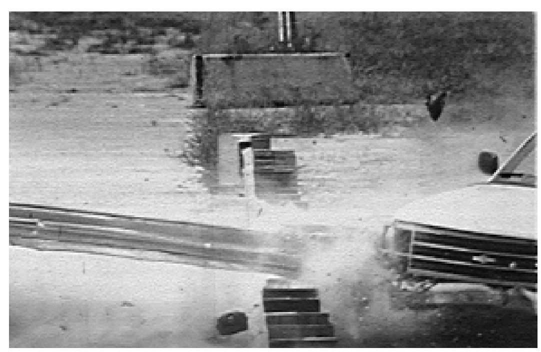


0.554 s



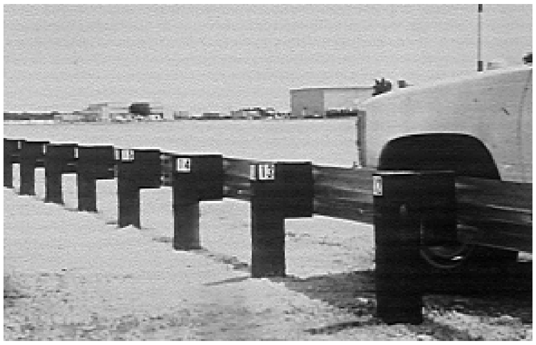
0.713 s





0.977 s

Figure 65. Sequential Photographs for Test 414588-1 (Overhead and Frontal Views) (continued).



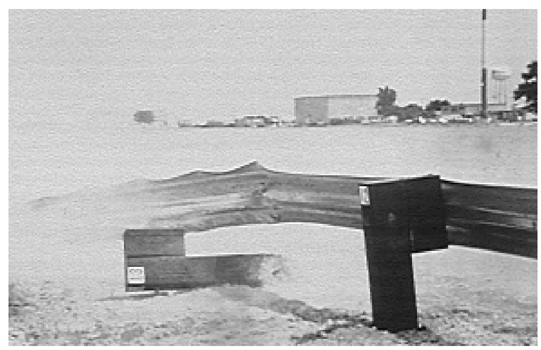
0.000 s

0.396 s

0.079 s

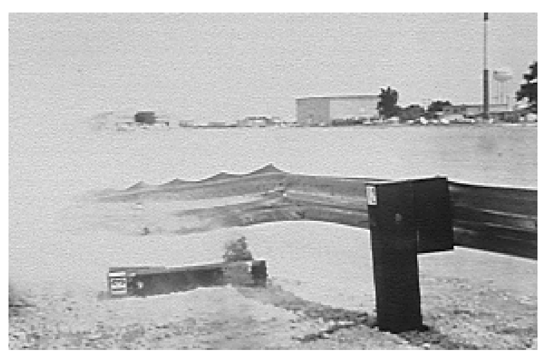
0.554 s

0.185 s



0.713 s

0.290 s



0.977 s

Figure 66. Sequential Photographs for Test 414588-1 (Rear View).

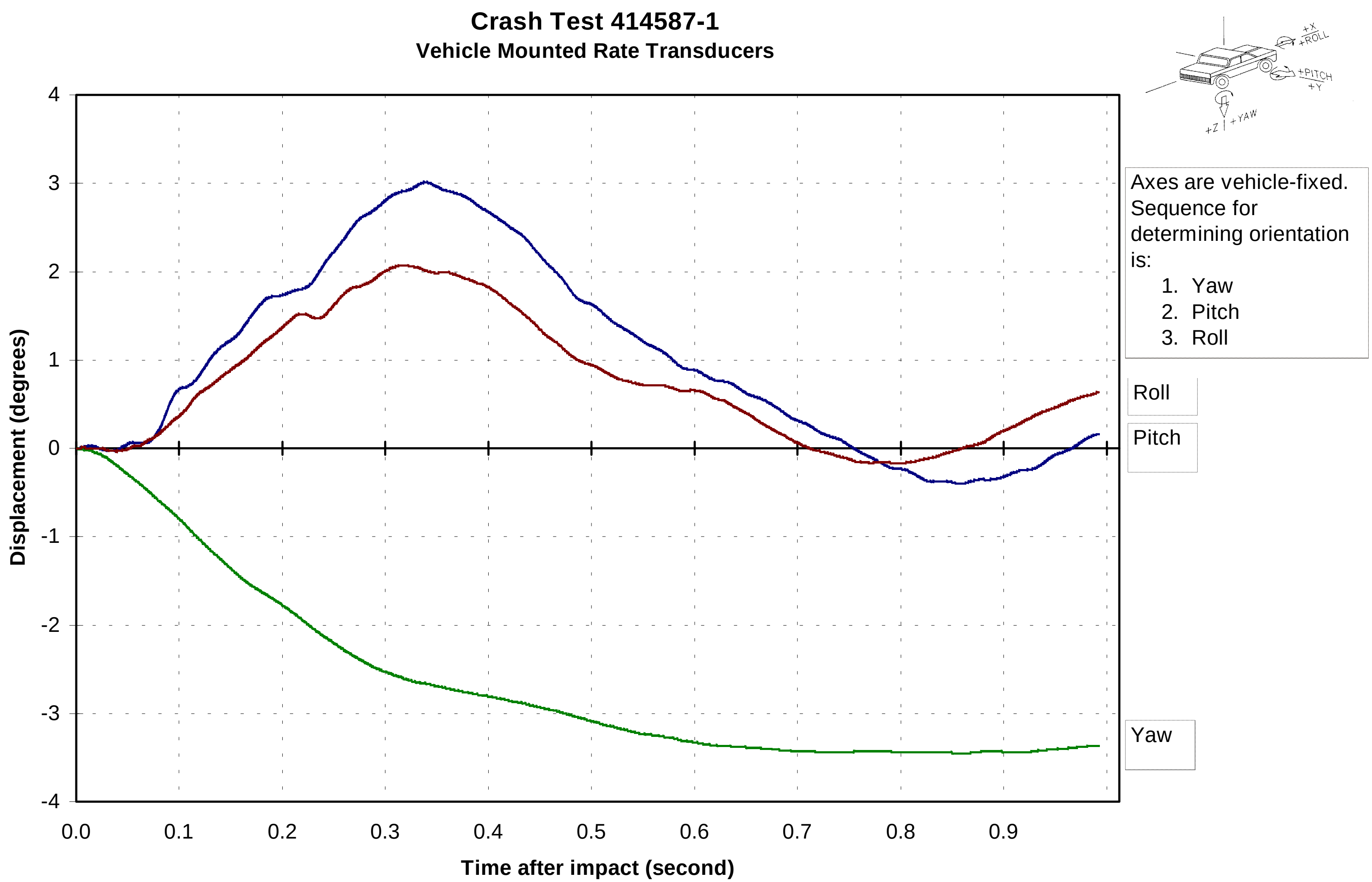


Figure 67. Vehicle Angular Displacements for Test 414587-1.

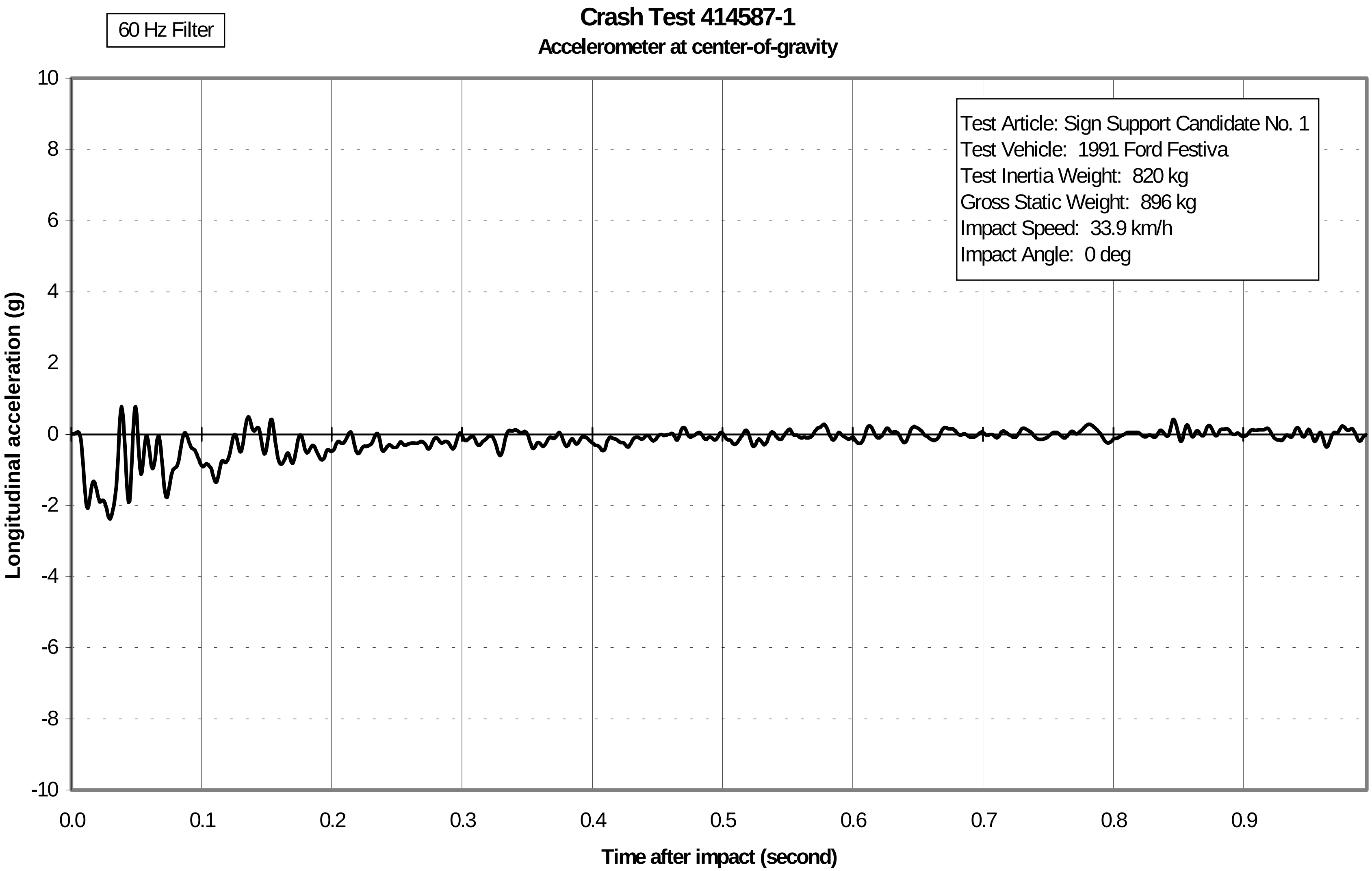


Figure 68. Vehicle Longitudinal Accelerometer Trace for Test 414587-1.

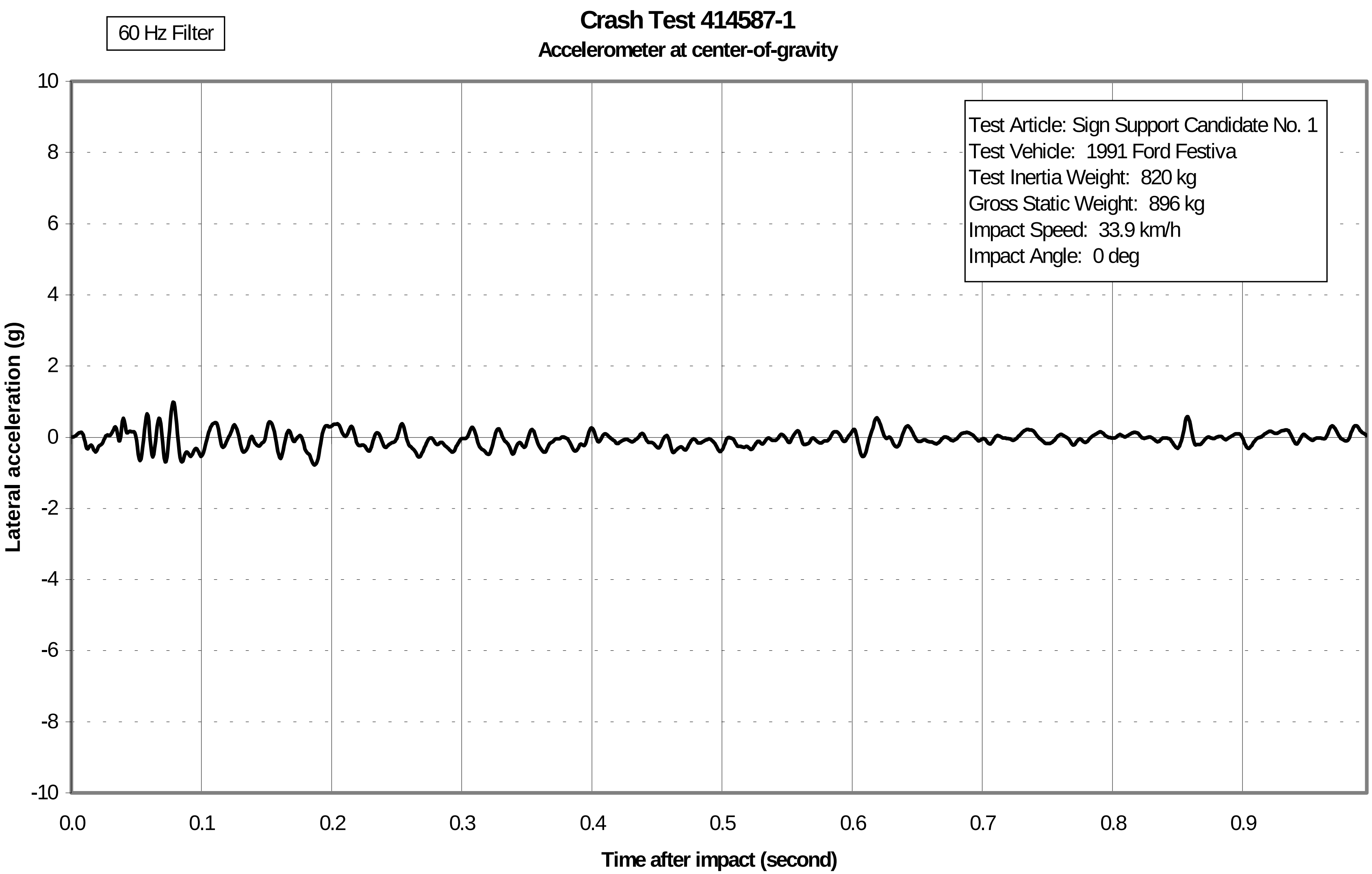


Figure 69. Vehicle Lateral Accelerometer Traces for Test 414587-1.

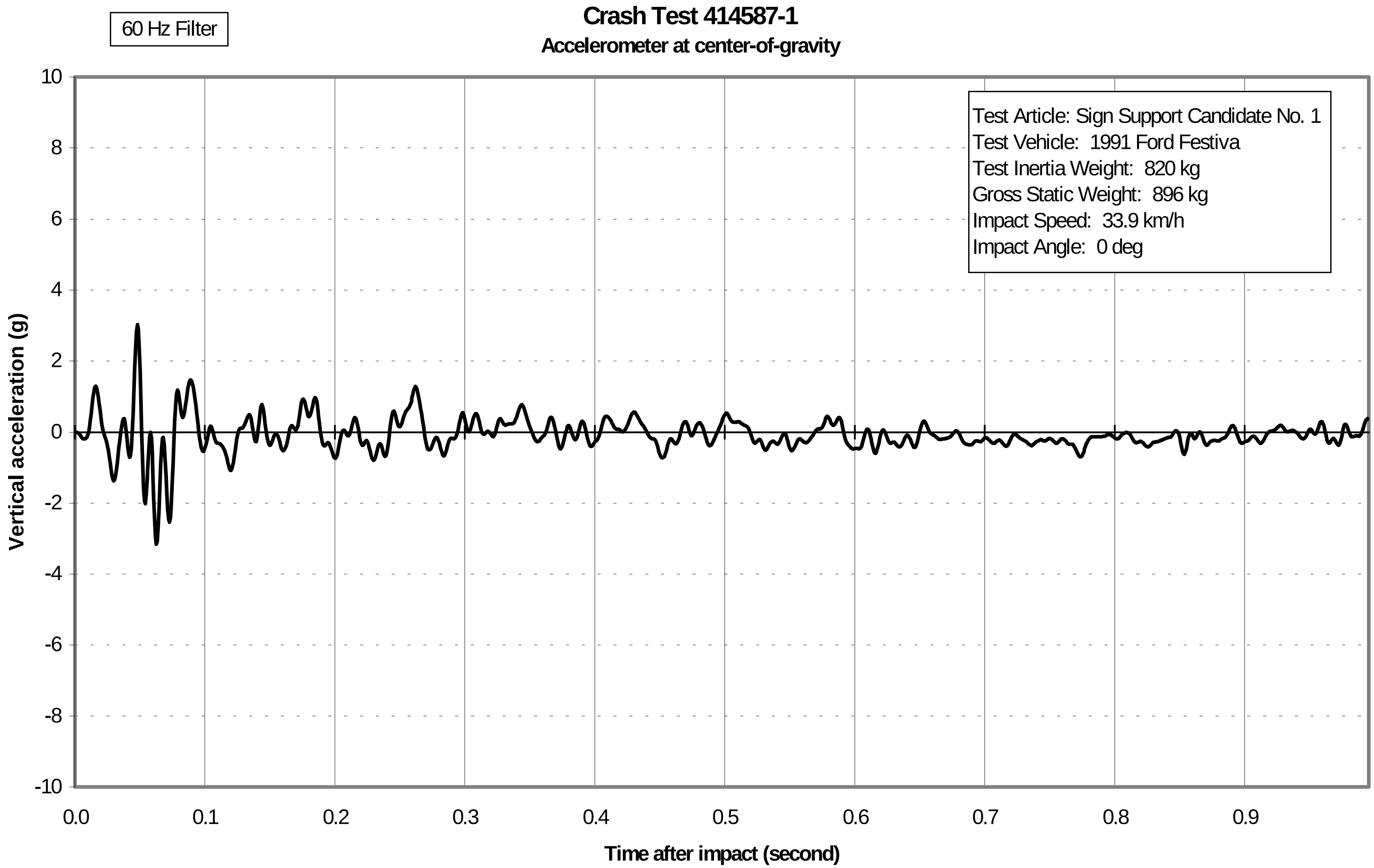


Figure 70. Vehicle Vertical Accelerometer Trace for Test 414587-1.

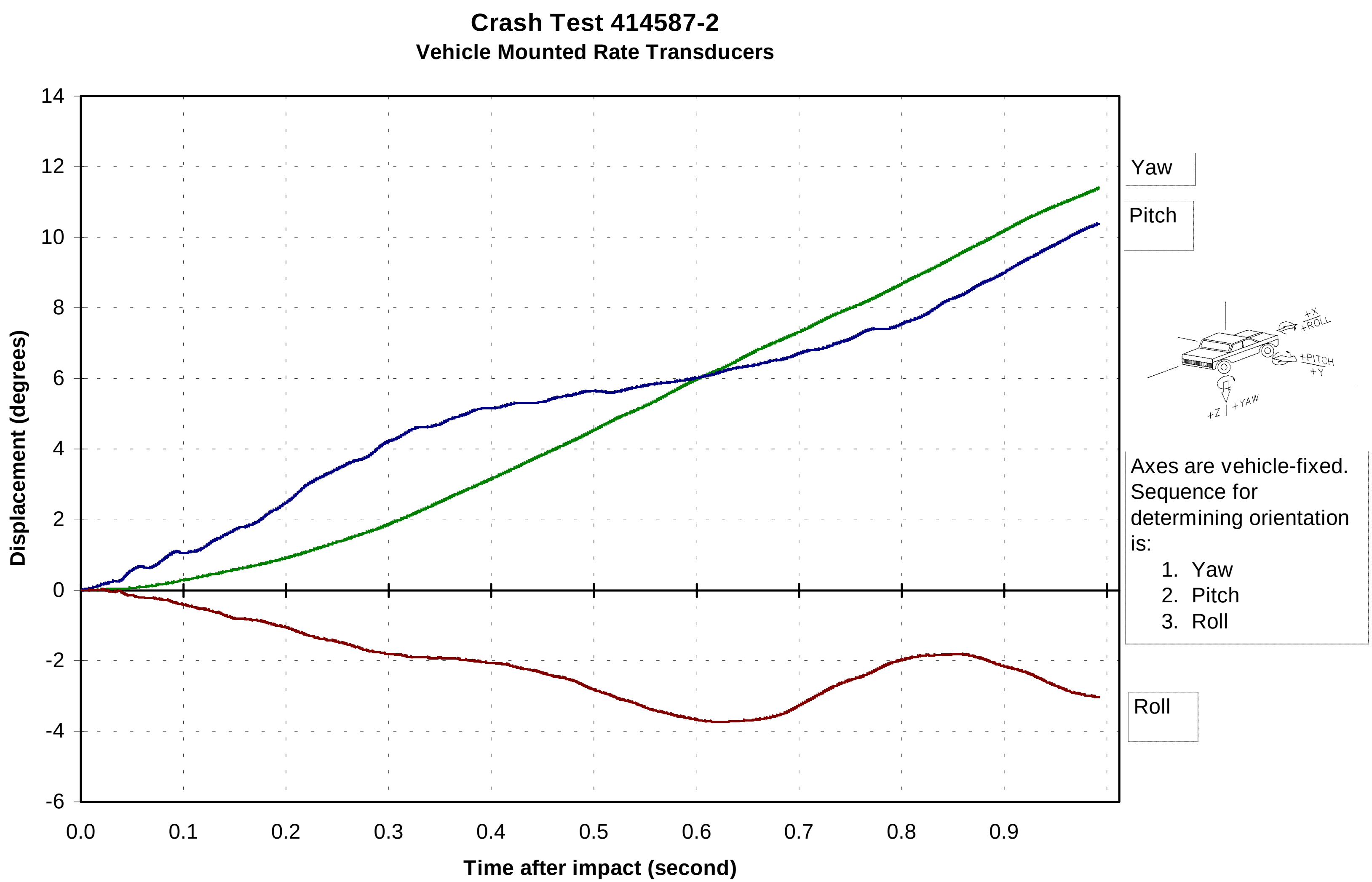


Figure 71. Vehicle Angular Displacements for Test 414587-2.

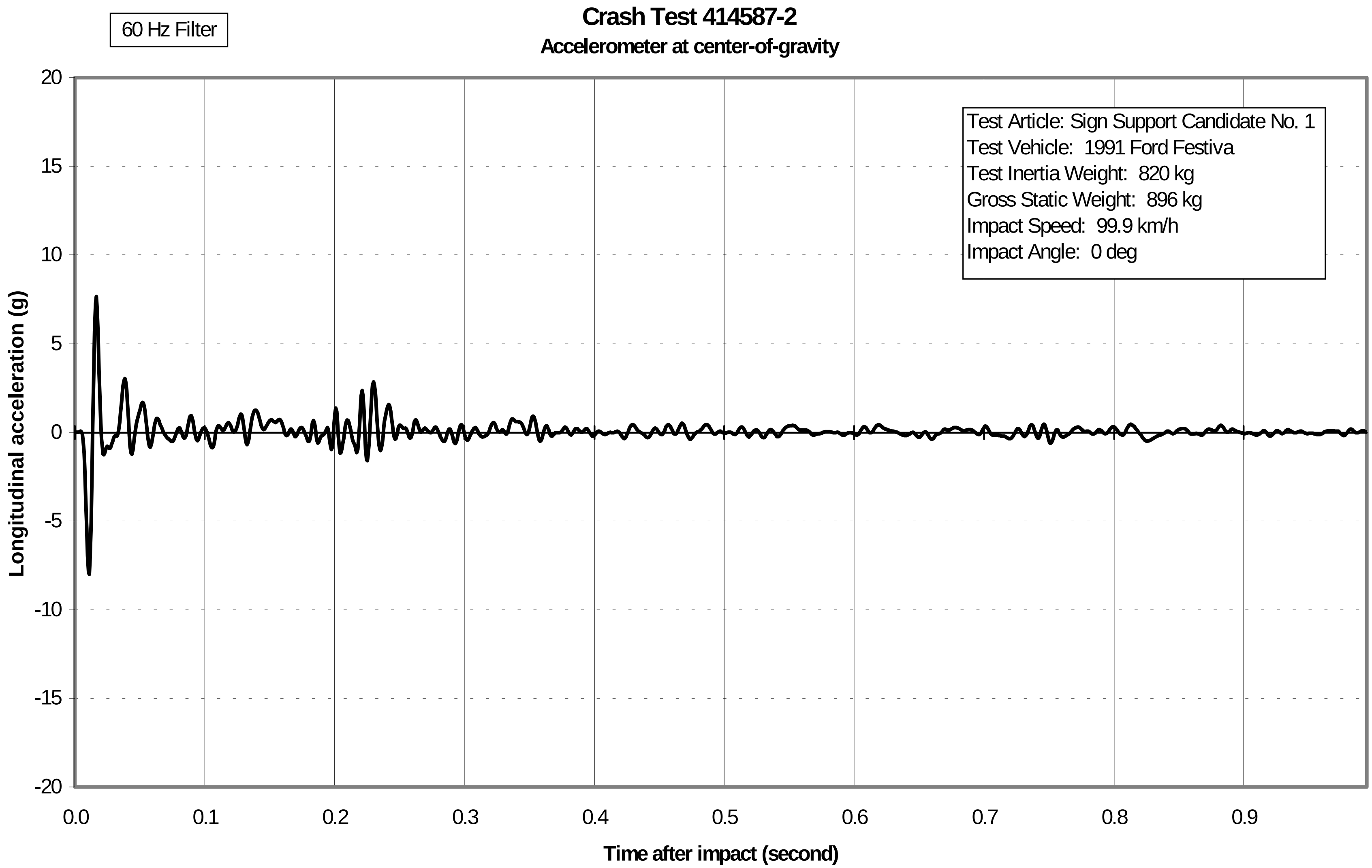


Figure 72. Vehicle Longitudinal Accelerometer Trace for Test 414587-2.

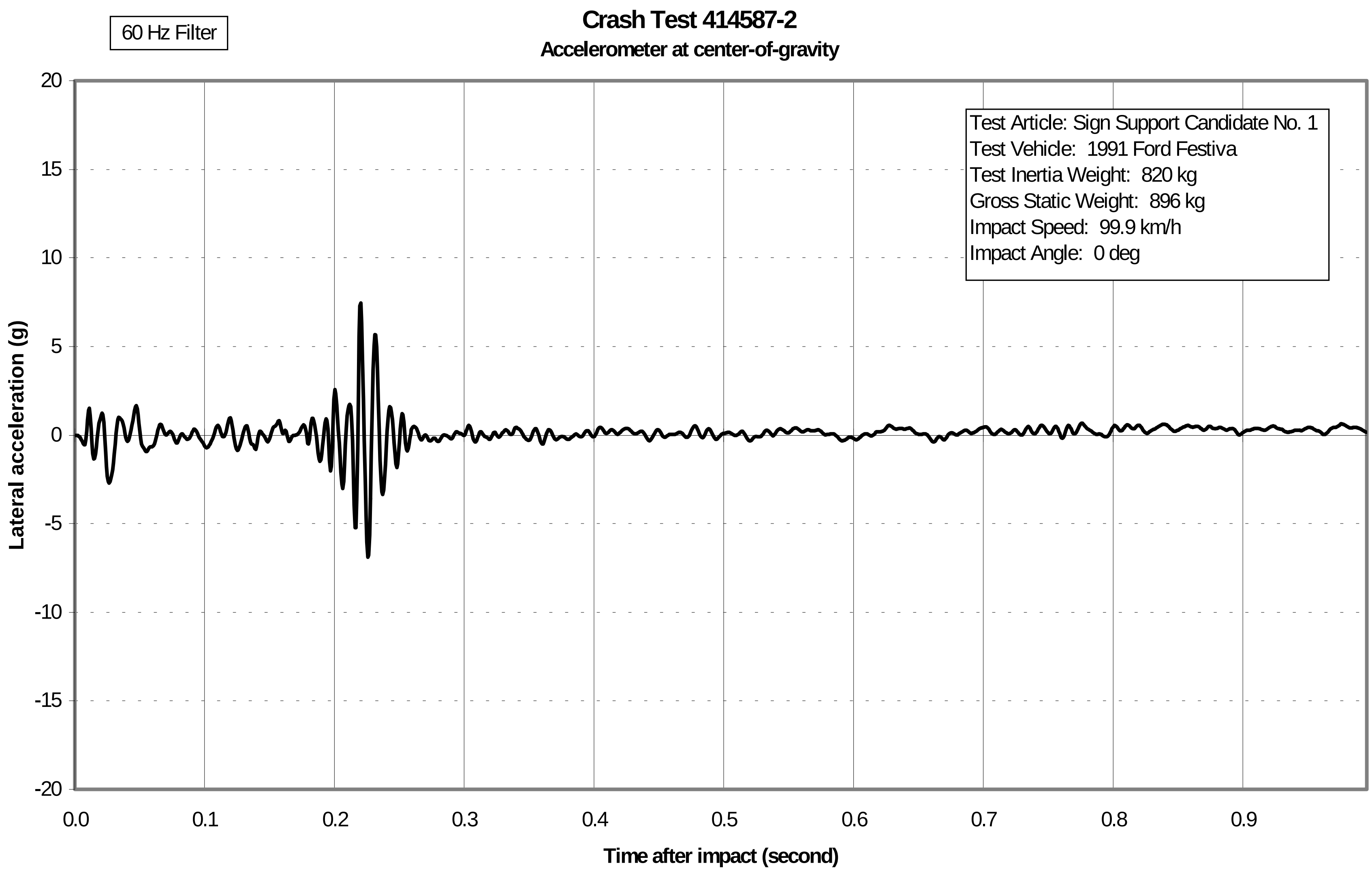


Figure 73. Vehicle Lateral Accelerometer Traces for Test 414587-2.

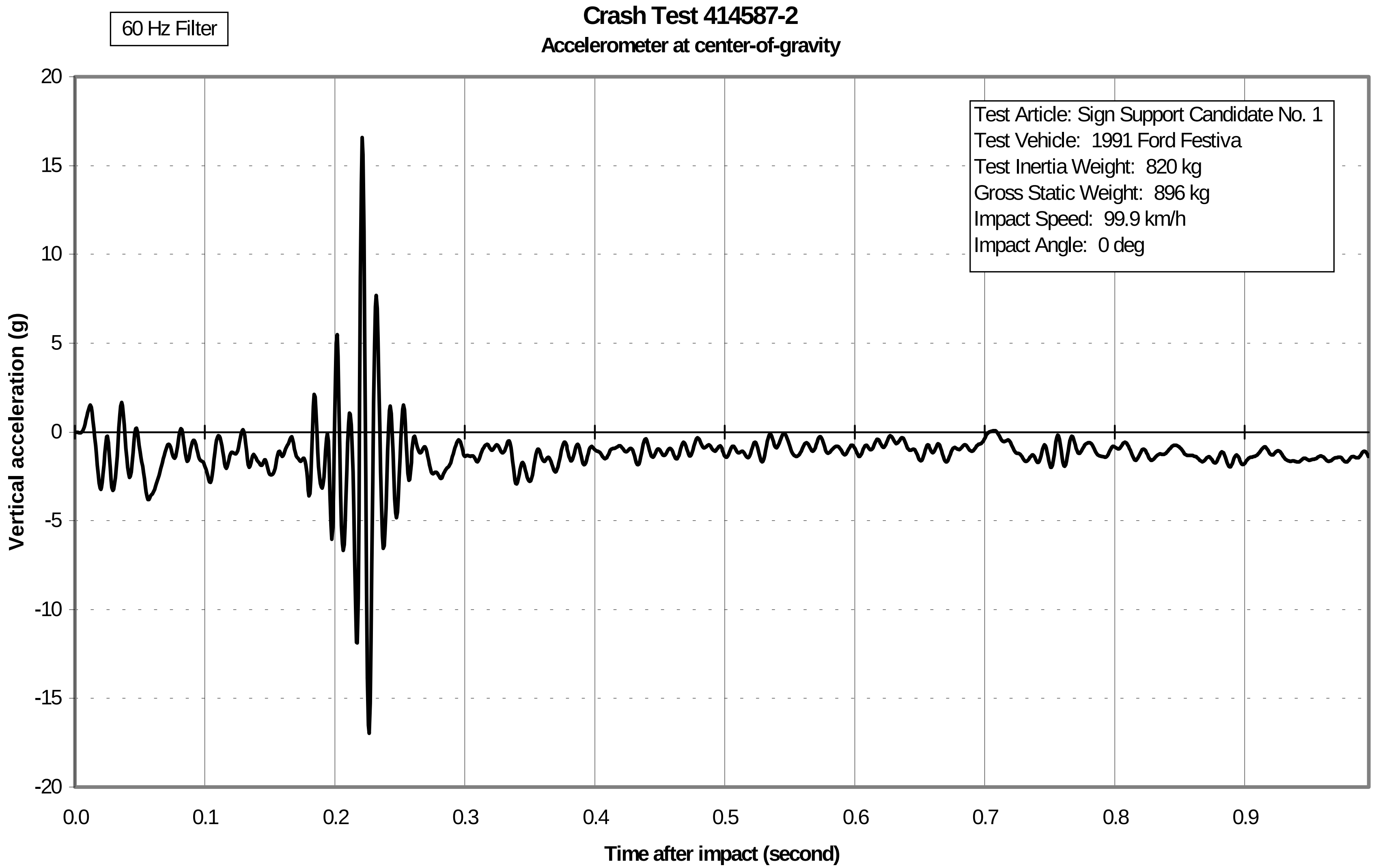


Figure 74. Vehicle Vertical Accelerometer Trace for Test 414587-2.

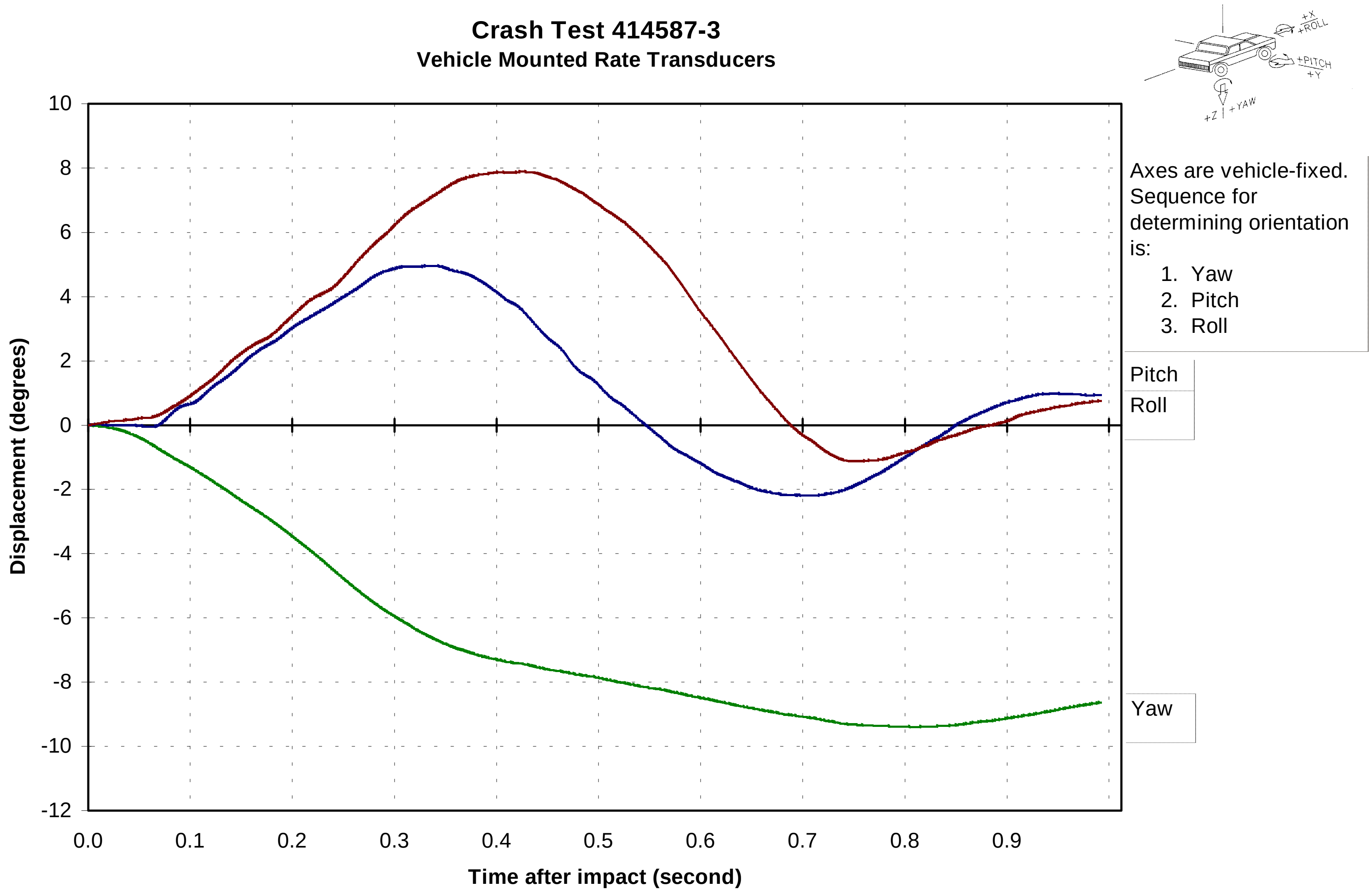


Figure 75. Vehicle Angular Displacements for Test 414587-3.

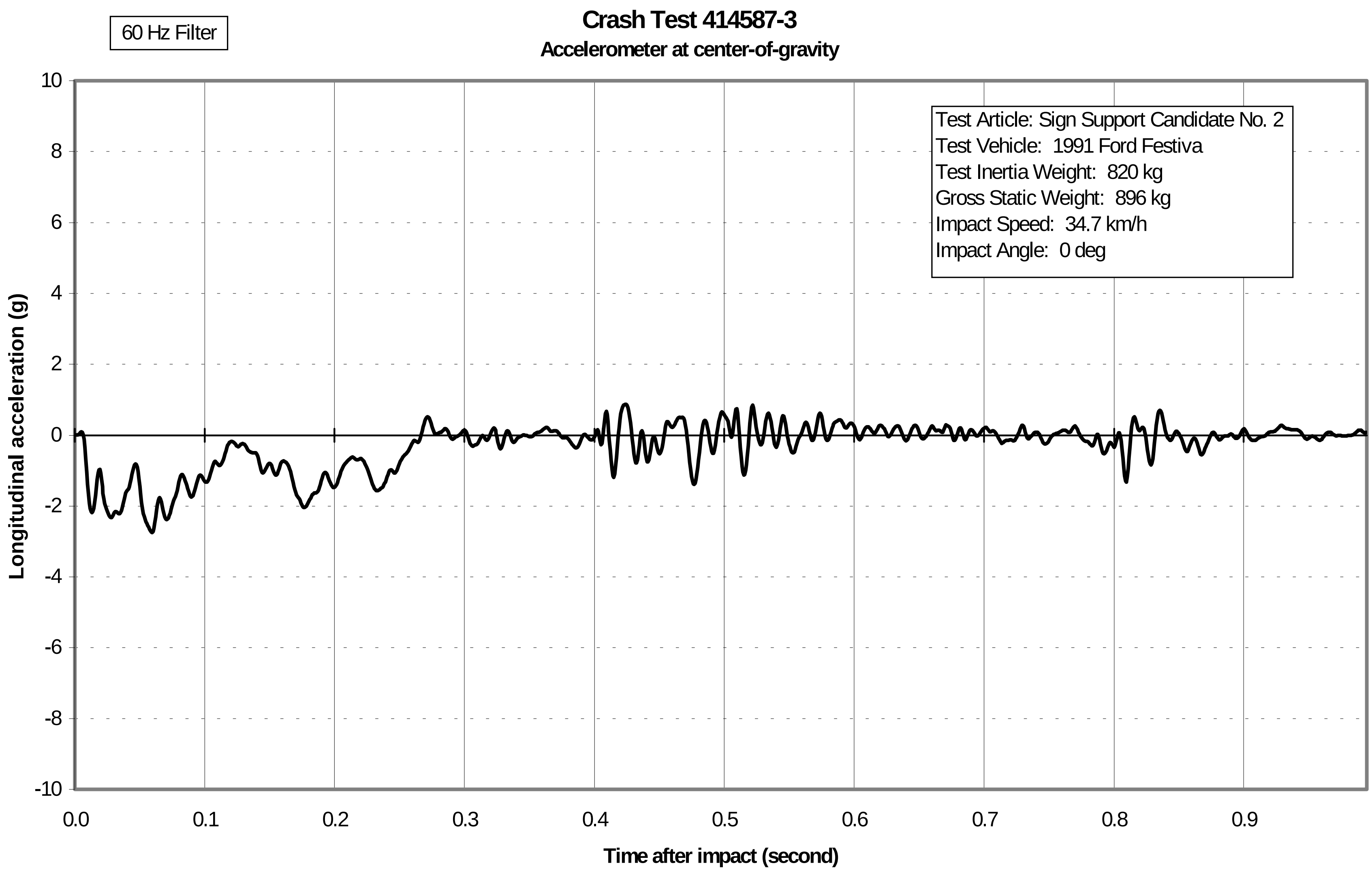


Figure 76. Vehicle Longitudinal Accelerometer Trace for Test 414587-3.

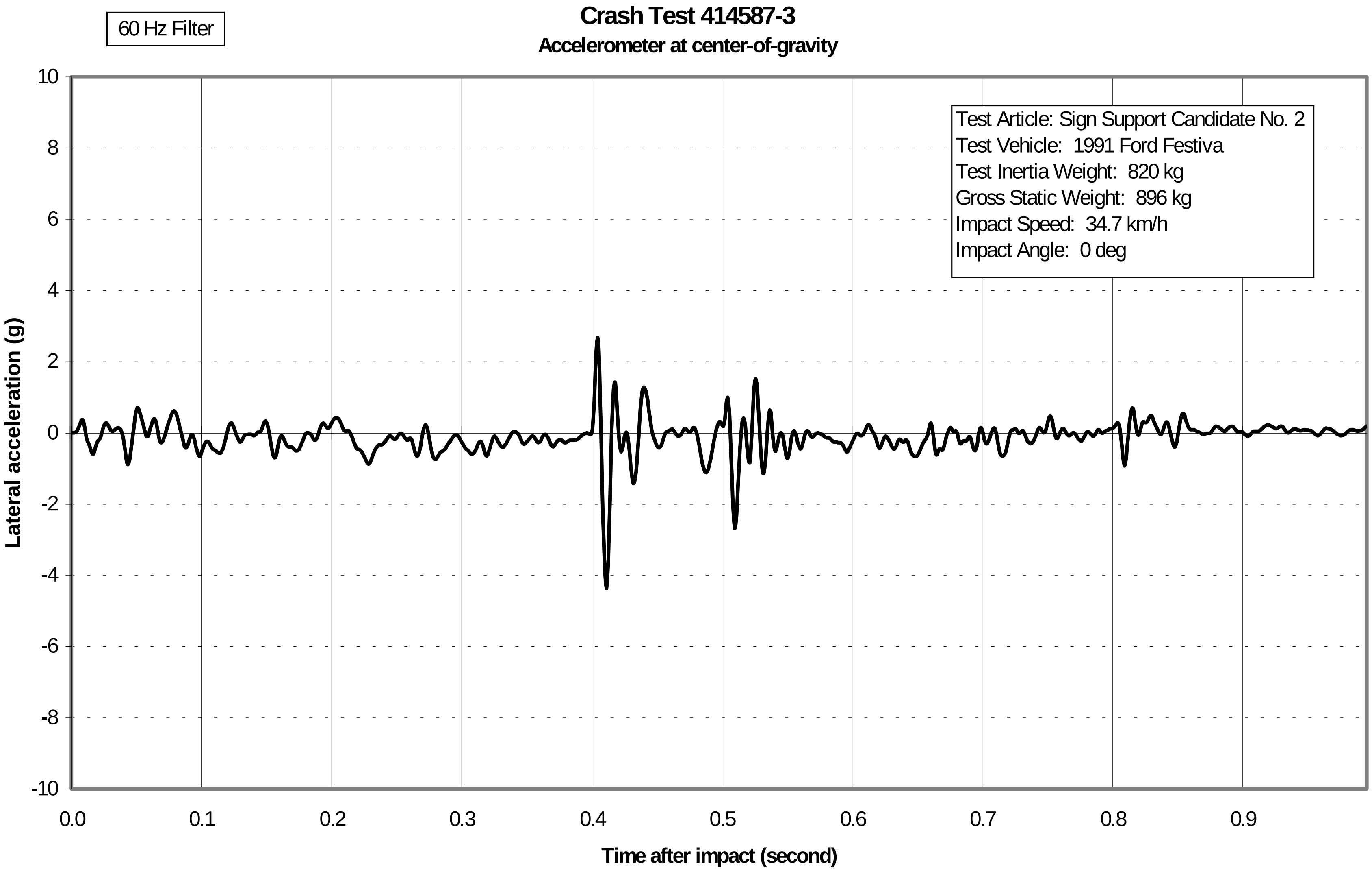


Figure 77. Vehicle Lateral Accelerometer Traces for Test 414587-3.

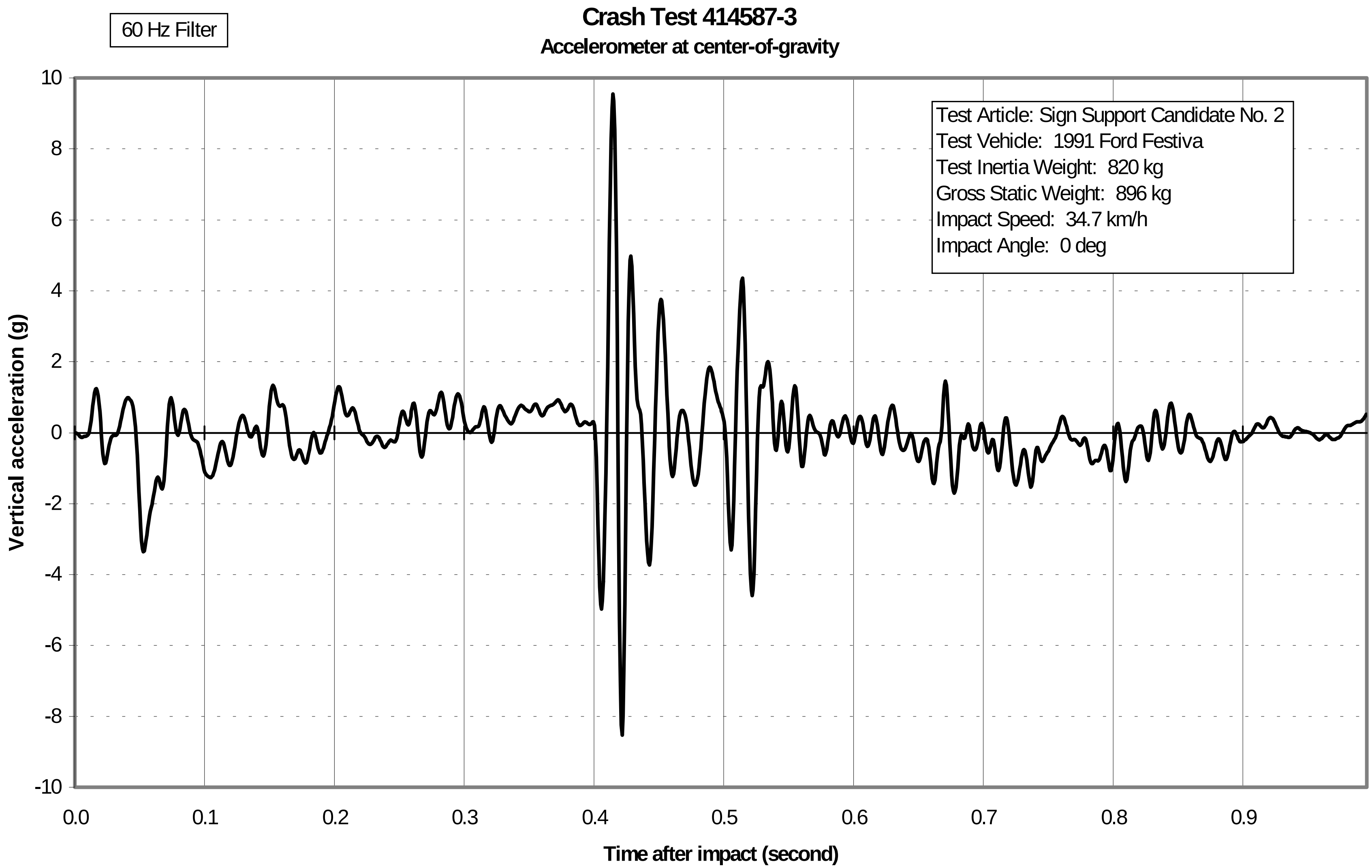


Figure 78. Vehicle Vertical Accelerometer Trace for Test 414587-3.

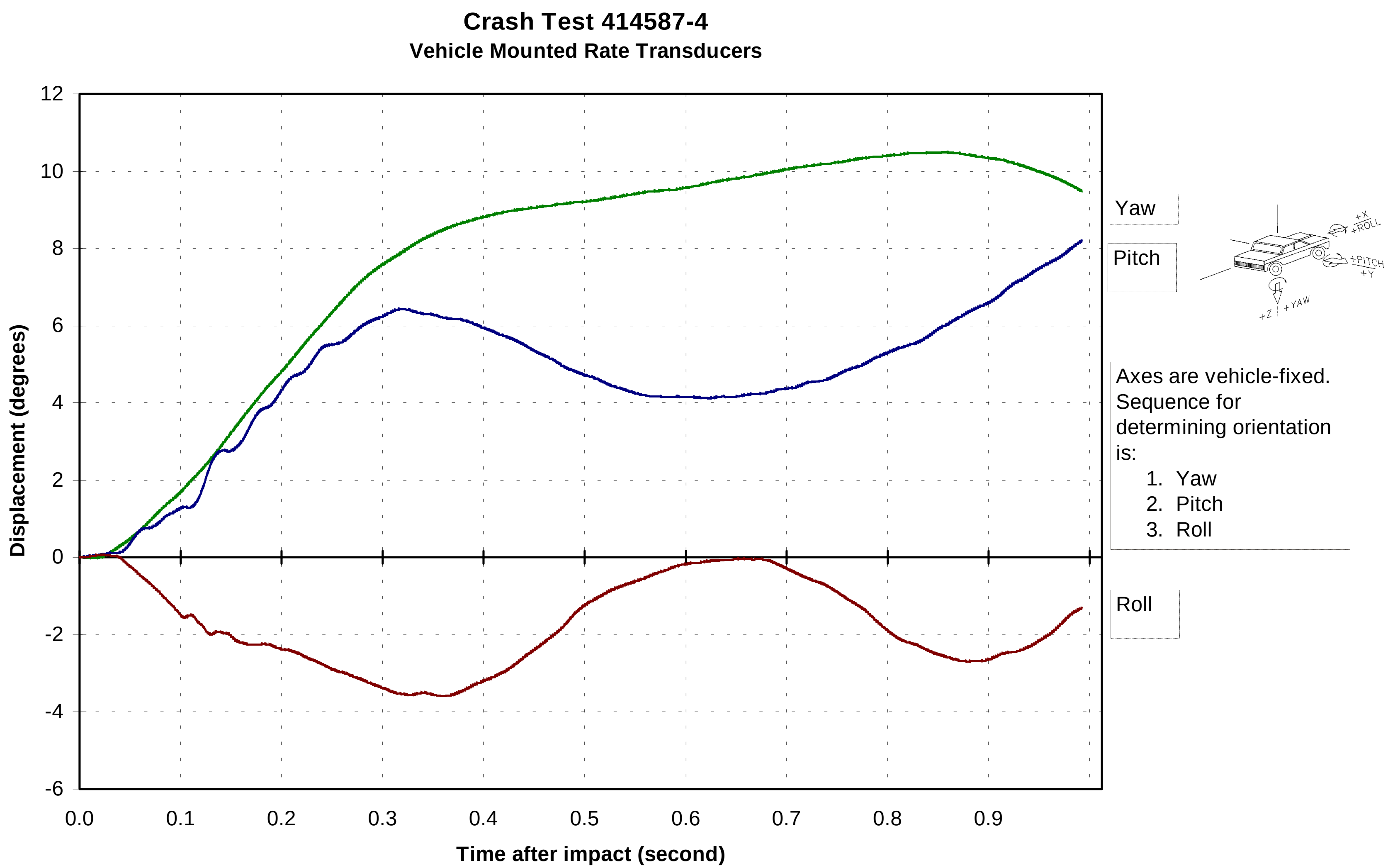


Figure 79. Vehicle Angular Displacements for Test 414587-4.

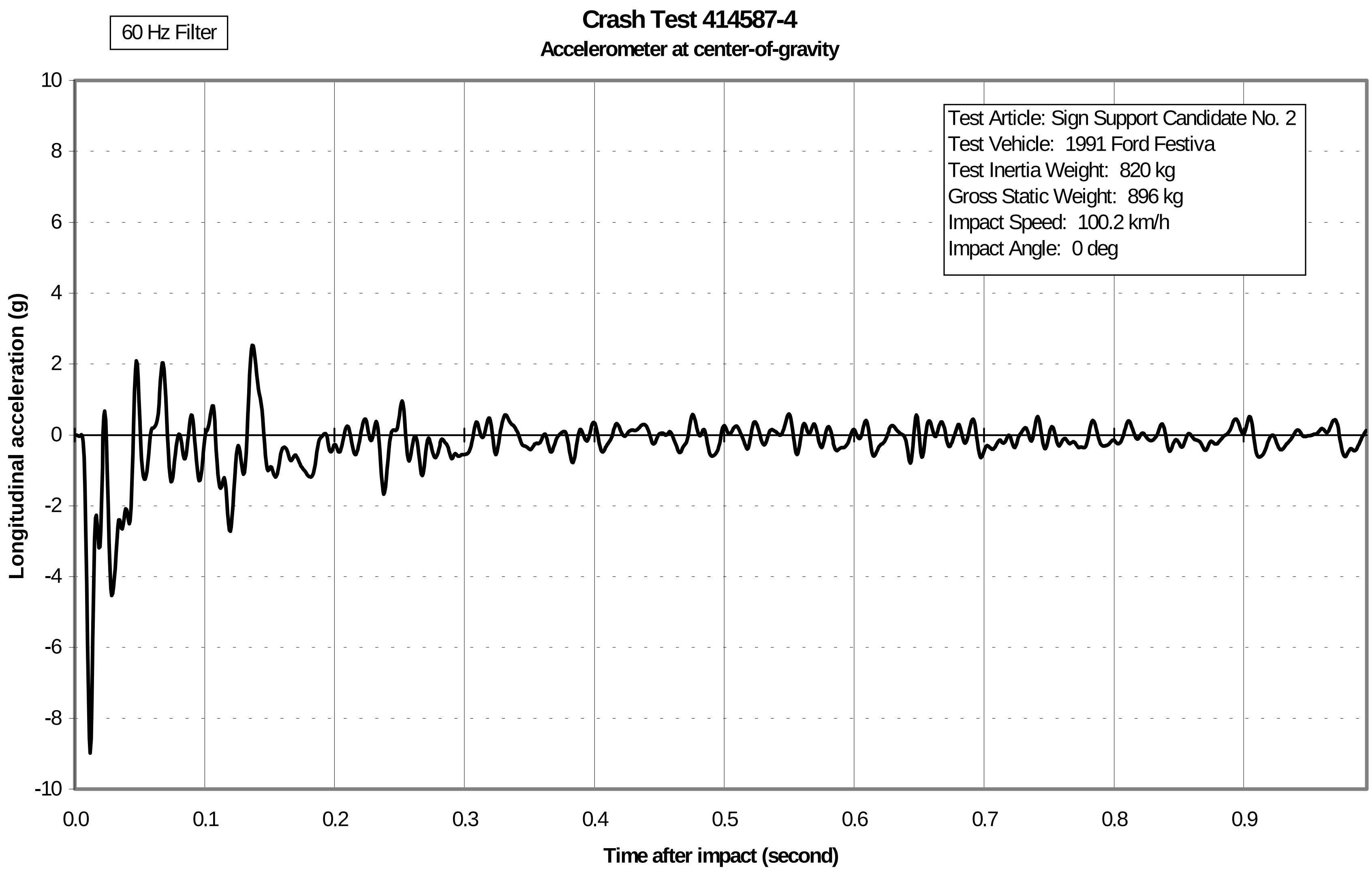


Figure 80. Vehicle Longitudinal Accelerometer Trace for Test 414587-4.

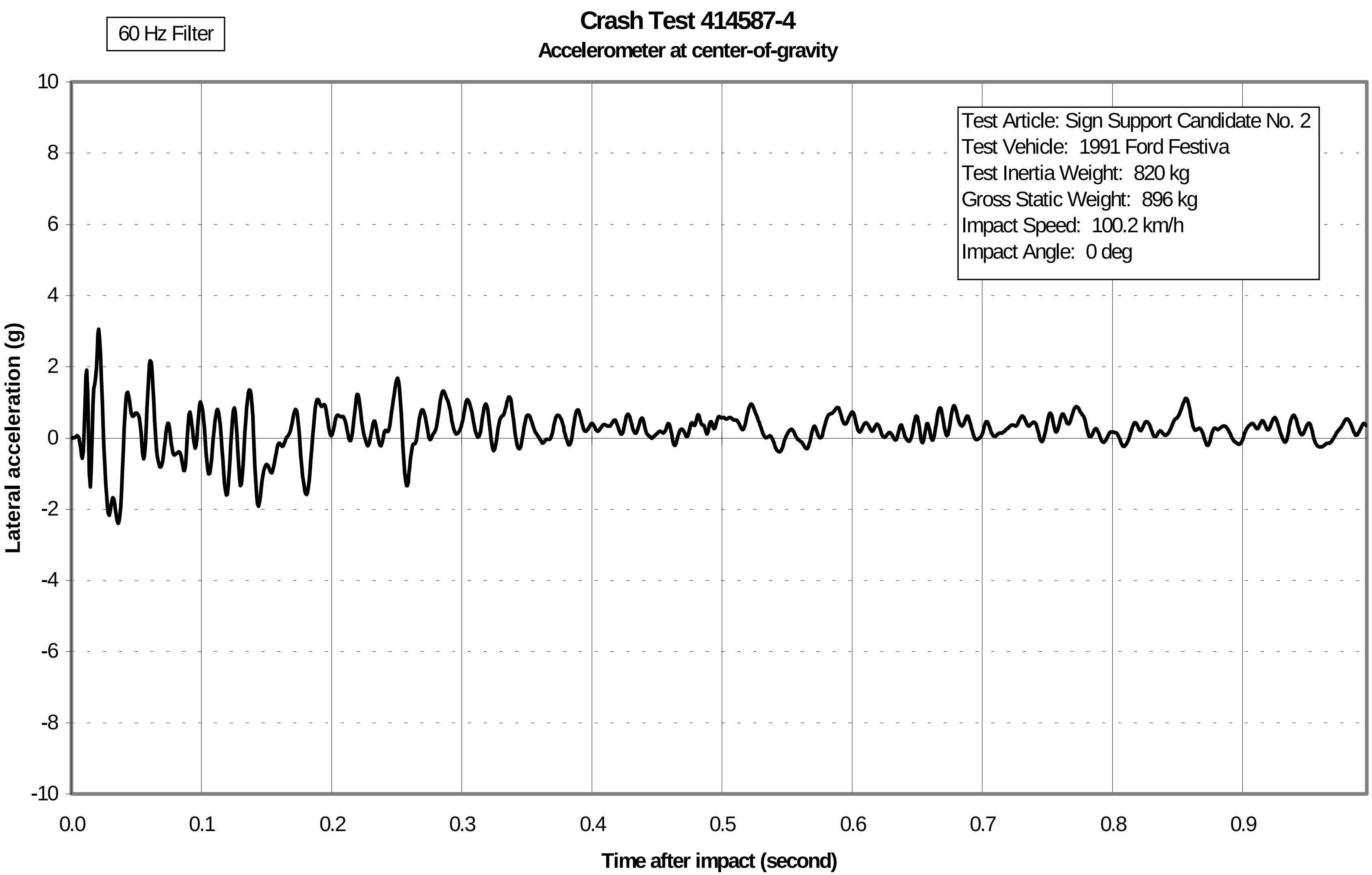


Figure 81. Vehicle Lateral Accelerometer Traces for Test 414587-4.

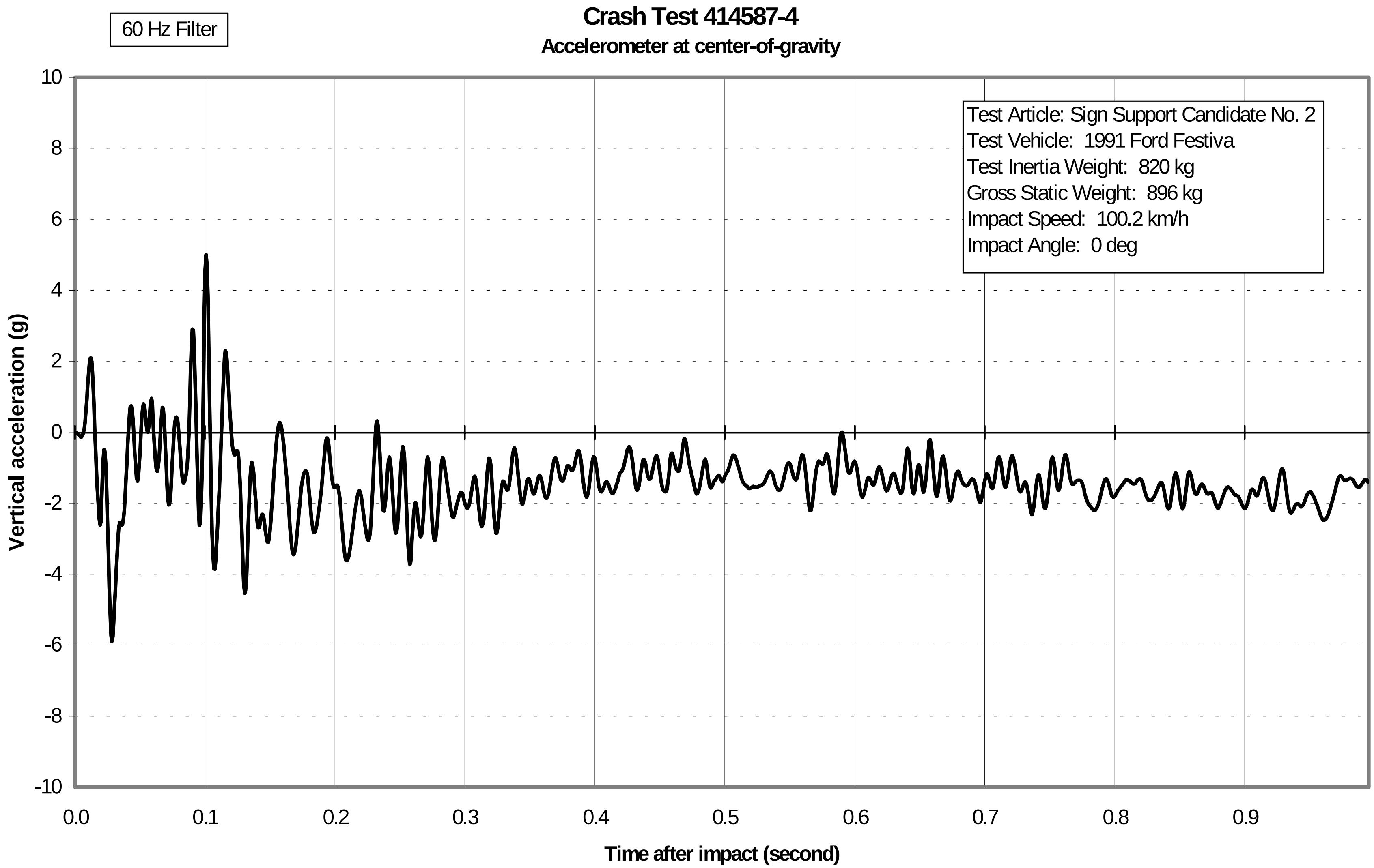


Figure 82. Vehicle Vertical Accelerometer Trace for Test 414587-4.

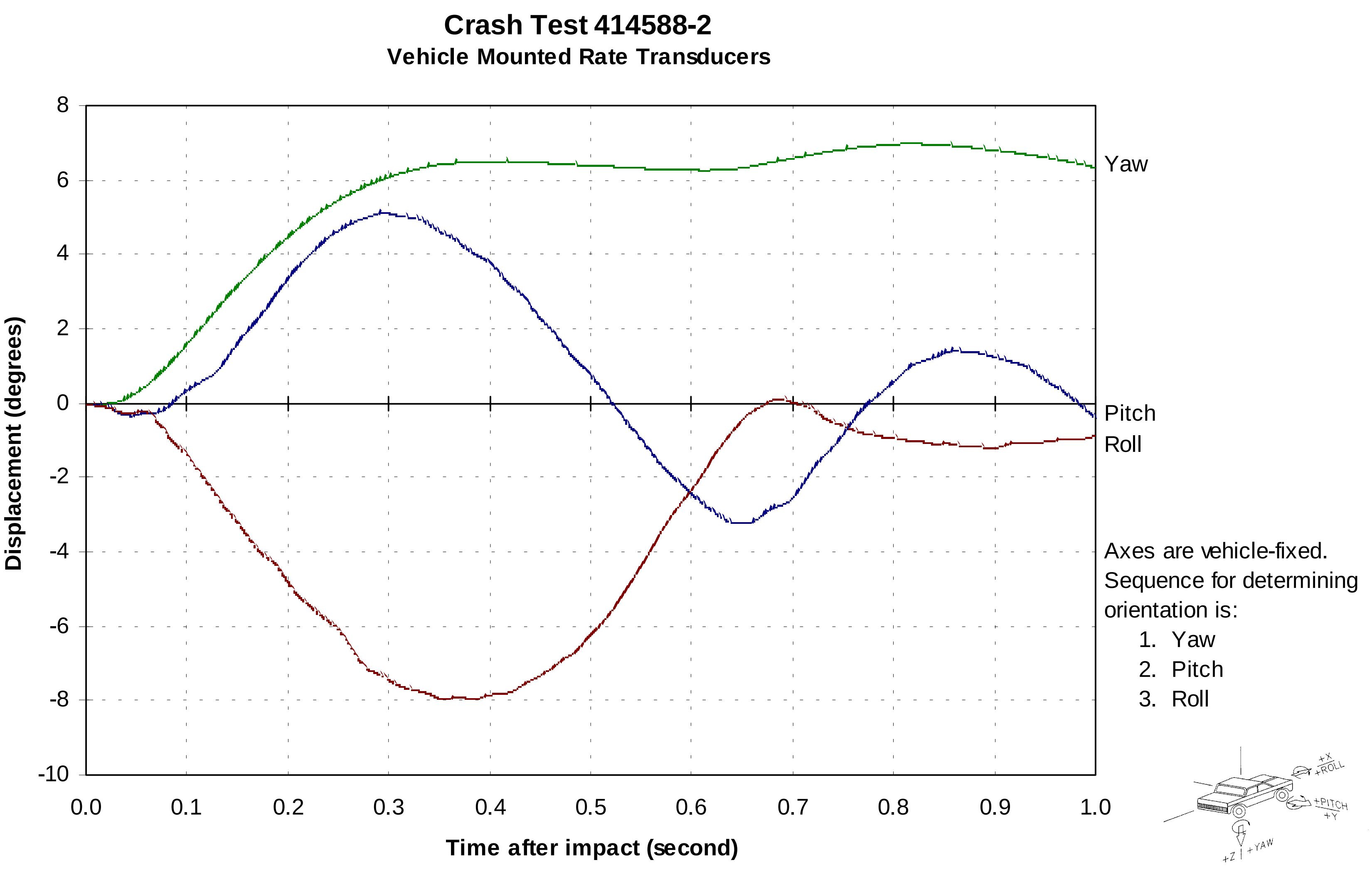


Figure 83. Vehicle Angular Displacements for Test 414588-2.

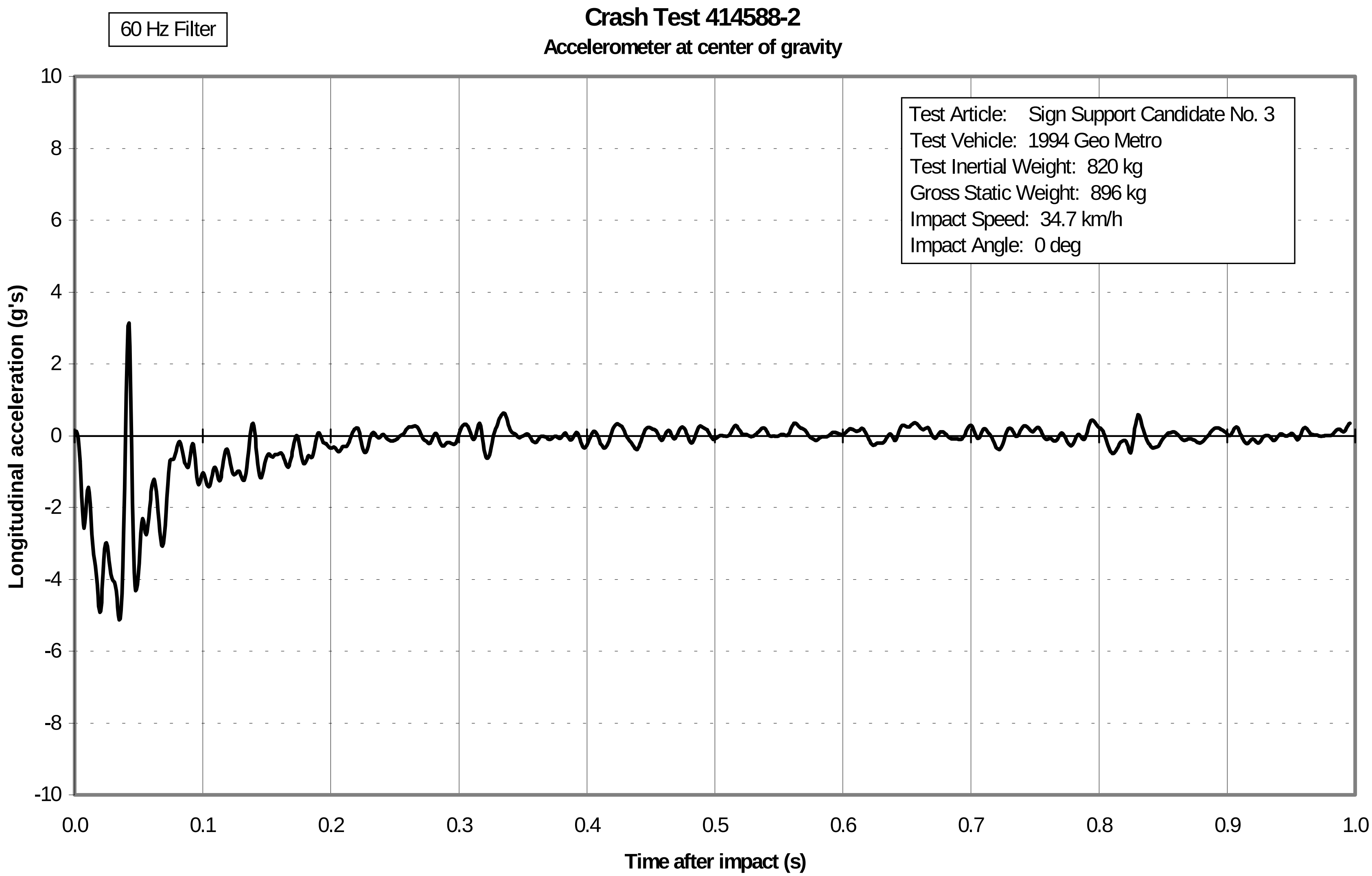


Figure 84. Vehicle Longitudinal Accelerometer Trace for Test 414588-2.

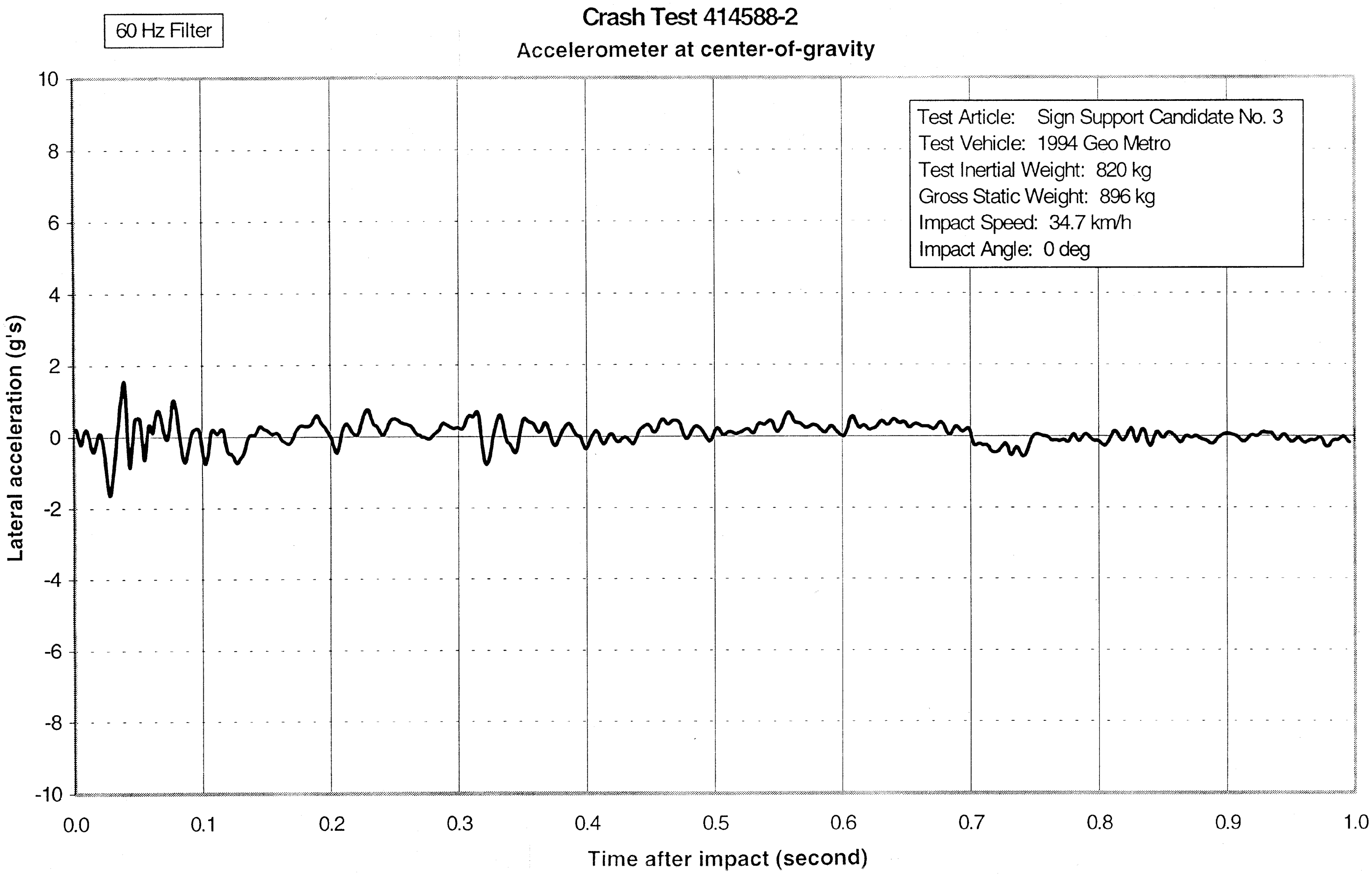


Figure 85. Vehicle Lateral Accelerometer Traces for Test 414588-2.

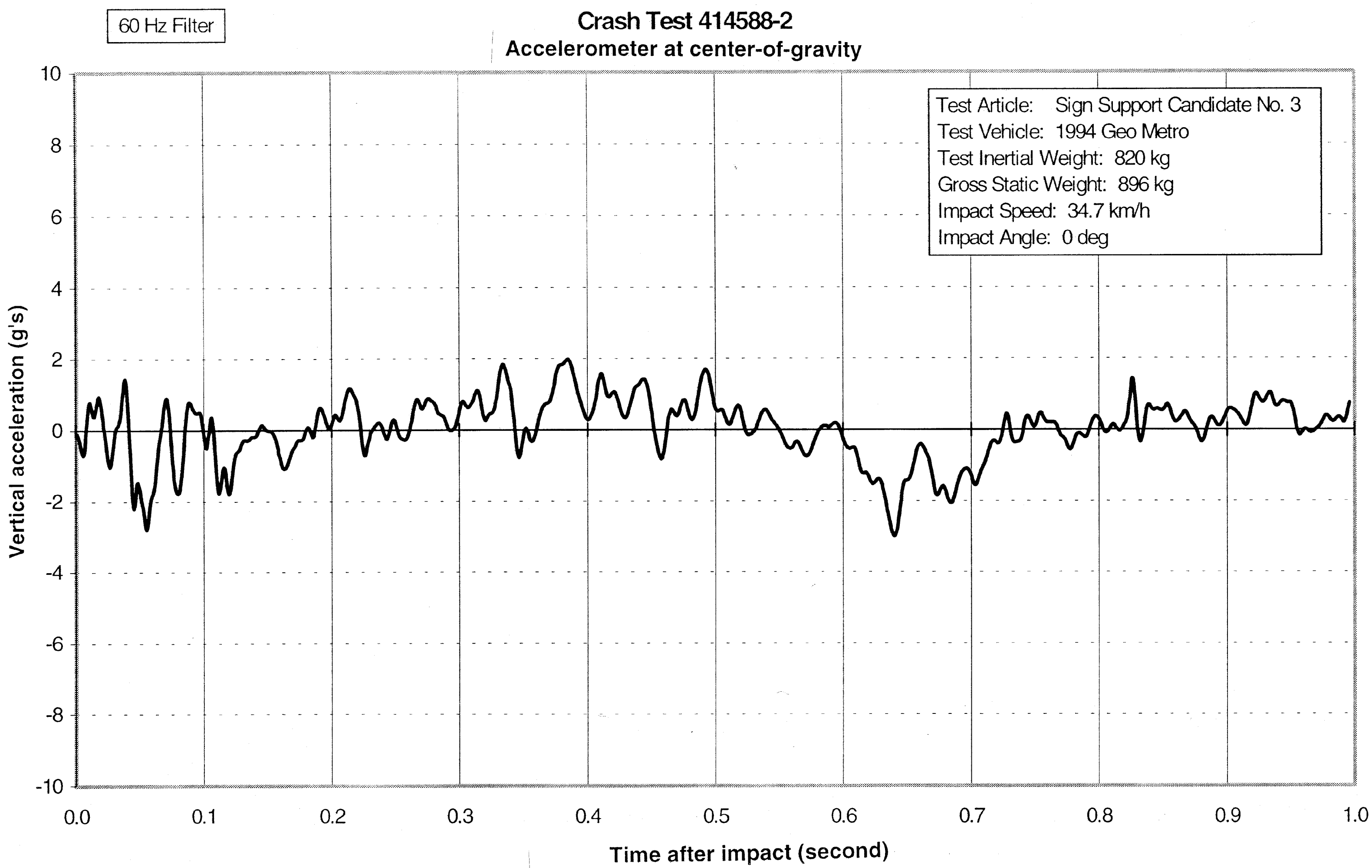


Figure 86. Vehicle Vertical Accelerometer Trace for Test 414588-2.

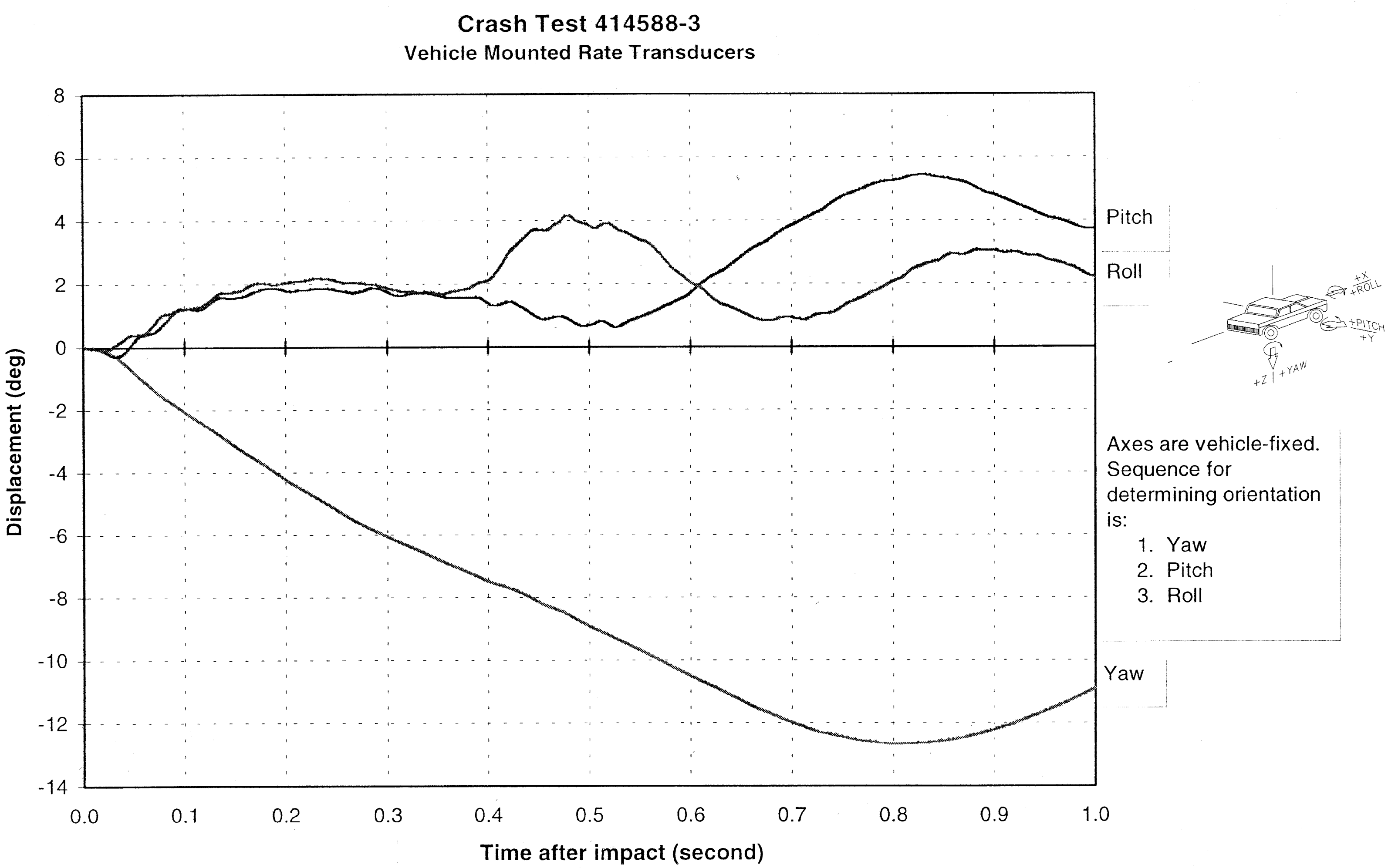


Figure 87. Vehicle Angular Displacements for Test 414588-3.

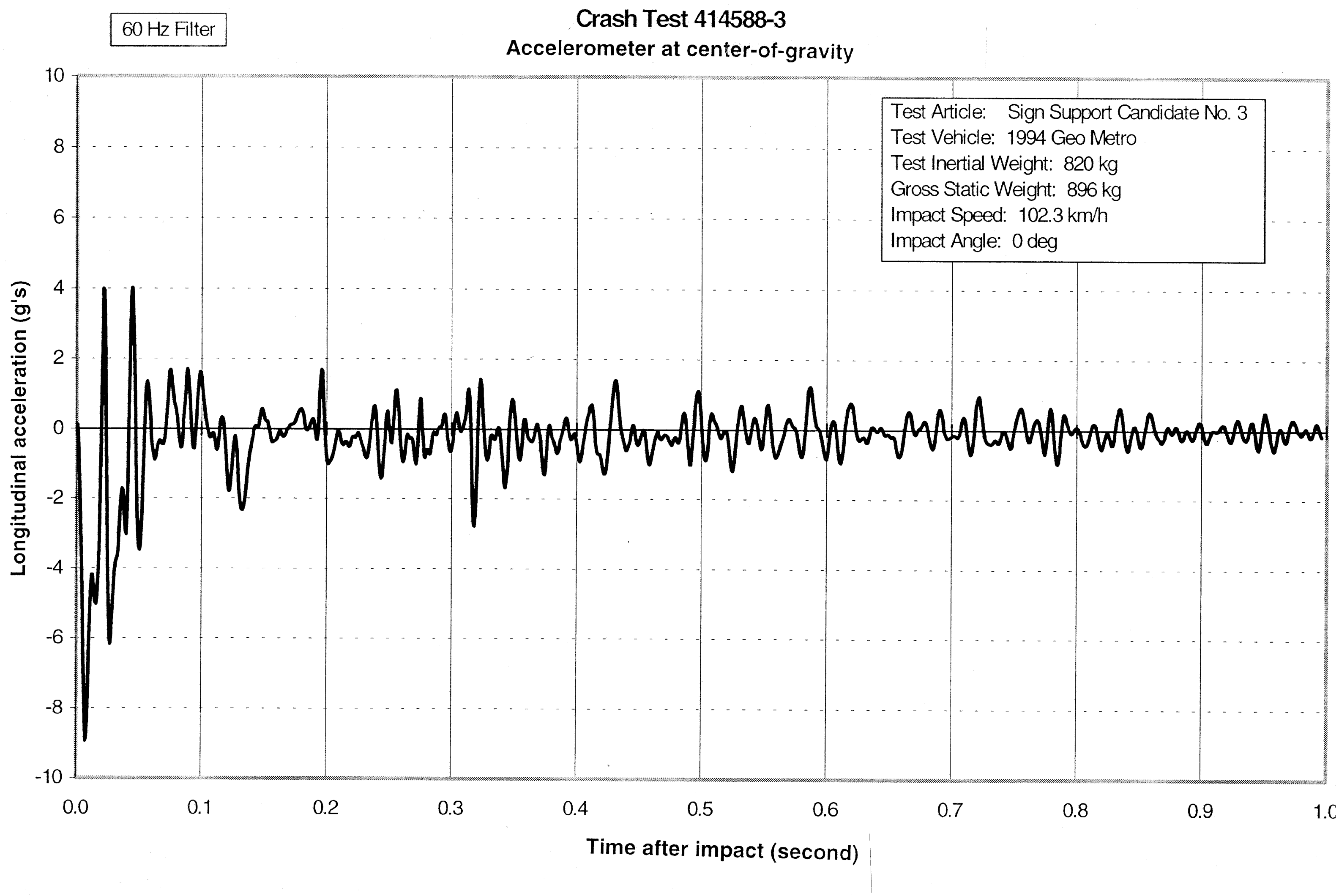


Figure 88. Vehicle Longitudinal Accelerometer Trace for Test 414588-3.

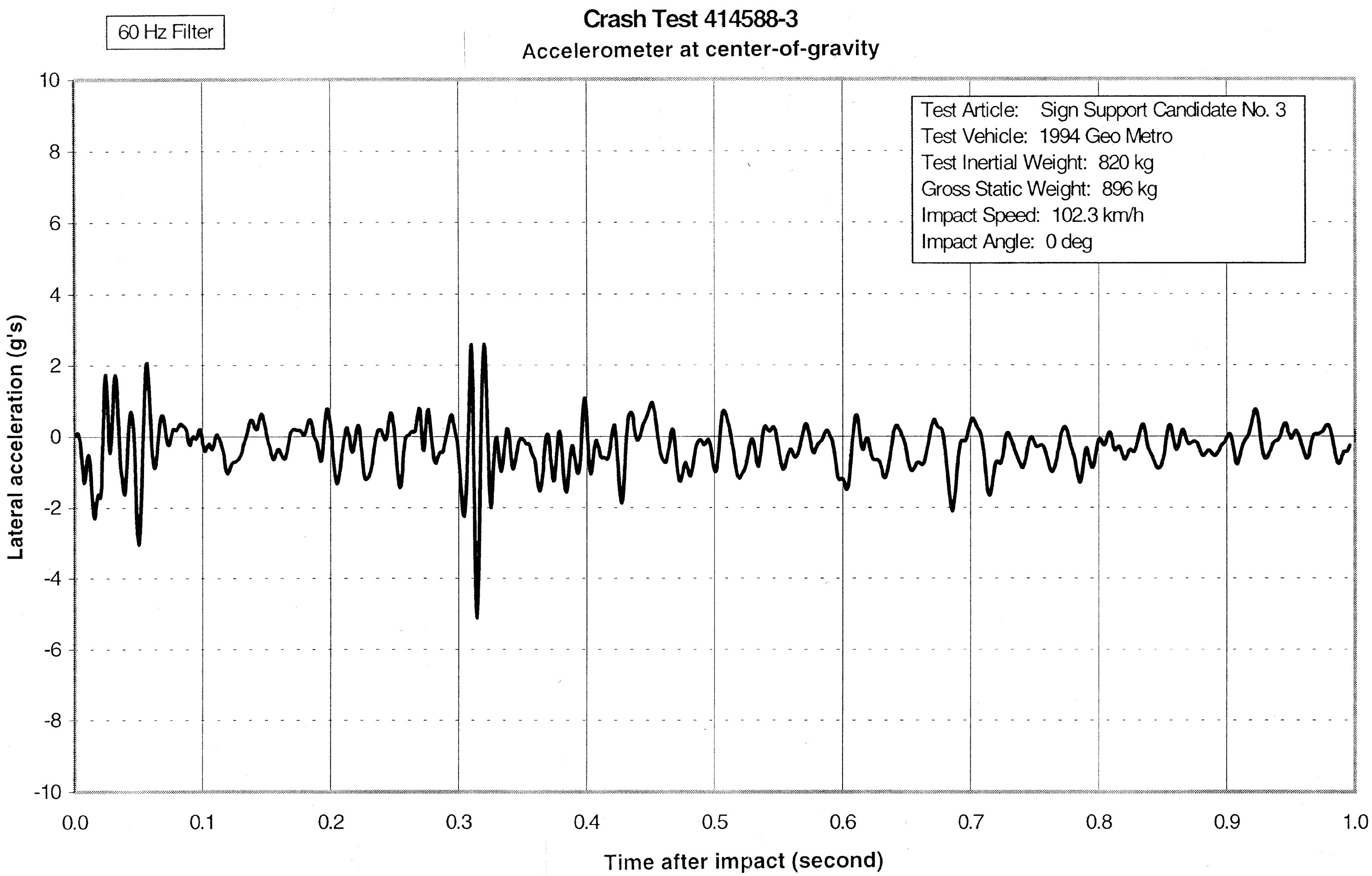


Figure 89. Vehicle Lateral Accelerometer Traces for Test 414588-3.

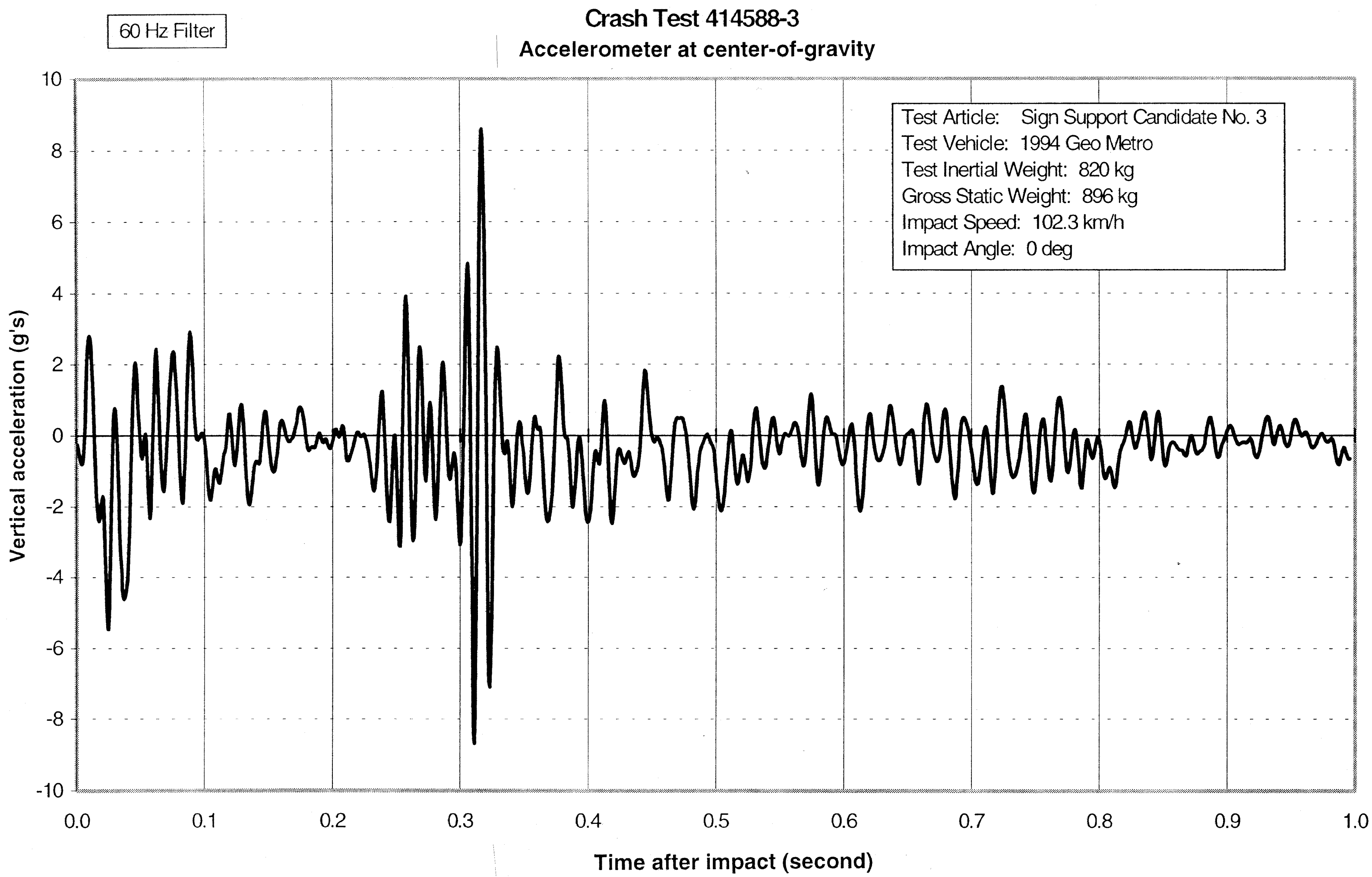


Figure 90. Vehicle Vertical Accelerometer Trace for Test 414588-3.

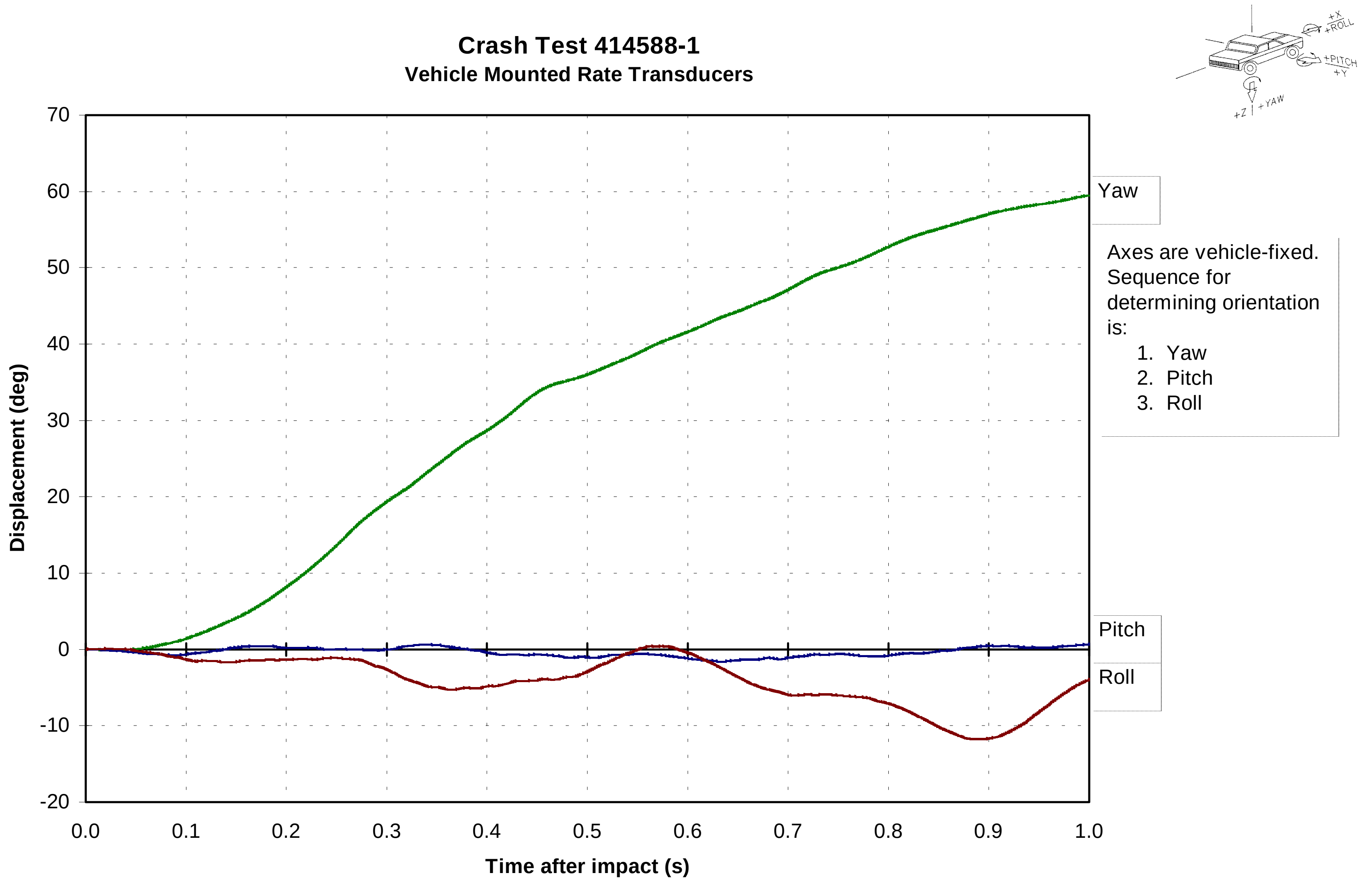


Figure 91. Vehicle Angular Displacements for Test 414588-1.

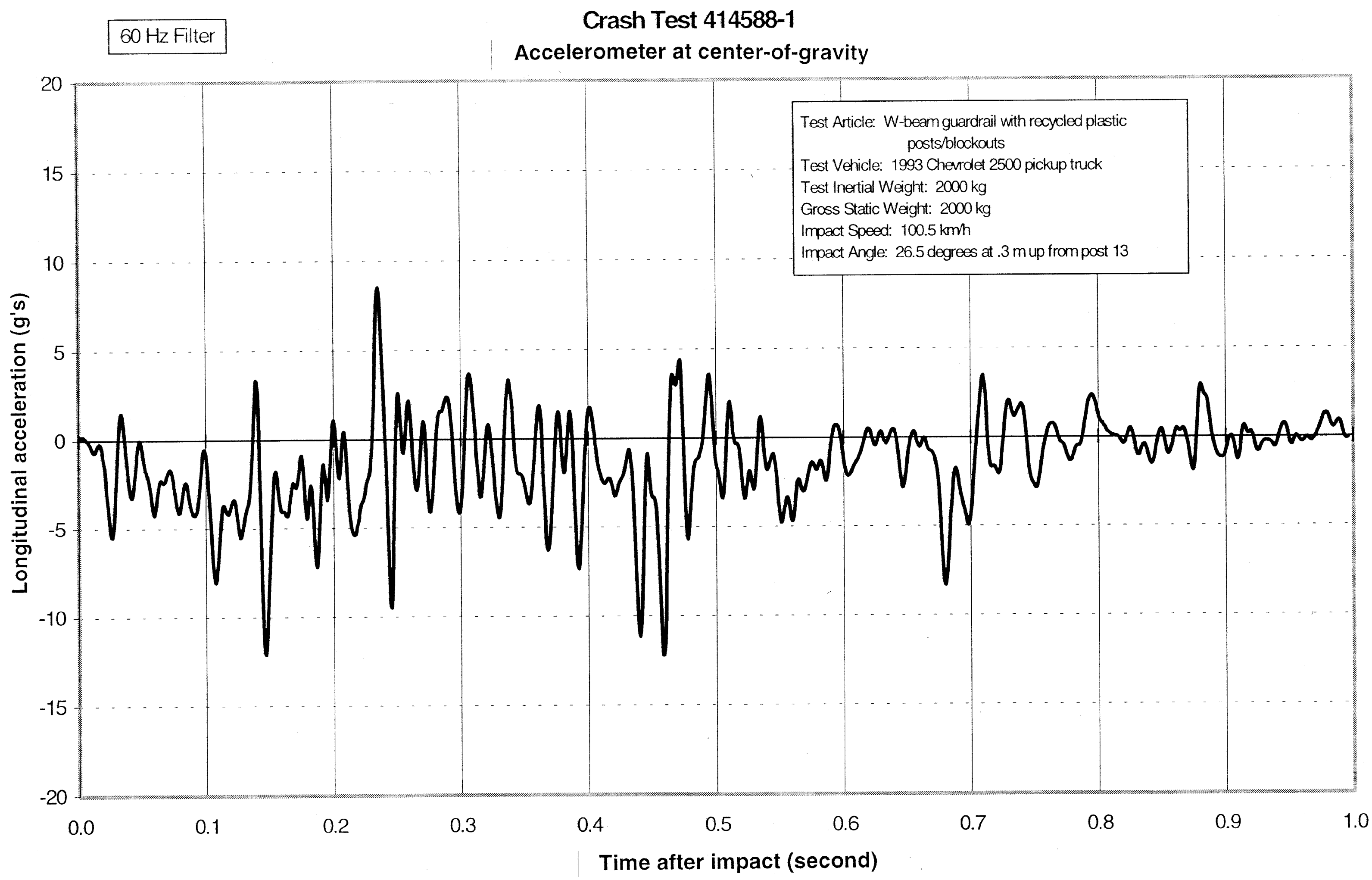


Figure 92. Vehicle Longitudinal Accelerometer Trace for Test 414588-1.

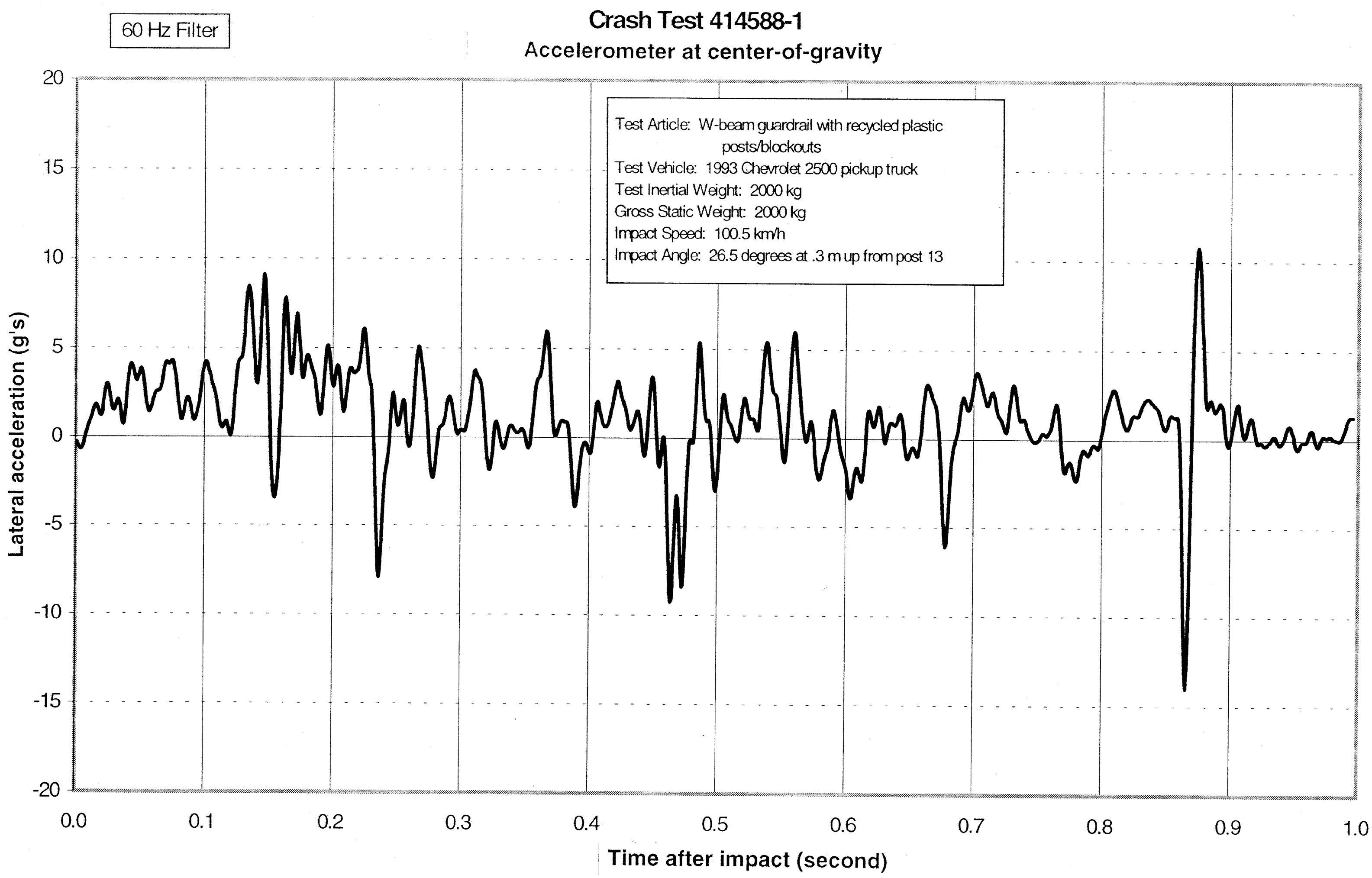


Figure 93. Vehicle Lateral Accelerometer Traces for Test 414588-1.

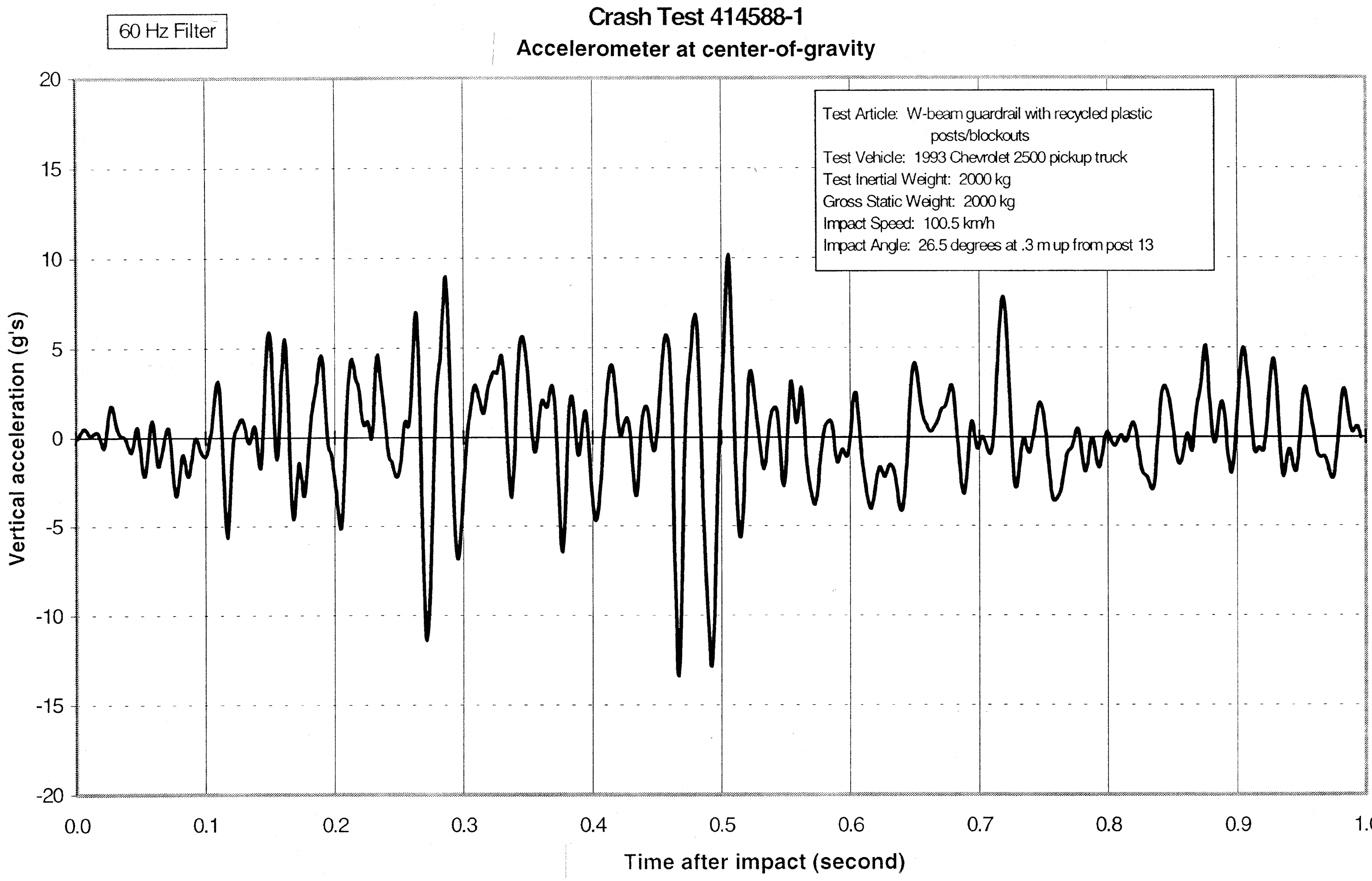


Figure 94. Vehicle Vertical Accelerometer Trace for Test 414588-1.