Technical Report Documentation Page

1. Report No. FHWA/TX-01/1792-4	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TESTING AND EVALUATION OF THE SOLAR PANEL SIGN SUPPORT SYSTEM		5. Report Date January 2001
		6. Performing Organization Code
7. Author(s) D. Lance Bullard, Jr., Roger P. Bligh, Wanda L. Menges, and Sandra K. Schoeneman		8. Performing Organization Report No. Report 1792-4
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. 0-1792
12. Sponsoring Agency Name and Address Texas Department of Transportation Construction Division Research and Technology Transfer Section P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Research: September 1998-August 2000
		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 Project Title: Roadside Safety Hardware for Traffic Control Devices

16. Abstract

The purpose of this series of tests is to verify the performance of the pedestal base sign installation when attached to the ground with a helical type screw-in foundation anchor assembly and equipped with the solar power (photovoltaic) hardware necessary to operate flashing signal beacons. Additionally, wind load analysis was also performed to determine the strength of the installation under extreme wind conditions.

A pedestal base sign installation equipped with photovoltaic equipment and attached to the ground with a helical type screw-in foundation anchor assembly successfully met the evaluation criteria set forth in National Cooperative Highway Research Program (*NCHRP) Report 350.* The installation was fabricated using a Pelco (model SP 1014 TX) square cast aluminum traffic signal base with a 114 mm (4.5 in) outside diameter × 3.96 m (13 ft) long spun aluminum pole. Attached to the pole was a 16 mm × 1.2 m × 1.2 m (0.625 in × 48 in × 48 in) plywood warning sign with the bottom of the sign height 2.1 m (7.0 ft). In addition, a 305 mm (12.0 in), LED lamp, flashing yellow signal beacon was mounted directly above the sign panel. A 1429 mm × 654 mm × 89 mm (56.3 in × 25.7 in × 3.5 in) solar panel weighing 235.8 N (53 lb) was attached atop the support. The battery cabinet for the panel was mounted behind the sign panel and weighed 520.4 N (117 lb). The helical type screw-in foundation anchored the assembly (model no. PB 5306) in *NCHRP Report 350* standard soil.

Under this project, the safety performance of selected work zone traffic control devices was evaluated through full-scale crash testing in accordance with *NCHRP Report 350* guidelines. The pedestal base sign support installation with solar voltaic equipment and a flashing beacon installed atop a screw-in helical type ground anchor was found to be in compliance with *NCHRP Report 350* guidelines and is considered suitable for implementation. Details of the pedestal base sign installation with solar voltaic equipment and a flashing beacon, as tested, are presented in this report. Installations that deviate in construction significantly from the details presented hereafter may require additional engineering evaluation and/or testing.

17. Key Words Signs, Sign Support, Pedestal Base, Solar Power, Signal Beacon, Wind Load, Traffic Signal, Crash Testing, Roadside Safety		18. Distribution Statement 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) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 92	22. Price

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TESTING AND EVALUATION OF THE SOLAR PANEL SIGN SUPPORT SYSTEM

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Report 1792-4
Project Number 0-1792
Research Project Title: Roadside Safety Hardware
for Traffic Control Devices

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

January 2001

TEXAS TRANSPORTATION INSTITUTE
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DISCLAIMER

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. The TxDOT project director for this research was Mr. Greg Brinkmeyer. We acknowledge and appreciate his assistance.

Special thanks go to the project panel:

- Greg Brinkmeyer, Traffic Operations Division-TE
- Dan Maupin, Traffic Operations-TE
- Paul Frerich, Yoakum District
- Larry Colclasure, Waco District
- Manny Aguilera, El Paso District
- David Mitchell, Traffic Operations Division-TM
- Billy Wehring, Highway Safety Service Company, Inc.
- Bill Yates, Safety Lights Company
- Garry Silagi, City of Austin

ACM Highway Products and David Mitchell (TxDOT Traffic Operations Division) provided assistance in procurement and installation of the solar voltaic components. The Yoakum District and David Mitchell provided assistance with installing the screw-in anchors. This assistance helped the project by saving money and time.

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I. INTRODUCTION

PROBLEM/BACKGROUND

FHWA has formally adopted the performance evaluation guidelines for highway safety features set forth in National Cooperative Highway Research Program (*NCHRP*) *Report 350* [1] as a "Guide or Reference" document in Federal Register, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a) (13) to 23 CFR, Part 625.5. FHWA has mandated, starting in October 1998, only support structures that have successfully met the performance evaluation guidelines set forth in *NCHRP Report 350* may be used on the National Highway System (NHS) for new installations.

Previous full-scale crash tests have demonstrated the crashworthiness of support structures with warning signs and flashing beacons attached to a pedestal-style cast aluminum base.[2] The solar panel and batteries which power the beacons are typically mounted on a separate support structure located near the right of way. Some districts within TxDOT expressed interest in combining all of the necessary hardware for a solar-powered beacon assembly onto a single support structure. Elimination of the second support structure and its foundation could result in a reduction of installation cost and time. However, before this practice is permitted, the crashworthiness of the support structure equipped with warning sign, flashing beacon, solar panel, and battery control cabinet must be demonstrated through full-scale crash testing. Specifically, the support structure must be properly configured to prevent the battery control cabinet or other components from penetrating into the occupant compartment of the vehicle once the breakaway base is activated and the support is released.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this project is to evaluate additional sign support structures and their anchor systems to determine the structures that perform satisfactorily when impacted by errant vehicles. The performance of these sign support structures would be evaluated in accordance with national safety performance guidelines set forth in *NCHRP Report 350* and the 1994 American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*.[3]

Two full-scale crash tests were performed on a pedestal base sign installation equipped with the solar power (photovoltaic) hardware necessary to operate flashing signal beacons. Additionally, wind load analysis was performed and the impact behavior and post-impact trajectory of the system was modeled and simulated.

This report presents details of this research. Chapter II outlines the research approach of the study, including the crash test matrix, and the evaluation criteria. A brief summary of the simulation performed on the slip base sign systems is given in Chapter III. Descriptions of the sign support structures tested are presented in Chapter IV. Results of the crash tests are presented in Chapter V. A summary of findings, conclusions, and recommendations is presented in Chapter VI.

II. STUDY APPROACH

CRASH TEST FACILITY

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809 hectare (2000 acre) complex of research and training facilities situated 16 km (10 mi) northwest of the main campus of Texas A&M University. The site, formerly a U.S. Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placement of the TxDOT sign installations was along the edge of a wide expanse of concrete aprons that were originally used as parking aprons for military aircraft. These aprons consist of unreinforced jointed concrete pavement in 3.8 m by 4.6 m (12.5 ft by 15.0 ft) blocks nominally 152 to 203 mm (6 to 8 in) deep. The aprons and runways are about 50 years old, and the joints have some displacement, but are otherwise flat and level. The sign supports were installed in *NCHRP Report 350* standard soil. Further details of each of the installations are presented in Chapter III.

CRASH TEST CONDITIONS

NCHRP Report 350 requires two tests for test level 3 evaluation of breakaway support structures:

> ***NCHRP Report 350* test designation 3-60**: This test involves an 820 kg (1806 lb) passenger vehicle (820C) impacting the support structure at a nominal speed and angle of 35 km/h (21.7 mi/h) and 0 to 20 degrees. The purpose of this test is to evaluate the breakaway, fracture, or yielding mechanism of the support and occupant risk.
>
> ***NCHRP Report 350* test designation 3-61**: This test involves an 820 kg (1806 lb) passenger car (820C) impacting the support structure at a nominal speed and angle of 100 km/h (62.1 mi/h) and 0 to 20 degrees. The test is intended to evaluate vehicle and test article trajectory and occupant risk.

Both of these tests were performed on the pedestal base installation with solar voltaic equipment attached. The crash test and data analysis procedures were performed in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

EVALUATION CRITERIA

Researchers evaluated the crash tests performed in accordance with *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 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	
Preferred	*Maximum*
3 m/s (9.8 ft/s)	*5 m/s (16.4 ft/s)*

  I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal 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 AASHTO Specification states:

> *Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 mi/h does not exceed 16 ft/s but preferably does not exceed 10 ft/s or less.*

III. ANALYSIS OF PEDESTAL BASE SIGN SUPPORTS

Two analytical efforts on the TxDOT pedestal base/solar voltaic sign system investigated the influence of sign size, support post size, and ground mounting height of various components on 1) the wind load capacity and 2) the impact behavior and post-impact trajectory of the system.

To analyze the wind load capacity of the sign system, the methodology presented in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* [(2)] was used to compute the applicable wind pressure for design wind speed of 113, 129, and 145 km/h (70, 80, and 90 mi/h). The wind-induced moments at the bottom of the pedestal base/solar voltaic sign installation were calculated and are shown in Tables 1, 2, and 3. The maximum moment capacity of the pedestal base is 13,560 Joules (10,000 ft•lb). The approximate wind speed that correlates with the base capacity is denoted in each of the three tables by an asterisk.

To analyze the impact behavior and post-impact trajectory of the system, an engineering model was developed based on conservation of energy and linear and angular momentum principles. The model is used to estimate the change in vehicular velocity resulting from impact with the support activation of the base mechanism. The resulting translational and angular velocities of the support pole are also computed. This information is used to determine the position of the vehicle, orientation of the support, and location of impact for any secondary contact that was predicted to occur between the support pole and vehicle for various small sign configurations.

The model used input information (e.g., weight, height, etc.) on the sign support components (e.g., sign blank, support post, beacon, solar panel, pedestal base, etc.) to calculate the system properties. The change in vehicle velocity is computed through consideration of vehicle crush, activation of the base mechanism, and momentum transfer to the support. The change in velocity during the momentum transfer phase of the impact is subsequently used to determine the resulting angular and translational velocities imparted to the sign support system. The longitudinal position of the vehicle, the forward distance traveled by the sign support, and angle of rotation of the sign support can then be computed for any instant in time. Various times are examined until other impact between the sign support and vehicle is detected or the vehicle passes beyond the support.

It was determined that the most effective method for determining the point of impact of the sign support on the vehicle was to present the results of the analysis graphically, as shown in Figures 1 through 4. Coordinates from a Geo Metro (which is currently the most common small car test vehicle) were used to create a vehicle side profile. The positions of the vehicle and support post were then tracked to the point of impact.

Table 1. **Pedestal Base Sign Installation with a Single Flashing Beacon and Solar Voltaic Hardware - As tested in 417921-3 and 4.**

Wind Speed, mph	Induced Moment, ft•lb (Joules)
70	6,336 (8,592)
80	8,276 (11,222)
88	10,014 (13,579)
90	10,474 (14,203)

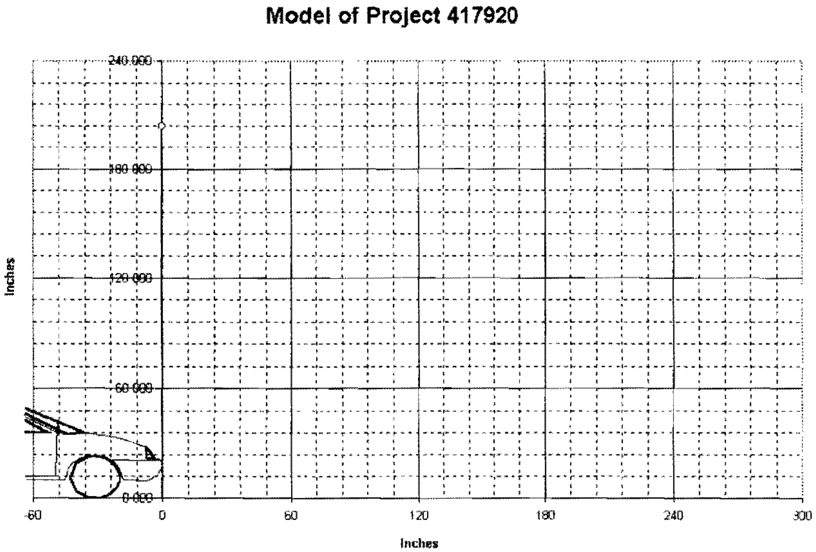
Table 2. **Pedestal Base Sign Installation with a Single Flashing Beacon and Solar Voltaic Hardware - As recommended for installation.**

Wind Speed, mph	Induced Moment, ft•lb (Joules)
70	6,509 (8,826)
80	8,501 (11,527)
87	10,008 (13,571)
90	10,759 (14,589)

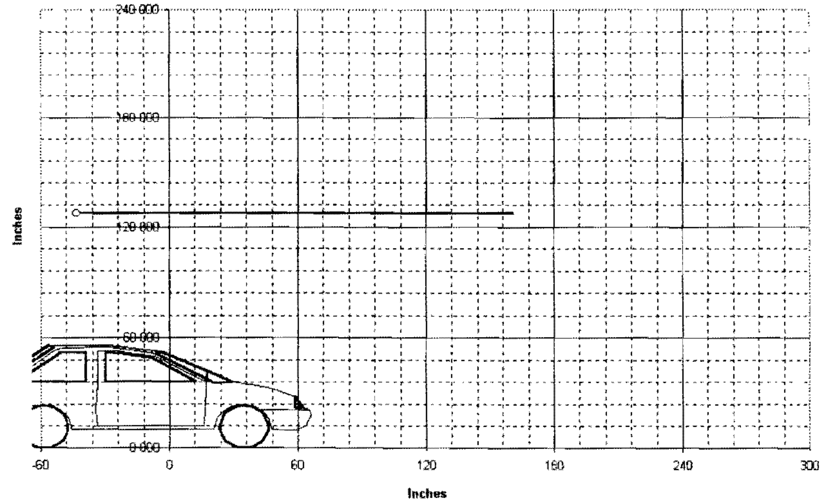
Table 3. **Pedestal Base Sign Installation with Dual Flashing Beacons and Solar Voltaic Hardware - As recommended for installation.**

Wind Speed, mph	Induced Moment, ft•lb (Joules)
70	8,503 (10,920)
78	9,999 (13,559)
80	10,519 (14,264)
90	13,313 (18,052)

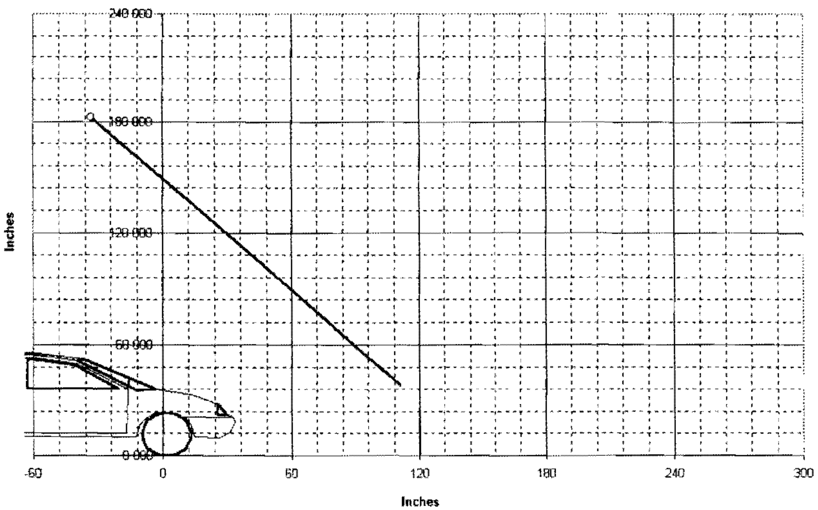
Shaded rows indicate maximum allowable design wind speed.



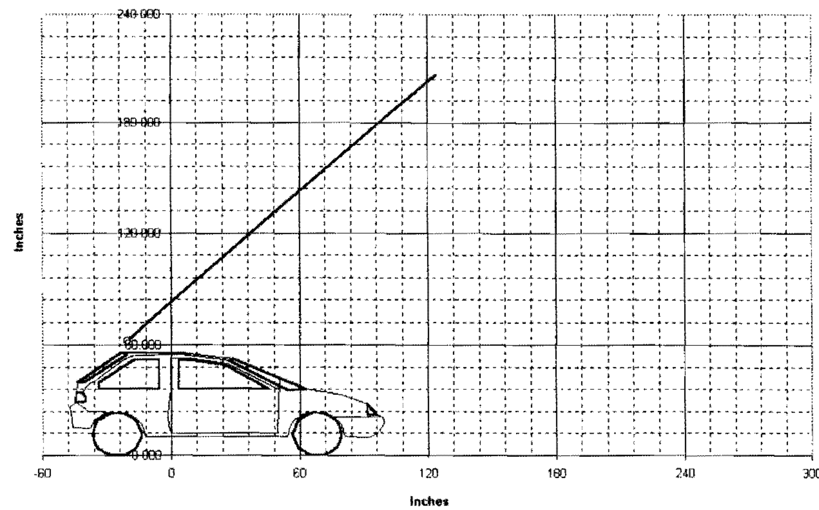
(a) support at 0 degree (impact)



(c) support at 90 degrees

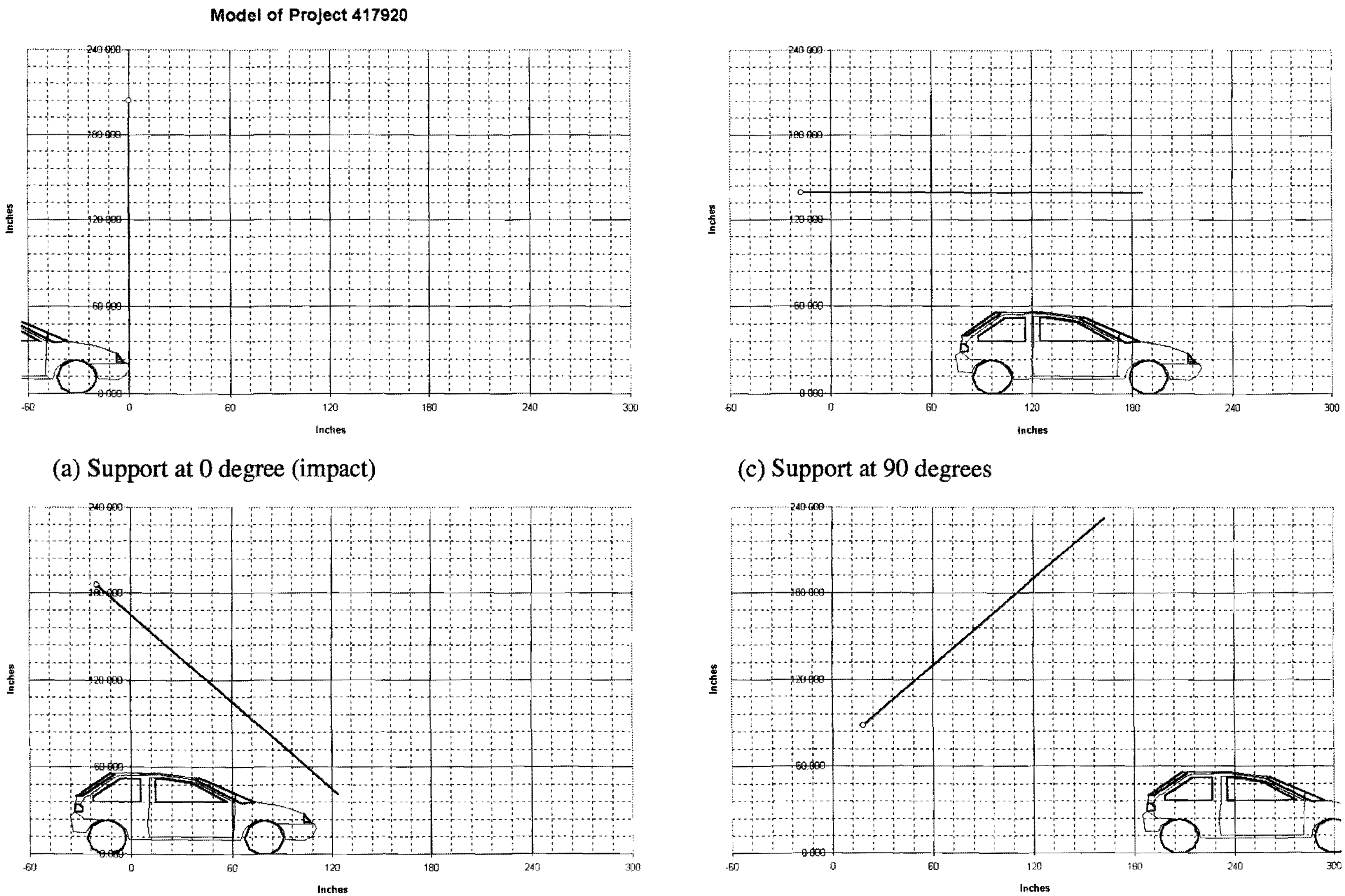


(b) support at 45 degrees



(d) support at 135 degrees

Figure 1. Simulation Results for Dual Beacon at 21.7 mi/h (35 km/h).



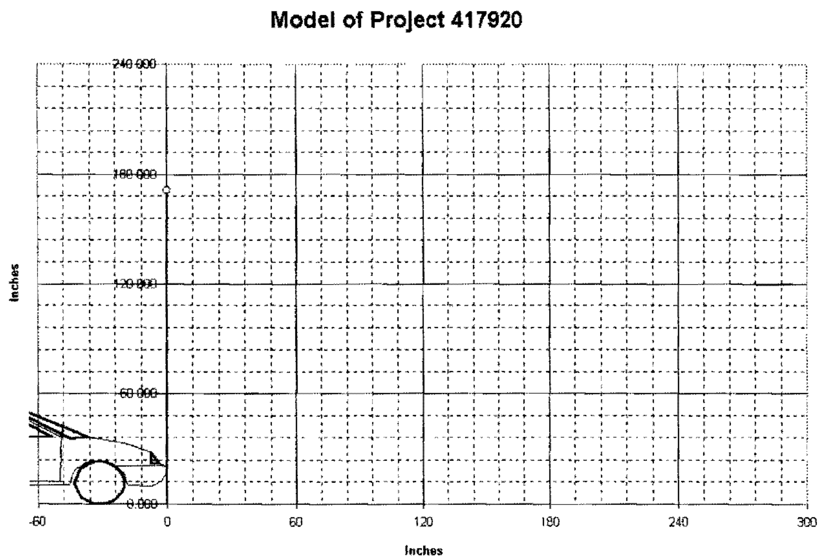
(a) Support at 0 degree (impact)

(c) Support at 90 degrees

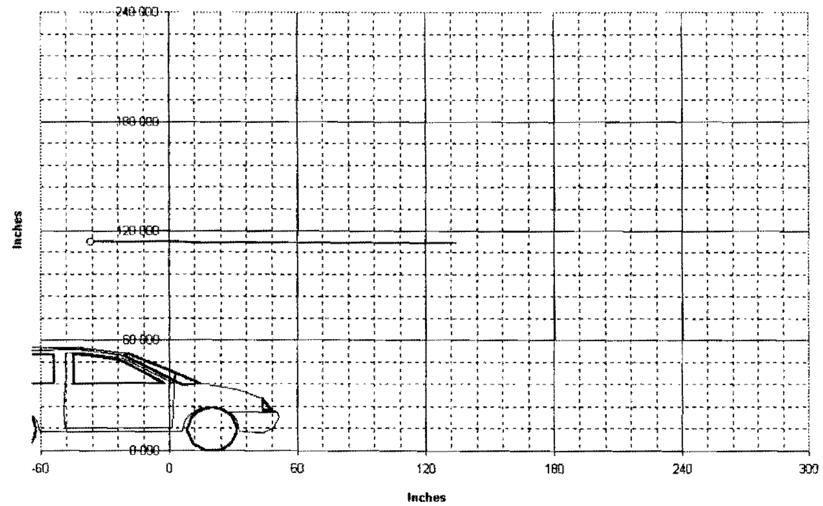
(b) Support at 45 degrees

(d) Support at 135 degrees

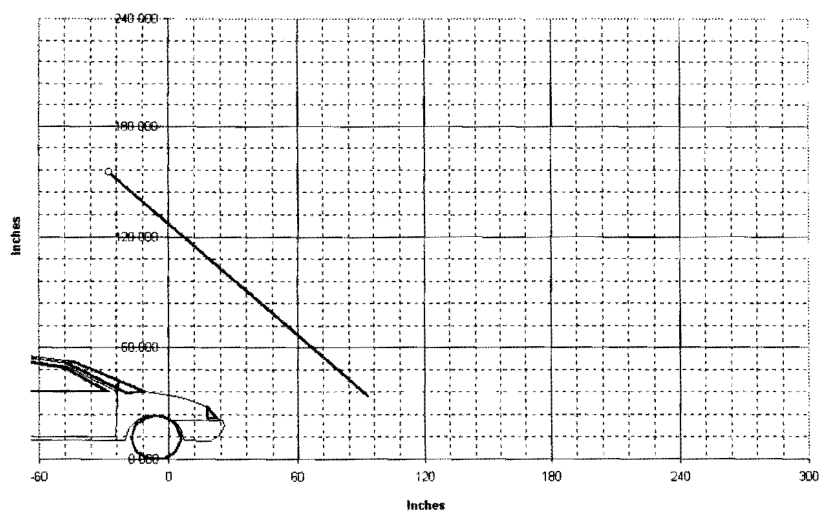
Figure 2. Simulation Results for Dual Beacon at 62.2 mi/h (100 km/h).



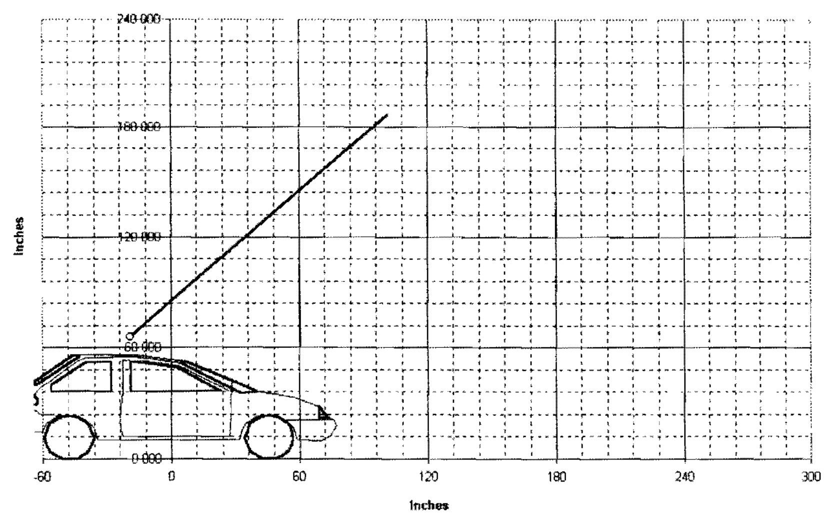
(a) Support at 0 degree (impact)



(c) Support at 90 degrees

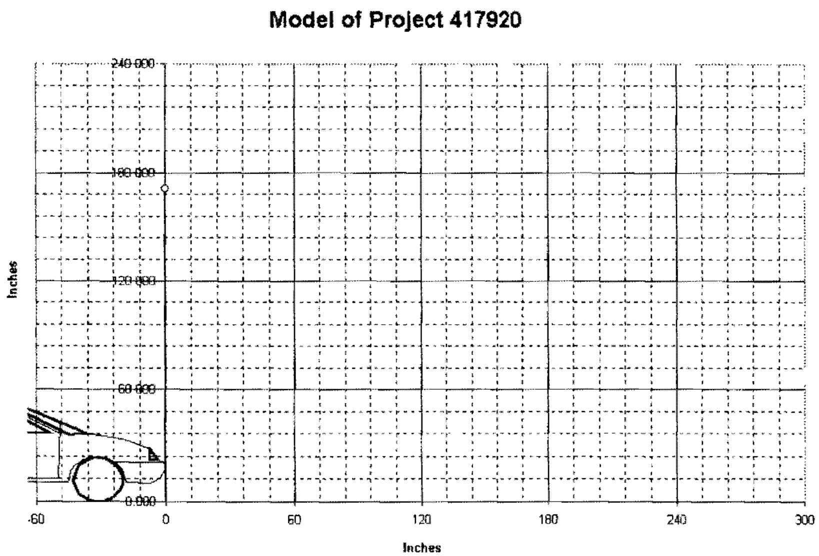


(b) Support at 45 degrees

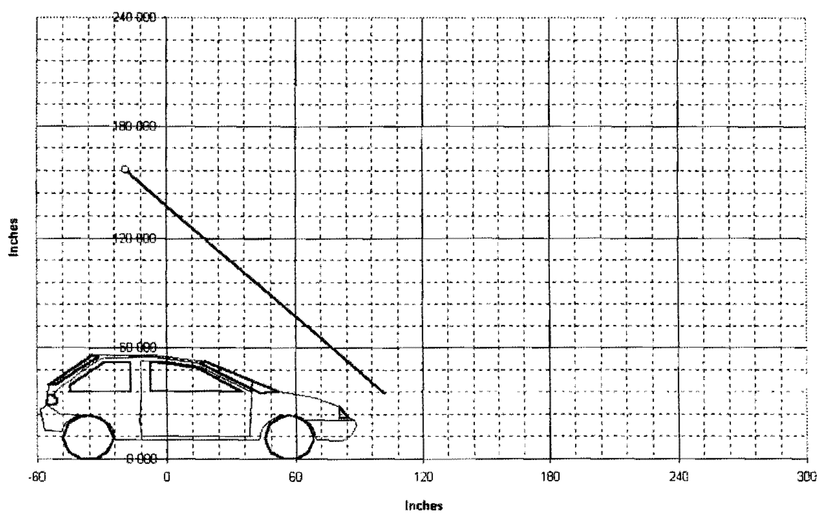


(d) Support at 135 degrees

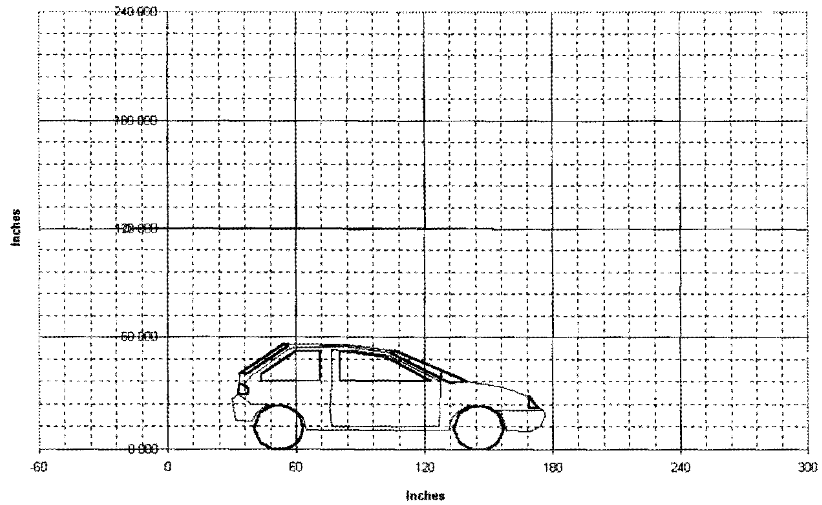
Figure 3. Simulation Results for Single Beacon at 21.7 mi/h (35 km/h).



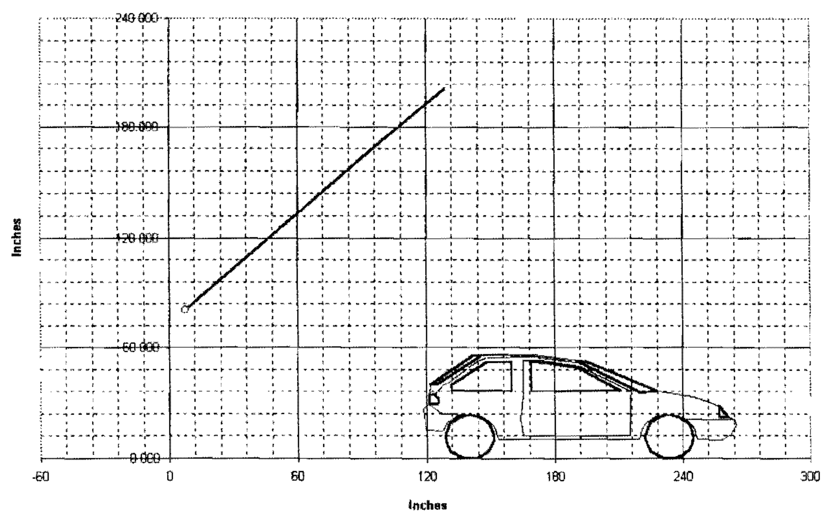
(a) Support at 0 degree (impact)



(b) Support at 45 degrees



(c) Support at 90 degrees



(d) Support at 135 degrees

Figure 4. Simulation Results for Single Beacon at 62.2 mi/h (100 km/h).

The analytical methodology was validated by comparing predicted outcomes from the model with results measured from previous full-scale crash tests. High-speed film from tests was used to determine various time-event data that could be compared to the model. Images were also captured from the high-speed film at the time of secondary impact with the support post to assist in the validation effort. The correlation obtained between the model and full-scale crash tests was considered satisfactory to proceed with the parametric investigation. The model predicted the installation, as proposed and shown in Figure 5, would perform satisfactorily when impacted by the 820 kg (1806 lb) passenger car at 35 km/h (21.7 mi/h) and 100 km/h (62.1 mi/h).

TxDOT pedestal base/solar voltaic sign systems installed in the field should not deviate from the installation details presented in this report without sufficient engineering analysis. In addition, the battery cabinet location should not be lowered to improve accessibility. Altering the mounting height of the battery cabinet may severely alter the impact performance of the installation when struck by an automobile.

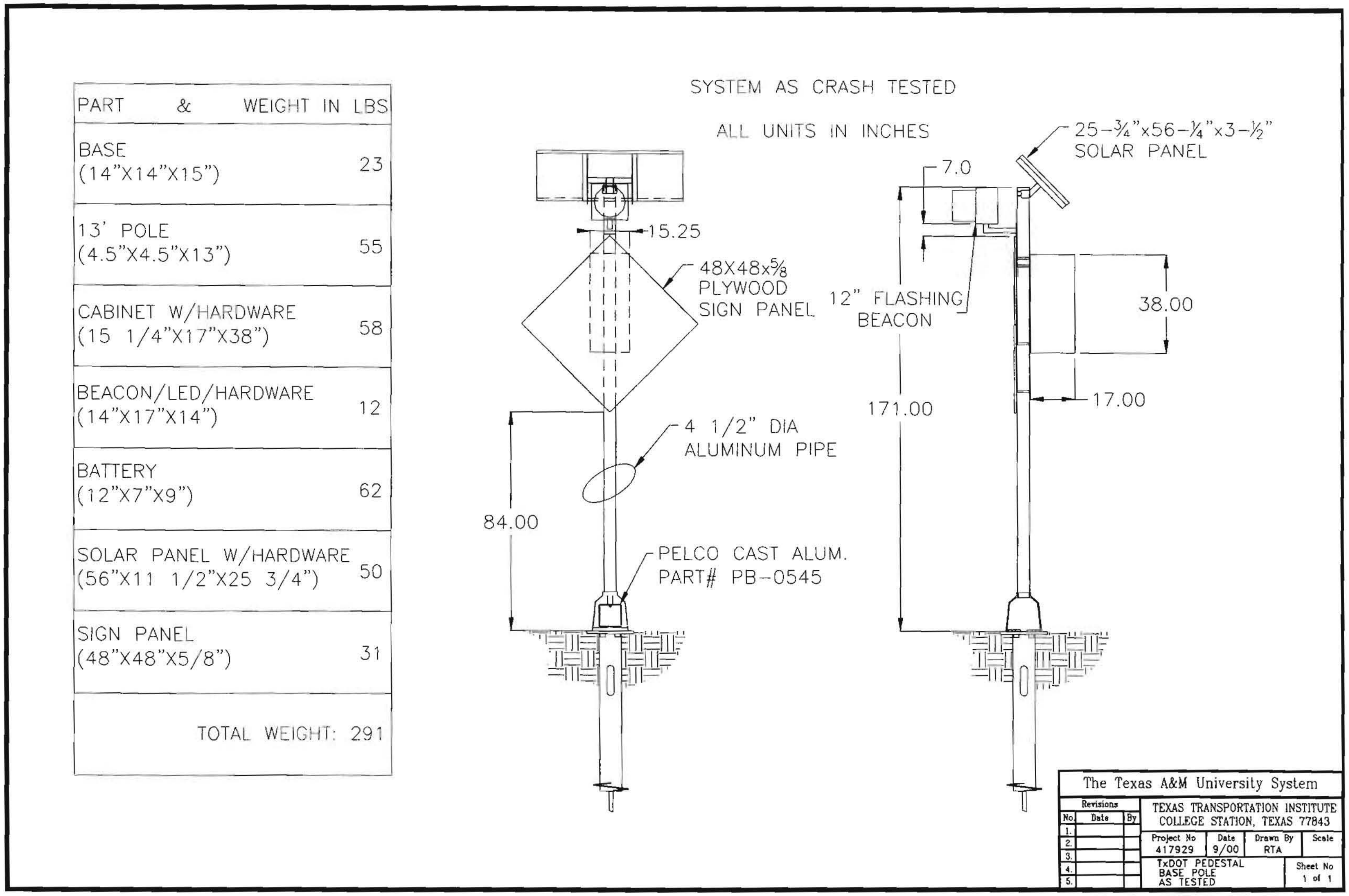


Figure 5. Solar Panel Sign Support as Used in Tests 417920-3 and 417920-4.

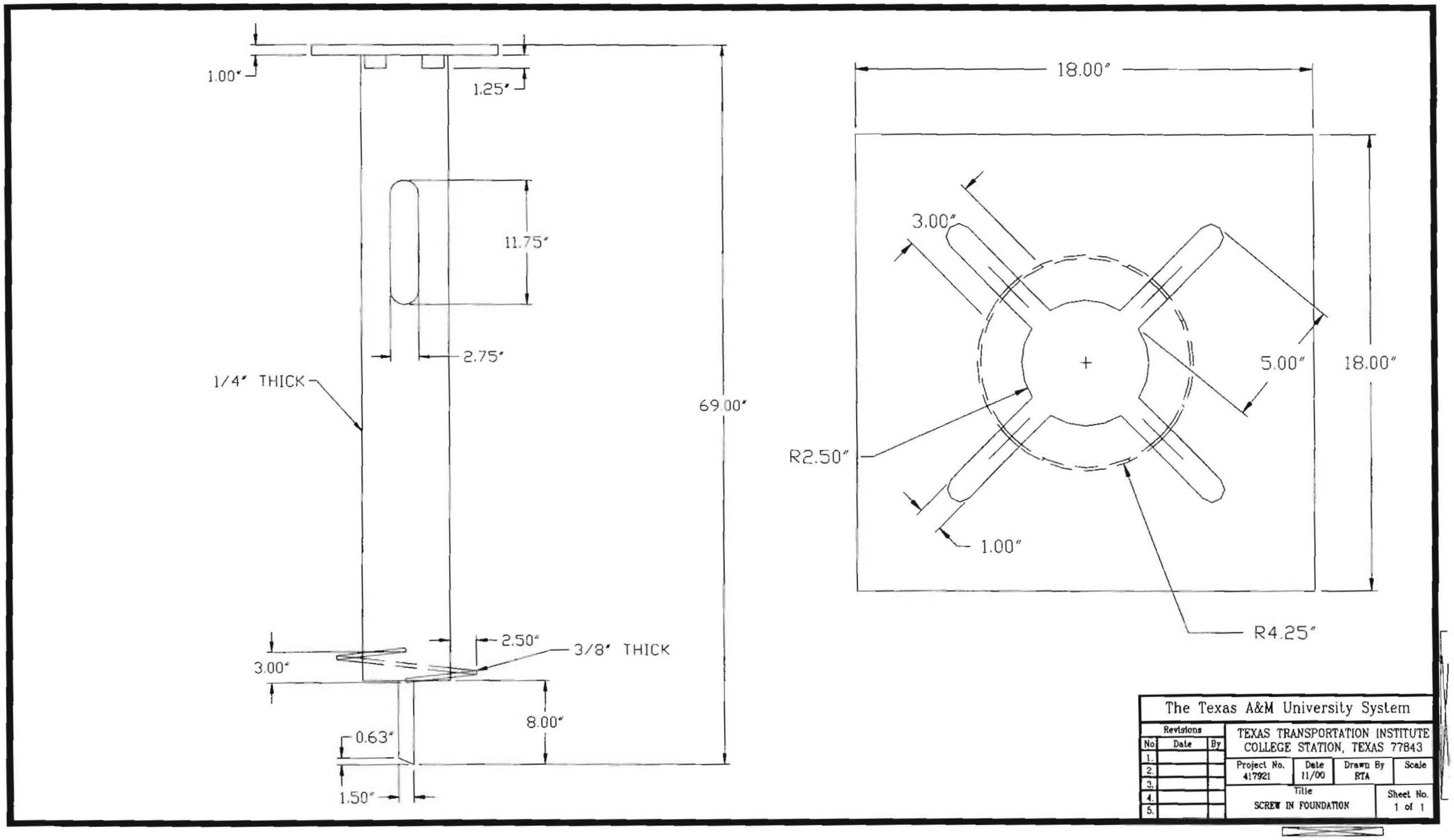


Figure 5. Solar Panel Sign Support as Used in Tests 417920-3 and 417920-4 (continued).

IV. TEST ARTICLES

TEST INSTALLATION FOR TESTS 417920-3 and -4

A pedestal base sign installation equipped with photovoltaic equipment was attached to the ground with a helical type screw-in foundation anchor assembly. This installation was constructed for crash testing and evaluation. The installation was fabricated using a Pelco (model SP 1014 TX) square-cast aluminum traffic signal base with a 114 mm (4.5 in) outside diameter × 3.96 m (13 ft) long spun aluminum pole. A 16 mm × 1.2 m × 1.2 m (0.625 in × 48 in × 48 in) plywood warning sign was attached to the pole at a mounting height of 2.1 m (7.0 ft). In addition, a 305 mm (12.0 in) LED lamp, flashing yellow signal beacon was mounted directly above the sign panel. A 1429 mm × 654 mm × 89 mm (56.3 in × 25.7 in × 3.5 in) solar panel weighing 235.8 N (53 lb) was attached atop the support. The battery cabinet for the panel was mounted behind the sign panel at a height of 2.7 m and weighed 520.4 N (117 lb). The helical type screw-in foundation anchor assembly (model no. PB 5306) was placed in *NCHRP Report 350* standard soil using an auger truck. Detailed drawings of the test installation are shown in Figure 5. The system was constructed identically for each test. Photographs of the test installations are shown in Figures 6 through 8.

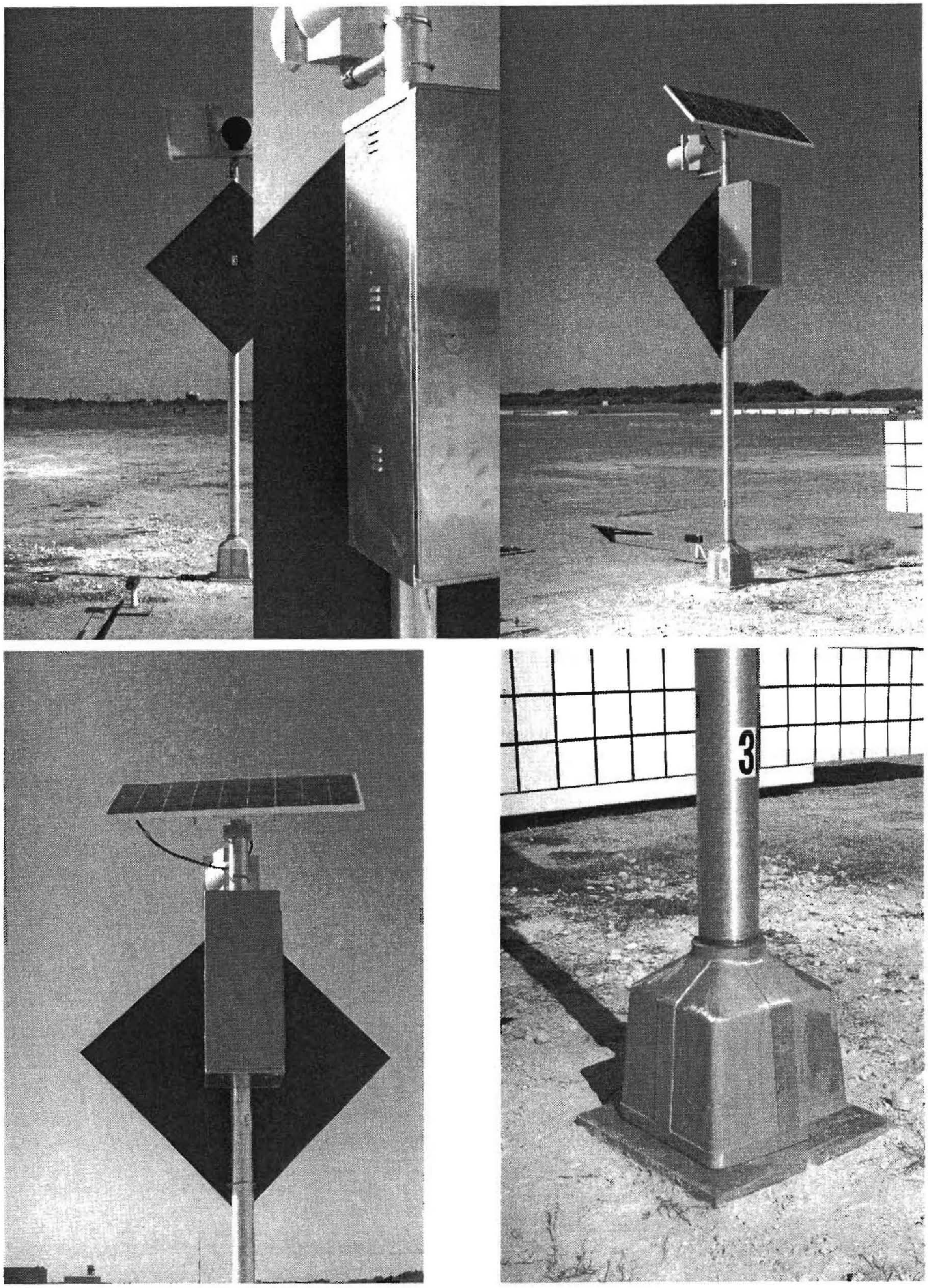


Figure 6. Solar Panel Sign Support before Test 417920-3.

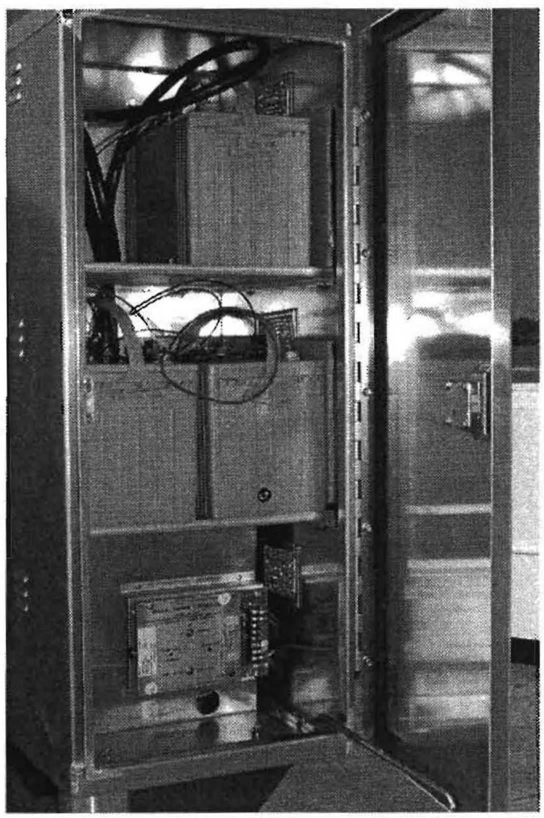


Figure 7. Power Unit Used for Tests 417920-3 and 417920-4.

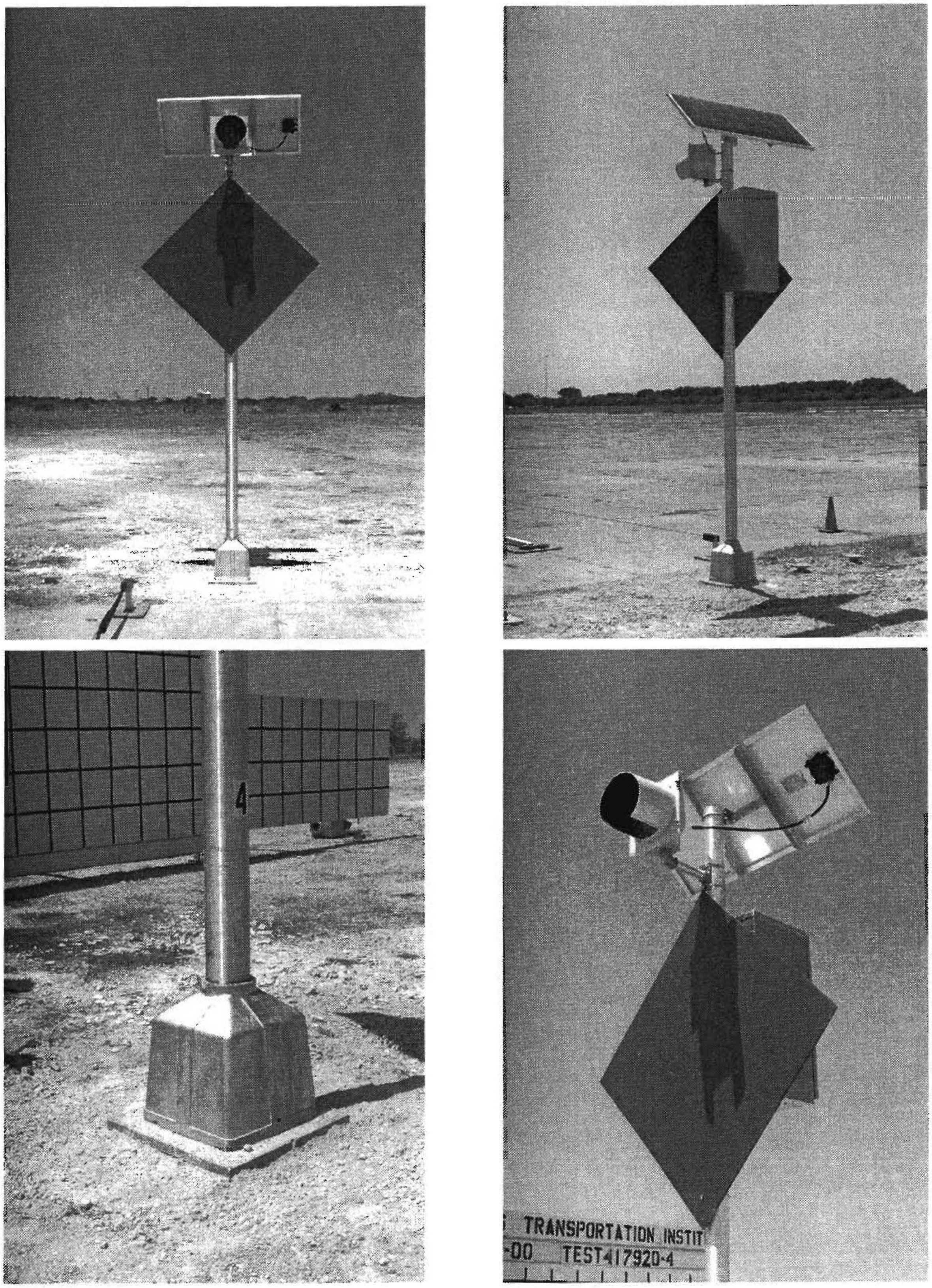


Figure 8. Pedestal Base Sign Support before Test 417920-4.

V. CRASH TEST RESULTS

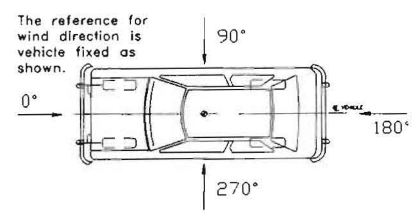
TEST NO. 417920-3 (*NCHRP Report 350* TEST NO. 3-60)

Test Vehicle

The crash test used a 1995 Geo Metro, shown in Figures 9 and 10. Test inertia weight of the vehicle was 820 kg (1806 lb), and its gross static weight was 896 kg (1974 lb). The height to the lower edge of the vehicle bumper was 400 mm (15.7 in), and it was 525 mm (20.7 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix B, Figure 23. 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.

Soil and Weather Conditions

The test was performed the morning of August 30, 2000. No rainfall was recorded during the 10 days prior to the test. The *NCHRP Report 350* standard soil in which the solar panel sign support was installed was moistened slightly just prior to the test in order to settle the dust to ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 11 km/h (7 mi/h); wind direction: 200 degrees (vehicle was traveling in a northerly direction); temperature: 33 °C (92 °F); relative humidity: 46 percent.



Test Description

The 820 kg (1806 lb) vehicle, traveling at 35.6 km/h (22.1 mi/h), contacted the solar powered sign support system with the left quarter point of the bumper. Shortly after contact the sign support system began to move and at 0.034 s the vehicle began to rotate slightly counterclockwise. The pedestal base fractured near ground level at 0.076 s, and the vehicle continued moving forward as the sign support system rotated upward in front of the vehicle. At 0.287 s, the vehicle lost contact with the sign support system and was traveling at a speed of 20.1 km/h (12.5 mi/h). The sign support system continued upward and over the roof of the vehicle. The flashing signal beacon on the sign support system contacted the rear hatch window at 0.688 s, and the sign panel contacted the roof at 0.707 s. While still in contact with the rear hatch of the vehicle, the sign support system became parallel with the ground at 0.760 s. The vehicle lost contact with the sign support system at 2.086 s. Brakes on the vehicle were applied shortly after loss of contact, and the vehicle subsequently came to rest 19.1 m (62.7 ft) behind the point of impact. Sequential photographs of the test can be found in Appendix C, Figure 25.

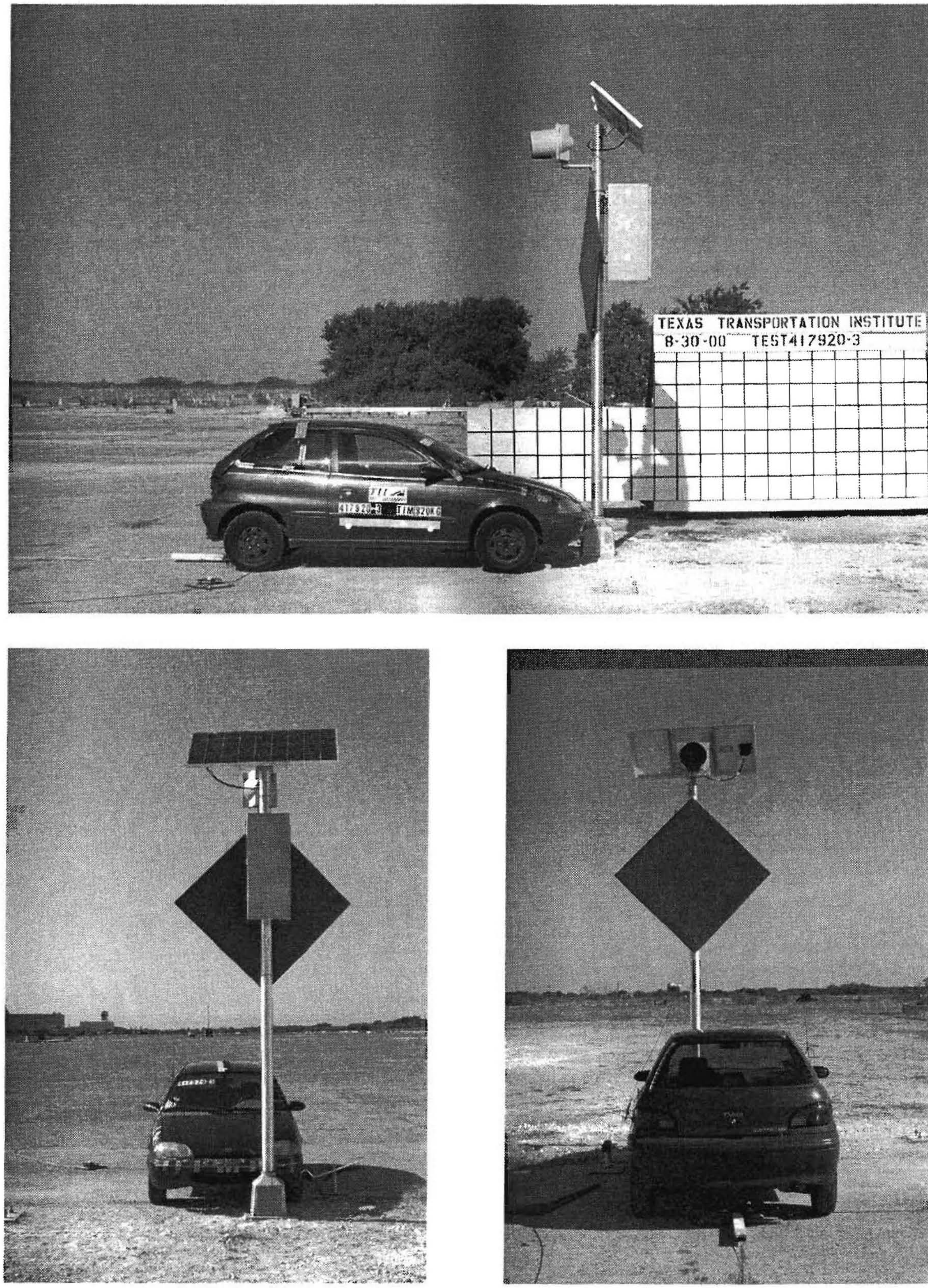


Figure 9. Vehicle/Installation Geometrics for Test 417920-3.

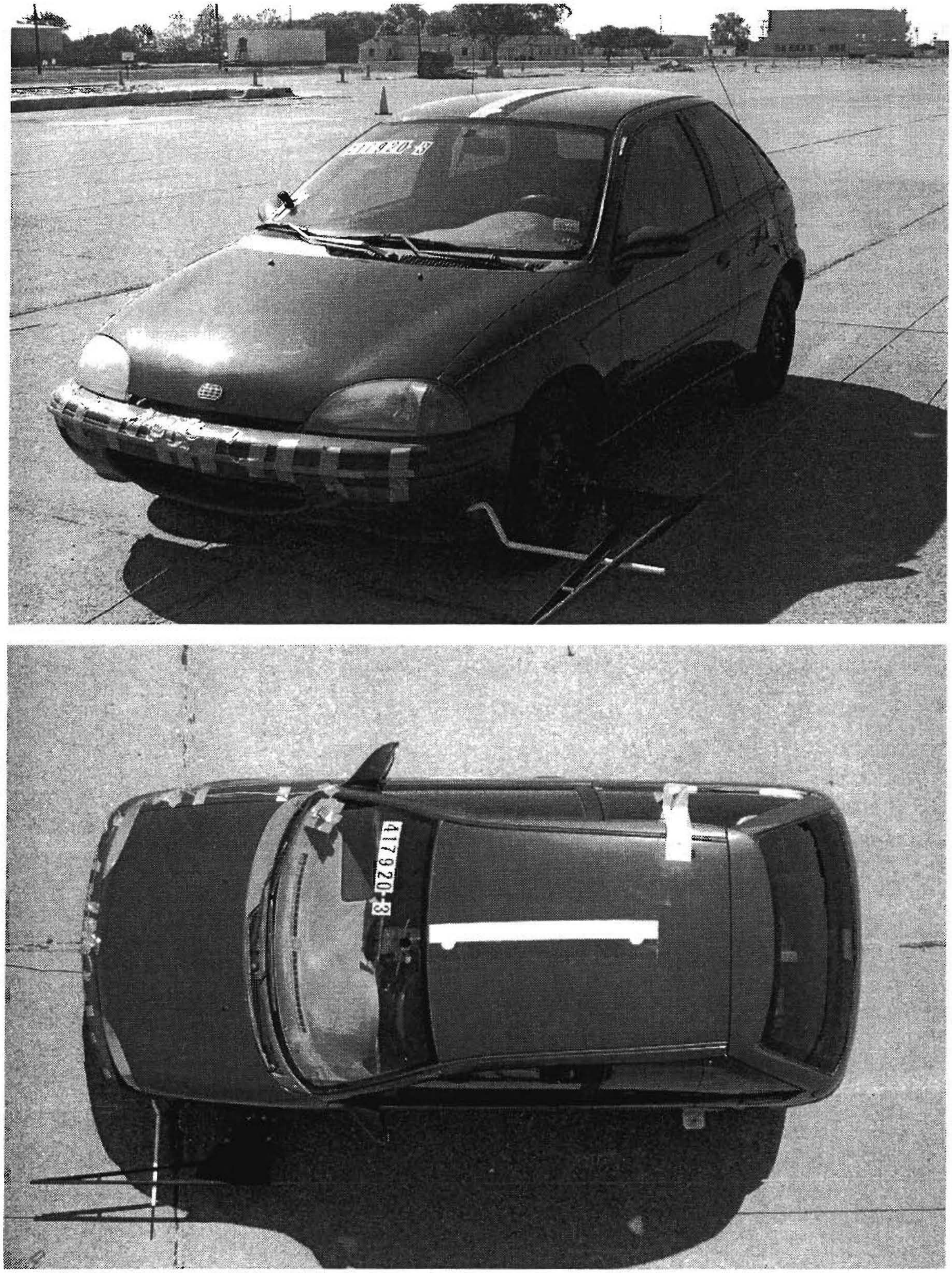


Figure 10. Vehicle before Test 417920-3.

Damage to Test Installation

Damage to the test installation is shown in Figures 11 and 12. The solar panel sign support system readily yielded to the vehicle by fracturing at the pedestal base. Test procedures fractured the base and broke the flashing signal beacon unit, but the rest of the unit remained usable. The sign system came to rest 7.0 m (23.0 ft) behind the point of contact.

Vehicle Damage

The 820 kg (1806 lb) vehicle sustained damage to the left front corner, hood, roof and rear hatch as shown in Figure 13. The left side strut and CV joint were damaged, as well as the front bumper, hood, fan, radiator, radiator support, and rear window. Maximum crush to the exterior of the vehicle was 260 mm (10.2 in) at the left front quarter point. Maximum occupant compartment deformation was 25 mm (1.0 in) in the floor pan area. Photographs of the interior of the vehicle are shown in Figure 14, and exterior vehicle crush and occupant compartment measurements are shown in Appendix B, Tables 6 and 7.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 4.3 m/s (14.1 ft/s) at 0.189 s, the highest 0.010-s occupant ridedown acceleration was -1.6 g's from 0.721 to 0.731 s, and the maximum 0.050-s average acceleration was -6.5 g's between 0.031 and 0.081 s. In the lateral direction, the occupant impact velocity was 0.3 m/s (1.0 ft/s) at 0.189 s, the highest 0.010 s occupant ridedown acceleration was -1.1 g's from 0.784 to 0.794 s, and the maximum 0.050 s average was -0.6 g's between 0.015 and 0.065 s. These data and other pertinent information from the test are summarized in Figure 15. Vehicle angular displacements are shown in Appendix D, Figure 27, and vehicle accelerations versus time traces are presented in Appendix E, Figures 29 through 31.

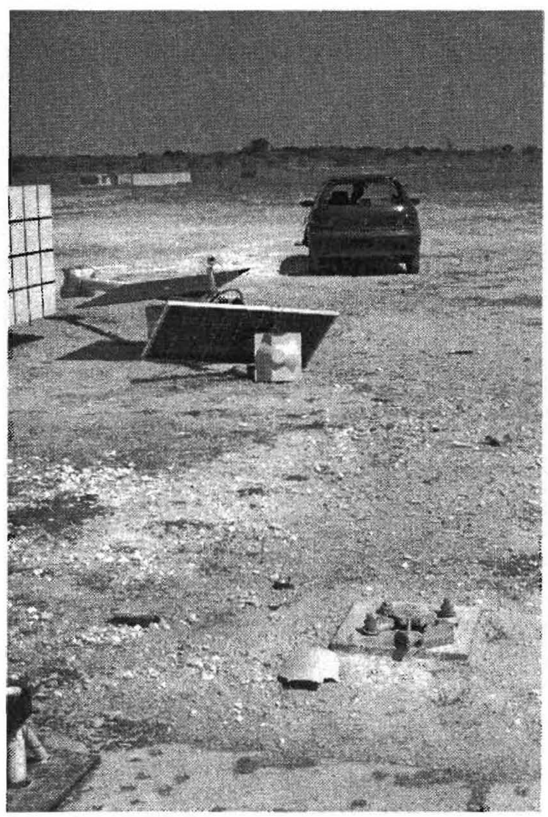


Figure 11. After Impact Trajectory for Test 417920-3.

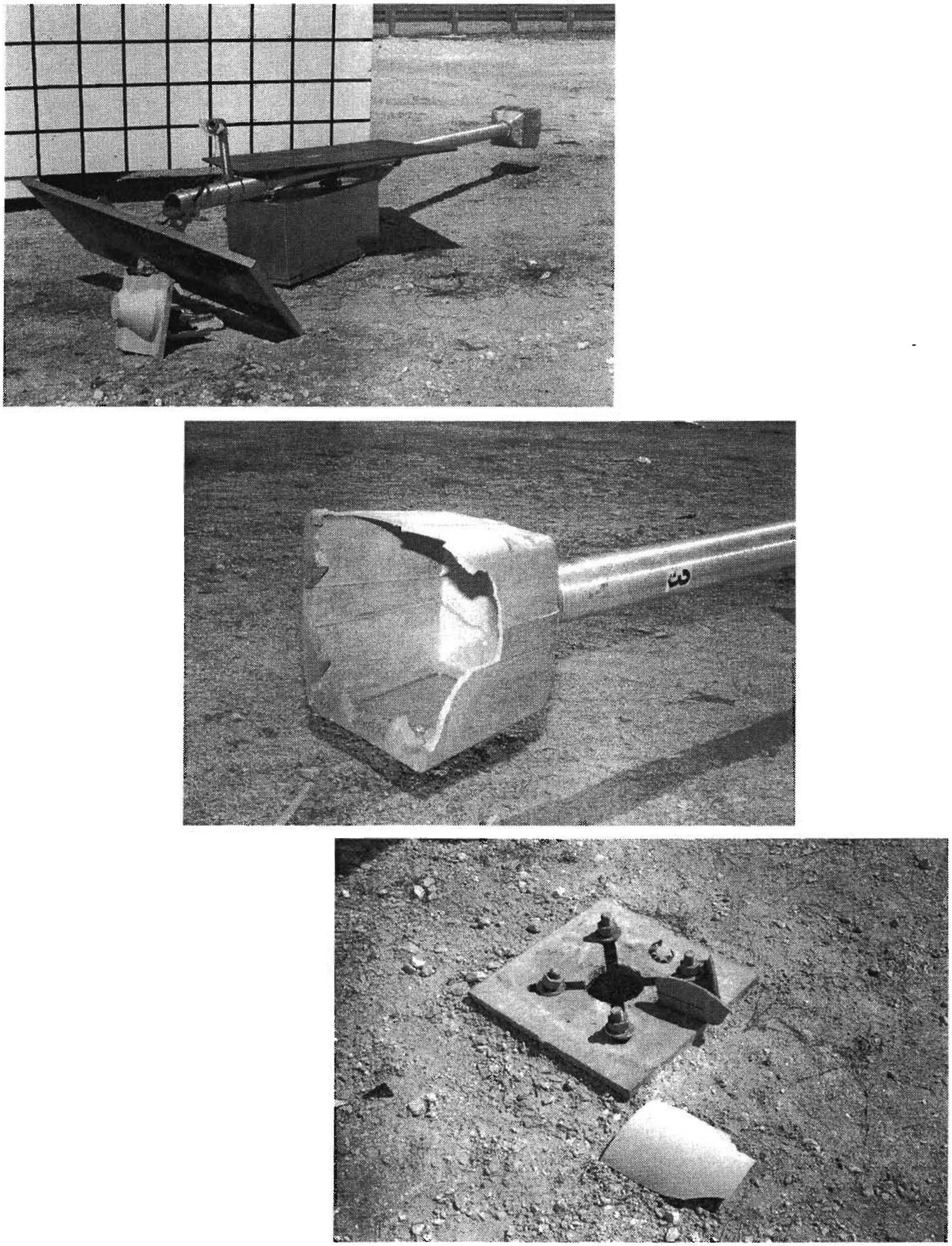


Figure 12. Installation after Test 417920-3.

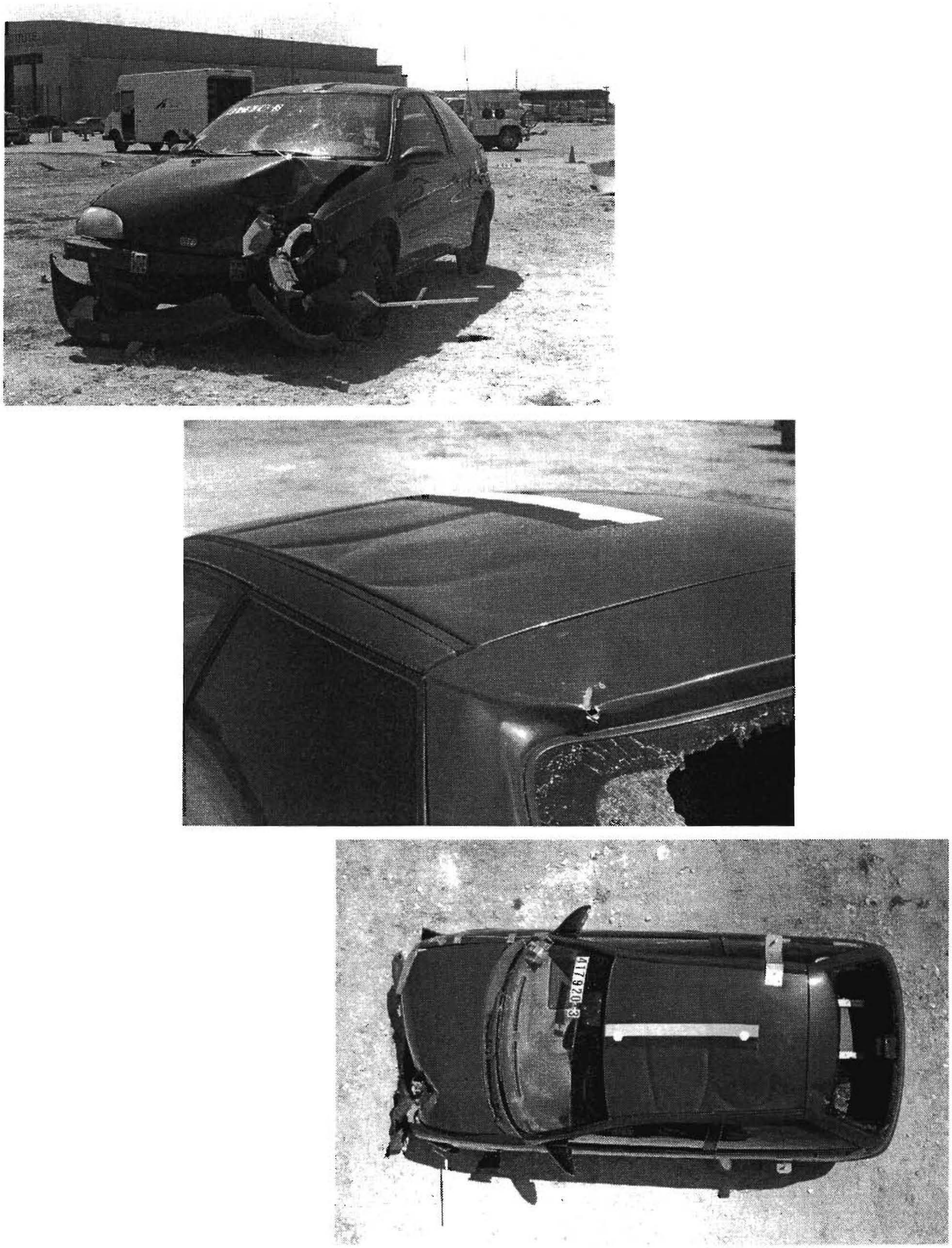
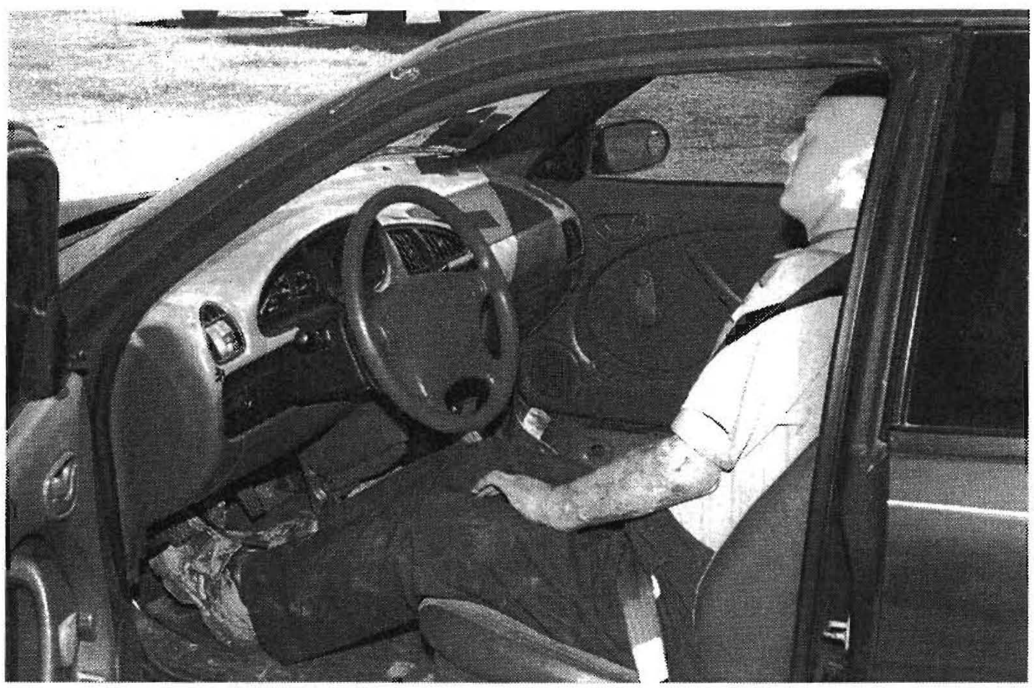


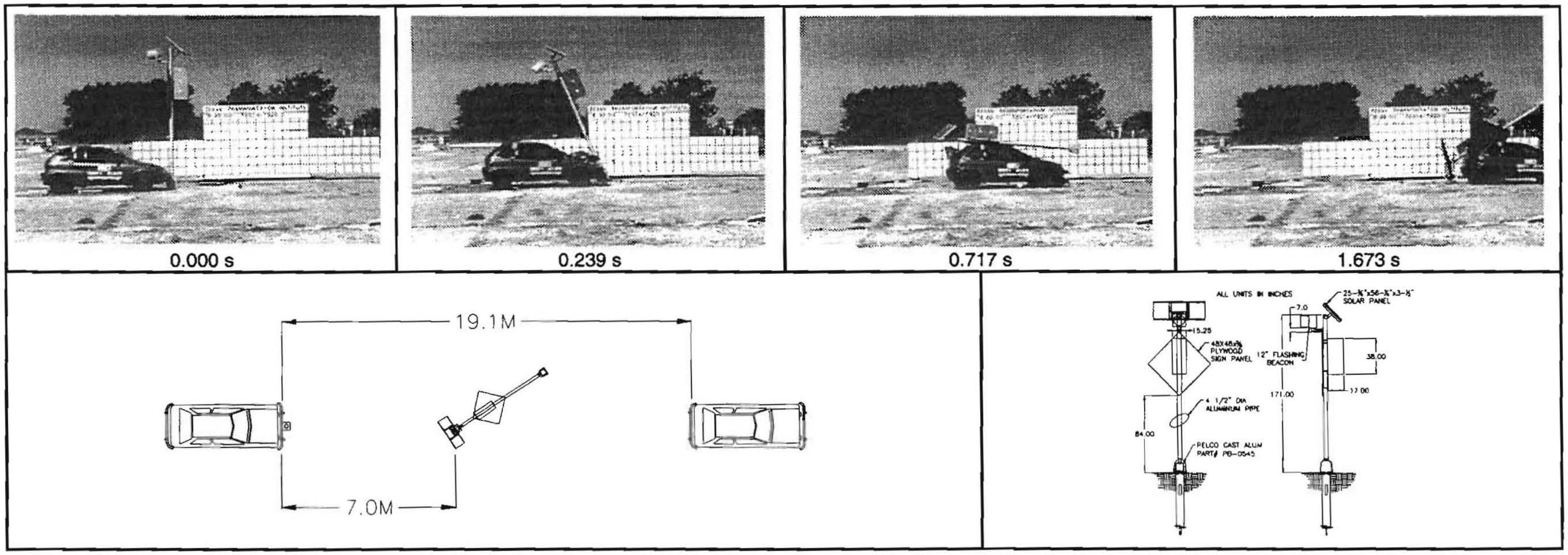
Figure 13. Vehicle after Test 417920-3.

Before test



After test

Figure 14. Interior of Vehicle for Test 417920-3.



General Information	
Test Agency	Texas Transportation Institute
Test No.	417920-3
Date	08/30/00
Test Article	
Type	Sign Support
Name	Pedestal Base/Solar Panel Sign Support
Installation Height (m)	3.4 (11.2 ft)
Material or Key Elements	Pedestal Base with Solar Panel for Beacon Lights and Plywood Sign Panel 16 mm x 1.2 m x 1.2 m (0.625 in x 48 in x 48 in)
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1995 Geo Metro
Mass (kg)	
Curb	800 (1764 lb)
Test Inertial	820 (1806 lb)
Dummy	76 (168 lb)
Gross Static	896 (1974 lb)

Impact Conditions	
Speed (km/h)	35.6 (22.1 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	20.1 (12.5 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.3 (14.1 ft/s)
y-direction	0.3 (1.0 ft/s)
THIV (km/h)	15.7 (9.8 mi/h)
Ridedown Accelerations (g's)	
x-direction	-1.6
y-direction	-1.1
PHD (g's)	1.6
ASI	0.59
Max. 0.050-s Average (g's)	
x-direction	-6.5
y-direction	-0.6
z-direction	-5.9

Test Article Debris Scatter (m)	
Longitudinal	7.0 (23 ft)
Lateral	nil
Working Width	N/A
Vehicle Damage	
Exterior	
VDS	12FD4
CDC	12FDEW6
Maximum Exterior Vehicle Crush (mm)	260 (10.2 in)
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	25 (1 in)
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	-13
Max. Pitch Angle (deg)	6
Max. Roll Angle (deg)	4

Figure 15. Summary of Results for Test 417920-3, *NCHRP Report 350* Test 3-60.

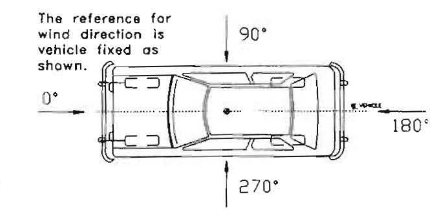
TEST NO. 417920-4 (*NCHRP Report 350* TEST NO. 3-61)

Test Vehicle

A 1996 Geo Metro, shown in Figures 16 and 17, was used for the crash test. Test inertia weight of the vehicle was 820 kg (1806 lb), and its gross static weight was 895 kg (1971 lb). The height to the lower edge of the vehicle bumper was 400 mm (15.7 in), and it was 525 mm (20.7 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix B, Figure 24. 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.

Soil and Weather Conditions

The test was performed the afternoon of August 30, 2000. No rainfall was recorded during the 10 days prior to the test. The *NCHRP Report 350* standard soil in which the solar panel sign support was installed was moistened slightly just prior to the test in order to settle the dust to ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 11 km/h (7 mi/h); wind direction: 200 degrees (vehicle was traveling in a northerly direction); temperature: 39 °C (102 °F); relative humidity: 25 percent.



Test Description

The vehicle, traveling at a speed of 99.0 km/h (61.5 mi/h), impacted the solar powered sign support system with the left front quarter point. Shortly after impact the sign support system moved, and at 0.010 s the base fractured near ground level. The sign support system began to rise in front of the vehicle at 0.024 s, and the flashing signal beacon separated from the support at 0.041 s. At 0.052 s the sign panel separated from the support, and at 0.073 s the battery cabinet opened. The solar panel separated from the support at 0.090 s. At 0.095 s, the vehicle lost contact with the sign support system and was traveling at a speed of 93.4 km/h (58.0 mi/h). As the vehicle exited the test site, the sign support continued up and over the top of the vehicle and eventually recontacted the ground at 0.373 s. Brakes on the vehicle were applied at 0.850 s after impact, and the vehicle subsequently came to rest 100.0 m (328.1 ft) behind the impact point. Sequential photographs of the test can be found in Appendix C, Figure 26.

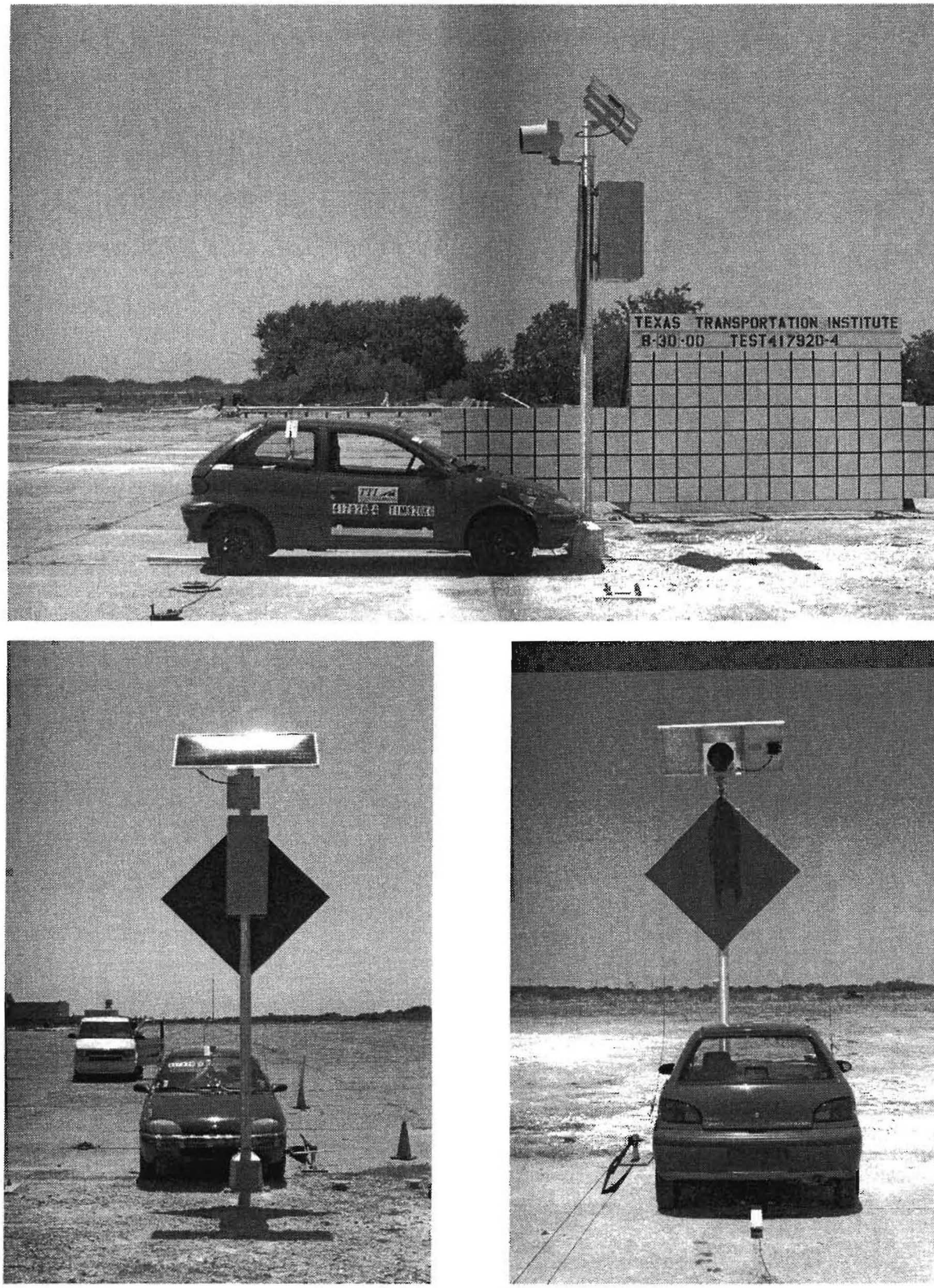


Figure 16. Vehicle/Installation Geometrics for Test 417920-4.

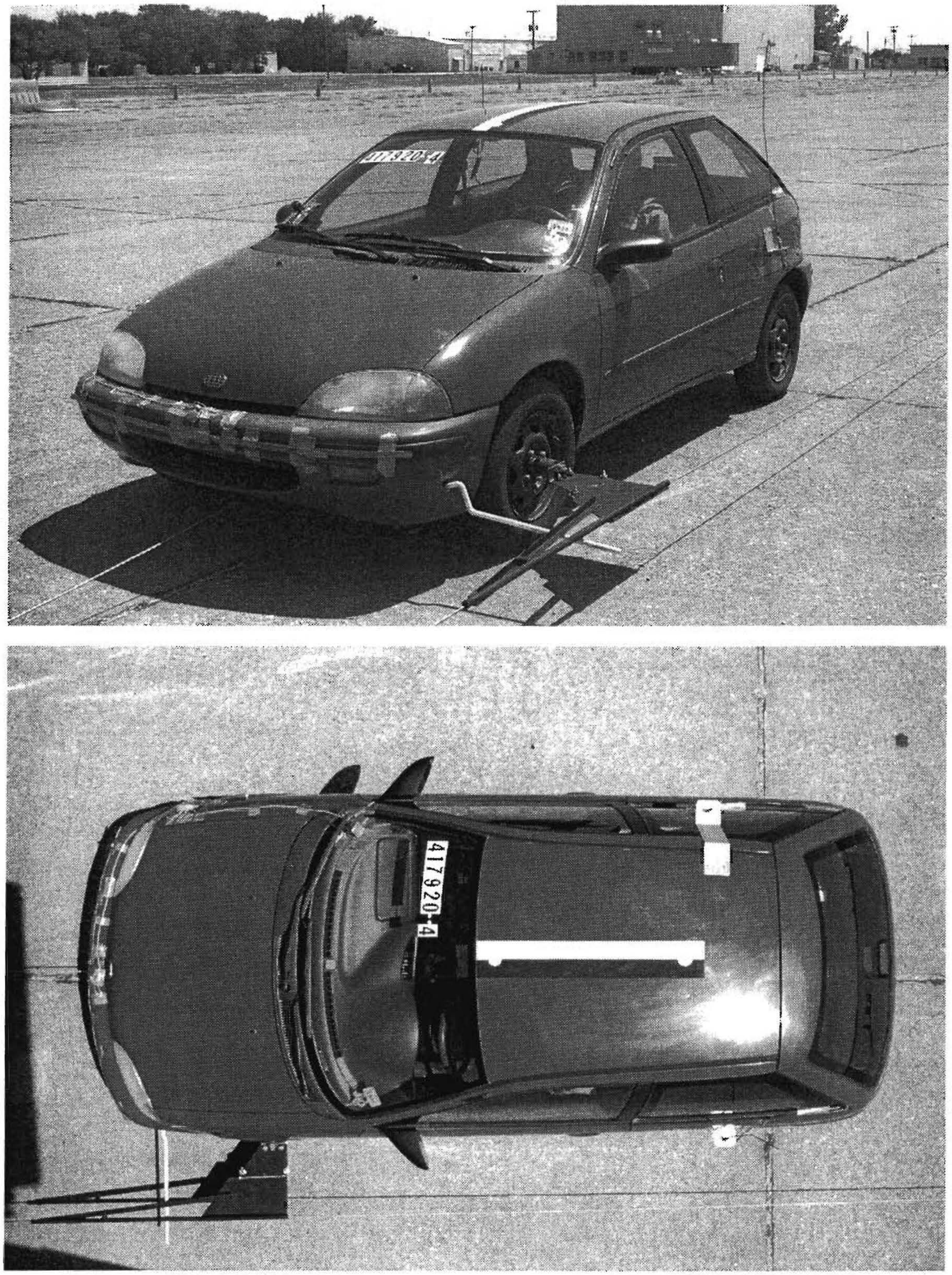


Figure 17. Vehicle before Test 417920-4.

Damage to Test Installation

The solar panel sign support system separated into several pieces as shown in Figures 18 and 19. The debris was scattered from 7.0 m (23.0 ft) in front of the impact point to 10.7 m (35.1 ft) behind the impact point and 1.5 m (4.9 ft) to the left side and 2.3 m (7.5 ft) to the right side.

Vehicle Damage

The vehicle sustained minimal damage to the left front quarter point as shown in Figure 20. The front bumper, inner bumper, radiator support, left front headlight, and the hood were damaged. Maximum exterior vehicle crush was 35 mm (1.38 in) at the left front quarter point. No deformation or intrusion of the occupant compartment occurred. Photographs of the interior of the vehicle are shown in Figure 21, and exterior vehicle crush and occupant compartment measurements are shown in Appendix B, Tables 8 and 9.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 1.4 m/s (4.6 ft/s) at 0.515 s, the highest 0.010 s occupant ridedown acceleration was -1.5 g's from 1.550 to 1.560 s, and the maximum 0.050 s average acceleration was -2.0 g's between 0.000 and 0.050 s. In the lateral direction, the occupant impact velocity was 0.9 m/s (3.0 ft/s) at 0.515 s, the highest 0.010 s occupant ridedown acceleration was -0.7 g's from 1.644 to 1.654 s, and the maximum 0.050 s average was -0.8 g's between 0.004 and 0.054 s. These data and other pertinent information from the test are summarized in Figure 22. Vehicle angular displacements are shown in Appendix D, Figure 28, and vehicle accelerations versus time traces are presented in Appendix E, Figures 32 through 34.

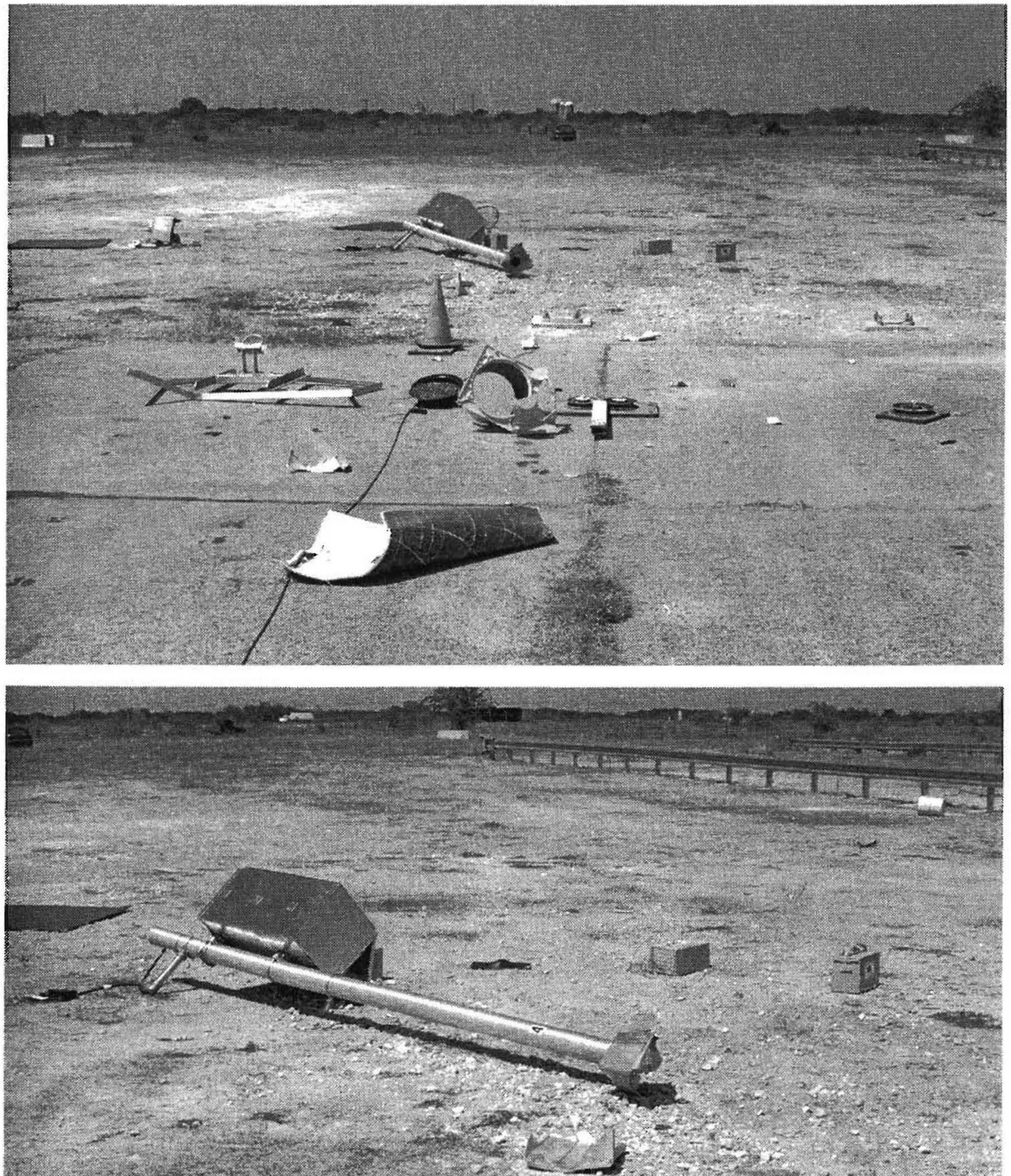


Figure 18. After Impact Trajectory for Test 417920-4.

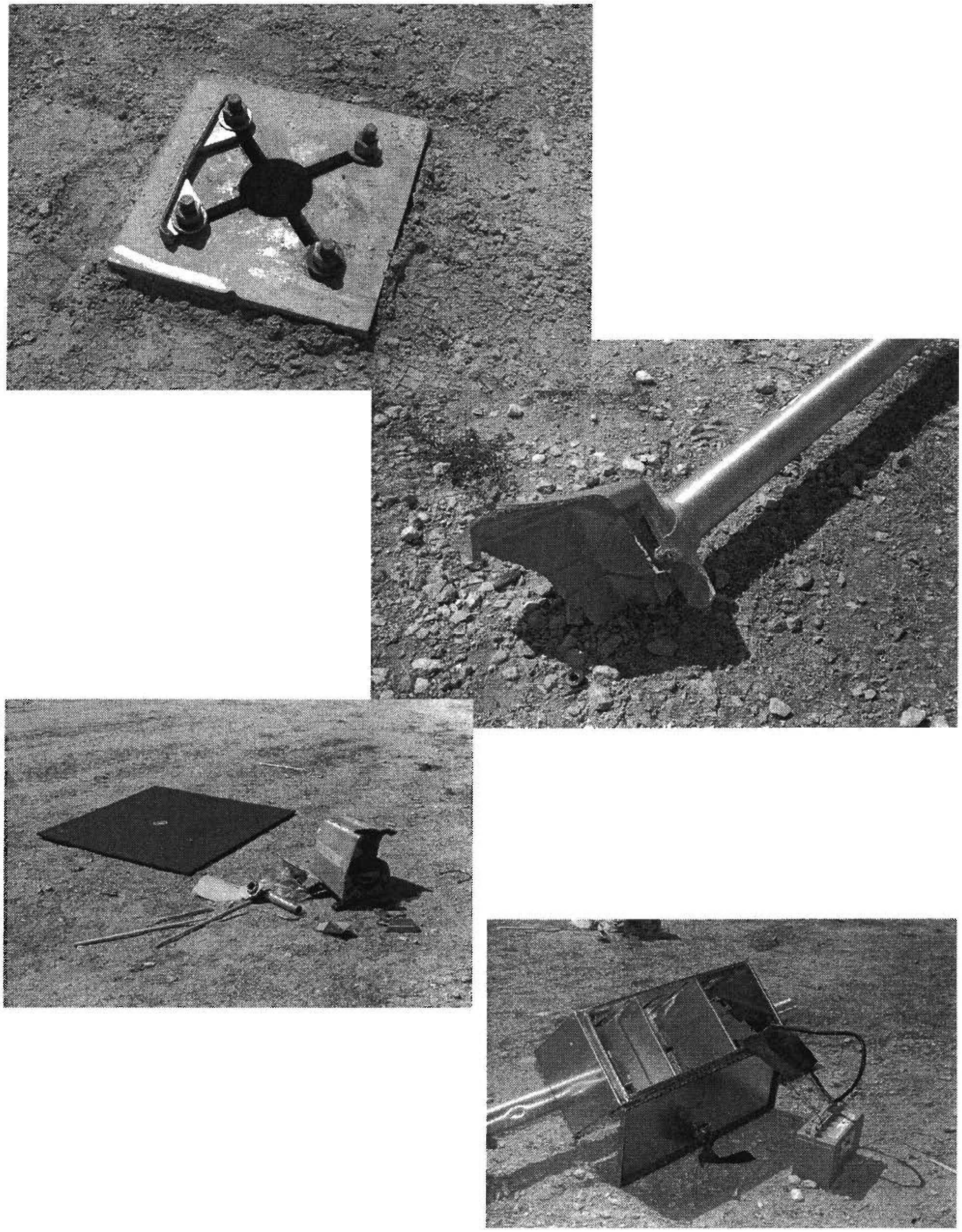


Figure 19. Installation after Test 417920-4.

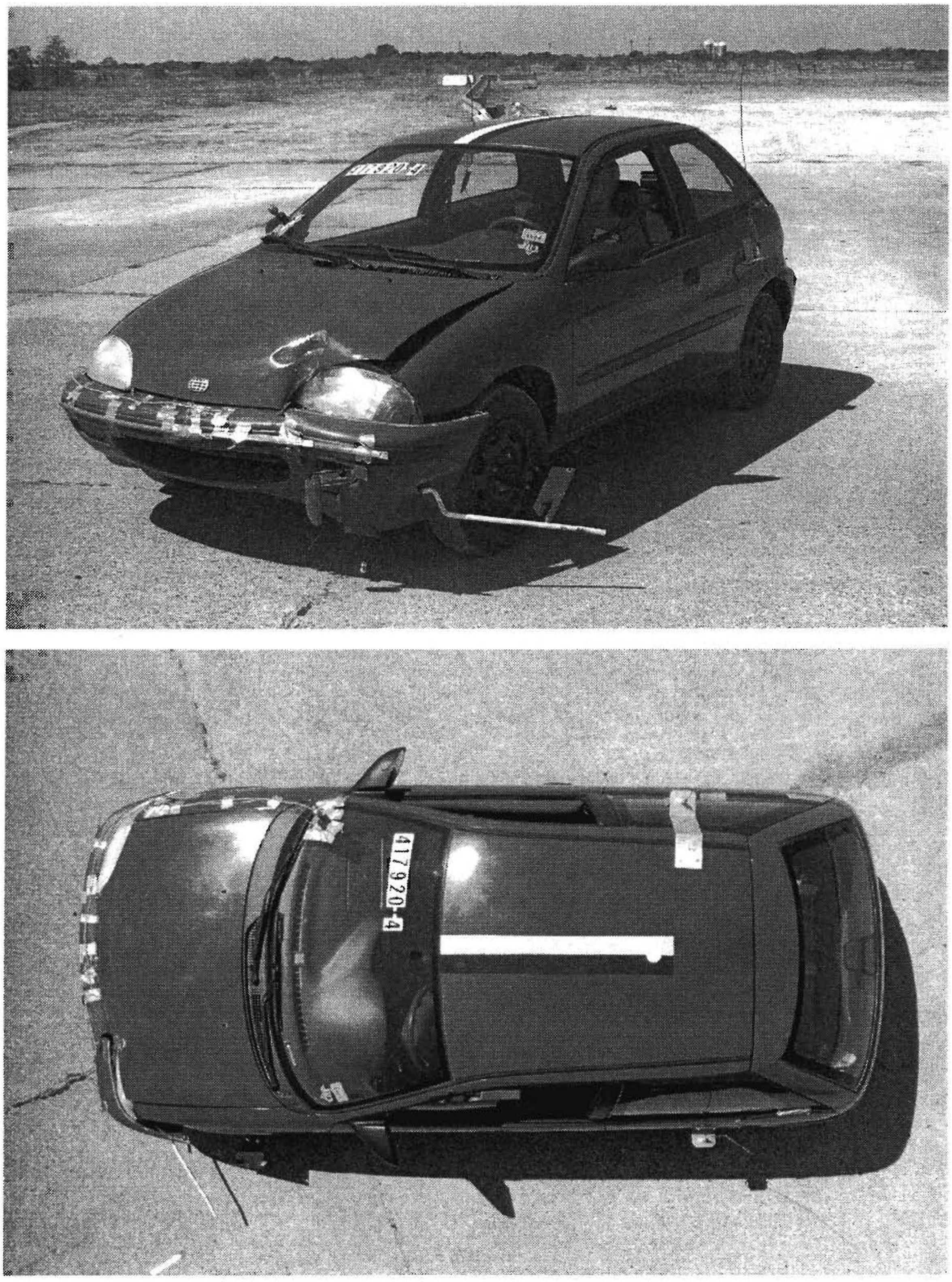


Figure 20. Vehicle after Test 417920-4.

Before test

After test

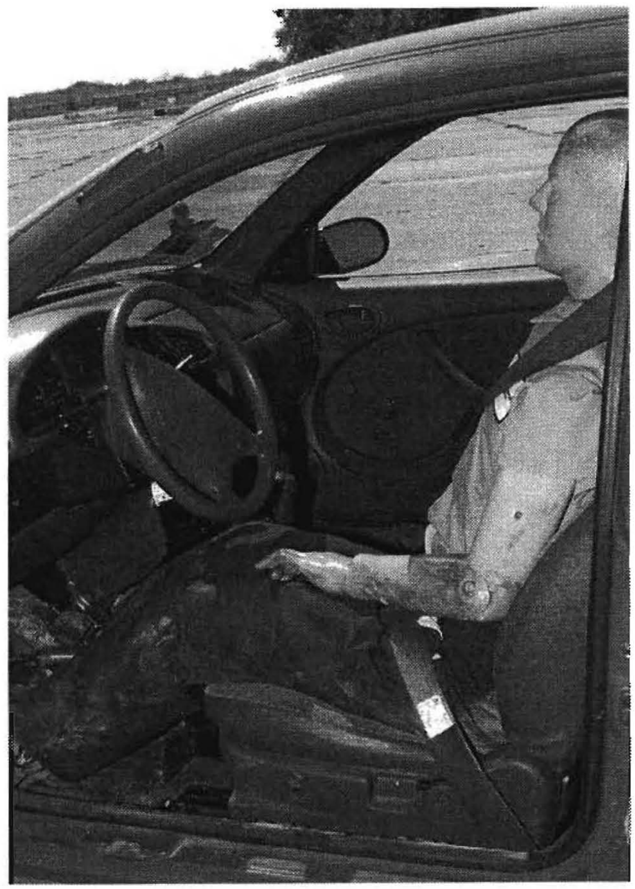
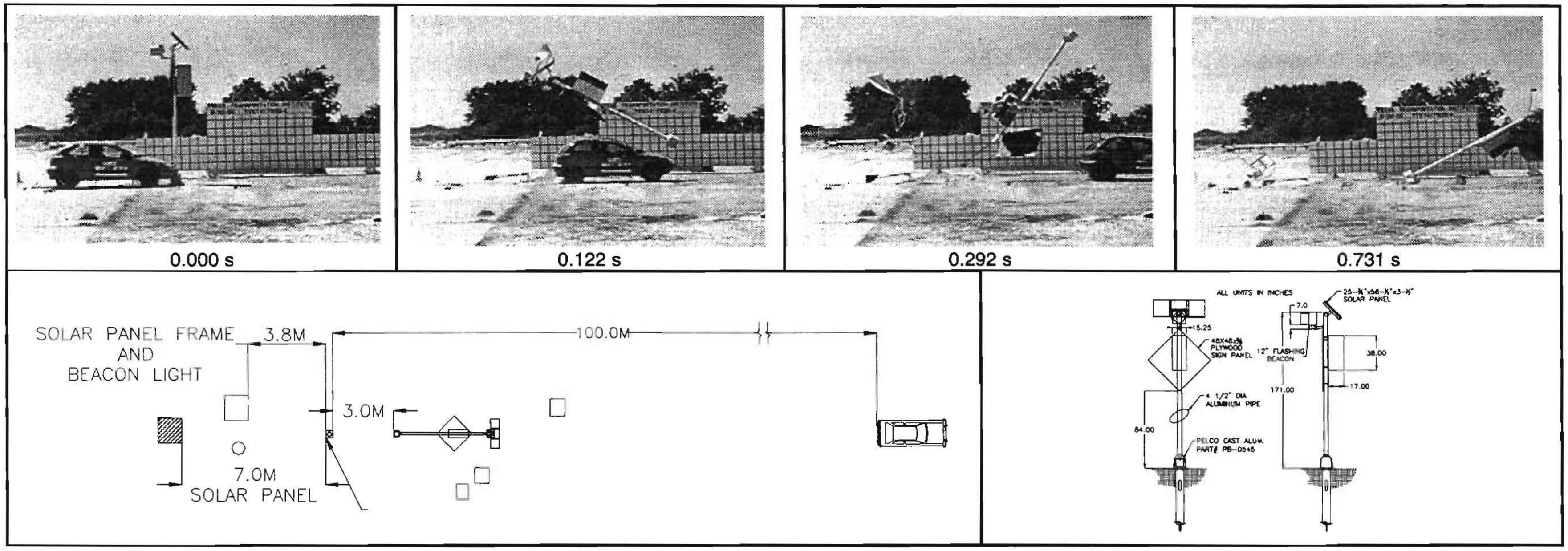


Figure 21. Interior of Vehicle for Test 417920-4.



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 417920-4
- Date 08/30/00

Test Article
- Type .... Sign Support
- Name .... Pedestal Base/Solar Panel Support
- Installation Height (m) ...... 3.4 (11.2 ft)
- Material or Key Elements ... Pedestal Base with Solar Panel for Beacon Lights and Plywood Sign Panel 16 mm x 1.2 m x (0.625 in x 48 in x 48 in)

Soil Type and Condition Standard Soil, Dry

Test Vehicle
- Type .... Production
- Designation 820C
- Model .... 1996 Geo Metro
- Mass (kg)
  - Curb .... 801 (1766 lb)
  - Test Inertial .... 820 (1806 lb)
  - Dummy .... 75 (165 lb)
  - Gross Static .... 895 (1971 lb)

Impact Conditions
- Speed (km/h) .... 99.0 (61.5 mi/h)
- Angle (deg) 0

Exit Conditions
- Speed (km/h) .... 93.4 (58.0 mi/h)
- Angle (deg) 0

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction .... 1.4 (4.6 ft/s)
  - y-direction .... 0.9 (3.0 ft/s)
- THIV (km/h) .... 6.1 (3.8 mi/h)
- Ridedown Accelerations (g's)
  - x-direction .... -1.5
  - y-direction .... -0.7
- PHD (g's) 1.6
- ASI 0.19
- Max. 0.050-s Average (g's)
  - x-direction .... -2.0
  - y-direction .... -0.8
  - z-direction .... -1.4

Test Article Debris Scatter (m)
- Longitudinal .... 7.0 (2.3 ft)
- Lateral .... 2.3 (7.5 ft)
- Working Width .... N/A

Vehicle Damage
- Exterior
  - VDS 11LFQ1
  - CDC 11FLEN1
- Maximum Exterior
  - Vehicle Crush (mm) ...... 35 (1.38 in)
- Interior
  - OCDI FS0000000
- Max. Occ. Compart.
  - Deformation (mm) .... nil

Post-Impact Behavior
(during 1.0 s after impact)
- Max. Yaw Angle (deg) ...... -3
- Max. Pitch Angle (deg) 9
- Max. Roll Angle (deg) 4

Figure 22. Summary of Results for Test 417920-4, *NCHRP Report 350* Test 3-61.

VI. FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

An assessment of each test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

Low-Speed Test Results (Test 417920-3, *NCHRP Report 350* Test 3-60)

- **Structural Adequacy**

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

Result: The cast aluminum pedestal base fractured as designed and permitted the support system to yield to the impacting vehicle.

- **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.*

Result: The detached elements did not penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 35 mm (1.38 in) in the floor pan area.

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

Result: The vehicle remained upright during and after the collision period.

H. *Occupant impact velocities should satisfy the following:*

Longitudinal Occupant Impact Velocity - m/s	
Preferred	*Maximum*
3 (9.8 ft/s)	*5 (16.4 ft/s)*

Result: Longitudinal occupant impact velocity was 4.3 m/s (14.1 ft/s).

I. *Occupant ridedown accelerations should satisfy the following:*

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

Result: Longitudinal ridedown acceleration was -1.6 g's and in the lateral ridedown acceleration was -1.1 g's.

- **Vehicle Trajectory**

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

Result: The vehicle did not intrude into adjacent traffic lanes.

N. *Vehicle trajectory behind the test article is acceptable.*

Result: The vehicle trajectory behind the test article is acceptable.

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results:

◆ **PASSENGER COMPARTMENT INTRUSION**

1. Windshield Intrusion

a. No windshield contact
b. Windshield contact, no damage
c. Windshield contact, no intrusion
d. Device embedded in windshield, no significant intrusion
e. Complete intrusion into passenger compartment
f. Partial intrusion into passenger compartment

2. Body Panel Intrusion yes or no

◆ **LOSS OF VEHICLE CONTROL**

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

- **PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES**

  1. **Harmful debris that could injure workers or others in the area**
  2. **Harmful debris that could injure occupants in other vehicles**

Result: None of the debris was considered harmful to others.

- **VEHICLE AND DEVICE CONDITION**

  1. **Vehicle Damage**

     a. None
     b. Minor scrapes, scratches or dents
     c. Significant cosmetic dents
     d. Major dents to grill and body panels
     e. Major structural damage

  2. **Windshield Damage**

     a. None
     b. Minor chip or crack
     c. Broken, no interference with visibility
     d. Broken and shattered, visibility restricted but remained intact
     e. Shattered, remained intact but partially dislodged
     f. Large portion removed
     g. Completely removed

  3. **Device Damage**

     a. None
     b. Superficial
     c. Substantial, but can be straightened
     d. Substantial, replacement parts needed for repair
     e. Cannot be repaired

In addition, the 1994 AASHTO Specification states:

> *Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 mi/h does not exceed 16 ft/s but preferably does not exceed 10 ft/s or less.*

Result: Maximum change in velocity for this test was 4.3 m/s (14.1 ft/s).

High-Speed Test Results (Test 417920-4, *NCHRP Report 350* Test 3-61)

- **Structural Adequacy**

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

Result: The solar powered sign support system met the requirements for structural adequacy. The case aluminum pedestal base fractured as designed and permitted the support system to yield to the impacting vehicle.

- **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.*

Result: The detached elements did not penetrate or show potential for penetrating the occupant compartment, nor did they present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

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

Result: The vehicle remained upright during and after the collision period.

H. *Occupant impact velocities should satisfy the following:*

Longitudinal Occupant Impact Velocity - m/s	
Preferred	*Maximum*
3 (9.8 ft/s)	*5 (16.4 ft/s)*

Result: Longitudinal occupant impact velocity was 1.4 m/s (4.6 ft/s).

I. *Occupant ridedown accelerations should satisfy the following:*

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

Result: Longitudinal ridedown acceleration was -1.5 g's and in the lateral ridedown acceleration was -0.7 g's.

- **Vehicle Trajectory**

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

Result: The vehicle traveled in a straightforward manner and came to rest 100.0 m (328.1 ft) behind the point of impact.

N. *Vehicle trajectory behind the test article is acceptable.*

Result: The vehicle trajectory behind the test article is acceptable.

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results:

◆ **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

   a. No windshield contact
   b. Windshield contact, no damage
   c. Windshield contact, no intrusion
   d. Device embedded in windshield, no significant intrusion
   e. Complete intrusion into passenger compartment
   f. Partial intrusion into passenger compartment

2. **Body Panel Intrusion** yes or no

◆ **LOSS OF VEHICLE CONTROL**

1. **Physical loss of control**
2. **Loss of windshield visibility**
3. **Perceived threat to other vehicles**
4. **Debris on pavement**

◆ **PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES**

1. **Harmful debris that could injure workers or others in the area**
2. **Harmful debris that could injure occupants in other vehicles**

None of the debris was considered harmful to others.

- **VEHICLE AND DEVICE CONDITION**

1. **Vehicle Damage**

   a. None
   b. Minor scrapes, scratches or dents
   c. <u>Significant cosmetic dents</u>
   d. Major dents to grill and body panels
   e. Major structural damage

2. **Windshield Damage**

   a. <u>None</u>
   b. Minor chip or crack
   c. Broken, no interference with visibility
   d. Broken and shattered, visibility restricted but remained intact
   e. Shattered, remained intact but partially dislodged
   f. Large portion removed
   g. Completely removed

3. **Device Damage**

   a. None
   b. Superficial
   c. Substantial, but can be straightened
   d. <u>Substantial, replacement parts needed for repair</u>
   e. Cannot be repaired

In addition, the 1994 AASHTO Specification states:

> *Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 mi/h does not exceed 16 ft/s but preferably does not exceed 10 ft/s or less.*

<u>Result</u>: Maximum change in velocity for this test was 1.6 m/s (5.1 ft/s).

CONCLUSIONS

A pedestal base sign installation equipped with photovoltaic equipment and attached to the ground with a helical type screw-in foundation anchor assembly successfully met the evaluation criteria set forth in *NCHRP Report 350*. A summary of the evaluation is given in Tables 4 and 5. The installation was fabricated using a Pelco (model SP 1014 TX) square cast aluminum traffic signal base with a 114 mm (4.5 in) O.D. × 3.96 m (13 ft) long spun aluminum pole. Attached to the pole was a 16 mm × 1.2 m × 1.2 m (0.625 in × 48 in × 48 in) plywood warning sign with bottom of the sign height at 2.1 m (7.0 ft). In addition, a 305 mm (12.0 in), LED lamp, flashing yellow signal beacon was mounted directly above the sign panel. A 1429 mm × 654 mm × 89 mm (56.3 in × 25.7 in × 3.5 in) solar panel weighing 235.8 N (53 lb) was attached atop the support.

Table 4. Performance Evaluation Summary for Test 417920-3, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 417920-3 | Test Date: 08/30/2000

<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 cast aluminum pedestal base fractured as designed and permitted the support system to yield to the vehicle.</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 detached elements did not penetrate or show potential for penetrating the occupant compartment, nor did they present undue hazard to others in the area. Maximum deformation of the occupant compartment was 35 mm (1.38 in) in the floor pan area.</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 (9.8 ft/s)</td><td>5 (16.4 ft/s)</td></tr></table></td><td>Longitudinal occupant impact velocity was 4.3 m/s (14.1 ft/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</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal ridedown acceleration was -1.6 g's and in the lateral ridedown acceleration was -1.1 g's.</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 traveled in a straightforward manner and came to rest 19.1 m (62.7 ft) directly behind the impact point.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle trajectory behind the test article is acceptable.</td><td>Pass</td></tr>
</table>

Table 5. Performance Evaluation Summary for Test 417920-4, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 417920-4 | Test Date: 08/30/2000

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The cast aluminum pedestal base fractured as designed and permitted the support system to yield to the vehicle.	Pass
<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.	The detached elements did not penetrate or show potential to penetrate the occupant compartment, nor did they present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.	Pass
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
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal / 3 (9.8 ft/s) / 5 (16.4 ft/s)	Longitudinal occupant impact velocity was 1.4 m/s (4.6 ft/s).	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal / 15 / 20	Longitudinal ridedown acceleration was -1.5 g's and in the lateral ridedown acceleration was -0.7 g's.	Pass
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle traveled in a straightforward manner and came to rest 100.0 m (328.1 ft) behind the point of impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory behind the test article is acceptable.	Pass

The battery cabinet for the panel was mounted behind the sign panel at a height of 2.7 m and weighed 520.4 N (117 lb). The helical type screw-in foundation anchor assembly (model no. PB 5306) was placed in *NCHRP Report 350* standard soil using an auger truck.

IMPLEMENTATION STATEMENT

Full-scale crash testing evaluated a pedestal base sign support installation with solar voltaic equipment and a flashing beacon installed atop a screw-in helical type ground anchor. The system met *NCHRP Report 350* guidelines and researchers consider it suitable for implementation.

Details of the pedestal base sign installation with solar voltaic equipment and a flashing beacon, as tested, are presented in this report. Installations that deviate in construction significantly from the details presented herein may require additional engineering evaluation and/or testing.

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*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. D.L. Bullard, Jr., R. P. Bligh, W.L. Menges, and S.K. Schoeneman, "Testing and Evaluation of the Pedestal Base Sign Supports," Report 1792-3, Texas Transportation Institute, College Station, Texas 2001.

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

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were performed 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. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Rate of turn transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded minutes before the test and also immediately afterward. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle are actuated 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 produces 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, is received at the data acquisition station, and demultiplexed onto separate tracks of a 28 track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with Society of Automotive Engineers (SAE J211) filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device along with its support instruments is returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made any time data are suspect.

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 0.0002 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

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was un-instrumented.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included two high-speed cameras: one placed behind the installation at an angle; and a second placed to have a field of view perpendicular to and aligned with the installation. 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, the test vehicle was released 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 researchers remotely activated the brakes on the vehicle to bring it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE 08/30/00 TEST NO. 417920-3 VIN NO.: 2C1MR2263S6771192

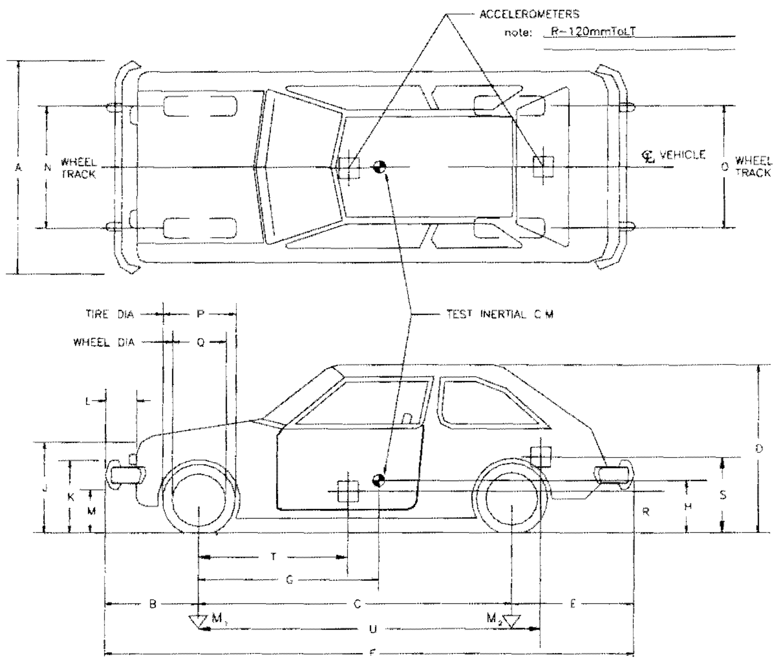
YEAR: 1995 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ______ ODOMETER: 90187 TIRE SIZE: 155 80R13

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

MASS DISTRIBUTION (kg) LF 255 RF 231 LR 171 RR 163

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: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1465	E 550	J 605	N 1385	R 390
B 780	F 3695	K 525	O 1360	S 550
C 2365	G 963.3	L 160	P 570	T 920
D 1425	H	M 400	Q 365	U 2515

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	497	486	521
M_2	303	334	374
M_T	800	820	896

Figure 23. Vehicle Properties for Test 417920-3.

Table 6. Exterior Crush Measurements for Test 417920-3.

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	Front of hood	700	260	860	60	60	260	170	60	10	-100

[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).

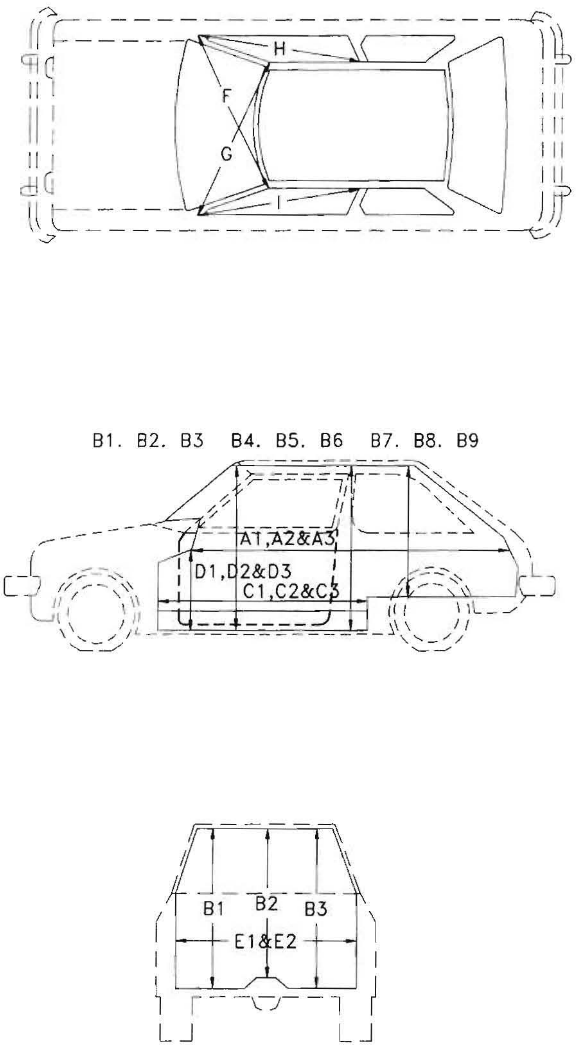
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 7. Occupant Compartment Measurements for Test 417920-3.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1450	1450
A2	2006	2006
A3	1432	1432
B1	960	960
B2	905	905
B3	965	965
B4	927	903
B5	907	898
B6	922	922
B7	----	----
B8	----	----
B9	----	----
C1	707	707
C2	705	705
C3	708	708
D1	237	237
D2	146	146
D3	252	252
E1	1218	1218
E2	1180	1180
F	1205	1205
G	1205	1205
H	1000	1000
I	1000	1000

DATE 08/30/00 TEST NO. 417920-4 VIN NO.: 2C1MR2262T6739531

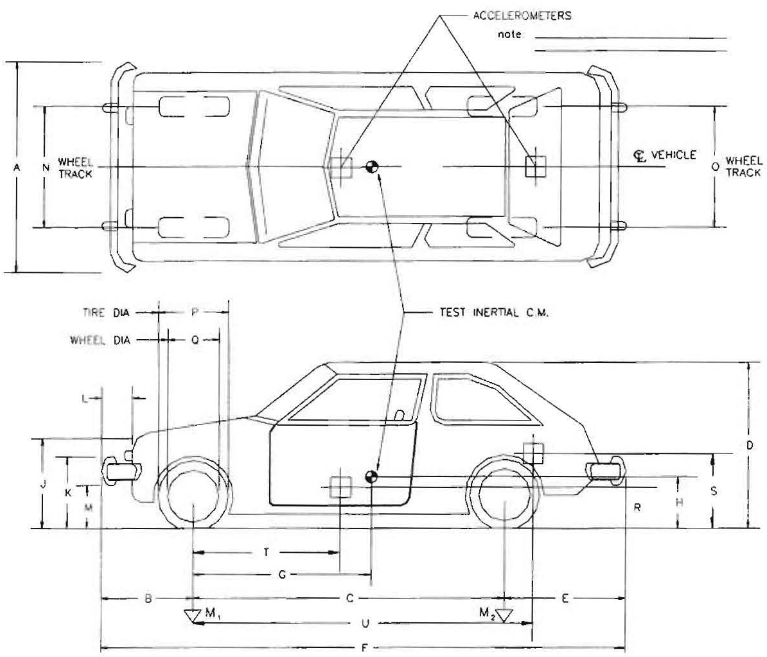
YEAR: 1996 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ________ ODOMETER: 119654 TIRE SIZE: 155 80R13

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

MASS DISTRIBUTION (kg) LF 249 RF 227 LR 176 RR 168

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: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1470	E	550	J	610	N	1380	R	390
B	775	F	3690	K	525	O	1365	S	550
C	2365	G	992.1	L	160	P	570	T	910
D	1430	H		M	400	Q	365	U	2520

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	492	476	512
M_2	309	344	383
M_T	801	820	895

Figure 24. Vehicle Properties for Test 417920-4.

Table 8. Exterior Crush Measurements for Test 417920-4.

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 Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	At front bumper	600	35	300	0	25	25	0			-380

[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.

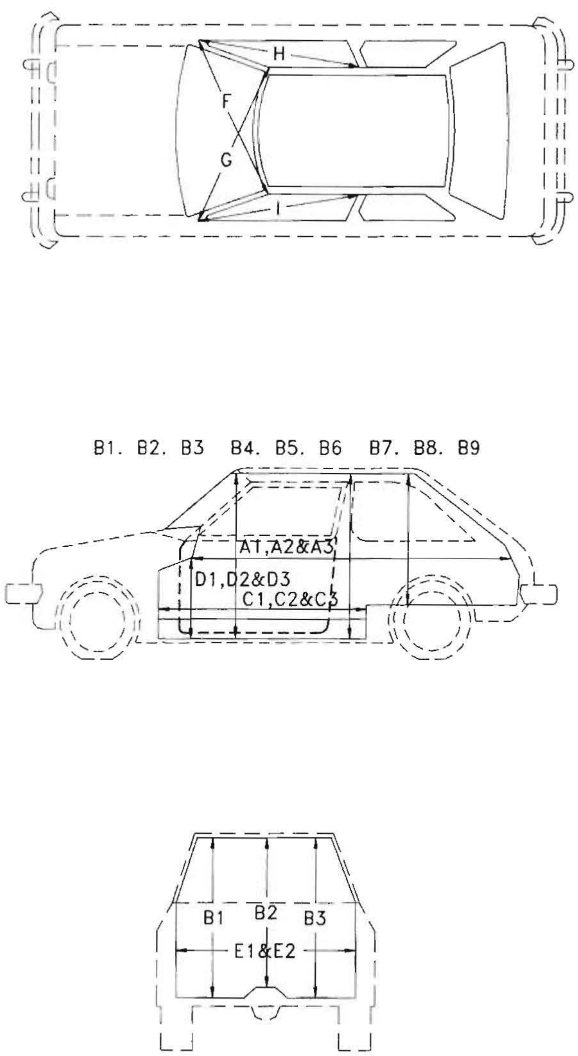
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 9. Occupant Compartment Measurements for Test 417920-4.

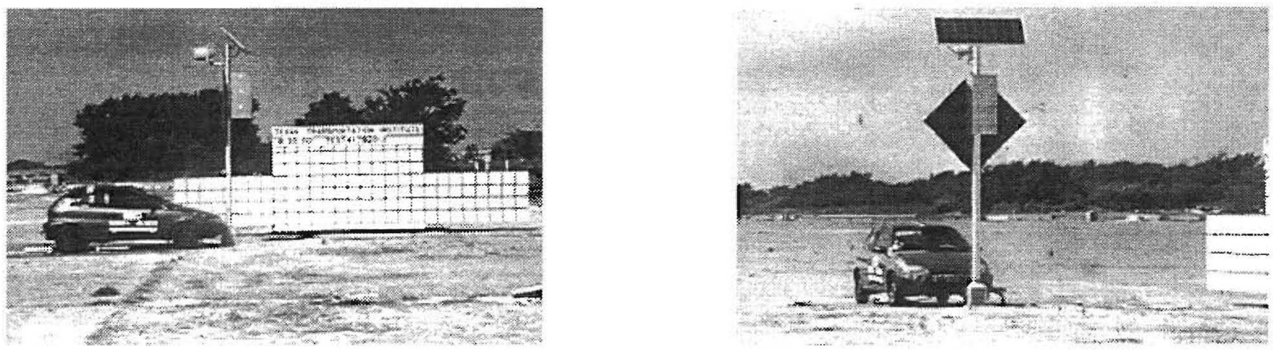
Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1427	1427
A2	1982	1982
A3	1414	1414
B1	960	960
B2	970	970
B3	958	958
B4	934	934
B5	901	901
B6	926	926
B7	----	----
B8	----	----
B9	----	----
C1	700	700
C2	705	705
C3	708	708
D1	235	235
D2	142	142
D3	238	238
E1	1215	1215
E2	1128	1128
F	1210	1210
G	1210	1210
H	1000	1000
I	1000	1000

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



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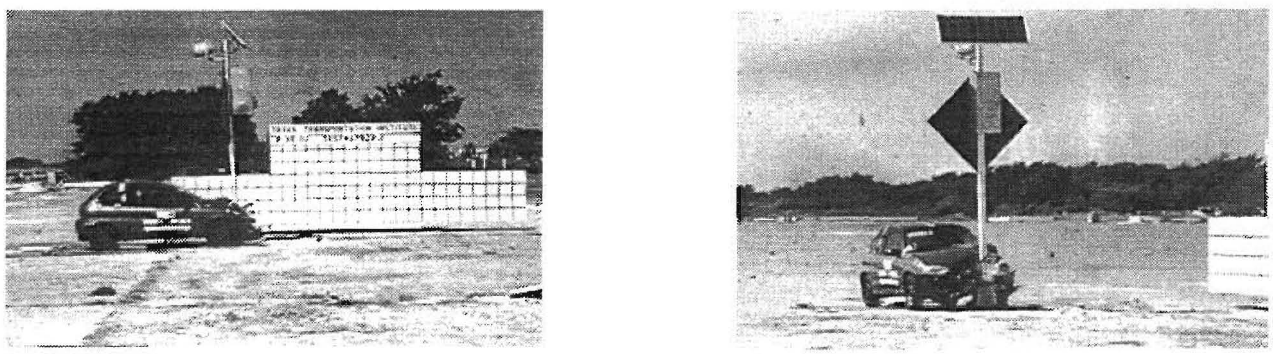
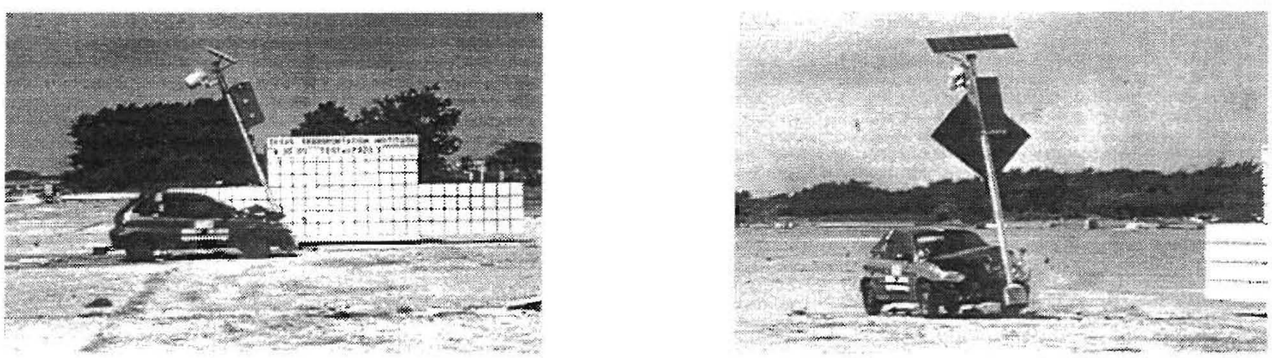
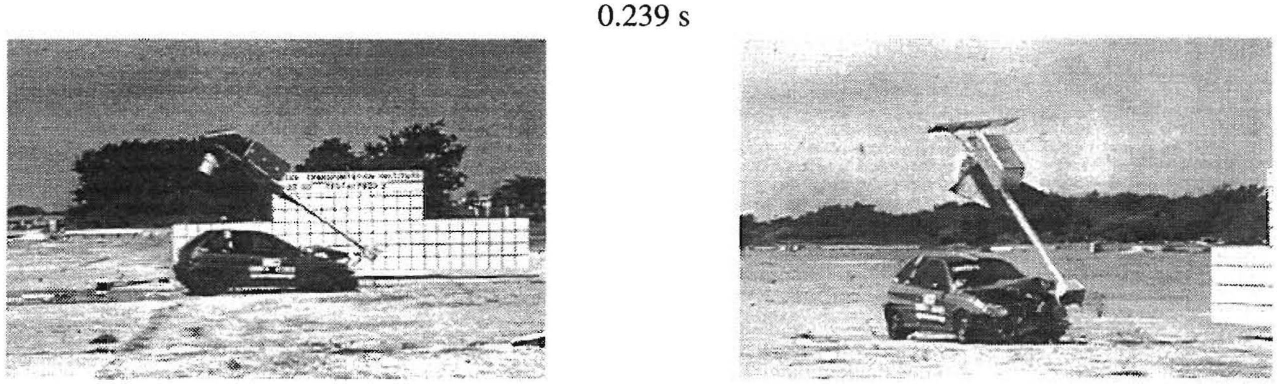


0.096 s



0.239 s

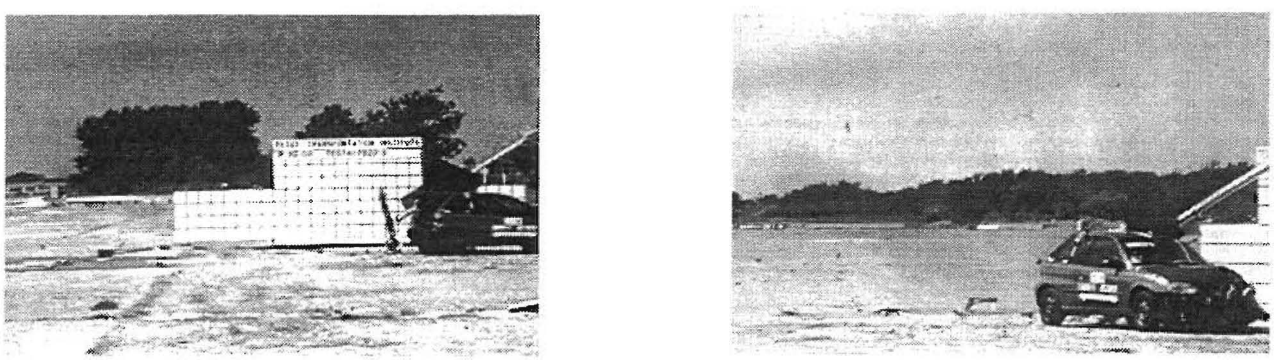


0.478 s

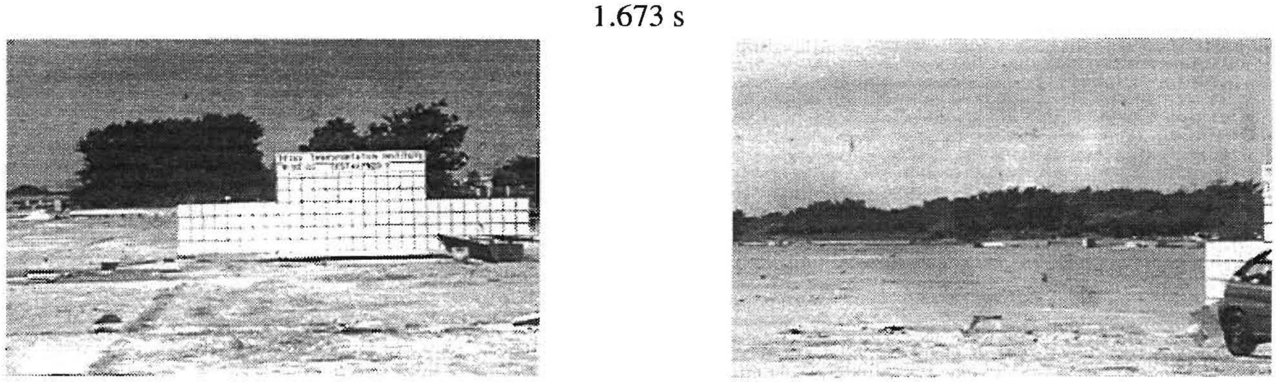
Figure 25. Sequential Photographs for Test 417920-3 (Perpendicular and Oblique Views).

0.717 s

1.075 s



1.673 s



2.868 s

Figure 25. Sequential Photographs for Test 417920-3 (Perpendicular and Oblique Views) (continued).

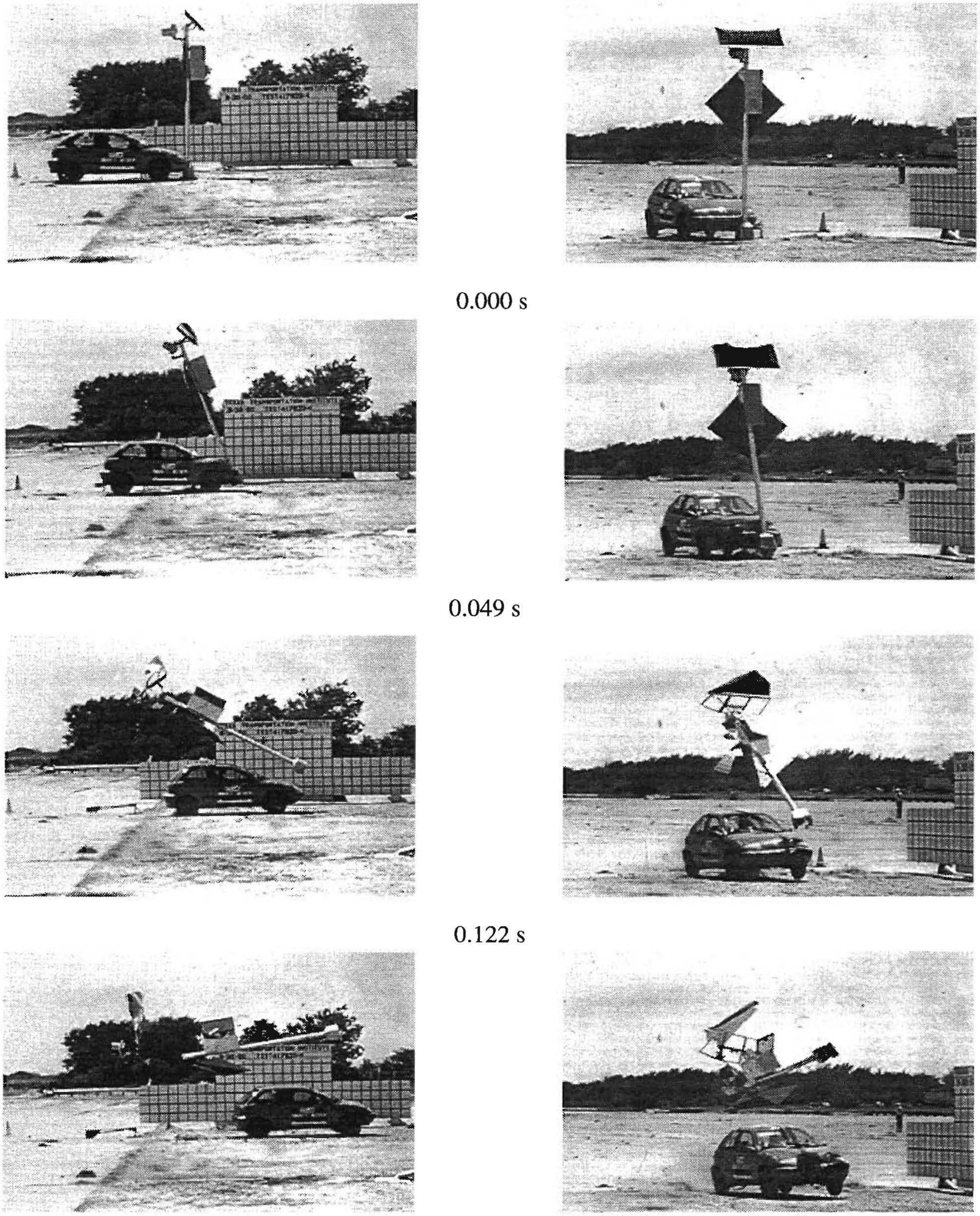
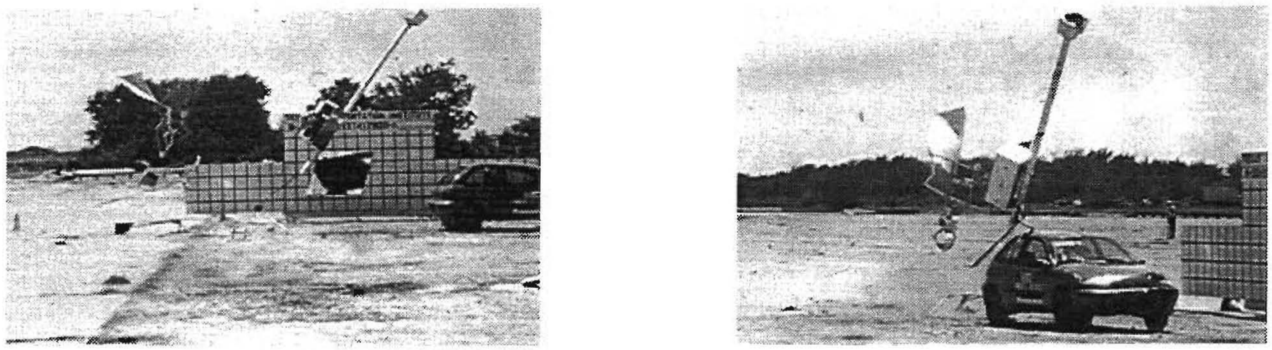
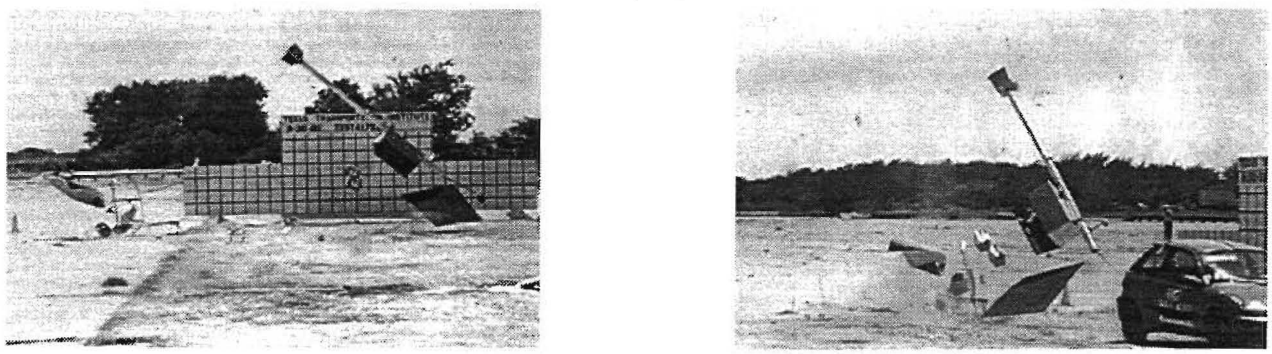


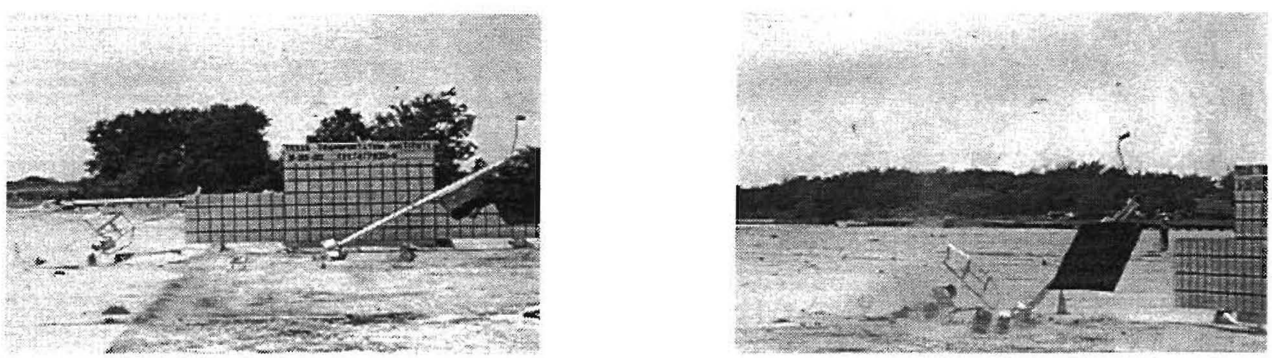
Figure 26. Sequential Photographs for Test 417920-4 (Perpendicular and Oblique Views).



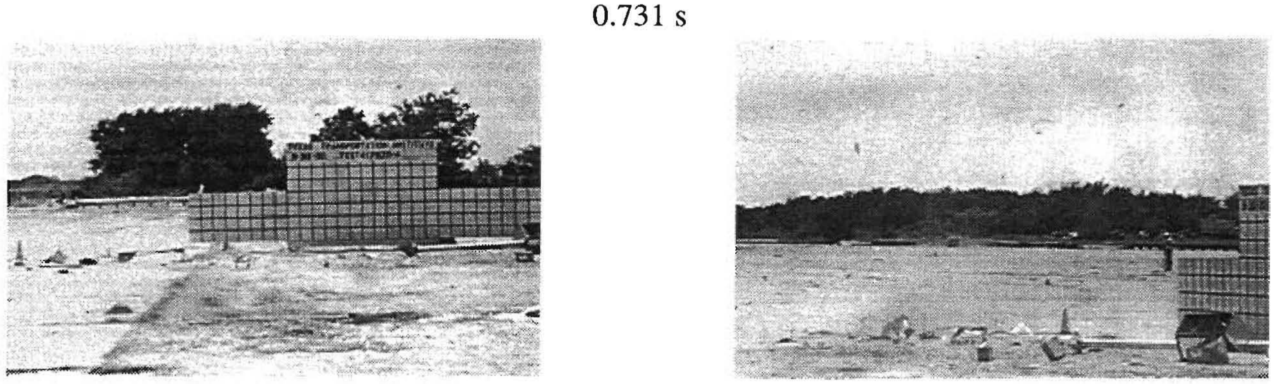
0.292 s



0.487 s



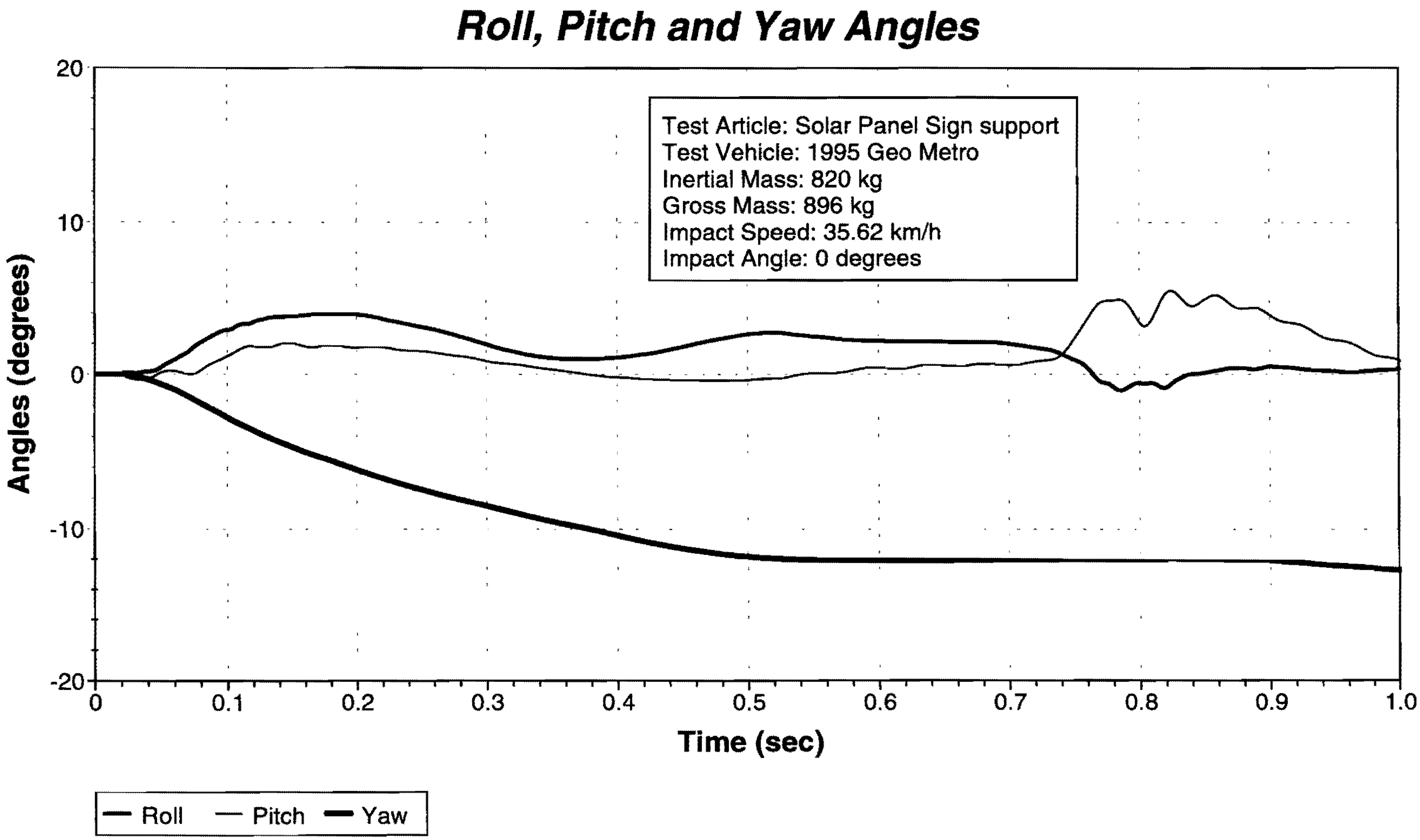
0.731 s



1.828 s

Figure 26. Sequential Photographs for Test 417920-4 (Perpendicular and Oblique Views) (continued).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS



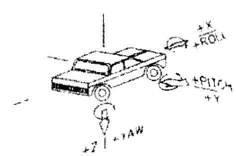


Figure 27. Vehicular Angular Displacements for Test 417920-3.

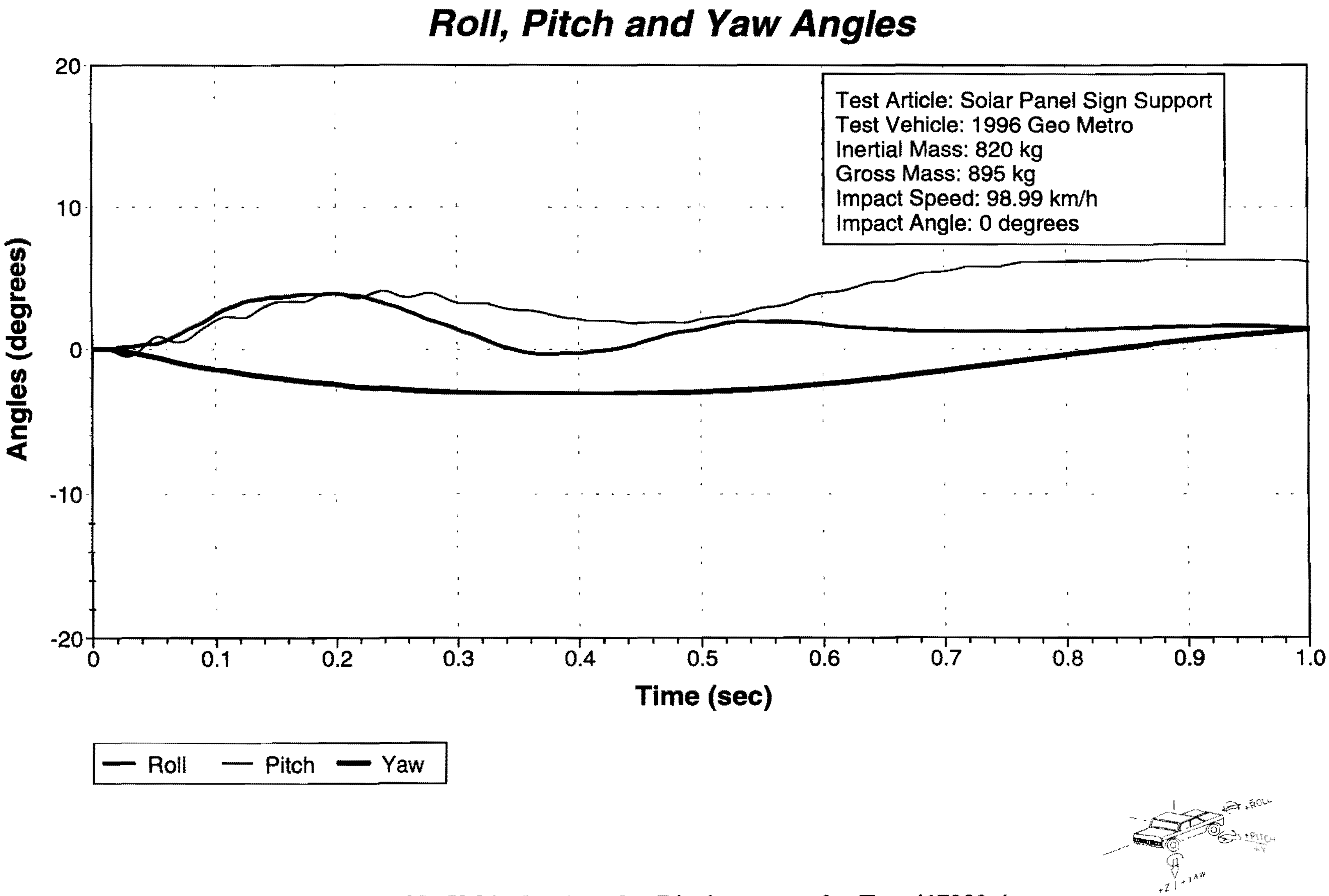


Figure 28. Vehicular Angular Displacements for Test 417920-4.

APPENDIX E. VEHICLE ACCELERATIONS

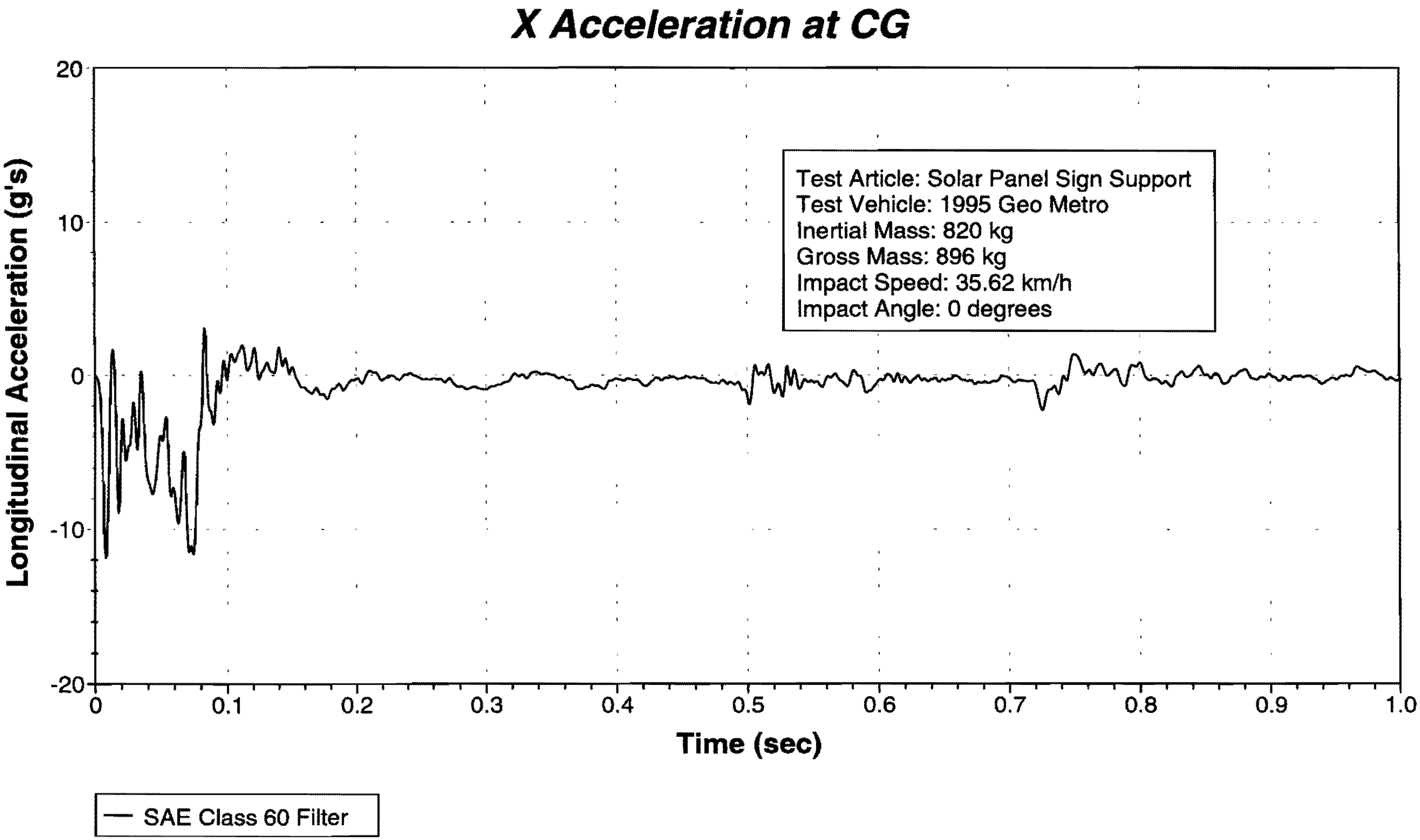


Figure 29. Vehicle Longitudinal Accelerometer Trace for Test 417920-3.

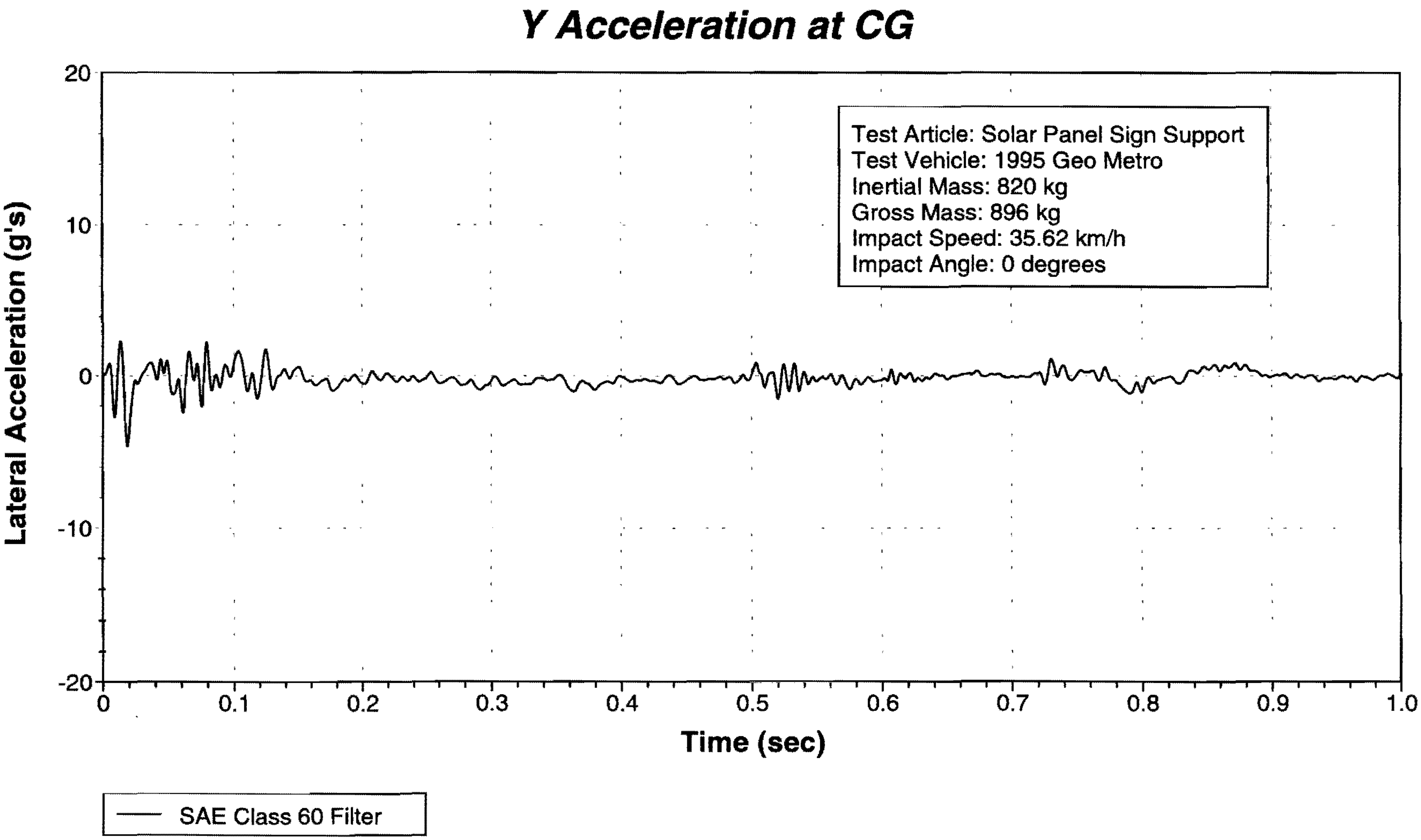


Figure 30. Vehicle Lateral Accelerometer Trace for Test 417920-3.

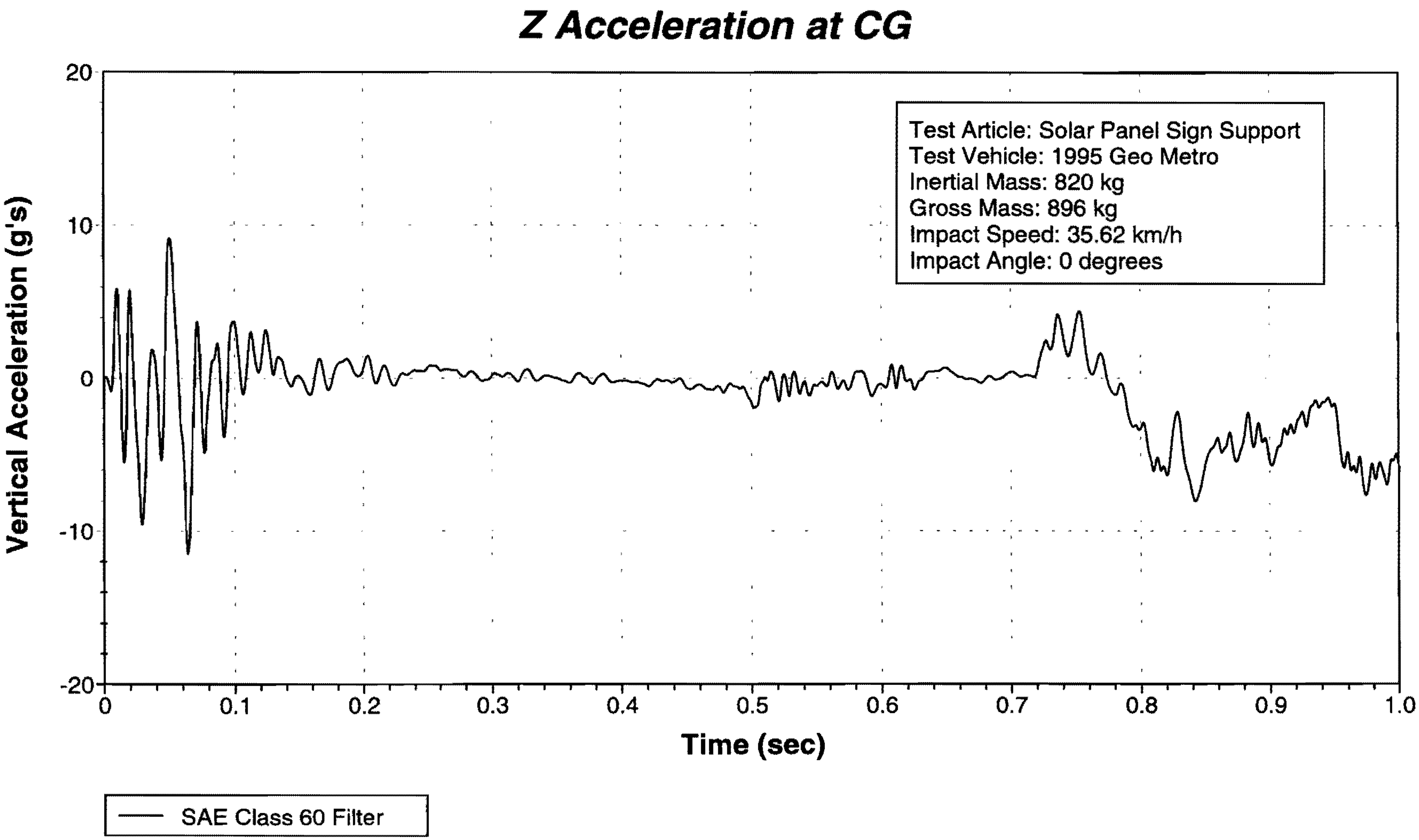


Figure 31. Vehicle Vertical Accelerometer Trace for Test 417920-3.

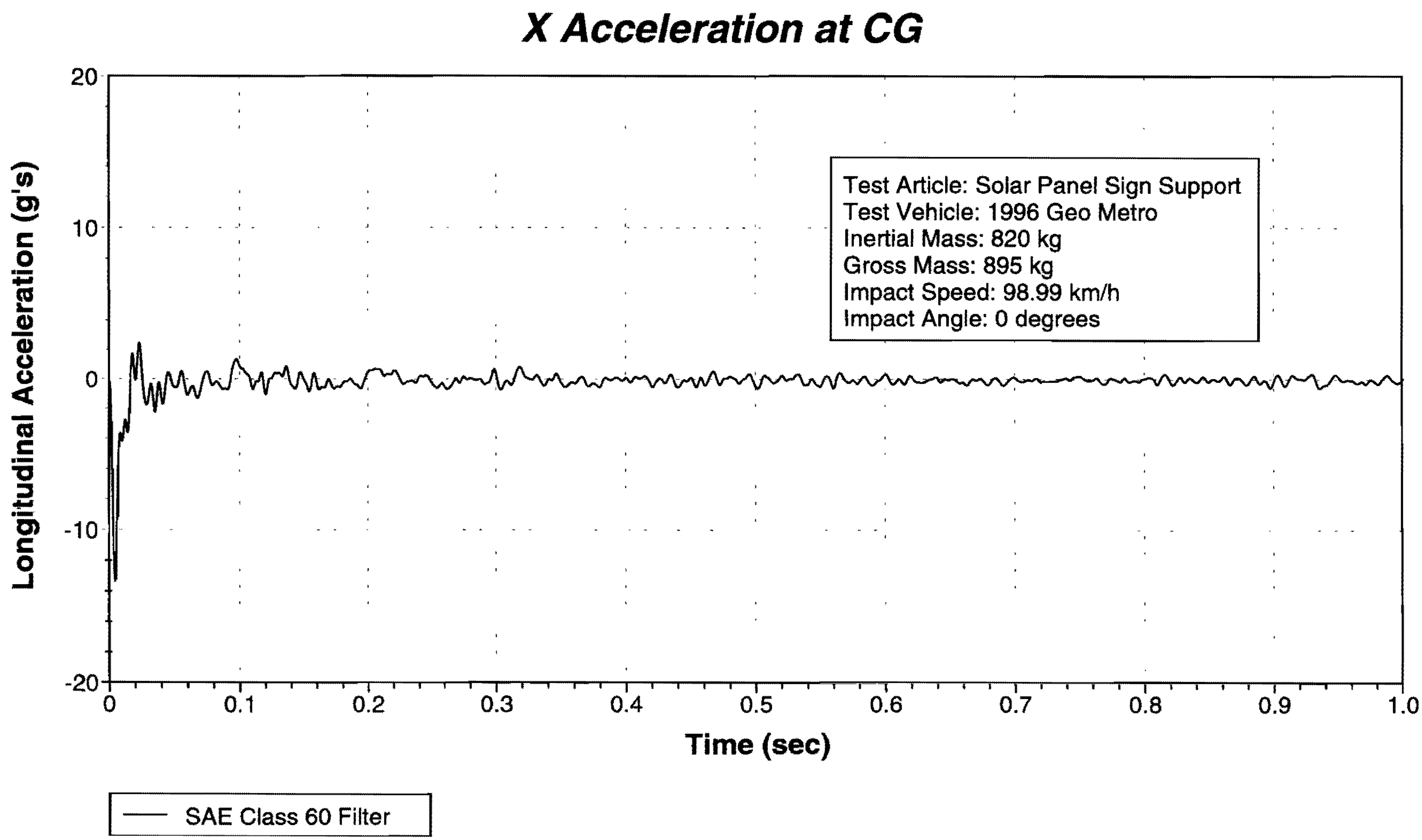


Figure 32. Vehicle Longitudinal Accelerometer Trace for Test 417920-4.

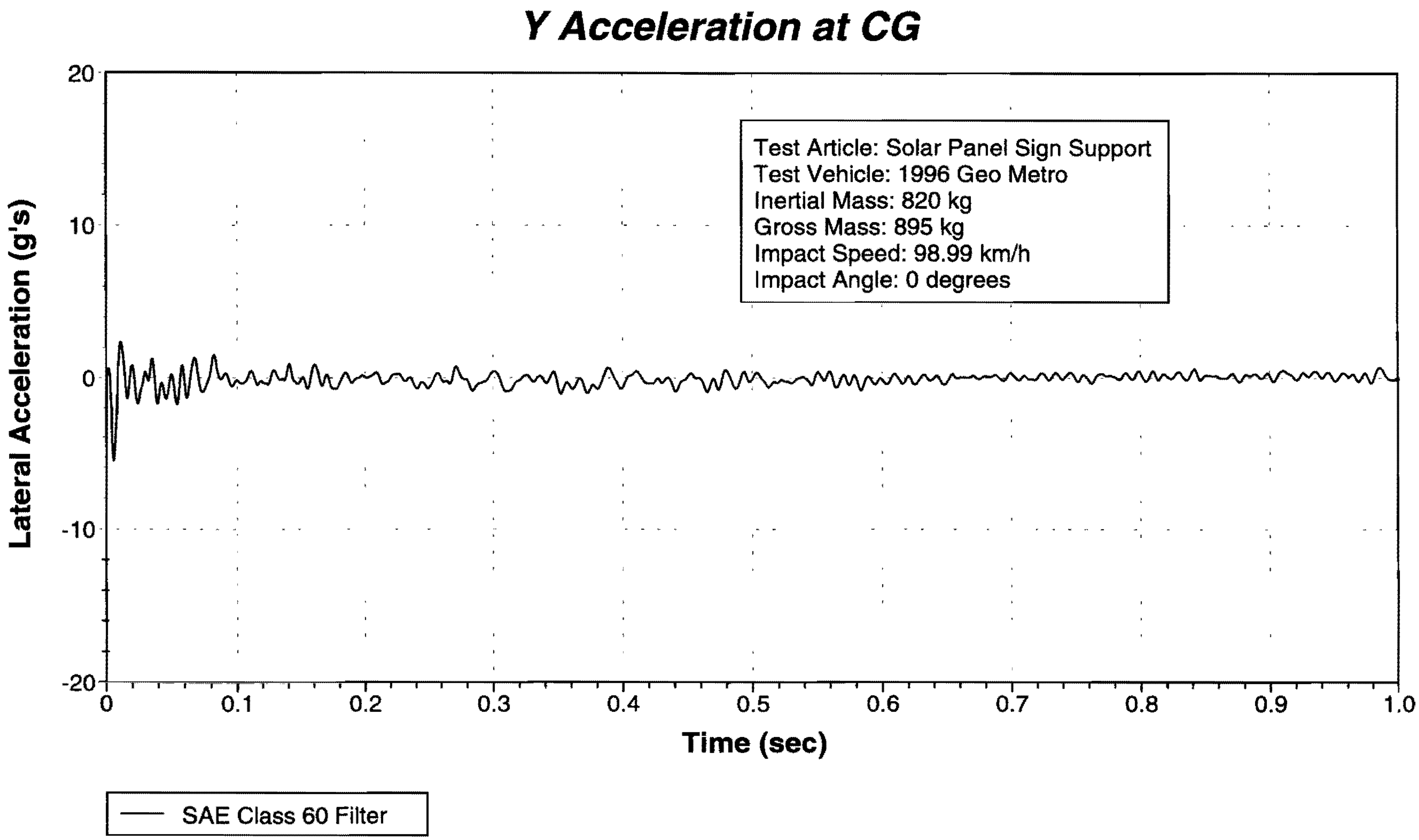


Figure 33. Vehicle Lateral Accelerometer Trace for Test 417920-4.

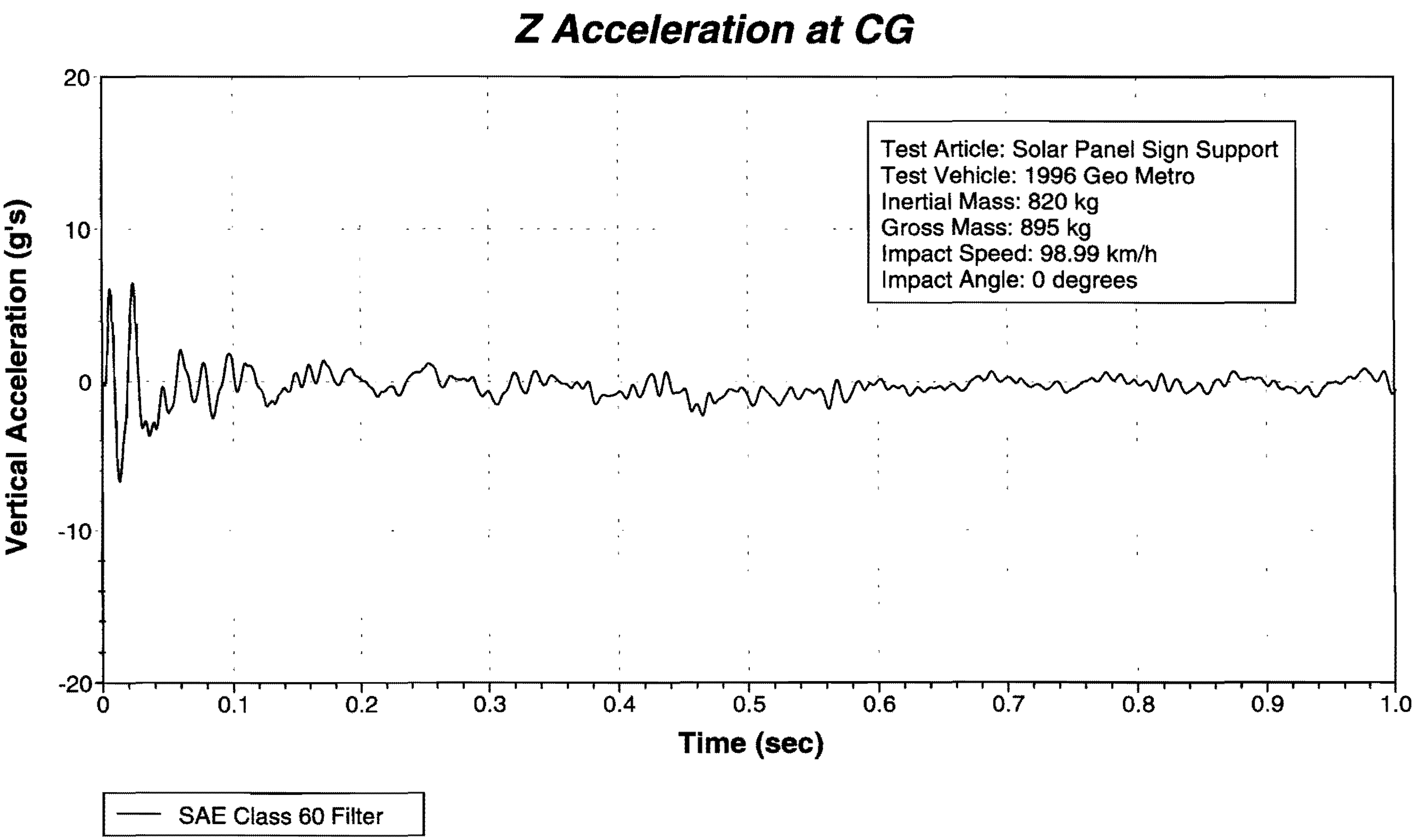


Figure 34. Vehicle Vertical Accelerometer Trace for Test 417920-4.