Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-00/1792-5		

4. Title and Subtitle	5. Report Date
TESTING AND EVALUATION OF SLIP BASE SIGN SUPPORTS	May 2001
	6. Performing Organization Code
7. Author(s) Roger P. Bligh, D. Lance Bullard, Jr., Wanda L. Menges, and Sandra K. Schoeneman	8. Performing Organization Report No. Report 1792-5
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 Research and Technology Implementation Office 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

Under this project, several issues related to the performance of slip base sign supports were investigated. These issues include: the effect of bolt torque on the impact performance of slip base sign supports, the effect of sign panel size and configuration on the trajectory and impact performance of slip base sign supports, and an evaluation of methods for retrofitting slip base stubs that incorporate a lifting ramp or cone. A summary of the findings and conclusions resulting from these investigations is provided.

Small slip-base sign supports with slip bolt torques in the range of 109 N·m (80 ft·lb) to 136 N·m (100 ft·lb) were determined to comply with *National Cooperative Highway Research Program Report 350*. A triangular-shaped, polycarbonate spacer cap was successfully tested as a retrofit option when repairing or upgrading existing sign supports with foundations that incorporate a lifting device. Test results indicate that slip base sign supports perform acceptably when used with conventional sign panels having an area of 0.84 m^2 (9 ft^2) or greater. A test with a lightweight plastic sign with an area of 0.58 m^2 (6.25 ft^2) was marginally acceptable.

17. Key Words	18. Distribution Statement
Sign Support, Slip Base, Crash Test	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	210	

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

TESTING AND EVALUATION OF SLIP BASE SIGN SUPPORTS

by

Roger P. Bligh, P.E.
Assistant Research Engineer
Texas Transportation Institute

D. Lance Bullard, Jr., P.E.
Assistant Research Engineer
Texas Transportation Institute

Wanda L. Menges
Associate Research Specialist
Texas Transportation Institute

and

Sandra K. Schoeneman
Research Associate
Texas Transportation Institute

Report 1792-5
Project Number 0-1792
Research Project Title: Roadside Safety Hardware
for Traffic Control Devices

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

May 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 Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), the Texas A&M University System, or the Texas Transportation Institute. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The use of names of specific products or manufacturers listed herein does 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. The TxDOT project director for this research was Mr. Greg Brinkmeyer. His guidance is acknowledged and appreciated. The assistance of Mr. Dan Maupin is also acknowledged and appreciated.

TABLE OF CONTENTS

Page

LIST OF FIGURES ix

LIST OF TABLES xiii

I. INTRODUCTION 1

II. STUDY APPROACH 3
PENDULUM TEST FACILITY 3
CRASH TEST FACILITY 3
CRASH TEST CONDITIONS 4
EVALUATION CRITERIA 4

III. EVALUATION OF LIFTING DEVICE RETROFIT 7
TEST ARTICLES 8
PENDULUM TEST RESULTS 9
Test No. 417928-P1 9
Test No. 417928-P2 9
Test No. 417928-P3 17
Test No. 417928-P4 17
Test No. 417928-P5 23
Test No. 417928-P6 23
SUMMARY 30

IV. EVALUATION OF BOLT TORQUE 35
PENDULUM TESTS 35
Test No. 417929-P1 36
Test No. 417929-P2 40
Test No. 417929-P3 46
Test No. 417929-P4 59
FULL-SCALE CRASH TESTING 69
Low-Speed Test (Test No. 417929-6, *NCHRP Report 350* Test No. 3-60) 69
High-Speed Test (Test No. 417929-7, *NCHRP Report 350* Test No. 3-61) 85
Low-Speed Test (Test No. 417929-8, *NCHRP Report 350* Test No. 3-60) 101
Low-Speed Test (Test No. 417929-9, *NCHRP Report 350* Test No. 3-60) 115
SUMMARY OF BOLT TORQUE EVALUATION 126

V. SUMMARY OF FINDINGS AND CONCLUSIONS 131
EVALUATION OF SLIP BOLT TORQUE 131
EVALUATION OF PERFORMANCE LIMITS FOR SLIP BASE SIGNS 131
EVALUATION OF LIFTING DEVICE RETROFIT 132

TABLE OF CONTENTS (Continued)

Page

VI. IMPLEMENTATION RECOMMENDATIONS 135

REFERENCES 137

APPENDIX A. PENDULUM TEST PROCEDURES 139
ELECTRONIC INSTRUMENTATION AND DATA PROCESSING 139
PHOTOGRAPHIC INSTRUMENTATION 139

APPENDIX B. CRASH TEST PROCEDURES 141
ELECTRONIC INSTRUMENTATION AND DATA PROCESSING 141
ANTHROPOMORPHIC DUMMY INSTRUMENTATION 142
PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING 142
TEST VEHICLE PROPULSION AND GUIDANCE 142

APPENDIX C. PENDULUM ACCELERATIONS. 145

APPENDIX D. SEQUENTIAL PHOTOGRAPHS 155

APPENDIX E. TEST VEHICLE PROPERTIES AND INFORMATION 167

APPENDIX F. VEHICLE ANGULAR DISPLACEMENTS 175

APPENDIX G. VEHICLE ACCELERATIONS 179

APPENDIX H. SUPPLEMENTAL CRASH TEST EVALUATION 191

LIST OF FIGURES

Figure		Page
1	Details of the Sign Support Installation.	10
2	Photographs of Typical Sign Support Installation.	12
3	Slip Base Sign Support before Test 417928-P1	13
4	Pendulum Bogie for Test 417928-P1	14
5	Slip Base Sign Support after Test 417928-P1	15
6	Slip Base Sign Support before Test 417928-P2	16
7	Pendulum Bogie for Test 417928-P2	18
8	Slip Base Sign Support after Test 417928-P2	19
9	Slip Base Sign Support before Test 417928-P3	20
10	Pendulum Bogie after Test 417928-P3	21
11	Slip Base Sign Support after Test 417928-P3	22
12	Slip Base Sign Support before Test 417928-P4	24
13	Pendulum Bogie for Test 417928-P4	25
14	Slip Base Sign Support after Test 417928-P4	26
15	Pendulum Bogie for Test 417928-P5	27
16	Slip Base Sign Support after Test 417928-P5	28
17	Pendulum Bogie for Test 417928-P6	29
18	Slip Base Sign Support after Test 417928-P6	31
19	Details of Sign Support Installation	37
20	Slip Base Sign Support before Test 417929-P1	39
21	Pendulum Bogie for Test 417929-P1	41
22	After Impact Trajectory for Test 417929-P1	42
23	Slip Base Sign Support after Test 417929-P1	43
24	Summary of Results for Test 417929-P1	44
25	Slip Base Sign Support before Test 417929-P2	45
26	Pendulum Bogie for Test 417929-P2	47
27	Slip Base Sign Support after Test 417929-P2	48
28	Bolts and Locking Ring Damage after Test 417929-P2	49
29	Summary of Results for Test 417929-P2	50
30	Details of Test Installation for 417929-P3.	52
31	Slip Base Sign Support before Test 417929-P3	54
32	Pendulum Bogie after Test 417929-P3	55
33	After Impact Trajectory for Test 417929-P3	56
34	Slip Base Sign Support after Test 417929-P3	57
35	Summary of Results for Test 417929-P3	58
36	Details of Test Installation for 417929-P4	60
37	Slip Base Sign Support before Test 417929-P4	62
38	Pendulum Bogie for Test 417929-P4	63
39	After Impact Trajectory for Test 417929-P4	65
40	Slip Base Sign Support after Test 417929-P4	66
41	Bolts and Keeper Plate Damage after Test 417929-P4	67

LIST OF FIGURES (Continued)

Figure **Page**

42 Summary of Results for Test 417929-P4 68
43 Details of Installation for Test 417929-6. 71
44 Single Slip Base Steel Sign Support with Concrete Footing before Test 417929-6 73
45 Vehicle/Installation Geometrics for Test 417929-6 74
46 Vehicle before Test 417929-6 75
47 After Impact Trajectory for Test 417929-6 76
48 Installation after Test 417929-6 77
49 Damage to Plastic Sign Substrate 78
50 Separation of Plastic Sign Substrate. 79
51 Vehicle after Test 417929-6 81
52 Interior of Vehicle for Test 417929-6 82
53 Summary of Results for Test 417929-6, *NCHRP Report 350* Test 3-60 83
54 Details of Test Installation for 417929-7. 86
55 Single Slip Base Steel Sign Support with Concrete Footing before Test 417929-7 88
56 Vehicle/Installation Geometrics for Test 417929-7 89
57 Vehicle before Test 417929-7 90
58 After Impact Trajectory for Test 417929-7 92
59 Installation after Test 417929-7 93
60 Vehicle after Test 417929-7 94
61 Interior of Vehicle for Test 417929-7 95
62 Summary of Results for Test 417929-7, *NCHRP Report 350* Test 3-61 96
63 Details of Test Installation for 417929-8. 102
64 Poz-Loc Slip Base Sign Support before Test 417929-8 104
65 Vehicle/Installation Geometrics for Test 417929-8 106
66 Vehicle before Test 417929-8 107
67 After Impact Trajectory for Test 417929-8 108
68 Installation after Test 417929-8 109
69 Vehicle after Test 417929-8 110
70 Interior of Vehicle for Test 417929-8 111
71 Summary of Results for Test 417929-8, *NCHRP Report 350* Test 3-60 113
72 Details of Test Installation for 417929-9. 116
73 Poz-Loc Slip Base Sign Support before Test 417929-9 118
74 Vehicle/Installation Geometrics for Test 417929-9 119
75 Vehicle before Test 417929-9 120
76 After Impact Trajectory for Test 417929-9 122
77 Installation after Test 417929-9 123
78 Vehicle after Test 417929-9 124
79 Interior of Vehicle for Test 417929-9 125
80 Summary of Results for Test 417929-9, *NCHRP Report 350* Test 3-60 127

LIST OF FIGURES (Continued)

Figure **Page**

81 Configuration of Pendulum Nose and Honeycomb 140
82 Pendulum Longitudinal Accelerometer Trace for Test 417928-P1 145
83 Pendulum Longitudinal Accelerometer Trace for Test 417928-P2 146
84 Pendulum Longitudinal Accelerometer Trace for Test 417928-P3 147
85 Pendulum Longitudinal Accelerometer Trace for Test 417928-P4 148
86 Pendulum Longitudinal Accelerometer Trace for Test 417928-P5 149
87 Pendulum Longitudinal Accelerometer Trace for Test 417928-P6 150
88 Pendulum Longitudinal Accelerometer Trace for Test 417929-P1 151
89 Pendulum Longitudinal Accelerometer Trace for Test 417929-P2 152
90 Pendulum Longitudinal Accelerometer Trace for Test 417929-P3 153
91 Pendulum Longitudinal Accelerometer Trace for Test 417929-P4 154
92 Sequential Photographs for Test 417929-P1 (Perpendicular View) 155
93 Sequential Photographs for Test 417929-P2 (Perpendicular View) 156
94 Sequential Photographs for Test 417929-P3 (Perpendicular View) 157
95 Sequential Photographs for Test 417929-P4 (Perpendicular View) 158
96 Sequential Photographs for Test 417929-6 (Perpendicular and Frontal Views) 159
97 Sequential Photographs for Test 417929-7 (Perpendicular and Frontal Views) 161
98 Sequential Photographs for Test 417929-8 (Perpendicular and Frontal Views) 163
99 Sequential Photographs for Test 417929-9 (Perpendicular and Frontal Views) 165
100 Vehicle Properties for Tests 417929-6 and 417929-7 167
101 Vehicle Properties for Tests 417929-8 and 417929-9 170
102 Vehicular Angular Displacements for Test 417929-6 175
103 Vehicular Angular Displacements for Test 417929-7 176
104 Vehicular Angular Displacements for Test 417929-8 177
105 Vehicular Angular Displacements for Test 417929-9 178
106 Vehicle Longitudinal Accelerometer Trace for Test 417929-6 179
107 Vehicle Lateral Accelerometer Trace for Test 417929-6 180
108 Vehicle Vertical Accelerometer Trace for Test 417929-6 181
109 Vehicle Longitudinal Accelerometer Trace for Test 417929-7 182
110 Vehicle Lateral Accelerometer Trace for Test 417929-7 183
111 Vehicle Vertical Accelerometer Trace for Test 417929-7 184
112 Vehicle Longitudinal Accelerometer Trace for Test 417929-8 185
113 Vehicle Lateral Accelerometer Trace for Test 417929-8 186

LIST OF FIGURES (Continued)

Figure **Page**

114 Vehicle Vertical Accelerometer Trace for Test 417929-8 187
115 Vehicle Longitudinal Accelerometer Trace for Test 417929-9 188
116 Vehicle Lateral Accelerometer Trace for Test 417929-9 189
117 Vehicle Vertical Accelerometer Trace for Test 417929-9 190

LIST OF TABLES

Table		Page
1	Results of Pendulum Testing of Lifting Device Retrofit Alternatives	32
2	Performance Evaluation Summary for Test 417929-6, *NCHRP Report 350* Test 3-60.	84
3	Performance Evaluation Summary for Test 417929-7, *NCHRP Report 350* Test 3-61.	97
4	Performance Evaluation Summary for Test 417929-8, *NCHRP Report 350* Test 3-60.	114
5	Performance Evaluation Summary for Test 417929-9, *NCHRP Report 350* Test 3-60.	128
6	Exterior Crush Measurements for Test 417929-7	168
7	Occupant Compartment Measurements for Test 417929-7	169
8	Exterior Crush Measurements for Test 417929-8	171
9	Occupant Compartment Measurements for Tests 417929-8 and 417929-9	172
10	Exterior Crush Measurements for Test 417929-9.	173

I. INTRODUCTION

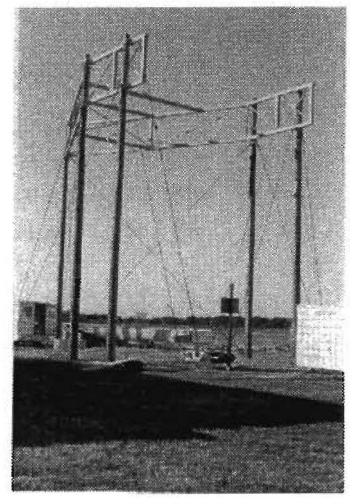
Through their research program, the Texas Department of Transportation (TxDOT) continues to be proactive in their ongoing commitment to providing safer roadsides for the traveling public. TxDOT-sponsored research has resulted in the development of many satisfactory sign support designs with demonstrated impact performance. The Department uses the results of in-service performance evaluations and feedback from field crews to continually assess the performance of these systems and identify areas in which design improvements can be realized in terms of cost, maintenance, or impact behavior.

This report summarizes the results of studies to investigate the effect of bolt torque on the impact performance of slip base sign supports and evaluate methods for retrofitting slip base stubs that incorporate a lifting ramp or cone. The research approach and testing methodologies followed for these studies are presented in Chapter II. The results of dynamic pendulum tests performed to evaluate lifting cone retrofit options for small, slip-base sign supports are presented in Chapter III. Chapter IV presents the results of dynamic pendulum tests and full-scale crash tests performed to determine the effect of different bolt torques on the activation and impact performance of small, slip base sign supports. A summary of findings and conclusions are presented in Chapter V, and implementation recommendations are presented in Chapter VI.

II. STUDY APPROACH

PENDULUM TEST FACILITY

Dynamic pendulum tests were used to investigate the effect of bolt torque on slip base activation and evaluate various methods for retrofitting older slip base stubs with lifting ramps or cones. These tests were performed at Texas Transportation Institute's (TTI) outdoor pendulum testing facility. The 820 kg pendulum bogie, which is built according to the specifications of the Federal Outdoor Impact Laboratory's (FOIL) pendulum, is shown in the adjacent photograph. Frontal crush of the ten-stage nose of the pendulum bogie simulates the crush of an actual vehicle. Cartridges of expendable aluminum honeycomb of differing densities are placed in a sliding nose assembly. A sketch of the honeycomb configuration used for the pendulum bogie is shown in figure 81 of Appendix A. A sweeper plate constructed of steel angles and plate is attached to the body of the pendulum with a ground clearance of 152 mm (6.0 in.) to replicate roughly an automobile's undercarriage. After a test, the honeycomb material is replaced and the bogie is reused.



Testing was performed in accordance with the guidelines presented in *National Cooperative Highway Research Program (NCHRP) Report 350*. Two uniaxial accelerometers were placed at the rear of the pendulum to measure longitudinal acceleration levels of the pendulum body. The measured acceleration levels were used to compute various measures of performance from which the crashworthiness of the lifting cone retrofit alternatives and different slip bolt torques could be assessed. The nominal impact speed used in the pendulum impacts was 35 km/h, which corresponds to the low-speed crash test recommended in *NCHRP Report 350* for the evaluation of breakaway devices. Additional details regarding the pendulum testing procedures followed in this study are presented in Appendix B.

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 an 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 evaluating the TxDOT slip base 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 203–305 mm (6–8 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.

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 of 35 km/h (21.7 mi/h) and an angle ranging from 0–20 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 of 100 km/h (62.1 mi/h) and an angle ranging from 0–20 degrees. The test is intended to evaluate vehicle and test article trajectory and occupant risk.

The crash test and data analysis procedures followed in this study were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in Appendix A.

EVALUATION CRITERIA

The crash tests performed as part of this study were evaluated in accordance with the criteria contained 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 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 (9.8 ft/s)	*5 (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 American Association of State Highway and Transportation Officials (AASHTO) *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,"*[1] states:

> *"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 to 60 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."*

III. EVALUATION OF LIFTING DEVICE RETROFIT

For many years, the TxDOT slip base design incorporated a lifting device on the lower base plate commonly referred to as a lifting ramp or lifting cone, depending on the fabrication method. The concept was first introduced in HP&R Study 2-10-68-146 to improve the impact performance of a 5 in. diameter sign support mounted on a multidirectional slip base. The purpose of the lifting device is to propel the sign support upward during impact to eliminate or reduce the severity of any secondary impacts of the sign or its support with the windshield or roof of the vehicle. The design originally consisted of three equally spaced triangular ramps inclined at a 30 degree angle as shown on the standard TxDOT sign mounting details for small roadside signs (SMD (1-3)-95). The standards were later revised to include a conical shape stamped or formed into the center of the lower triangular base plate. Because this lifting cone alternative was more cost effective than welding individual ramps, it saw widespread use throughout Texas.

During the development of a new triangular slip base system for TxDOT, it was determined that the lifting cone was unnecessary and, in some instances, detrimental to overall impact performance. Therefore, since the addition of lifting ramps and/or cones can significantly increase fabrication costs, the lifting cone was removed from the new slip base design.

This change in design created a need to develop retrofit alternatives that would enable existing slip base foundations to be utilized when repair or upgrading of a sign support is needed. The basic concept is to provide sufficient space between the upper and lower plates of the slip base so that sign supports utilizing the new slip base system can be installed on an existing foundation without interference from the lifting cone. Under TxDOT research project 7-3911 the impact performance of several options, including a series of stacked washers and various types of spacer rings, was investigated through dynamic pendulum tests of slip base sign support systems. While each option performed acceptably and did not impede the breakaway performance of the small sign support, a plastic spacer ring was considered to be the most cost-effective alternative and was subsequently subjected to full-scale crash testing to verify its impact performance.

Subsequent to the completion of project 7-3911, several additional spacer concepts were conceived for retrofitting slip base foundations with lifting devices. Based on the previous testing experience under project 7-3911, it was decided that the performance of the new spacer concepts could be adequately evaluated through dynamic pendulum testing.

A series of six full-scale pendulum tests was performed to investigate the effect of various lifting cone retrofit alternatives on the dynamic activation response of a triangular slip base small sign support. An 820 kg (1800 lb) pendulum was outfitted with a crushable honeycomb nose, which was calibrated to simulate the frontal crush stiffness of a small passenger car. Two uniaxial accelerometers were placed at the rear of the pendulum to measure longitudinal acceleration levels of the pendulum body. The measured acceleration levels were used to compute various measures of performance from which the crashworthiness of the lifting cone retrofit alternatives could be assessed. The nominal impact speed used in the pendulum impacts was 35 km/h (21.8 mi/h). Thus, the pendulum mass and impact speed were comparable to the low-speed crash test with a small car (Test Designation 3-60) that is recommended in *NCHRP Report 350* for the evaluation of breakaway devices.

TEST ARTICLES

The test installation for the pendulum test series conformed to a Type A sign mount as shown on TxDOT's standard sign mounting details (SMD) for small roadside signs. The support post was a 73 mm (2.875 in.) O.D. schedule 10 steel tube, which was cold formed from high strength steel sheet having a yield strength of 379 MPa (55,000 psi). This support was considered to be more discerning in terms of evaluating the activation of the slip base than the schedule 80 pipe due to the potential for the thin-wall support to collapse or buckle during impact if the activation forces are excessive. A 914 mm (36 in.) × 1220 mm (48 in.) × 16 mm (0.625 in.) thick plywood sign blank was attached to the schedule 10 post using two mounting clamps. The mounting height to the bottom of the sign blank was 2.1 m (7 ft).

The upper slip base assembly consists of an integral collar and triangular base plate that are cast from ASTM A536 Grade 65-45-12 ductile iron. The collar is formed by casting a 68.6 mm (2.7 in.) hole through the part perpendicular to the base plate and then machining the hole to a final diameter of 74.4 mm (2.93 in.). After machining, the base assembly is hot dip galvanized in accordance with ASTM A-153.

To erect the slip base assembly, the end of the schedule 10 support was inserted through the upper slip base casting. A 73 mm (2.875 in.) zinc plated split ring shaft collar was then hammered onto the end of the support post until the bottom edge of the post was flush with the bottom surface of the shaft collar. To prevent the casting from slipping off during an impact, the shaft collar was secured to the tube using a 9.5 mm (3/8 in.) diameter × 19 mm (0.75 in.) long bolt that was torqued to 61 N·m (45 ft·lb) using a torque wrench with an Allen head adaptor. The split shaft collar was recessed into a counterbore that is cast into the bottom of the triangular plate. The counterbore is designed such that the split shaft collar extends approximately 1.4 mm (0.055 in.) beyond the bottom of the upper base plate to provide separation between the slip plates. The clamping forces on the ring also help prevent rotation of the sign panel under service loads.

The lower slip base plate and a short section of a pipe stub were welded to a steel base plate, which was bolted to a steel reaction plate in the pendulum test area. The distance from the ground surface to the top face of the permanent lower triangular slip plate was 76 mm (3 in.). The slip base was oriented such that the direction of impact was perpendicular to one of the flat faces of the triangular plate. The first three tests utilized a slip base foundation with a 25 mm (1 in.) tall lifting cone stamped into the center of the triangular base plate. The last three tests used a slip base foundation with three equally spaced 25 mm (1 in.) tall lifting ramps welded in the center of the triangular base plate.

Various types of spacers were placed over the lifting device to provide the required separation between the upper and lower slip plates. A 30 ga. galvanized steel keeper plate was placed between the top of the spacer and the upper slip plate. The slip plates were then clamped together using three 15.9 mm (0.625 in.) diameter A325 bolts which were tightened to a prescribed torque of 51.5 N·m (38 ft·lb). High-strength washers were used under both the head and nut of each bolt.

Details of the sign support installation used to evaluate the different lifting cone retrofit options are shown in figure 1. Photographs of the typical sign support installation used in the pendulum tests are shown in figure 2.

PENDULUM TEST RESULTS

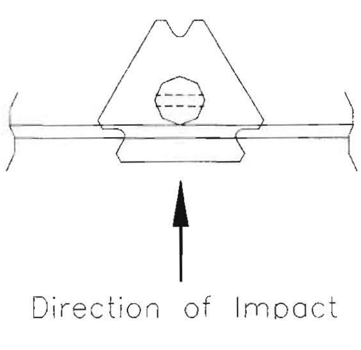
Test No. 417928-P1

In the first test, a molded polycarbonate plastic cap was placed over the lifting cone. The cap was fabricated by forming a 92 mm (3.63 in.) diameter × 25 mm (1 in.) deep hole in the bottom of a 137 mm (5.38 in.) diameter × 30 mm (1.19 in.) thick polyethylene disk. The top surface of the cap provided a flat, solid surface upon which the keeper plate could be placed. Photographs of the molded polyethylene cap and the completed test installation are shown in figure 3.

The pendulum bogie, shown in figure 4, impacted the sign support at a speed of 34.9 km/h (21.7 mi/h) at a height of 480 mm (18.9 in.). The upper section of the support slipped away, leaving the black polycarbonate cap over the lifting cone on the foundation slip base plate, as shown in figure 5. The keeper plate with one bolt still attached traveled 16 m (60.9 ft) and came to rest with the bottom end of the support. The sign panel was detached from and laying on top of the support. Analysis of the measured acceleration data indicated that no occupant contact occurred. The maximum 0.050 s longitudinal average acceleration was -1.1 g's, and the change in velocity was 0.76 m/s (2.51 ft/s). The longitudinal accelerometer trace for the test is shown in Appendix C, figure 82. Maximum crush of the honeycomb nose was 33 mm (1.3 in.).

Test No. 417928-P2

In the second pendulum test, split rings manufactured from high-density polyethylene (HDPE) were placed over the lifting cone. The split rings were fabricated by making a beveled cut through a thicker polyethylene ring. The 25 mm (1 in.) thick ring had an outside diameter of 140 mm (5.5 in.) and an inside diameter of 89 mm (3.5 in.). The bevel cut was made through the rind such that thickness of each of the two resulting rings was 6.4 mm (0.25 in.) on one edge and 19 mm (0.75 in.) on the other edge. The concept behind using the split rings rather than a single ring of uniform thickness was to permit a necessary leveling of the upper slip base plate in the field through rotation of one ring relative to the other. In practice, it was found that the rings were difficult to work with and use as a leveling aid. Photographs of the completed test installation incorporating the beveled split rings are shown in figure 6.



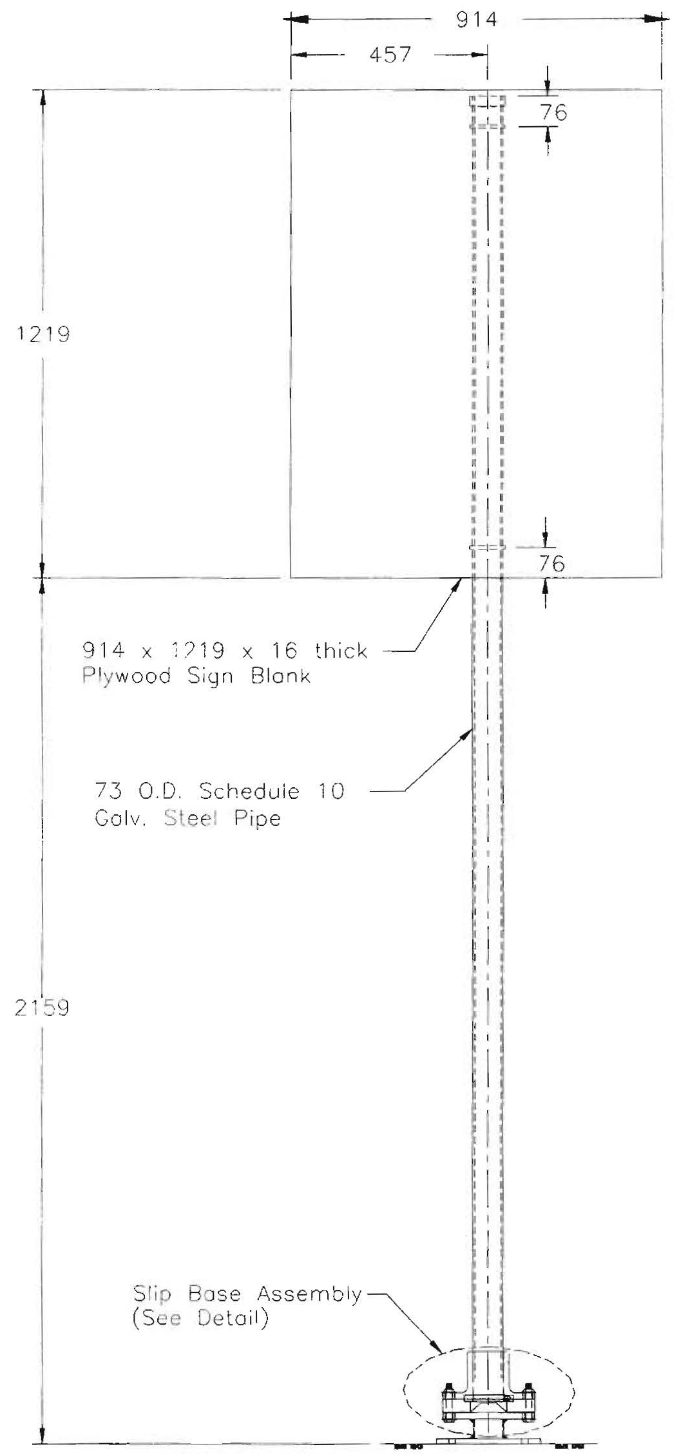


Figure 1. Details of the Sign Support Installation.

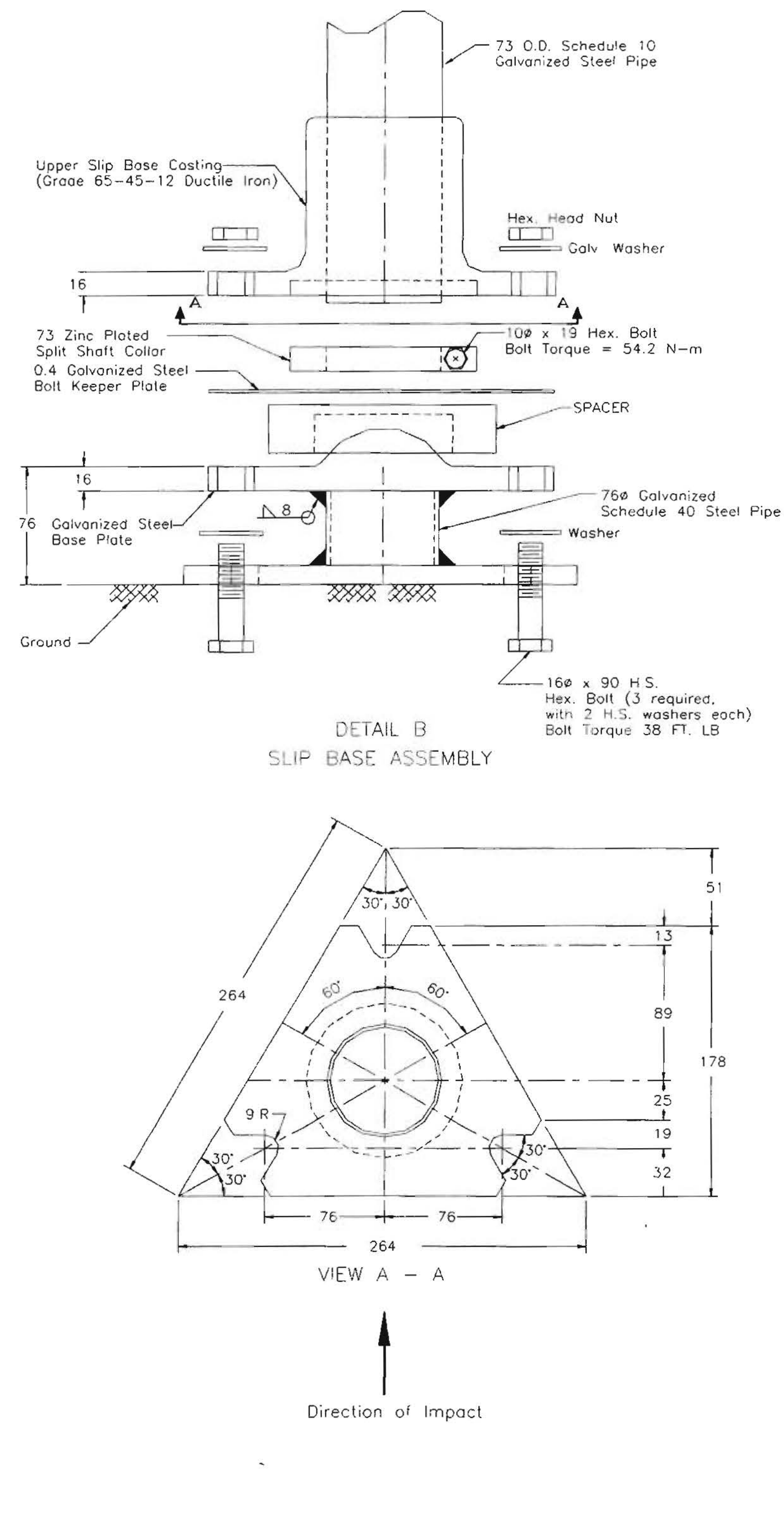
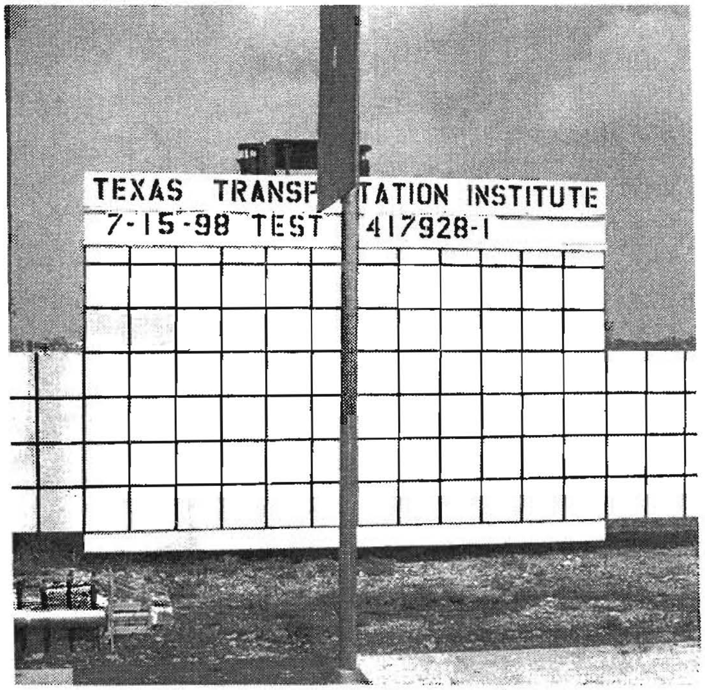


Figure 1. Details of the Sign Support Installation (Continued).



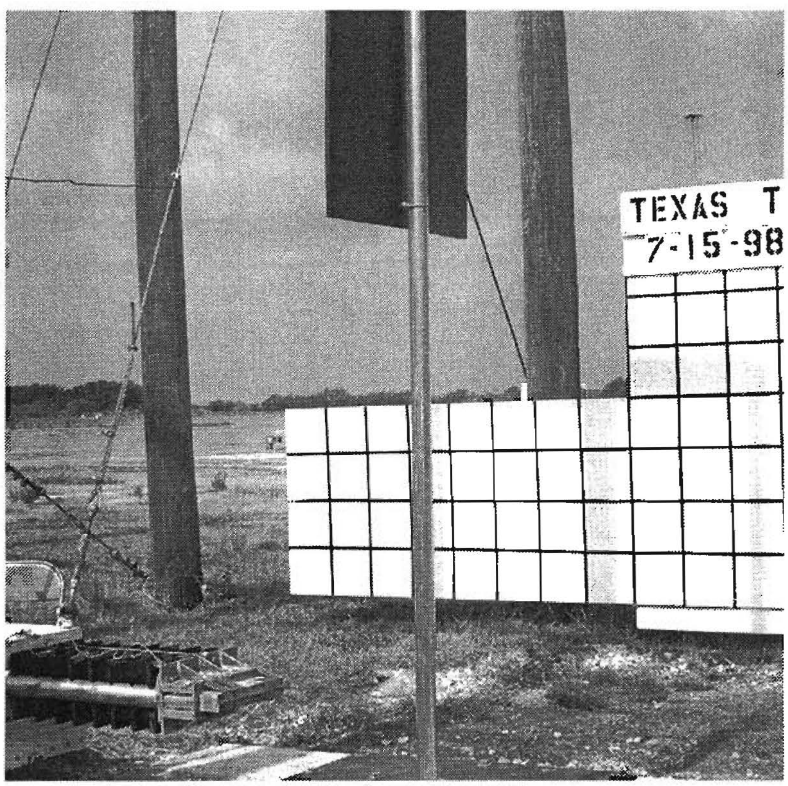


Figure 2. Photographs of Typical Sign Support Installation.

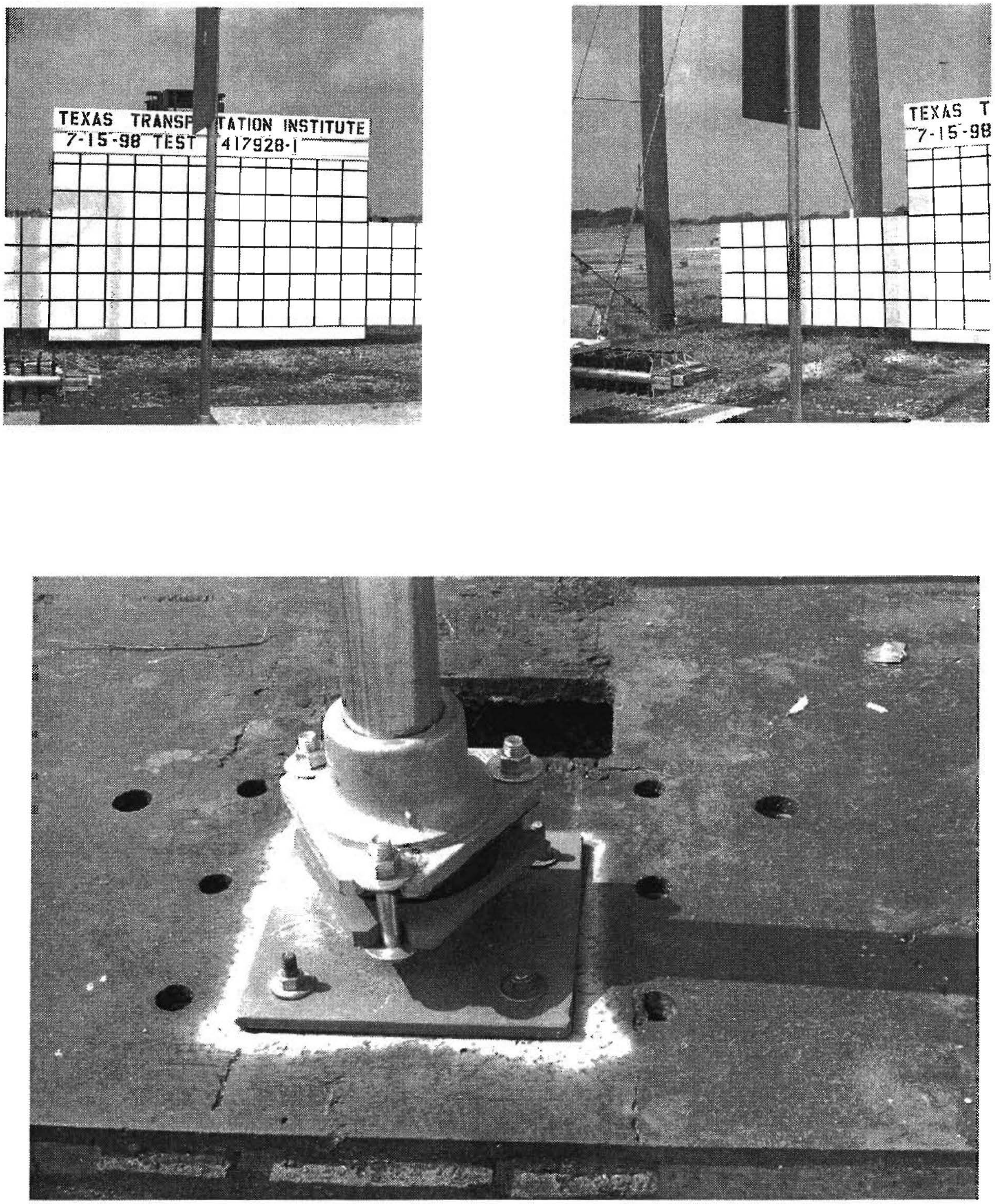
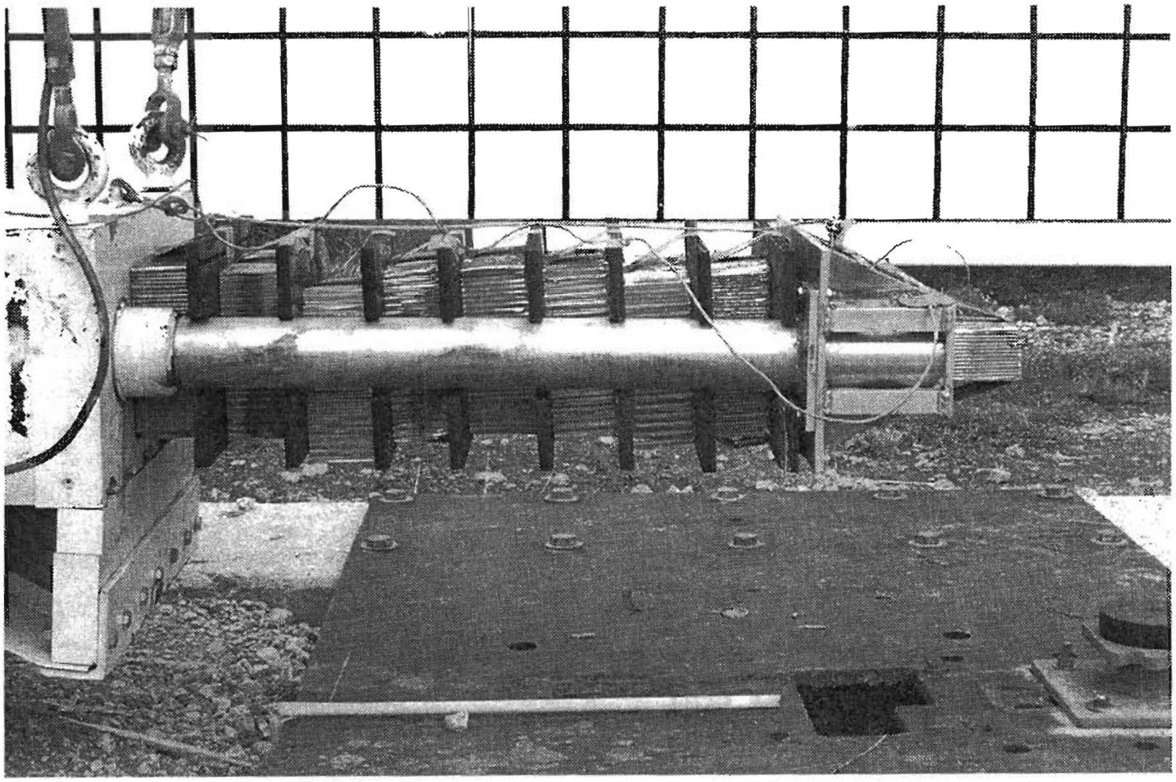
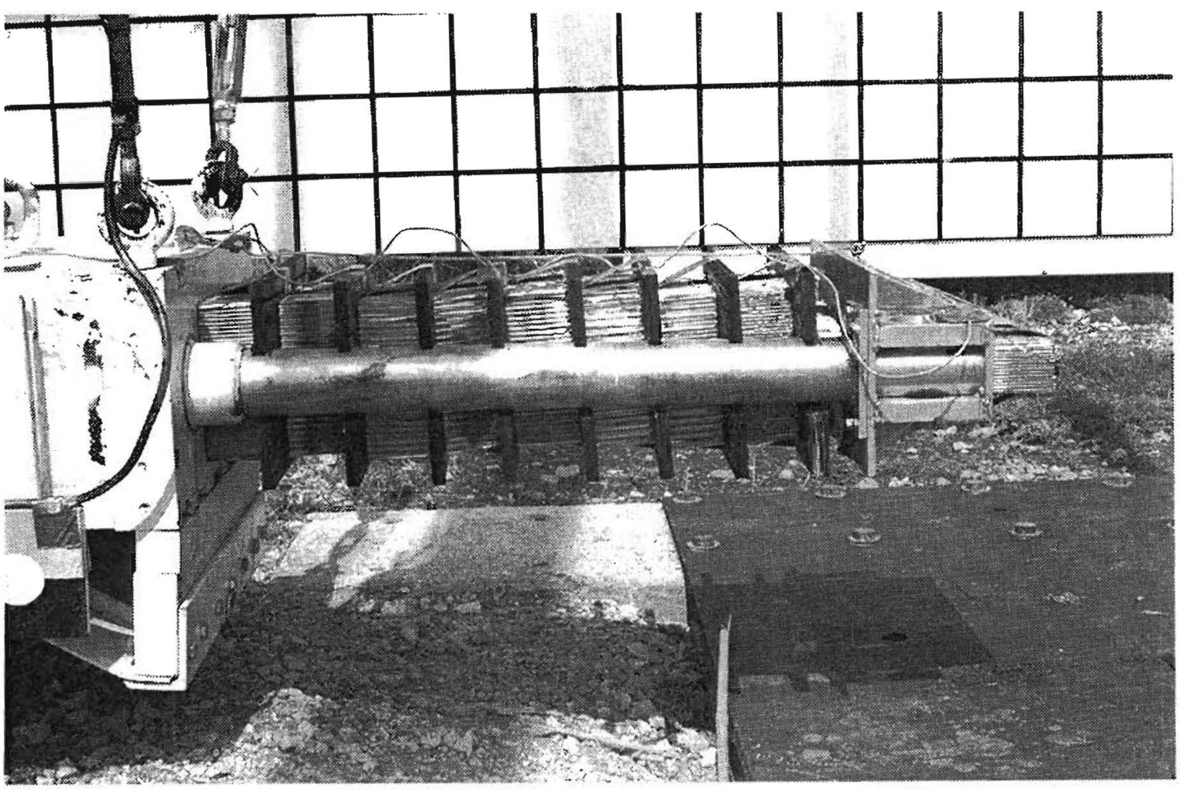


Figure 3. Slip Base Sign Support before Test 417928-P1.



(a) before test



(b) after test

Figure 4. Pendulum Bogie for Test 417928-P1.

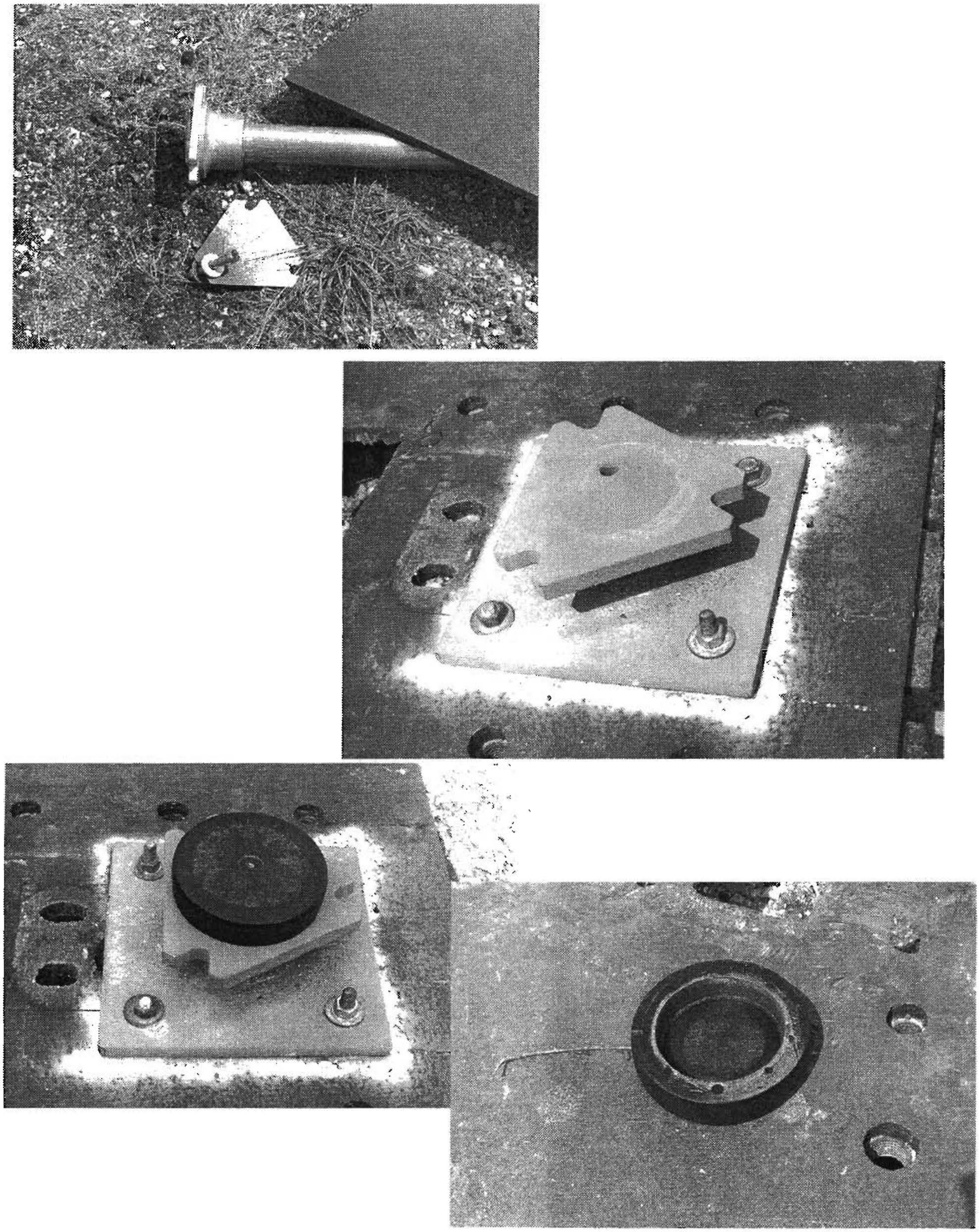


Figure 5. Slip Base Sign Support after Test 417928-P1.

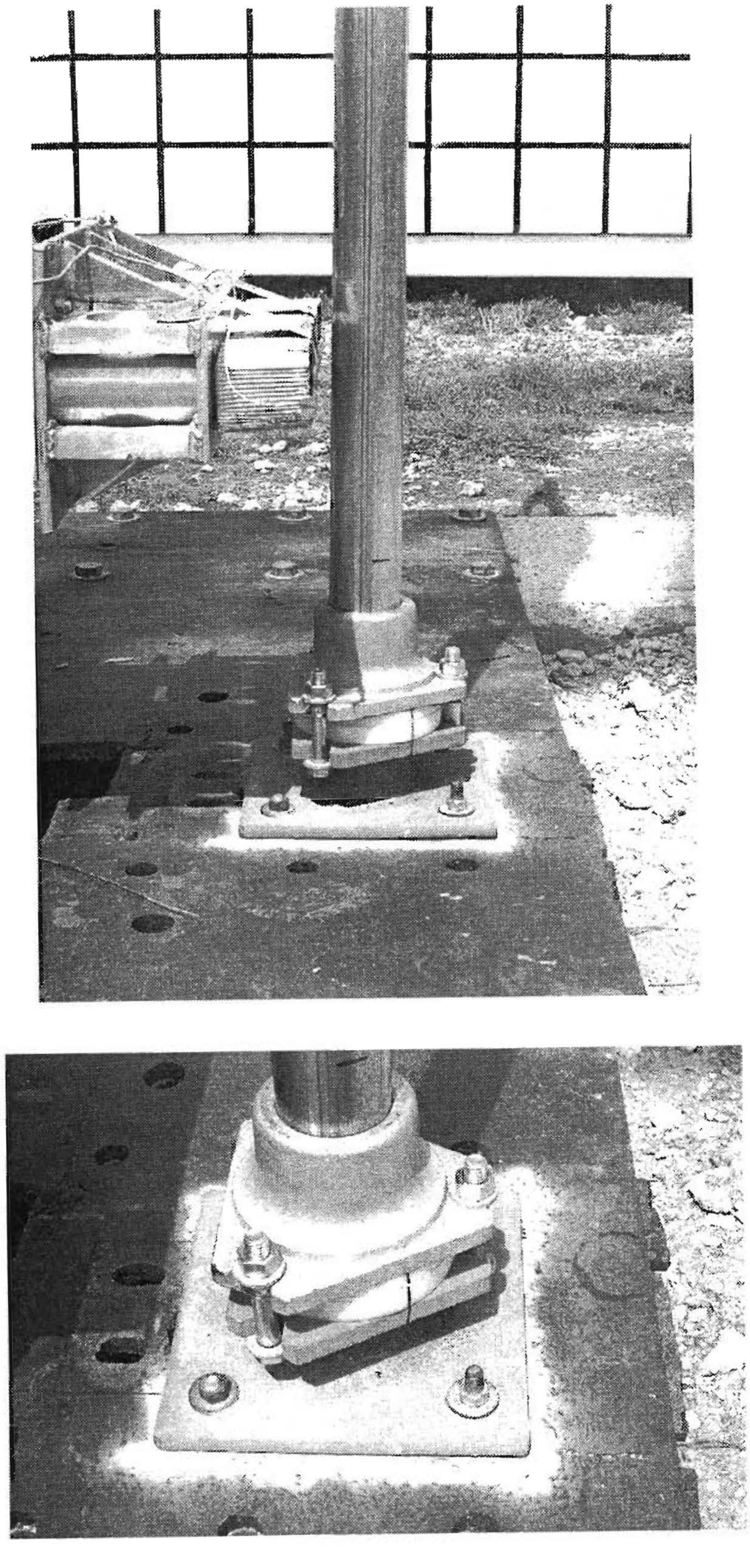


Figure 6. Slip Base Sign Support before Test 417928-P2.

The pendulum bogie, shown in figure 7, impacted the sign support at a speed of 35.1 km/h (21.8 mi/h) at a height of 480 mm (18.9 in.). The upper section of the support slipped away, leaving the bottom half of the split ring on the base and the upper half lying next to the base, as shown in figure 8. The keeper plate with one bolt still attached traveled 13.3 m (52.5 ft) and came to rest near the upper end of the support post. The bottom of the plywood sign panel was detached from the support, but the top end was still attached. A slight indention on the inside face of the upper split ring resulted from scraping the top of the lifting cone as the slip base activated. It was observed after the test that the shaft collar on the end of the support post had deformed the keeper plate inside the opening of the ring as the slip bolts were tightened to their specified torque. No occupant contact occurred. The maximum 0.050 s longitudinal average acceleration was -0.9 g, and the change in velocity was 0.75 m/s (2.45 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 83. Maximum crush of the honeycomb nose was 36 mm (1.4 in.).

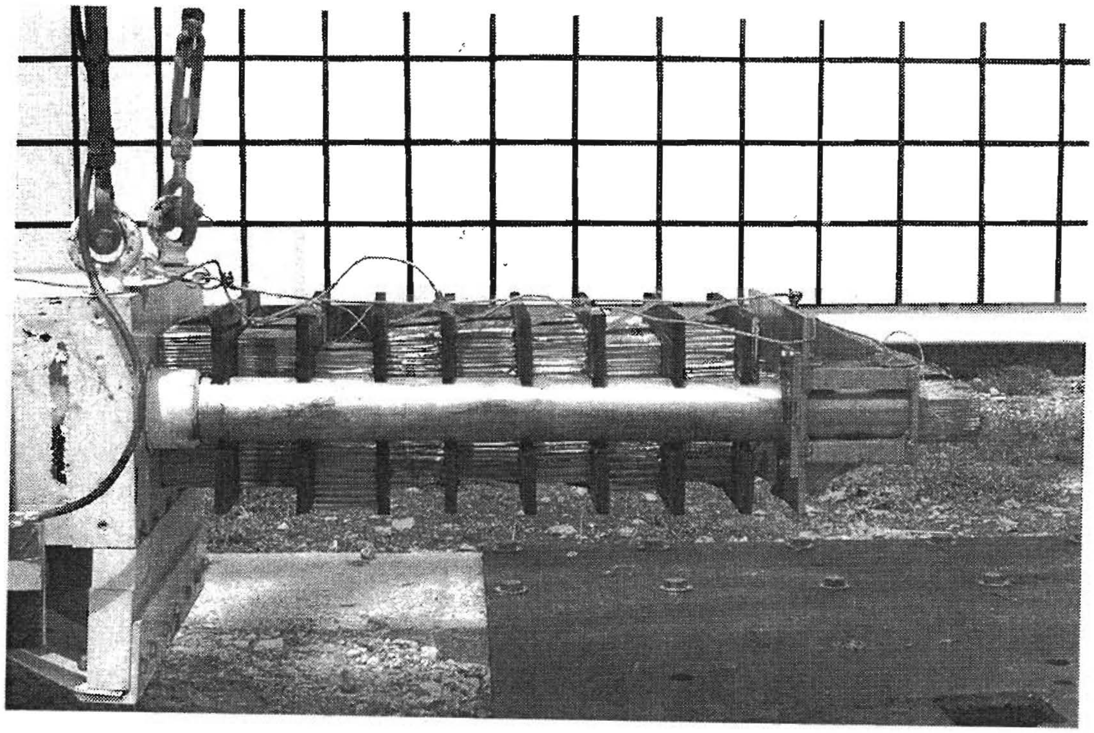
Test No. 417928-P3

The spacer used to retrofit the lifting cone in the third pendulum test was a 25 mm (1 in.) thick rubber ring. The outside of the rubber spacer was fabricated in a hexagon shape having side length of 89 mm (3.5 in.) and side-to-side dimension of 152 mm (6 in.). An 89 mm (3.5 in.) diameter circular hole was cut out of the center of the rubber spacer to form a ring that set over the lifting cone. The bolt keeper plate was then placed on top of the rubber spacer. Photographs of the molded polyethylene cap and the completed test installation are shown in figure 9.

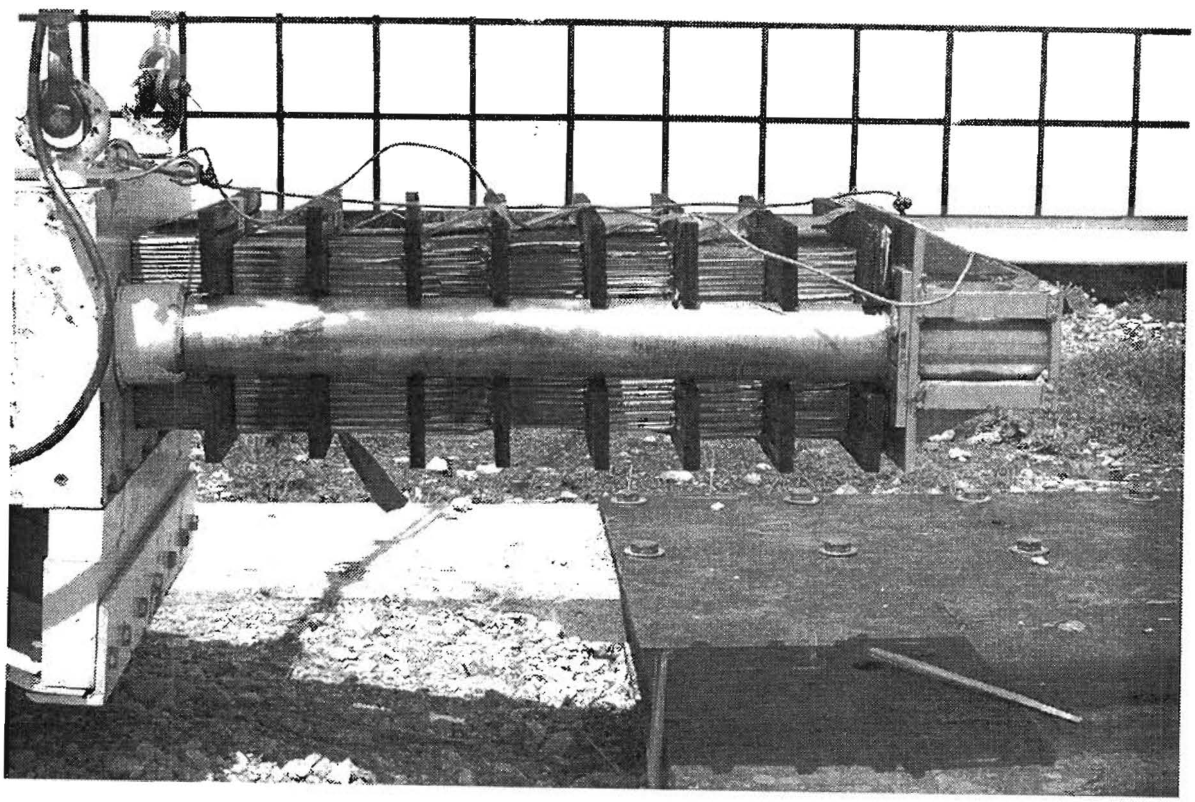
The pendulum bogie, shown in figure 10, impacted the sign support at a speed of 35.0 km/h (21.8 mi/h) at a height of 475 mm (18.7 in.). As shown in figure 11, the slip base activated as intended and the released support post rotated away from the pendulum leaving the rubber hexagon ring on the lower slip plate. The keeper plate traveled 3.8 m (12.5 ft) and the upper end of the support post came to rest 16.8 m (55.1 ft) downstream from the point of impact. All three bolts tore out of the keeper plate, and the keeper plate was deformed to the inside diameter of the ring. The sign panel was loose but still attached to the support. No occupant contact occurred. The maximum 0.050 s longitudinal average acceleration was -0.9 g's, and the change in velocity was 0.79 m/s (2.61 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 84. Maximum crush of the honeycomb nose was 33 mm (1.3 in.).

Test No. 417928-P4

The test installation for the fourth pendulum test was identical to that of the first pendulum test (Test No. 417928-P1) with the exception of the lifting device used on the lower slip base foundation plate. The base plate with the lifting cone that was used in the first three pendulum tests was replaced with one that had lifting ramps. This design consisted of three equally spaced 25 mm (1 in.) tall triangular ramps with a 30 degree incline angle welded in the center of the triangular base plate. Both the lifting cone and lifting ramps were widely implemented in the field over a number of years. The objective of the test was to verify that the



(a) before test



(b) after test

Figure 7. Pendulum Bogie for Test 417928-P2.

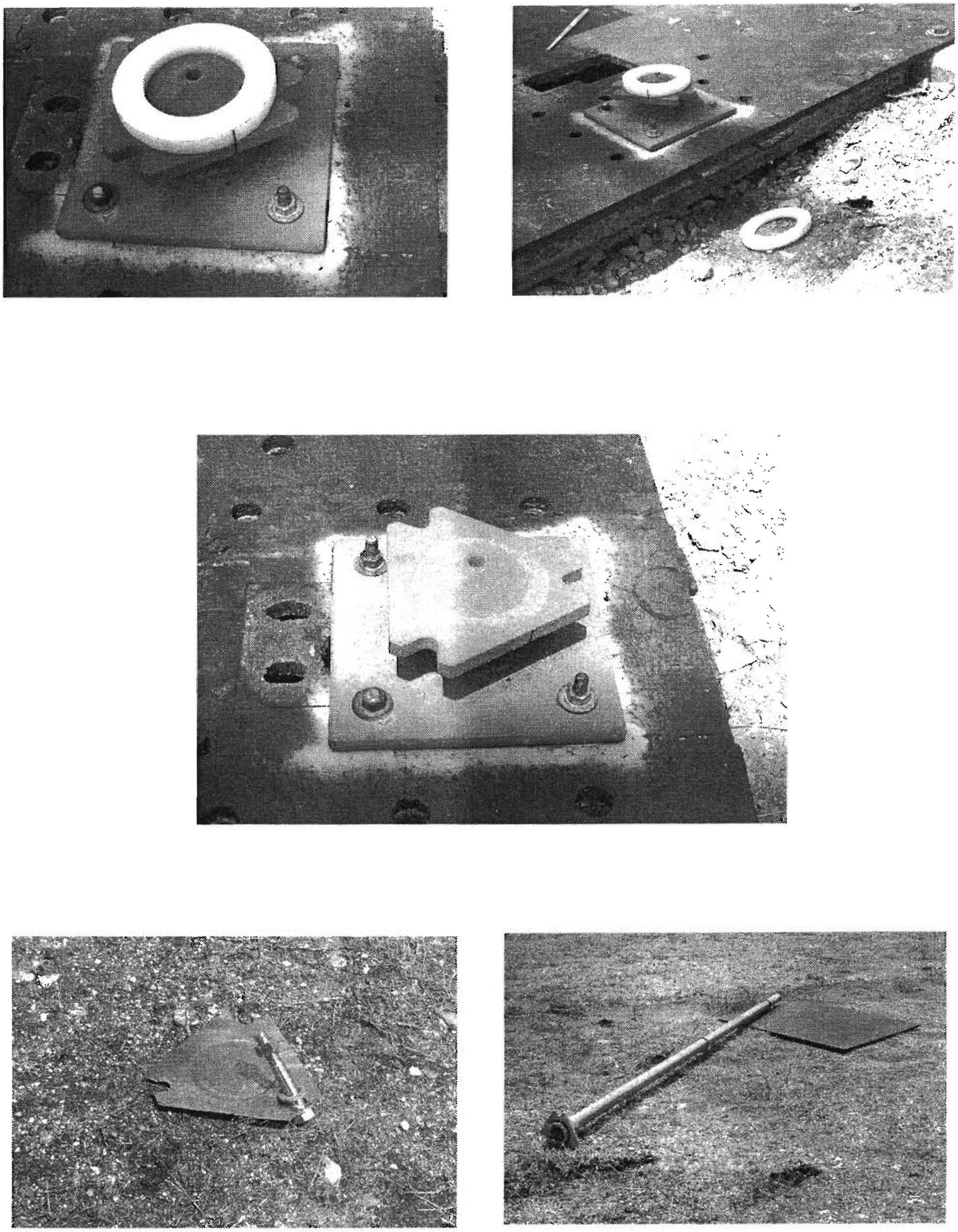


Figure 8. Slip Base Sign Support after Test 417928-P2.

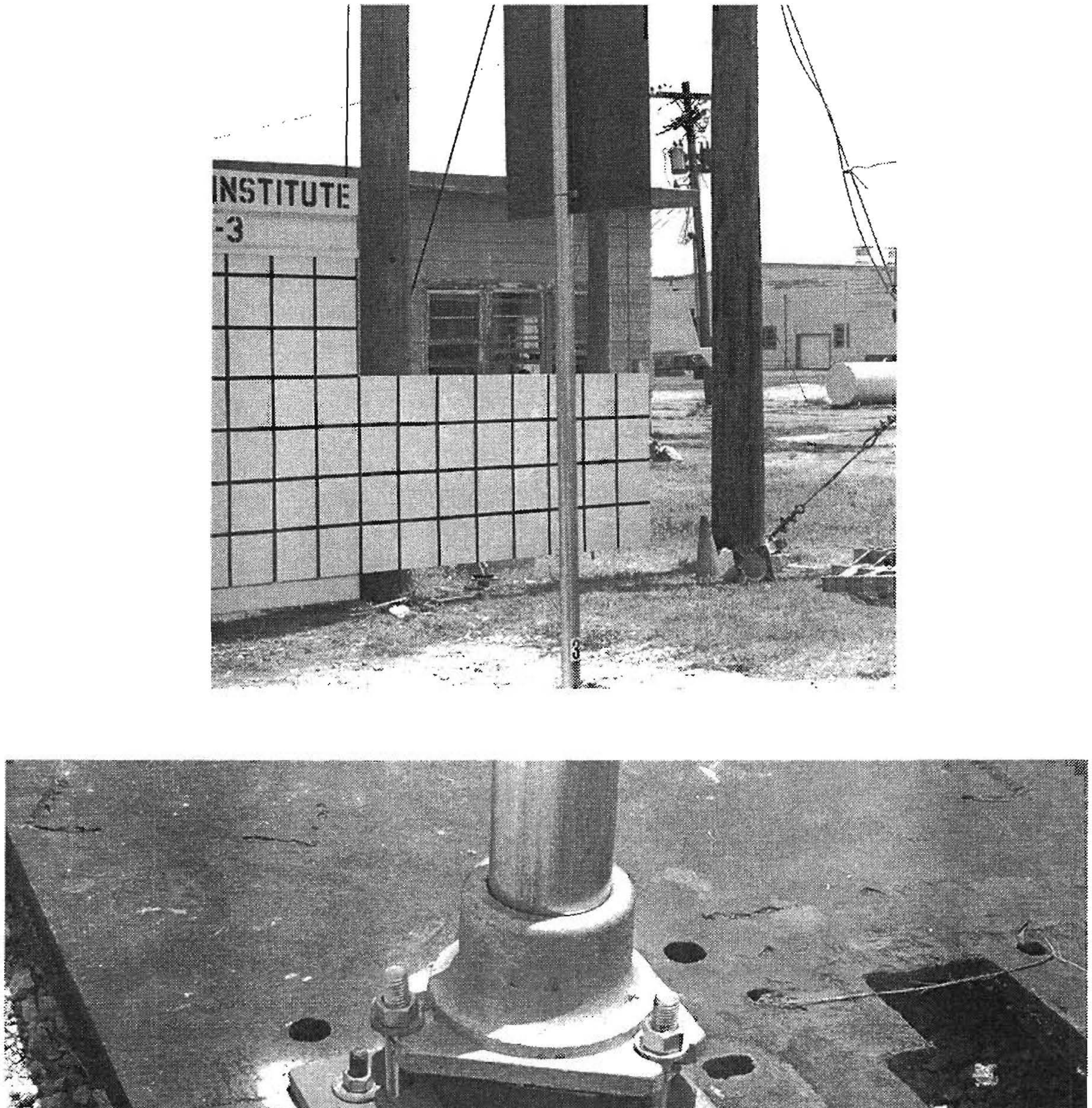


Figure 9. Slip Base Sign Support before Test 417928-P3.

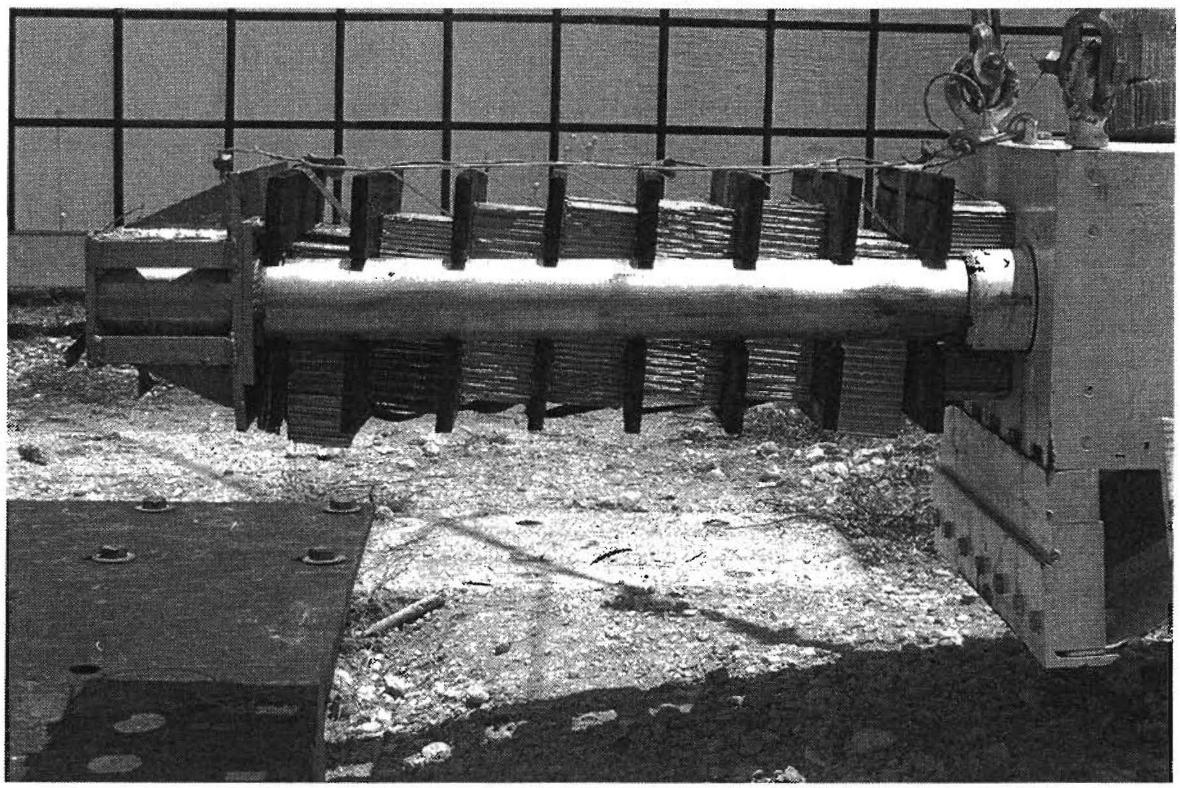


Figure 10. Pendulum Bogie after Test 417928-P3.

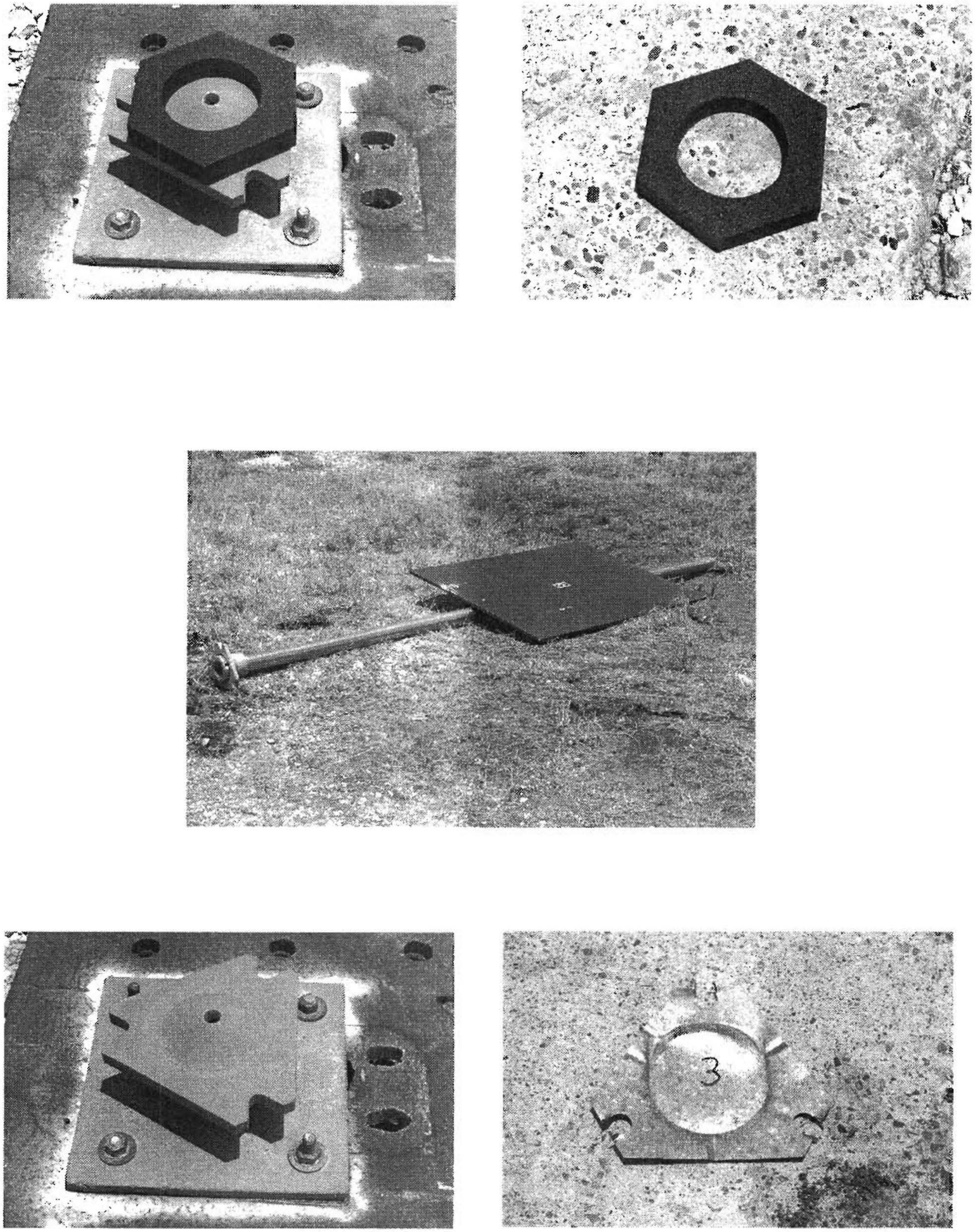


Figure 11. Slip Base Sign Support after Test 417928-P3.

geometry of the lifting ramps would not adversely affect the activation of the retrofit slip base system with the polycarbonate plastic spacer cap. A photograph of the slip base foundation plate with welded lifting ramps and the completed retrofit slip base installation are shown in figure 12.

The pendulum bogie, shown in figure 13, impacted the sign support at a speed of 34.9 km/h (21.7 mi/h) at a height of 475 mm (18.7 in.). The slip base activated as intended and the released support post rotated away from the pendulum. The black polycarbonate cap traveled 13.7 m (45.0 ft) downstream from the point of contact. The keeper plate came to rest 16 m (52.5 ft) down from the point of impact near the upper end of the support post. The bottom of the sign panel detached from the support post, but the upper end of the panel was still loosely attached. No occupant contact occurred. The maximum 0.050-s longitudinal average acceleration was -0.9 g, and the change in velocity was 0.79 m/s (2.61 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 85. Maximum crush of the honeycomb nose was 40 mm (1.6 in.). Photographs of the installation after the test are shown in figure 14.

Test No. 417928-P5

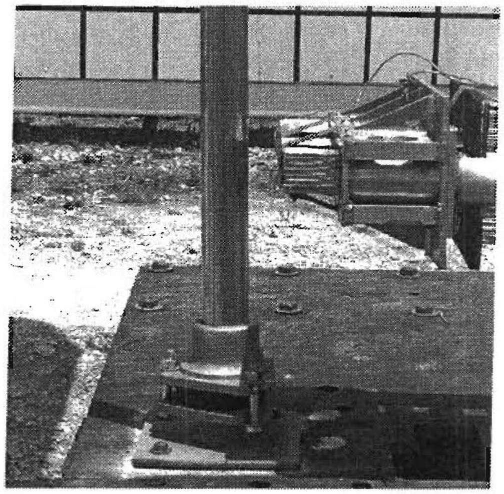
Since the beveled split rings evaluated in Test No. 417928-P2 were found to be impractical, they were not retested with the lifting ramps. Instead, the fifth pendulum test was conducted with a single high density polyethylene spacer ring. The black 25 mm (1 in.) thick ring had an outside diameter of 140 mm (5.5 in.) and an inside diameter of 89 mm (3.5 in.).

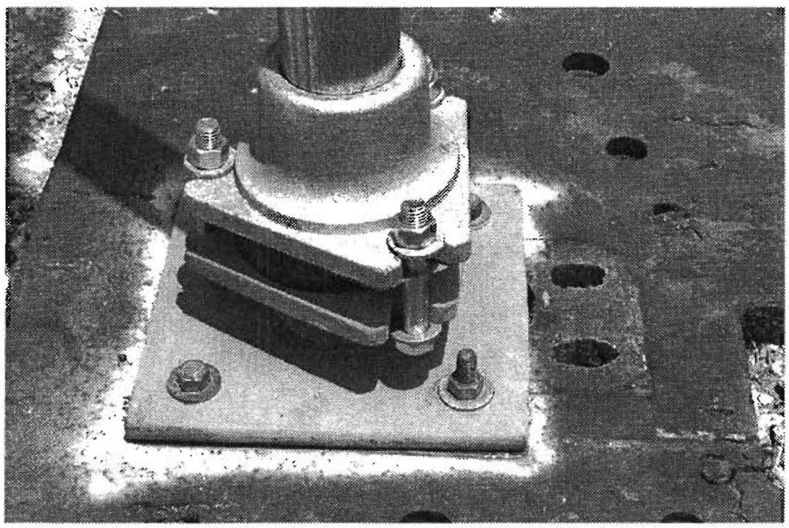
The pendulum bogie, shown in figure 15, impacted the sign support at a speed of 35.0 km/h (21.8 mi/h) at a height of 475 mm (18.7 in.). The slip base activated as intended and the released support post rotated away from the pendulum. The black HDPE ring was found 2.4 m (8.0 ft) downstream from the point of contact. The keeper plate came to rest 13.7 m (44.5 ft) down from the point of impact adjacent to the support post. Scrapes from the lifting ramp were observed on the inside face of the spacer ring, and the keeper plate was deformed to the inside diameter of the ring. The lower sign panel clamp failed, but the upper end of the panel was still loosely attached to the support. No occupant contact occurred. The maximum 0.050 s longitudinal average acceleration was -0.9 g, and the change in velocity was 0.72 m/s (2.36 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 86. Maximum crush of the honeycomb nose was 40 mm (1.6 in.). Photographs of the installation after the test are shown in figure 16.

Test No. 417928-P6

The test installation for the final pendulum test was identical to that used for the third pendulum test (Test No. 417928-P3) with the exception of the lifting device used on the lower slip base foundation plate. The base plate was configured with lifting ramps rather than a lifting cone. The objective of the test was to verify that the geometry of the lifting ramps would not adversely affect the activation of the retrofit slip base system with the rubber hexagon ring. The rear hole in the keeper plate tore out while the slip bolts were being tightened.

The pendulum bogie, shown in figure 17, impacted the sign support at a speed of 35.0 km/h (21.8 mi/h) at a height of 468 mm (18.4 in.). The slip base activated as intended and





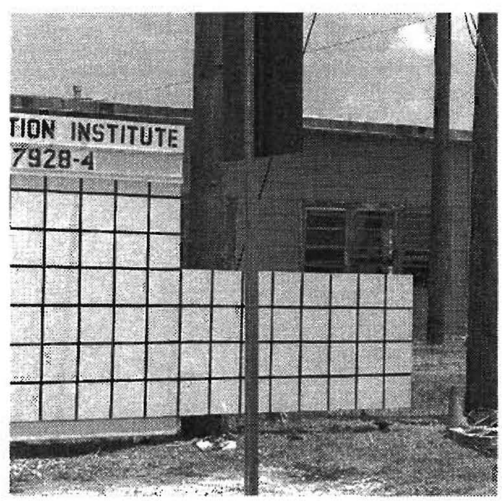
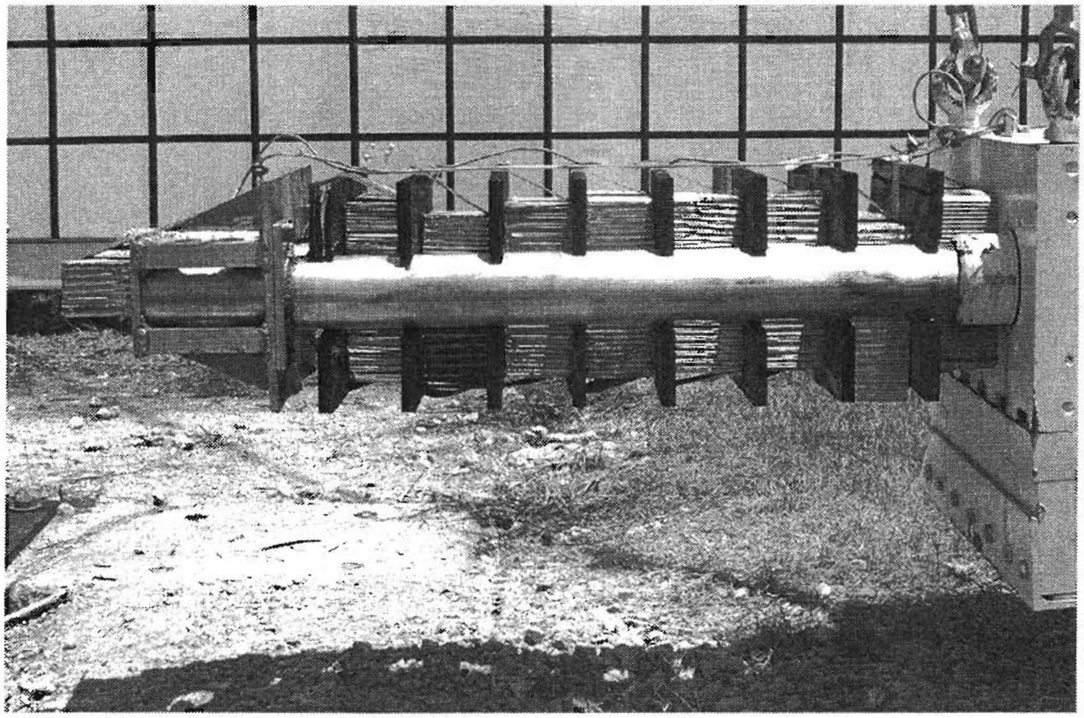
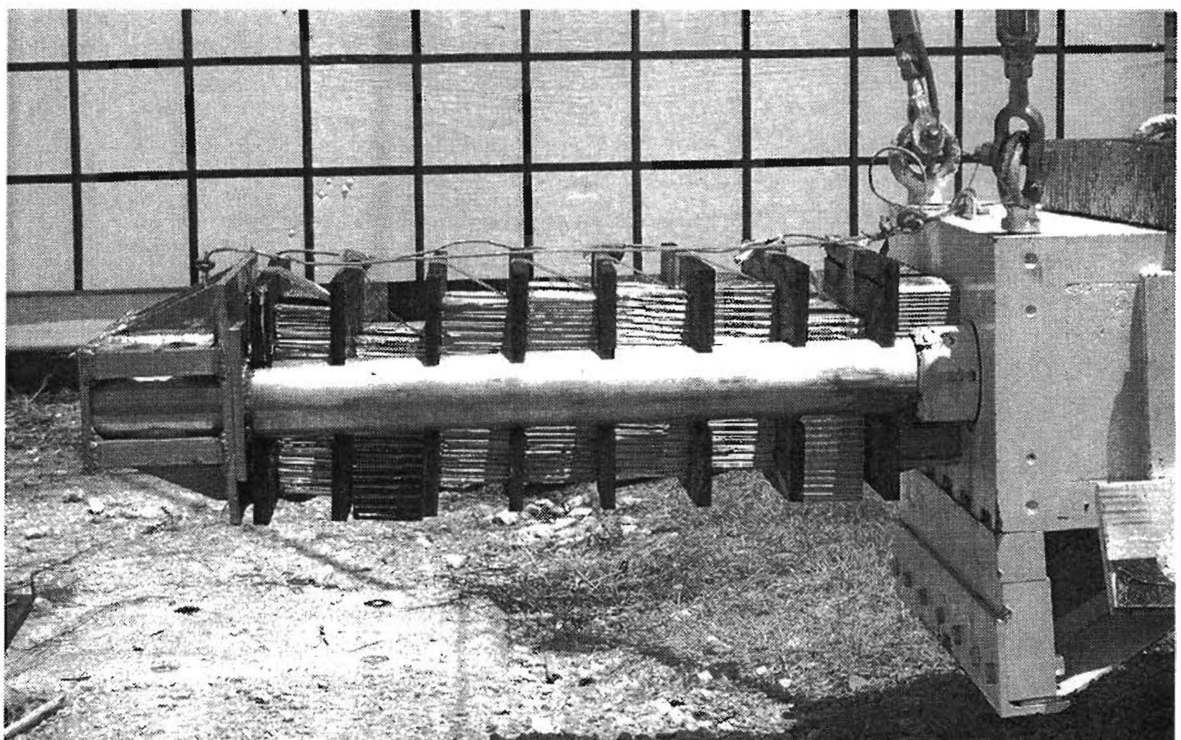


Figure 12. Slip Base Sign Support before Test 417928-P4.



(a) before test



(b) after test

Figure 13. Pendulum Bogie for Test 417928-P4.

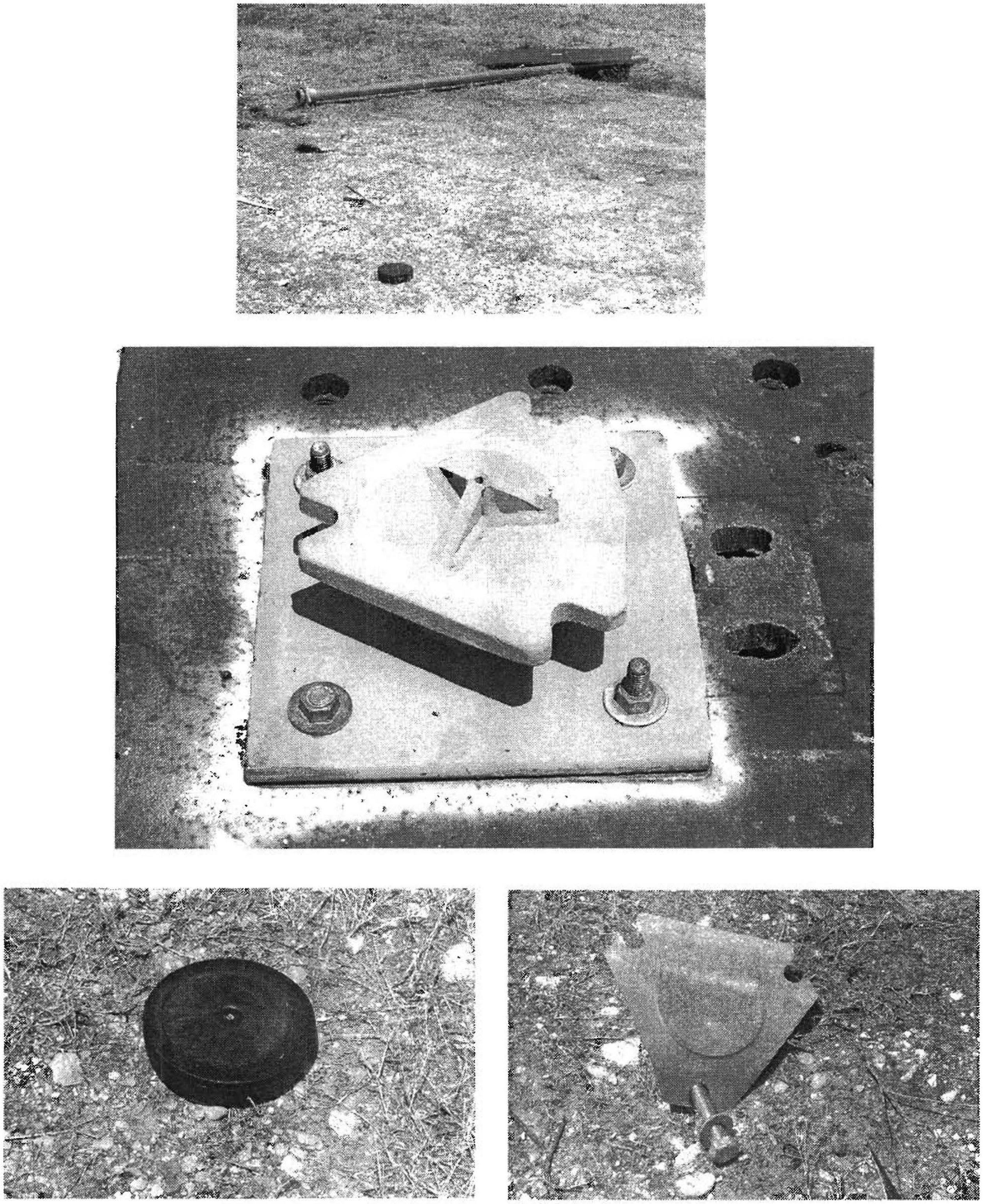


Figure 14. Slip Base Sign Support after Test 417928-P4.

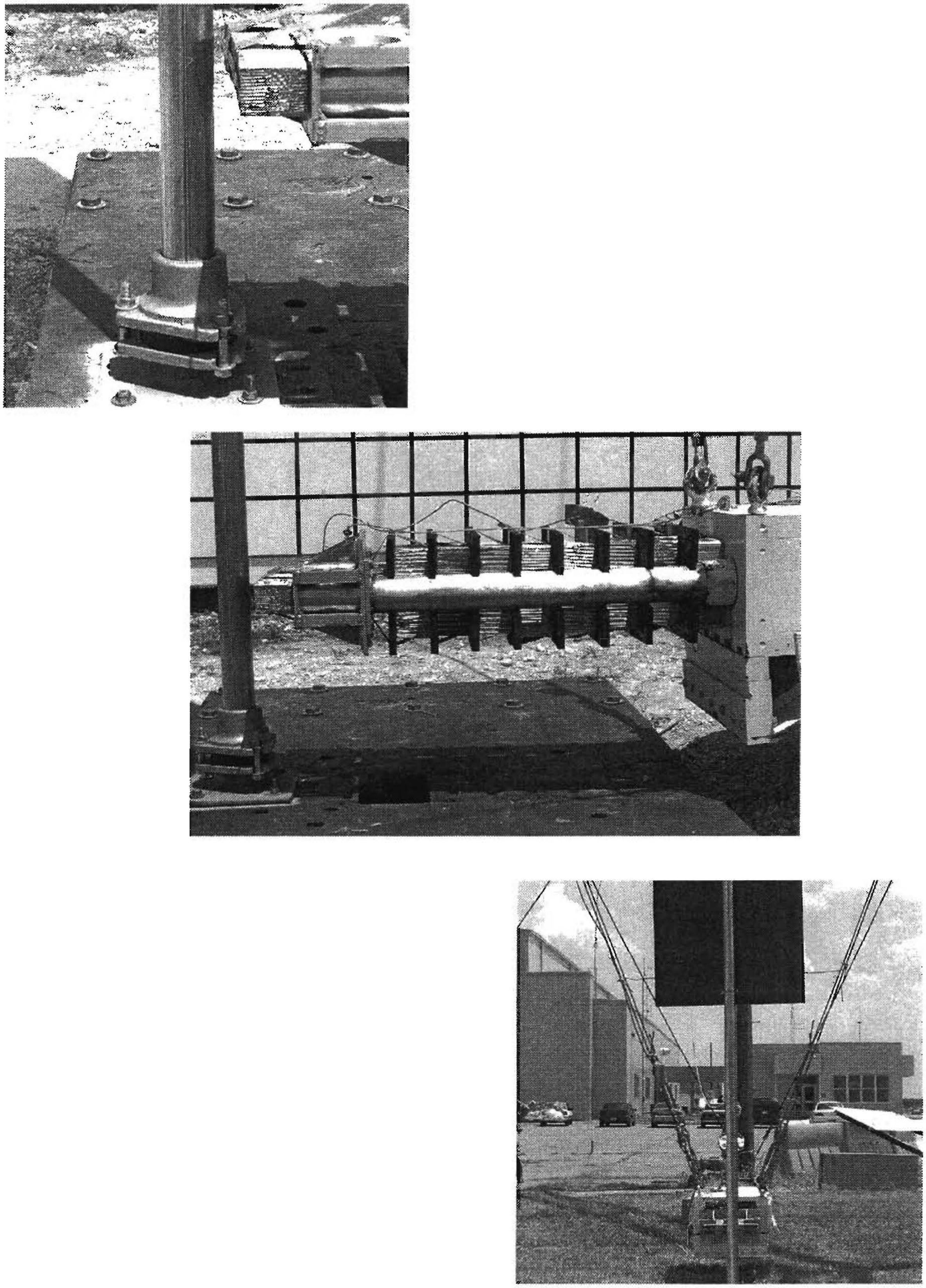


Figure 15. Pendulum Bogie for Test 417928-P5.

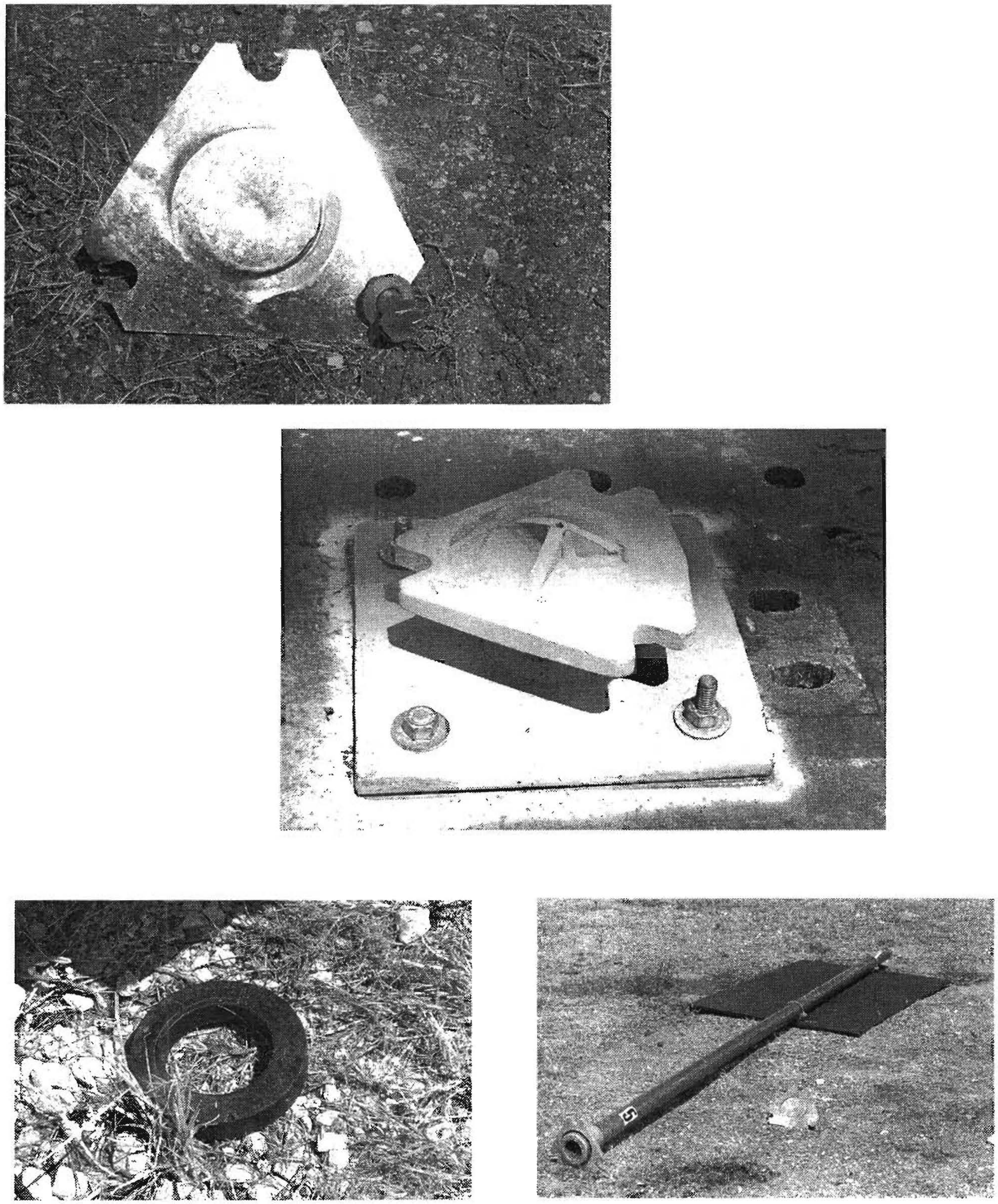
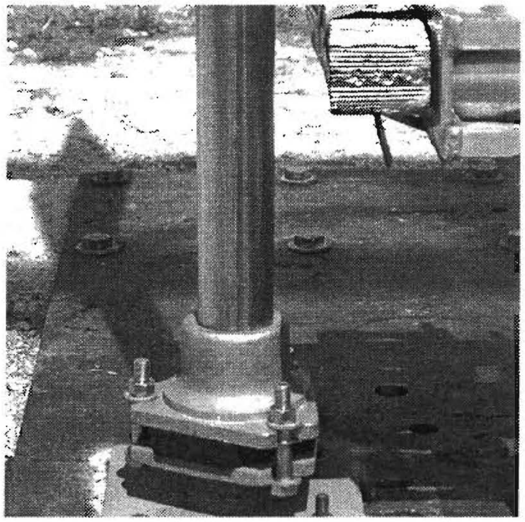
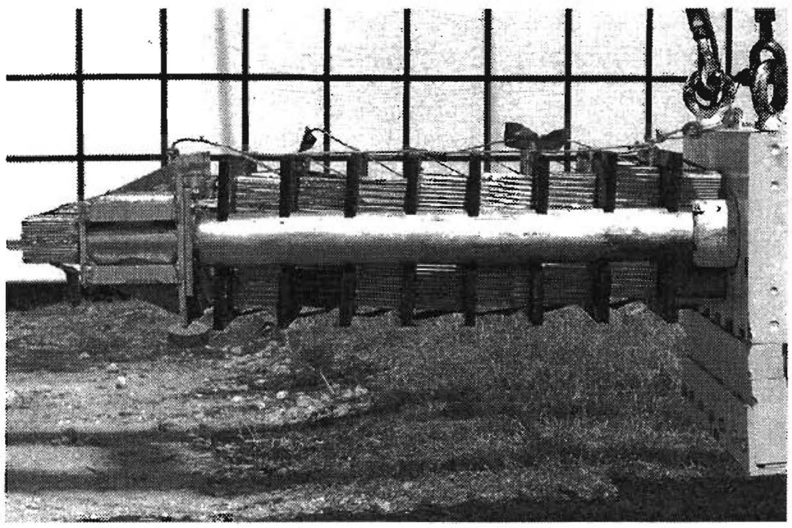


Figure 16. Slip Base Sign Support after Test 417928-P5.





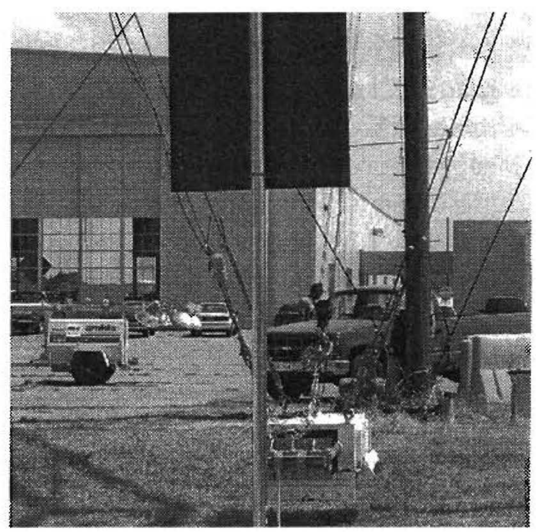


Figure 17. Pendulum Bogie for Test 417928-P6.

the released support post rotated away from the pendulum. The rubber hexagon ring and keeper plate traveled 2.6 m (8.5 ft) downstream from the point of impact, and the upper end of the support post came to rest 18.3 m (60.0 ft) downstream from its initial position. The sign panel was detached from the support. The keeper plate was deformed to the inside diameter of the rubber ring and had a small tear in the center. No occupant contact occurred. The maximum 0.050 s longitudinal average acceleration was -0.9 g's, and the change in velocity was 0.78 m/s (2.55 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 87. Maximum crush of the honeycomb nose was 41 mm (1.6 in.). Photographs of the installation after the test are shown in figure 18.

SUMMARY

The acceleration-time histories for these pendulum impacts are presented in Appendix C. These measured accelerations were used to compute various measures of performance including the force required to activate the slip base, the kinetic energy dissipated during impact, the occupant impact velocity (which is an occupant risk evaluation criterion specified in *NCHRP Report 350*), and total change in velocity of the pendulum. A summary of these results is shown in Table 1.

The results of the tests looked very similar to one another. There was no occupant contact computed for any of the tests. The change in velocity of the pendulum did not vary more than 10 percent. The 50 ms peak accelerations were very low and essentially the same for all tests.

These results indicate that all of the spacer options that were investigated offer acceptable crashworthiness when used to retrofit existing slip bases with lifting cones and lifting ramps. None of the spacer options had a discernable effect on the breakaway performance of the slip base. The acceleration levels and occupant impact velocities computed for the various spacer configurations were well below the desirable limits of *NCHRP Report 350.*

However, from a functional standpoint, several observations and recommendations can be made. The ring type spacers that have a hole through the entire thickness permit deformation of the bolt keeper plate. During the tightening of the slip bolts, the split ring collar on the end of the support post bears against the bolt keeper plate. These forces are sufficient to cause the keeper plate to deform inward and conform to the inside diameter of the ring. This behavior is analogous to the stamping or pressing of sheet metal. In one test (Test No. 417928-P6), the deformation of the keeper plate inside the ring was sufficient to permit the peaks of the lifting ramps to tear through the plate. Since the TxDOT slip base relies on the bearing or clamping forces on the split ring collar to resist rotation of the support post under wind load, any deformation of the keeper plate that might act to relieve these clamping forces is undesirable. It is therefore preferable that a spacer cap similar to that evaluated in Tests No. 417928-P1 and 417928-P3 be used rather than a spacer ring. The top of the cap provides a flat surface for the split ring collar to bear against during the tightening of the slip bolts.

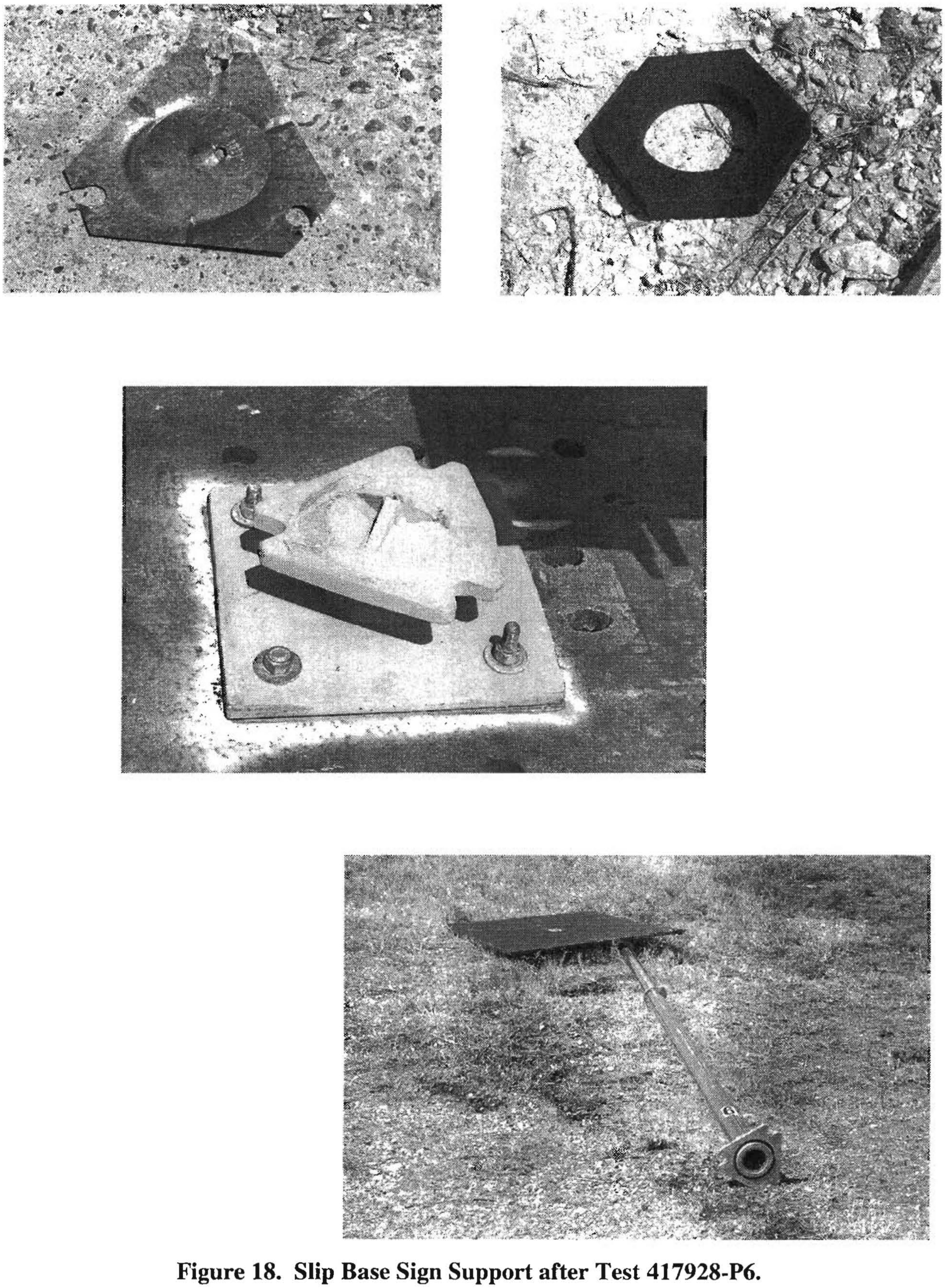


Figure 18. Slip Base Sign Support after Test 417928-P6.

Table 1. Results of Pendulum Testing of Lifting Device Retrofit Alternatives.

Test No.	Spacer Description	Lifting Device	Impact Speed, km/h (mi/h)	Max. Nose Crush, mm (in.)	Peak 50 ms Acceleration (g's)	Max. 10 ms Force, kN (kips)	Kinetic Energy, N·m (ft·lb)	Velocity Change, m/s (ft/s)
P1	Polycarbonate Cap	Stamped Cone	34.9 (21.7)	33 (1.3)	-1.1	21.35 (4.80)	81.6 (60.2)	0.76 (2.5)
P2	Split HDPE Rings	Stamped Cone	35.1 (21.8)	36 (1.4)	-0.9	17.21 (3.87)	72.9 (53.8)	0.75 (2.5)
P3	Rubber Hexagon Ring	Stamped Cone	35.0 (21.7)	33 (1.3)	-0.9	20.64 (4.64)	85.4 (63.0)	0.79 (2.6)
P4	Polycarbonate Cap	Welded Ramps	34.9 (21.7)	40 (1.6)	-0.9	20.55 (4.62)	99.0 (73.0)	0.79 (2.6)
P5	HDPE Ring	Welded Ramps	35.0 (21.7)	40 (1.6)	-0.9	18.82 (4.23)	86.8 (64.0)	0.72 (2.4)
P6	Rubber Hexagon Ring	Welded Ramps	35.0 (21.7)	41 (1.6)	-0.9	21.00 (4.72)	91.1 (67.2)	0.78 (2.6)

Although the round cap that was evaluated in the pendulum test program performed acceptably, consideration should be given to the use of a triangular-shaped cap that matches the geometry of the slip base plate. The hole molded into the center of the cap would remain unchanged. However, the triangular configuration would provide support for the corners of keeper plate and slip base plates and should minimize the potential for rotation of upper slip plate during tightening of the slip bolts. The additional cost of the cap associated with providing the triangular shape should be minimal for molded product.

In regard to material selection, it is recommended that the cap be molded or fabricated from polycarbonate or acrylonitrile-butadiene-styrene (ABS) plastic. The compressibility of a rubber spacer cap could permit deformation of the keeper plate or relaxation of the clamping force between the slip base plates. Since the TxDOT slip base relies on the bearing or clamping forces on the split ring collar to resist rotation of the support post under wind load, either of these behaviors could potentially permit sign panel rotation. Additionally, if the bolt tension or clamping force is relaxed, it could result in greater incidence of sign post blow downs under cyclical loads. Although HDPE provides a better option than rubber, it is a softer plastic than polycarbonate or ABS and is more susceptible to gouging or damage during an impact and may be more susceptible to creep relaxation during long periods of high temperature.

IV. EVALUATION OF BOLT TORQUE

By design, the slip bolts in a slip base sign support are intended to "slip" or release during impact thus permitting relative motion of the two base plates they connect. The activation force for the slip base must be maintained at a level that will result in acceptable deceleration and velocity change of an impacting vehicle. Additionally, the activation force of the slip base applied at bumper level should not exceed the flexural capacity of the support post. If the flexural capacity of the support post is exceeded, the resultant bending deformation of the support post could prevent proper activation and release of the slip base.

However, although a lower amount of bolt tension or torque is theoretically desirable from a breakaway standpoint, it is counterproductive in terms of resisting service loads. The slip bolts must be retained in proper position within their slots to resist wind loads applied to the sign. There have been reports of slip base sign installations blowing down in regions subject to high winds. Such behavior is often precipitated by the slip bolts "walking" out of their slots when subjected to cyclical wind loads that vary the amount of tension in the bolts. Although a 30-gauge bolt keeper plate is used to keep the slip bolts in position, this thin gauge plate readily tears out and in some cases is not sufficient for preventing displacement of the bolts. The higher the bolt tension, the less likely the bolts will "walk" out of position.

The amount of tension in the slip bolts and, hence, the activation force of the slip base is controlled by the amount of torque applied to the bolts. The TxDOT sign mounting detail standards specify a slip bolt torque of 51.5 N·m (38 ft·lb). The use of a higher bolt torque is desired to increase the ability to withstand cyclical service loads and reduce the occurrence of blow down of small slip base sign support installations without adversely affecting impact performance. This issue was investigated through dynamic pendulum testing and full-scale vehicle crash testing as described below.

PENDULUM TESTS

The effect of bolt torque on the dynamic breakaway response of slip base small sign supports was initially investigated through a series of four full-scale pendulum tests. The 842 kg pendulum was outfitted with a crushable honeycomb nose, which was calibrated to simulate the frontal crush stiffness of a small passenger car. Two uniaxial accelerometers were placed at the rear of the pendulum to measure longitudinal acceleration levels of the pendulum body. The measured acceleration levels were used to compute various measures of performance from which a comparative analysis of the effect of keeper plate thickness could be conducted. The nominal impact speed for the pendulum impacts, which is controlled by the height at which the pendulum is released, was 35 km/h (21.8 mi/h). Thus, the pendulum mass and impact speed were comparable to the low-speed crash test with a small car (Test Designation 3-60), which is recommended in *NCHRP Report 350* for the evaluation of breakaway devices. Additional details regarding the pendulum testing procedures are presented in Appendix A.

Test No. 417929-P1

Test Article

The test installation for the first pendulum test in the bolt torque series conformed to a Type A sign mount as shown on TxDOT's standard sign mounting details for small roadside signs. The support post was a 73 mm (2.875 in.) O.D. schedule 10 steel tube, which was cold formed from high strength steel sheet having a yield strength of 379 MPa (55,000 psi). This support was considered to be more discerning in terms of evaluating the activation of the slip base than the schedule 80 pipe due to the potential for the thin-wall support to collapse or buckle during impact if the activation forces are excessive. A 914 mm (36 in.) × 1220 mm (48 in.) × 16 mm (0.625 in.) thick plywood sign blank was attached to the schedule 10 post using two mounting clamps. The mounting height to the bottom of the sign blank was 2.1 m (7 ft).

The upper slip base assembly consists of an integral collar and triangular base plate that are cast from ASTM A536 Grade 65-45-12 ductile iron. The collar is formed by casting a 68.6 mm (2.7 in.) hole through the part perpendicular to the base plate and then machining the hole to a final diameter of 74.4 mm (2.93 in.). After machining, the base assembly is hot dip galvanized in accordance with ASTM A-153.

To erect the slip base assembly, the end of the schedule 10 support was inserted through the upper slip base casting. A 73 mm (2.875 in.) zinc-plated, split-ring shaft collar was then hammered onto the end of the support post until the bottom edge of the post was flush with the bottom surface of the shaft collar. To prevent the casting from slipping off during an impact, the shaft collar was secured to the tube using a 9.5 mm (3/8 in.) diameter × 19 mm (0.75 in.) long bolt that was torqued to 61 N·m (45 ft·lb) using a torque wrench with an Allen head adaptor. The split shaft collar was recessed into a counterbore that is cast into the bottom of the triangular plate. The counterbore is designed such that the split shaft collar extends approximately 1.4 mm (0.055 in.) beyond the bottom of the upper base plate to provide separation between the slip plates. The clamping forces on the ring also help prevent rotation of the sign panel under service loads.

A flat lower slip base plate and a short section of a pipe stub were welded to a steel base plate, which was bolted to a steel reaction plate in the pendulum test area. The distance from the ground surface to the top face of the permanent lower triangular slip plate was 76 mm (3 in.). The slip base was oriented such that the direction of impact was perpendicular to one of the flat faces of the triangular plate. A 30 ga. galvanized steel keeper plate was placed between the upper and lower slip plates. The slip plates were then clamped together using three 15.9 mm (0.625 in.) diameter A325 bolts with high-strength washers under both the head and nut of each bolt. The slip bolts were tightened to a torque of 209 N·m (154 ft·lb), which created tensile loads equivalent to the proof load 15.9 mm (0.625 in.) diameter A325 bolts.

Details of the sign support installation used for this pendulum test are shown in figure 19. Photographs of the completed sign support installation are shown in figure 20.

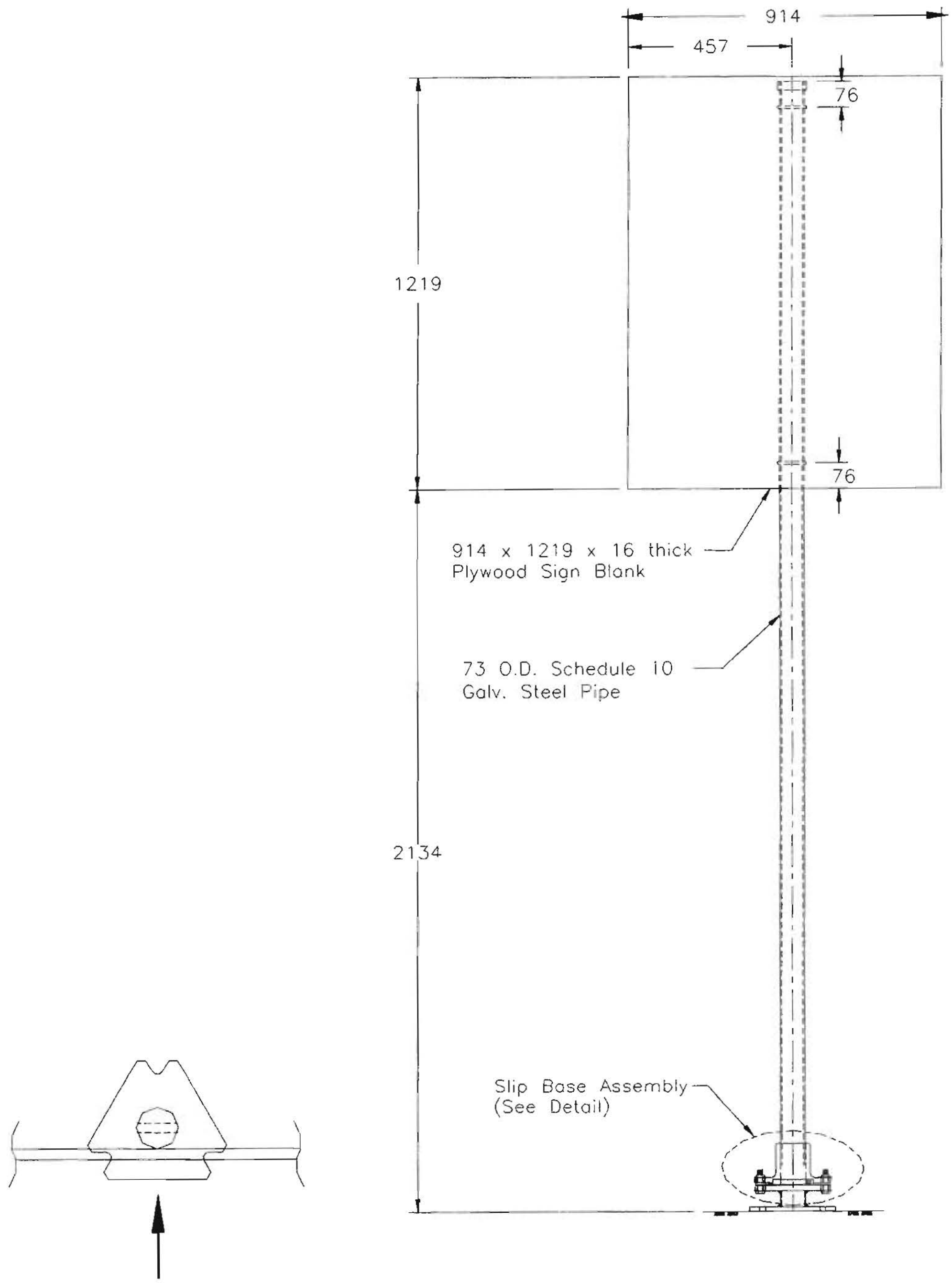


Figure 19. Details of Sign Support Installation.

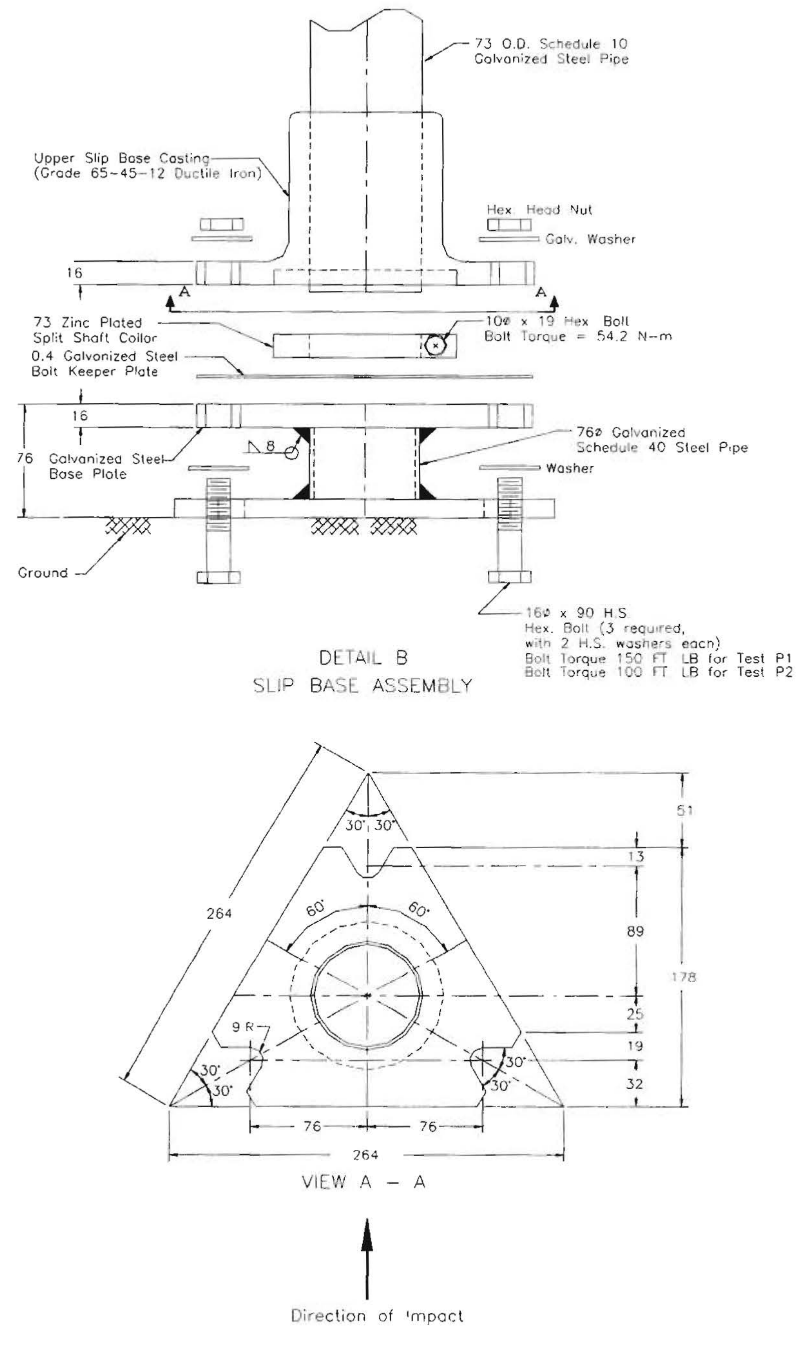


Figure 19. Details of Sign Support Installation (Continued).

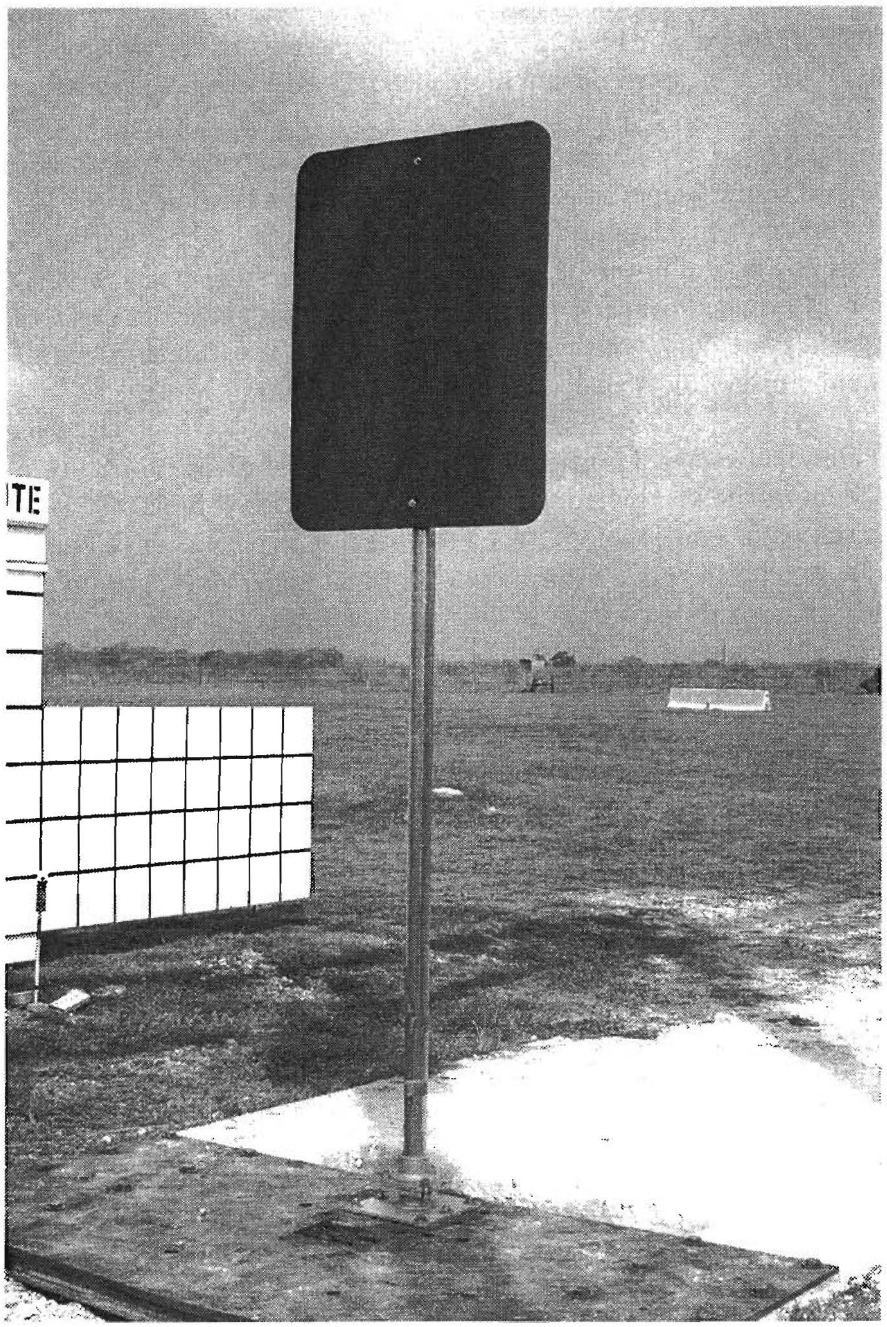


Figure 20. Slip Base Sign Support before Test 417929-P1.

Test Results

The test was performed the morning of March 11, 1999. The pendulum bogie, shown in figure 21, impacted the sign support at a speed of 35.6 km/h (22.1 mi/h) at a height of 468 mm (18.4 in.). Shortly after impact, the first section of honeycomb crushed. At 0.008 s, the pendulum nose plate contacted the schedule 10 support post. By 0.012 s, the rear sections of honeycomb began to crush, and at 0.036 s the support post bent just above the upper slip base casting and conformed to the front end of the pendulum. As the pendulum continued forward, the sweeper plate contacted the upper slip base casting causing the base to activate at 0.168 s. Sequential photographs of this test captured from high-speed film are presented in Appendix D, figure 92.

Photographs of the installation after the test are shown in figures 22 and 23. The locking ring separated from the support post and came to rest near the bolt keeper plate approximately 1.5 m (5.0 ft) down from the point of impact. The upper end of the support post came to rest 4.6 m (15.1 ft) downstream from its initial position. There was a bend or kink in the support post 125 mm (5 in.) from the lower end just above the upper slip base casting. Researchers noted a second bend and flattening of the schedule 10 support post 610 mm (24.0 in.) above the lower end. Maximum crush of the honeycomb nose was 155 mm (6.1 in.).

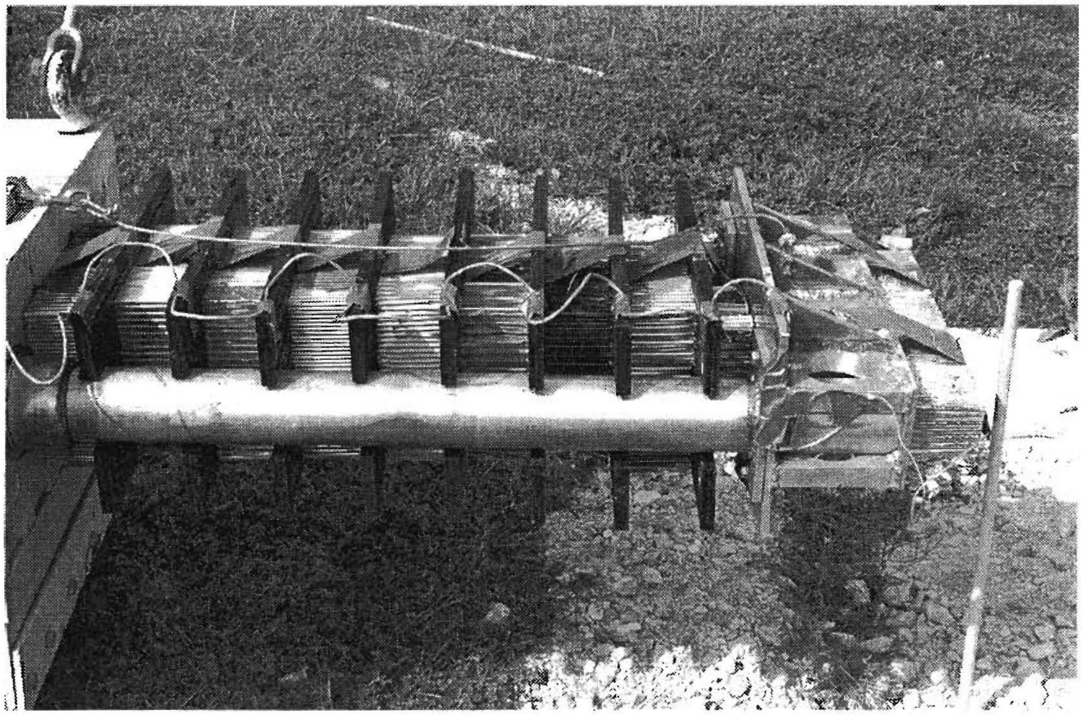
Longitudinal occupant impact velocity was 7.2 m/s (23.6 ft/s) at 0.176 s, the highest 0.010 s occupant ridedown acceleration was -0.4 g's from 0.485 to 0.495 s, and the maximum 0.050 s longitudinal average was -5.1 g's. The maximum change in velocity was 7.2 m/s (23.7 ft/s). These data and other information pertinent to the test are summarized in figure 24. The longitudinal accelerometer trace is shown in Appendix C, figure 88.

In summary, the performance of the schedule 10 support with the slip base bolts torqued to 209 N·m (154 ft·lb) was unacceptable. The activation force was too high, causing the support post to bend and collapse. The occupant impact velocity exceeded the maximum acceptable value of 5 m/s (16.4 ft/s) specified in *NCHRP Report 350* for breakaway structures.

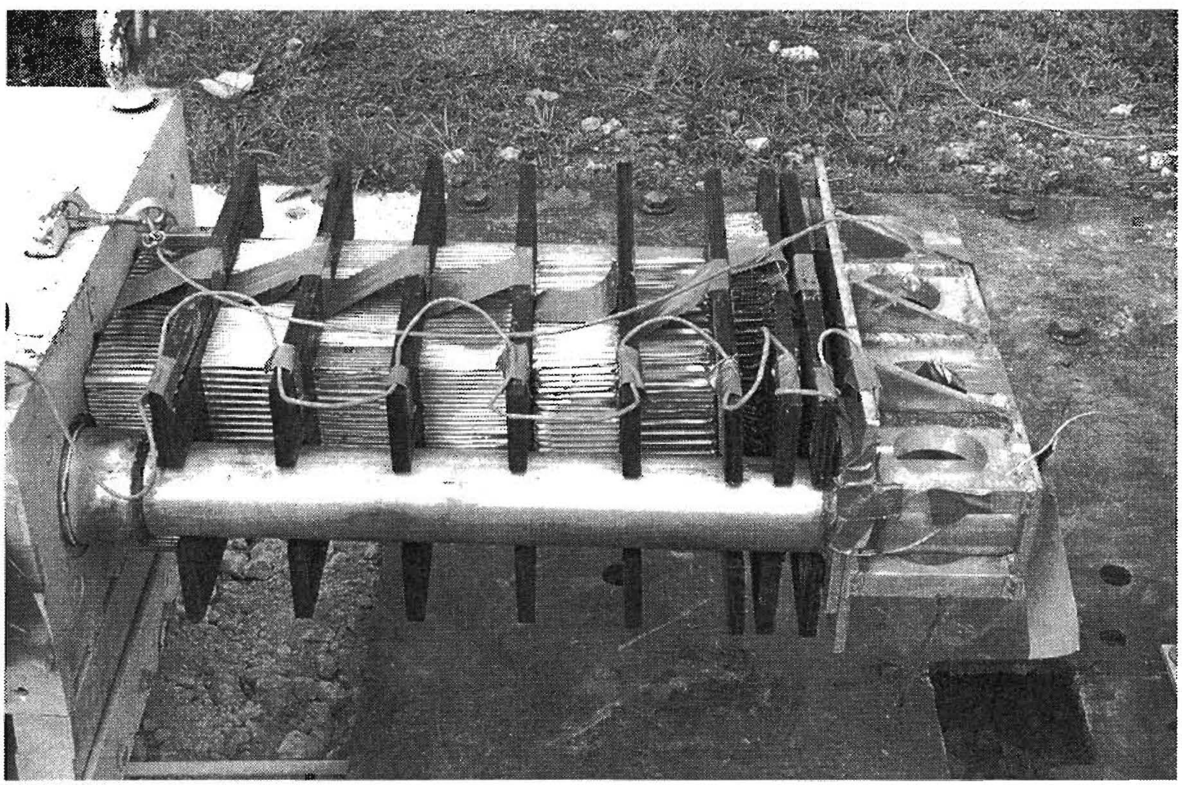
Test No. 417929-P2

Test Article

The test installation used for the second pendulum test in the bolt torque series was identical to the installation used for the first pendulum test (Test No. 417929-P1) with the exception of the torque used for the slip bolts. In this test, a bolt torque of 136 N·m (100 ft·lb) was specified. Details of the sign support installation used for this pendulum test are shown in figure 19. Photographs of the completed sign support installation are shown in figure 25.



(a) before test



(b) after test

Figure 21. Pendulum Bogie for Test 417929-P1.

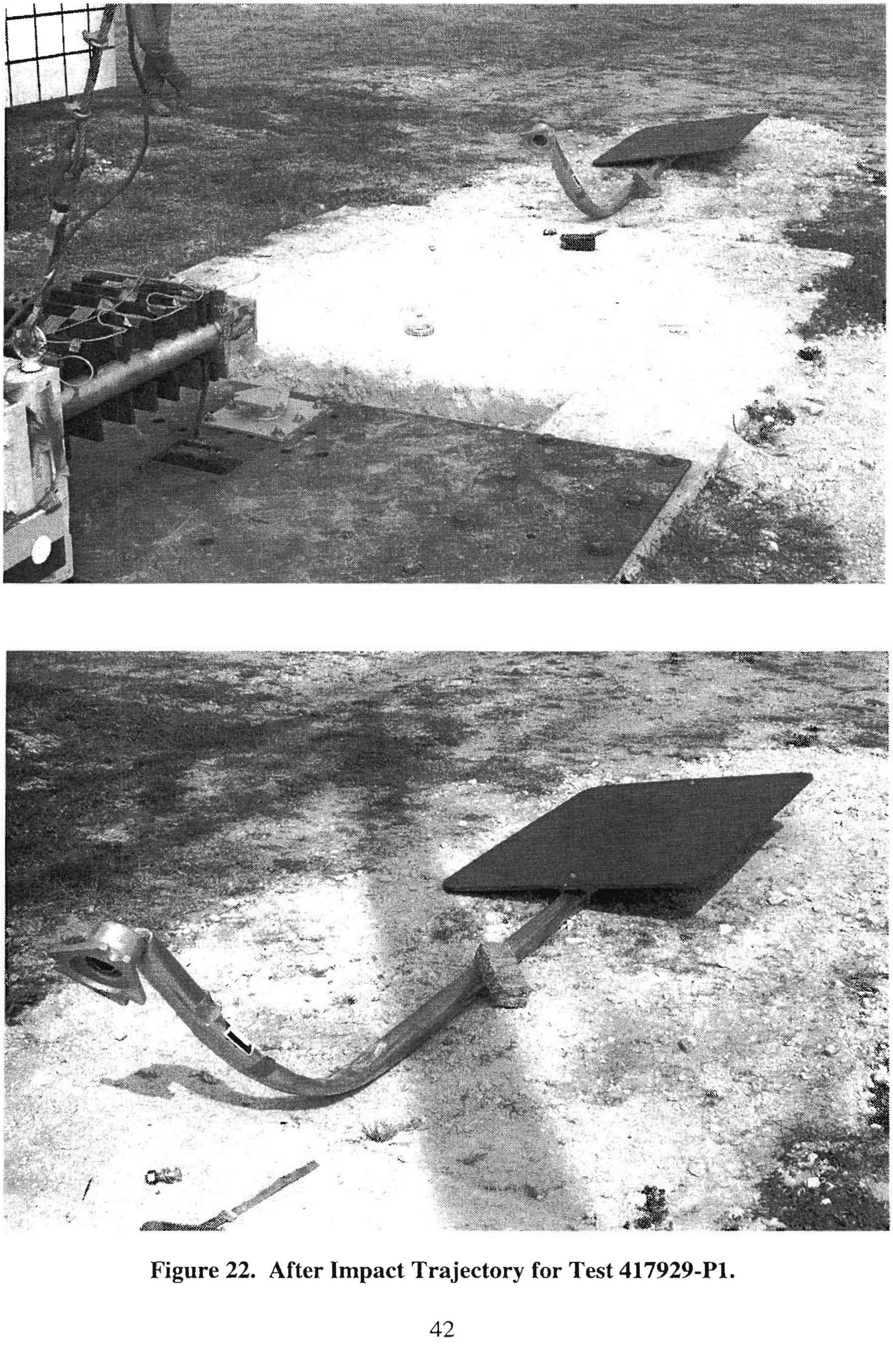


Figure 22. After Impact Trajectory for Test 417929-P1.

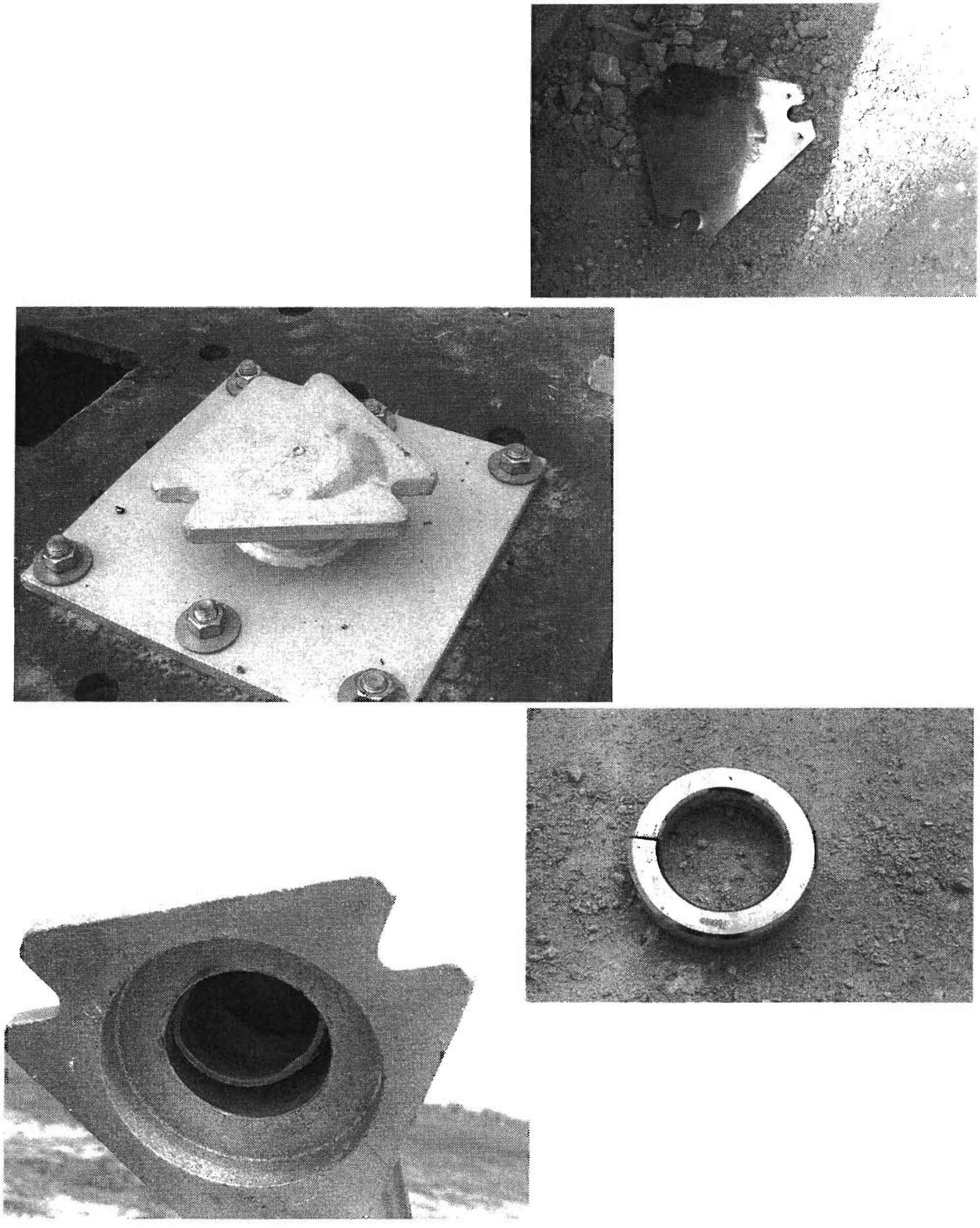
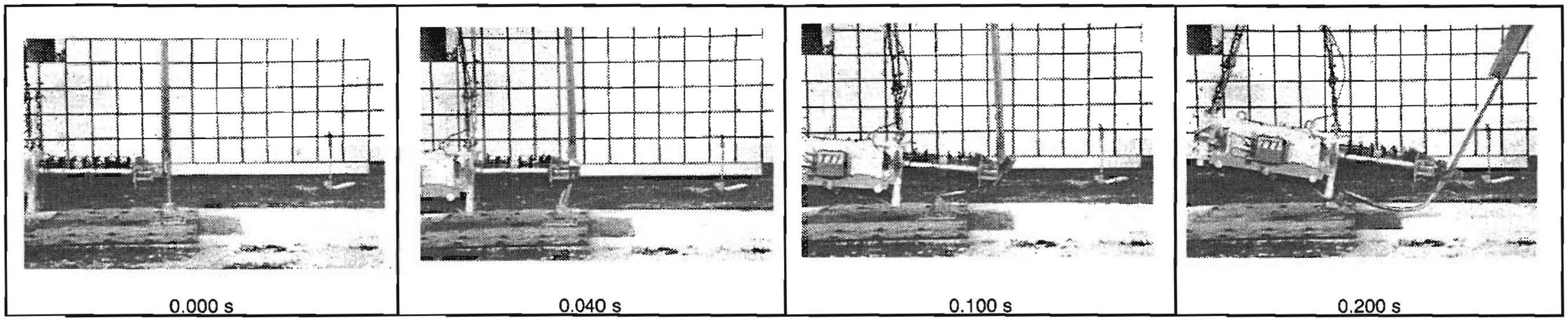


Figure 23. Slip Base Sign Support after Test 417929-P1.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-P1
Date	03/11/99

Test Article

Type	Sign Support
Name	Slip Base Sign Support
Installation Height (m)	2.1 m (7.0 ft)
Material or Key Elements	Locking ring, torqued to 61 N·m (45 ft·lbs) 30 gauge keeper plate, three 16 mm diameter x 102 mm (5/8 in. diameter x 4 in.) grade 5 bolts torqued to 209 N·m (154 ft·lb), w/ a 1.0 m x 1.2 m x 16 mm (3 ft x 4 ft x 5/8 in.) plywood sign panel mounted at 2.1 m (7.0 ft)

Soil Type . . . . Steel Plate

Test Vehicle

Type	Bogie
Designation	Pendulum
Test Inertial Mass	839 kg

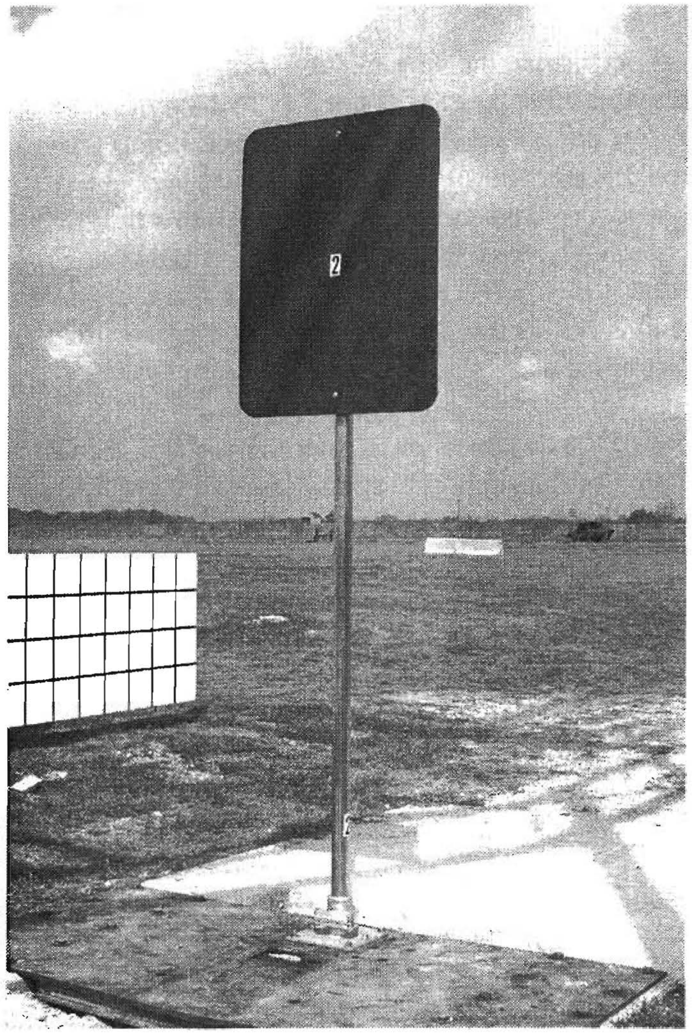
Impact Conditions

Speed (km/h)	35.6 (22.1 mi/h)
Angle (deg)	0

Occupant Risk Values

Occupant Impact Velocity (m/s)	
x-direction	7.2 (23.7 ft/s)
Ridedown Acceleration (g's)	
x-direction	-0.4
Max. 0.050-s Average (g's)	
x-direction	-5.1
Max. Change in Velocity (m/s)	7.2 (23.7 ft/s)

Figure 24. Summary of Results for Test 417929-P1.



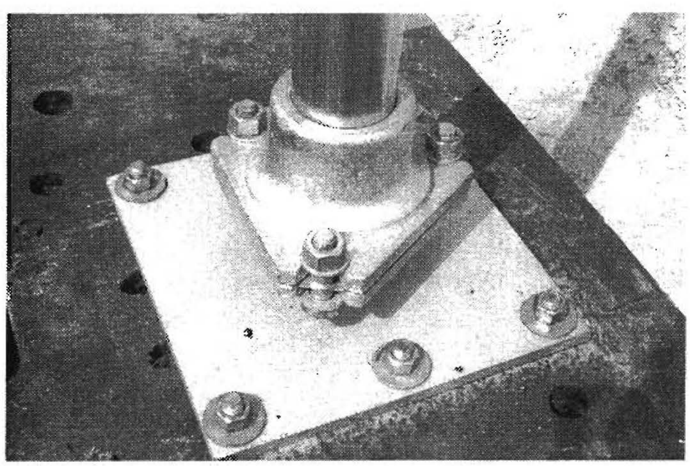


Figure 25. Slip Base Sign Support before Test 417929-P2.

Test Results

The test was performed the morning of March 11, 1999. The pendulum bogie, shown in figure 26, impacted the sign support at a speed of 36.1 km/h (22.4 mi/h) at a height of 468 mm (18.4 in.). Shortly after impact the first section of honeycomb crushed. At 0.010 s, the pendulum nose plate contacted the schedule 10 support post and the post began to move. By 0.012 s, the rear sections of honeycomb began to crush, and by 0.036 s the slip base began to activate. The support post had completely separated from the base at 0.048 s. The pendulum bogie was traveling at a speed of 30.2 km/h (18.8 mi/h) at 0.082 s as the sign support exited the test site. Sequential photographs of this test captured from high-speed film are presented in Appendix D, figure 93.

Photographs of the test installation after the test are shown in figures 27 and 28. Some permanent deformation of the support post was observed, but the post did not buckle or collapse. The locking ring and upper slip base casting slipped off the end of the support post. The locking ring came to rest 5.3 m (17.4 ft) down from the point of impact, while the slip base casting traveled 18.3 m (60.0 ft) downstream of its initial position. The bolt keeper plate came to rest adjacent to the support post and sign panel 19.1 m (62.7 ft) down from the impact point. Maximum crush of the honeycomb nose was 150 mm (5.9 in.).

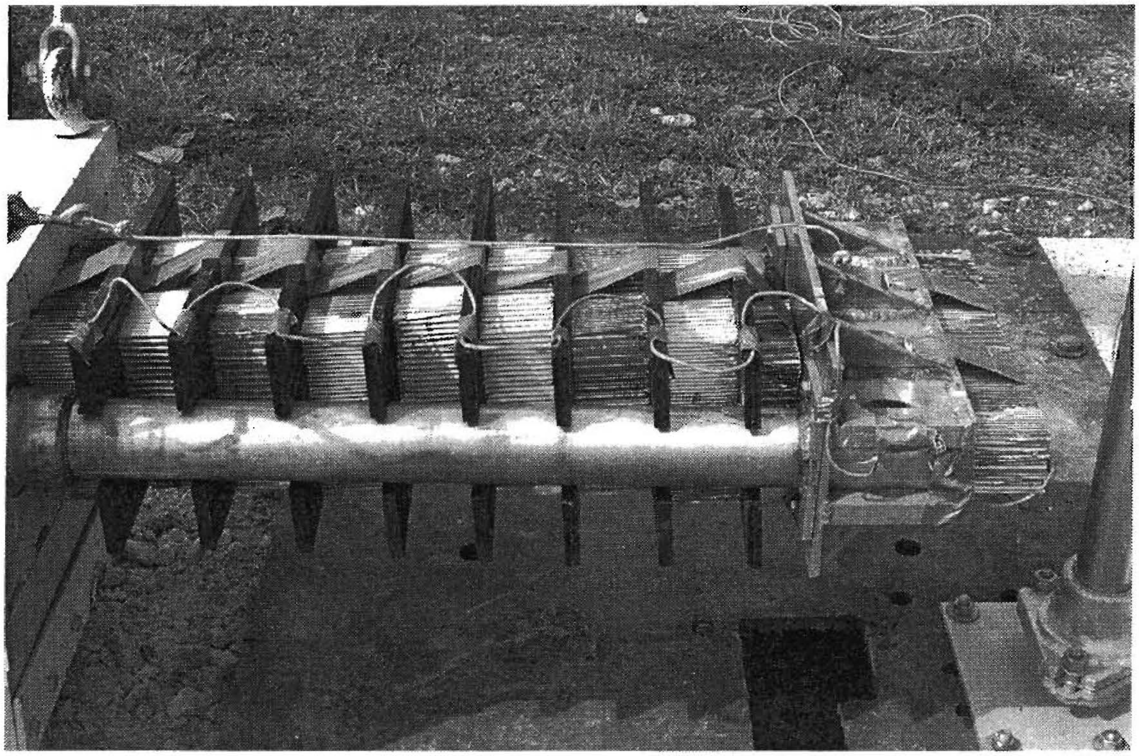
Longitudinal occupant impact velocity was 2.3 m/s (7.5 ft/s) at 0.395 s, the highest 0.010 s occupant ridedown acceleration was -0.6 g's from 0.468 to 0.478 s, and the maximum 0.050 s longitudinal average was -2.9 g's. The maximum change in velocity was 5.9 m/s (19.4 ft/s). These data and other information pertinent to the test are summarized in figure 29. The longitudinal accelerometer trace is shown in Appendix C, figure 89.

In summary, the performance of the schedule 10 support with the slip base bolts torqued to 136 N·m (100 ft·lb) was considered acceptable. The occupant impact velocity and ridedown acceleration were below the desirable levels specified in *NCHRP Report 350* for breakaway structures. Although there was some permanent deformation of the support post that would cause it to have to be replaced, the post did not kink, collapse, or otherwise hinder the activation of the slip base. However, based on the permanent deformation that occurred, it is clear that 136 N·m (100 ft·lb) is at or near the maximum acceptable torque for the schedule 10 support. Any torque above this value would likely result in kinking or collapsing of the support post similar to that observed in Test No. 417929-P1.

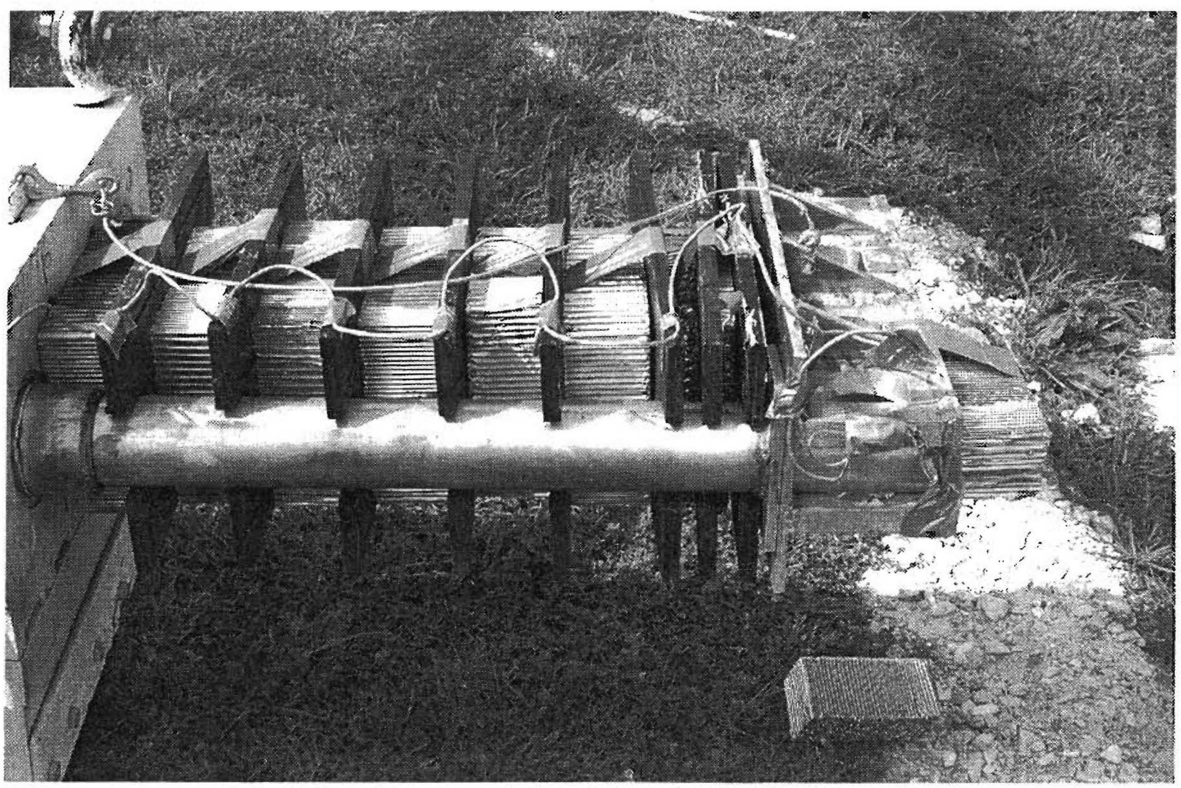
Test No. 417929-P3

Test Article

The test installation for the pendulum tests conformed to a TxDOT Type F sign mount as shown on the standard sign mounting details for small roadside signs (SMD (1-1)-98). A prefabricated T-shaped bracket with a 52 mm (2 in.) diameter thin wall horizontal member was attached to a 64 mm (2.5 in.) diameter schedule 80 pipe support. A 1.52 m (5 ft) wide × 1.22 m



(a) before test



(after test)

Figure 26. Pendulum Bogie for Test 417929-P2.

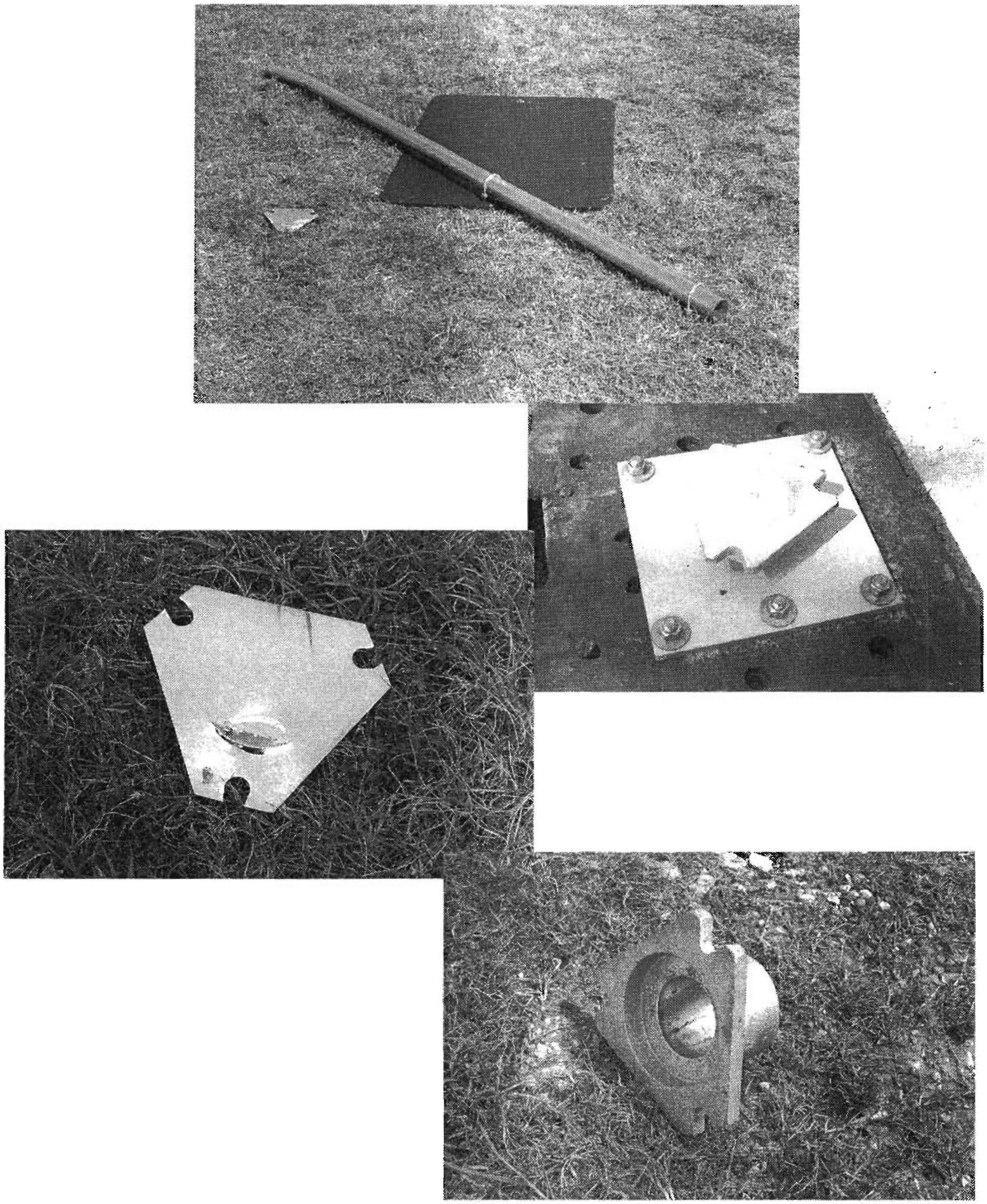
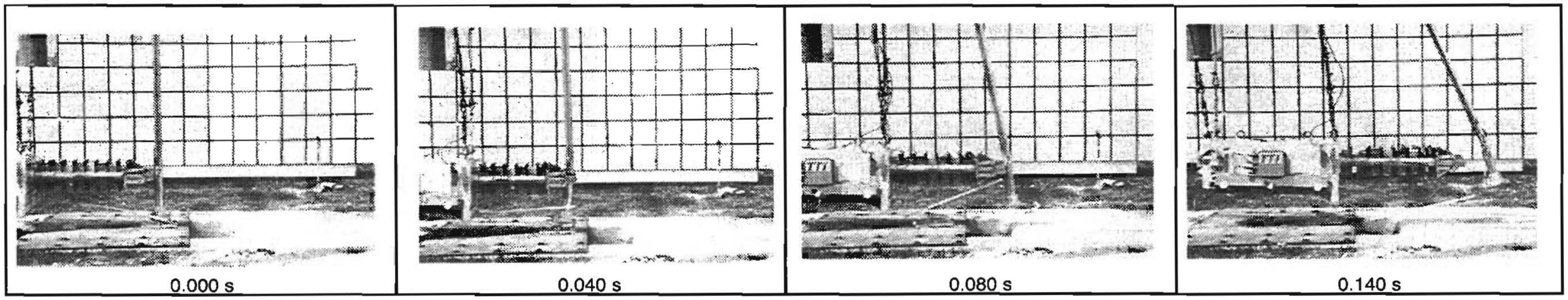


Figure 27. Slip Base Sign Support after Test 417929-P2.

Figure 28. Bolts and Locking Ring Damage after Test 417929-P2.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-P2
Date	03/11/99

Test Article

Type	Sign Support
Name	Slip Base Sign Support
Installation Height (m)	2.1 m (7.0 ft)
Material or Key Elements	Locking ring, torqued to 61 N·m (45 ft·lbs) 30 gauge keeper plate, three 16 mm diameter × 102 mm (5/8 in diameter × 4 in.) grade 5 bolts torqued to 136 N·m (100 ft·lb) w/ a 1.5 m × 1 .2 m × 16 mm (5 ft × 4 ft × 5/8 in.) plywood sign panel mounted at 2.1 m (7.0 ft)

Soil Type	Steel Plate

Test Vehicle

Type	Bogie
Designation	Pendulum
Test Inertial Mass	839 kg

Impact Conditions

Speed (km/h)	36.1 (22.4 mi/h)
Angle (deg)	0

Occupant Risk Values

Occupant Impact Velocity (m/s)	
x-direction	2.3 (7.5 ft/s)
Ridedown Acceleration (g's)	
x-direction	-0.6
Max. 0.050 s Average (g's)	
x-direction	-2.9
Max. Change in Velocity (m/s)	5.9 (19.4 ft/s)

Figure 29. Summary of Results for Test 417929-P2.

(4 ft) tall × 16 mm (0.62 in.) thick plywood sign panel was connected to the thin wall horizontal member and 73 mm (2.875 in.) O.D. schedule 80 support post using three mounting clamps. The mounting height from the ground to the bottom of the sign panel was 2.1 m (7 ft).

The details of the slip base assembly were identical to those used in the previous pendulum tests. The slip bolts were tightened to a torque of 136 N·m (100 ft·lb). This is the same torque that was used to evaluate the performance of the slip base with a schedule 10 support in Test No. 417929-P2. Although there was no concern about the schedule 80 support collapsing during impact, there was a need to evaluate the effect of the extra mass of the schedule 80 support and T-shaped bracket on the *NCHRP Report 350* occupant risk parameters.

Details of the sign support installation used for this pendulum test are shown in figure 30. Photographs of the completed sign support installation are shown in figure 31.

Test Results

The test was performed the morning of March 11, 1999. The pendulum bogie, shown in figure 32, impacted the sign support at a speed of 36.1 km/h (22.1 mi/h) at a height of 468 mm (18.4 in.). Shortly after impact, the first section of honeycomb began to crush. The pendulum nose plate contacted the schedule 80 support pole at 0.008 s. At 0.010 s, the rear sections of the honeycomb began to crush, and the pole began to slip away from the base. The pole was completely separated from the base by 0.030 s. The pendulum bogie was traveling at a speed of 34.2 km/h (21.3 mi/h) at 0.092 s as the sign support exited the test site. Sequential photographs from high-speed film are presented in Appendix D, figure 94.

Photographs of the test installation after the test are shown in figures 33 and 34. The locking ring and upper slip base casting stayed attached to the pole. The keeper plate and upper section of the support traveled 16.0 m (52.5 ft) downstream from the point of impact. The sign panel remained attached to the support post and the entire system was considered to be reusable. Maximum crush of the honeycomb nose was 42 mm (1.7 in.).

No occupant contact occurred and the maximum 0.050 s longitudinal average was -1.0 g's. These data and other information pertinent to the test are summarized in figure 35. The maximum change in velocity was 0.4 m/s (1.3 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 90.

In summary, the performance of the schedule 80 support with the slip base bolts torqued to 136 N·m (100 ft·lb) was considered acceptable. Contrary to expectations based on the results with the schedule 10 support, there was no occupant contact and the maximum crush of the honeycomb pendulum nose was only 42 mm (1.7 in.).

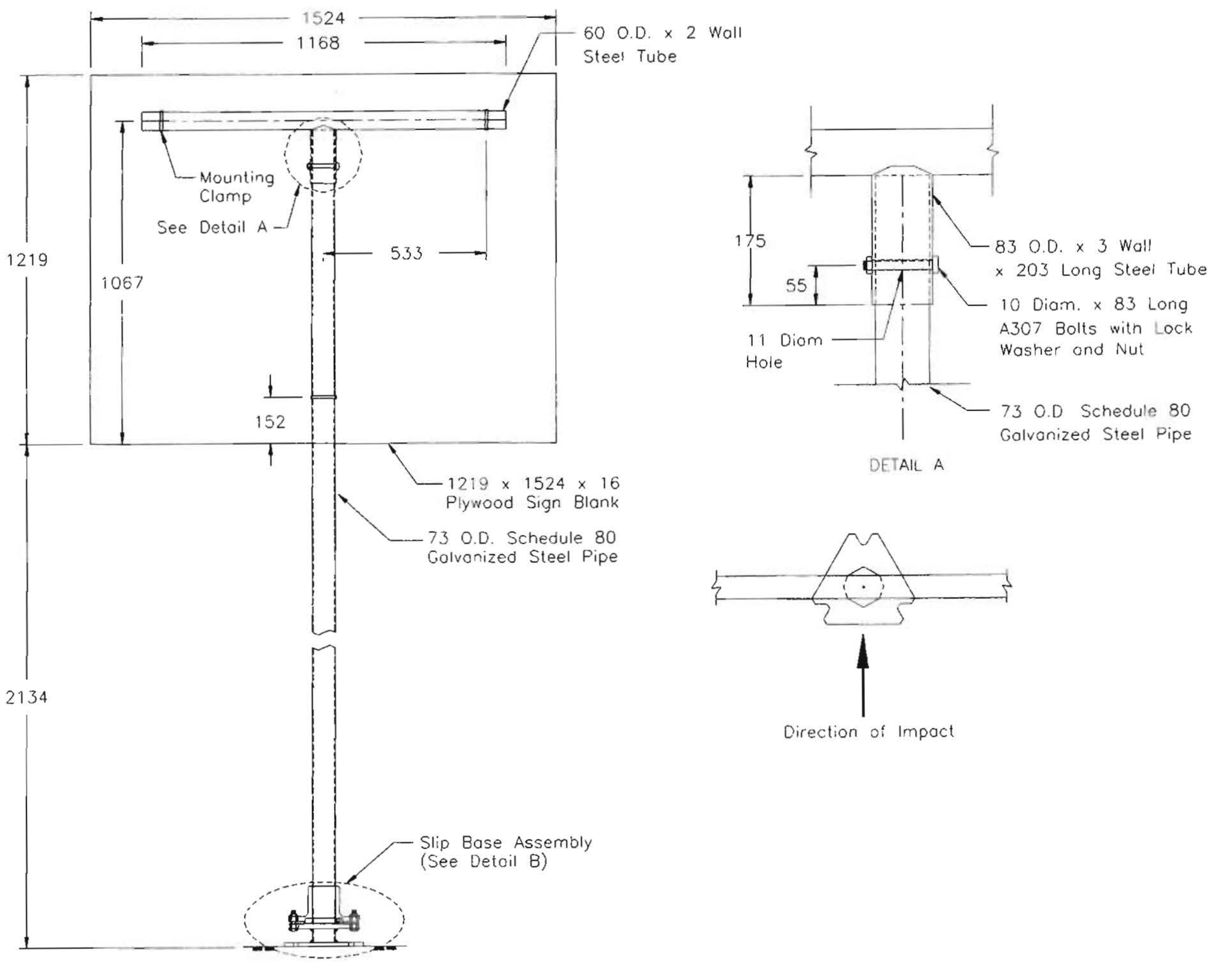
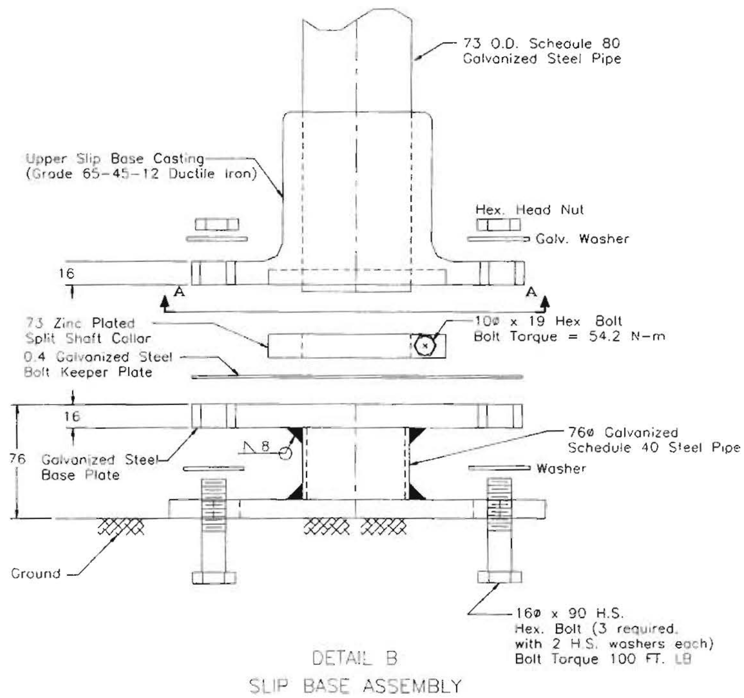


Figure 30. Details of Test Installation for 417929-P3.



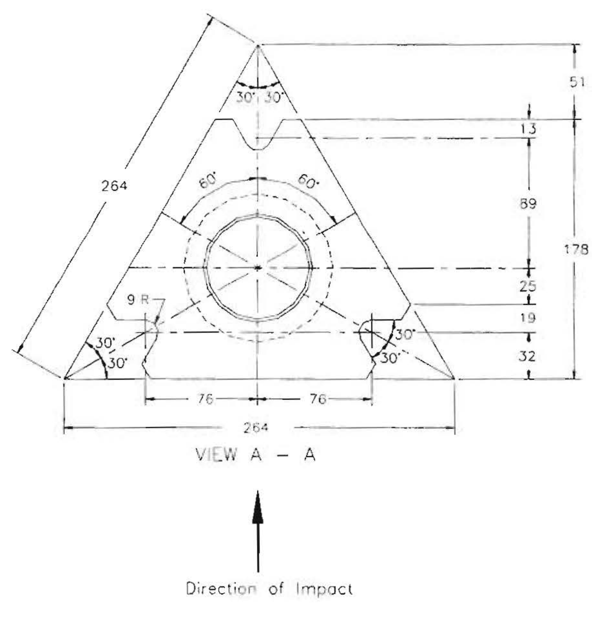


Figure 30. Details of Test Installation for 417929-P3 (Continued).

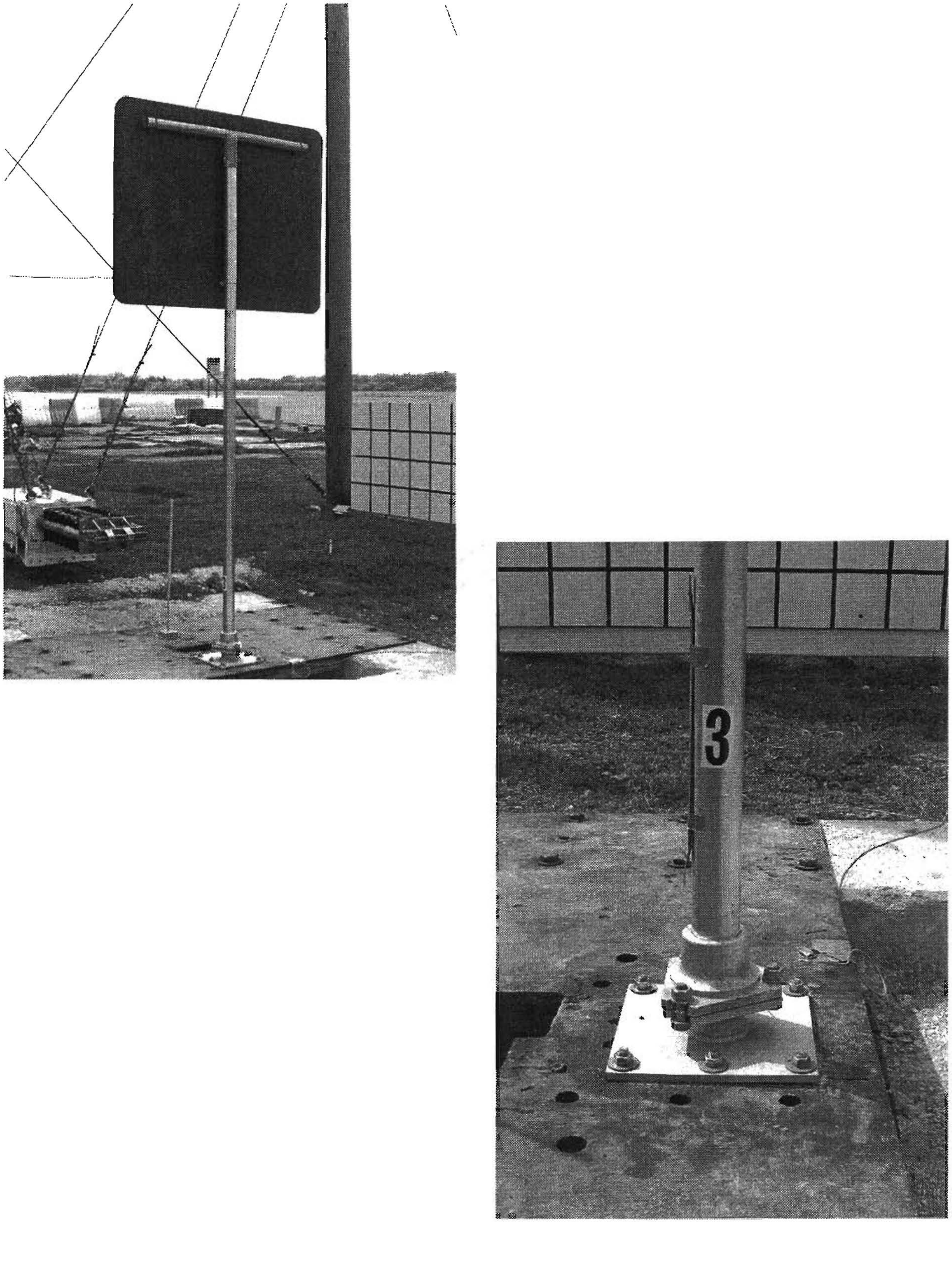
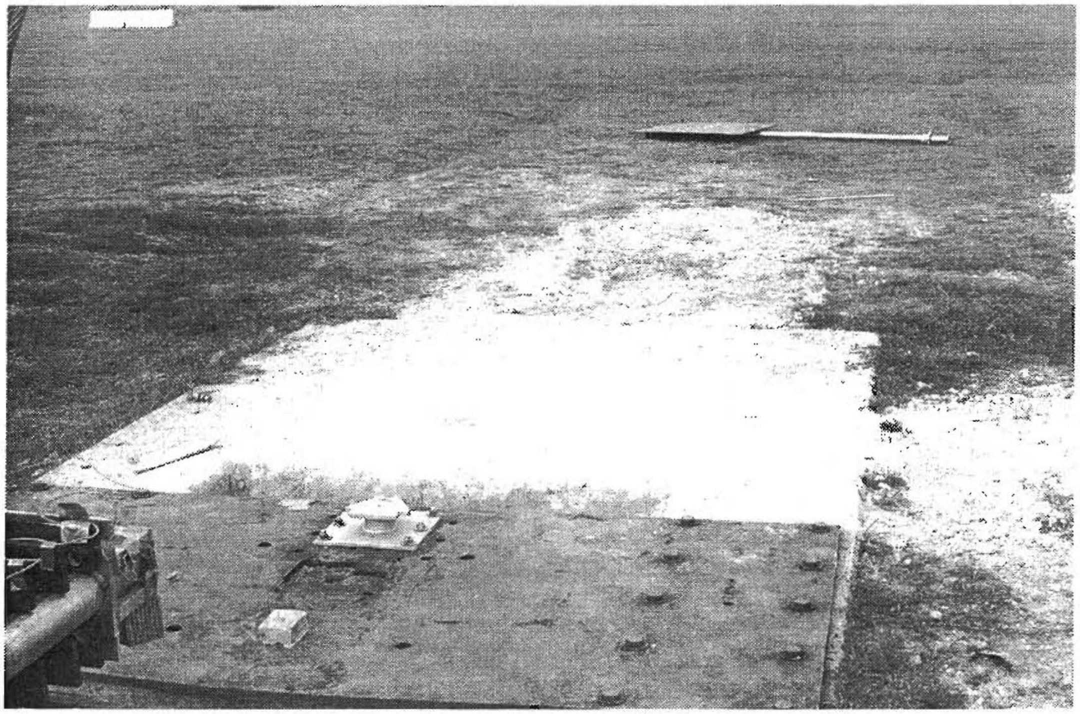


Figure 31. Slip Base Sign Support before Test 417929-P3.

Figure 32. Pendulum Bogie after Test 417929-P3.



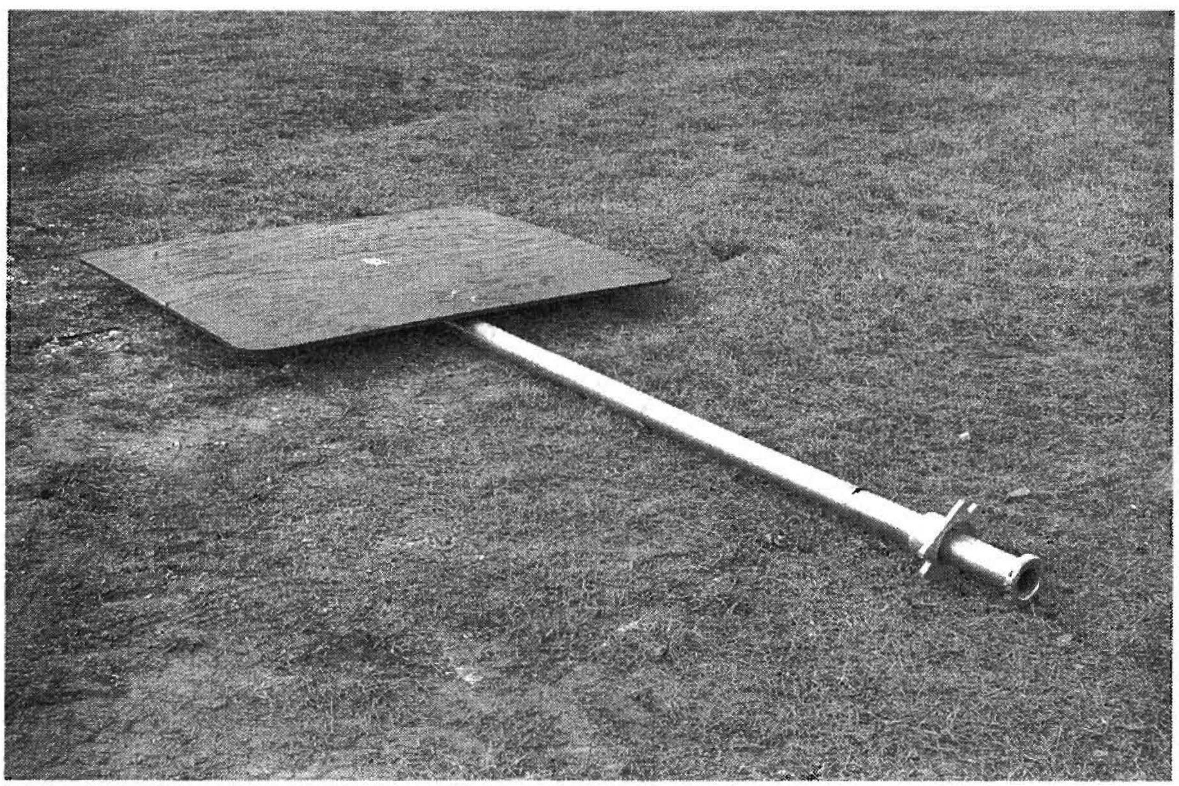


Figure 33. After Impact Trajectory for Test 417929-P3.

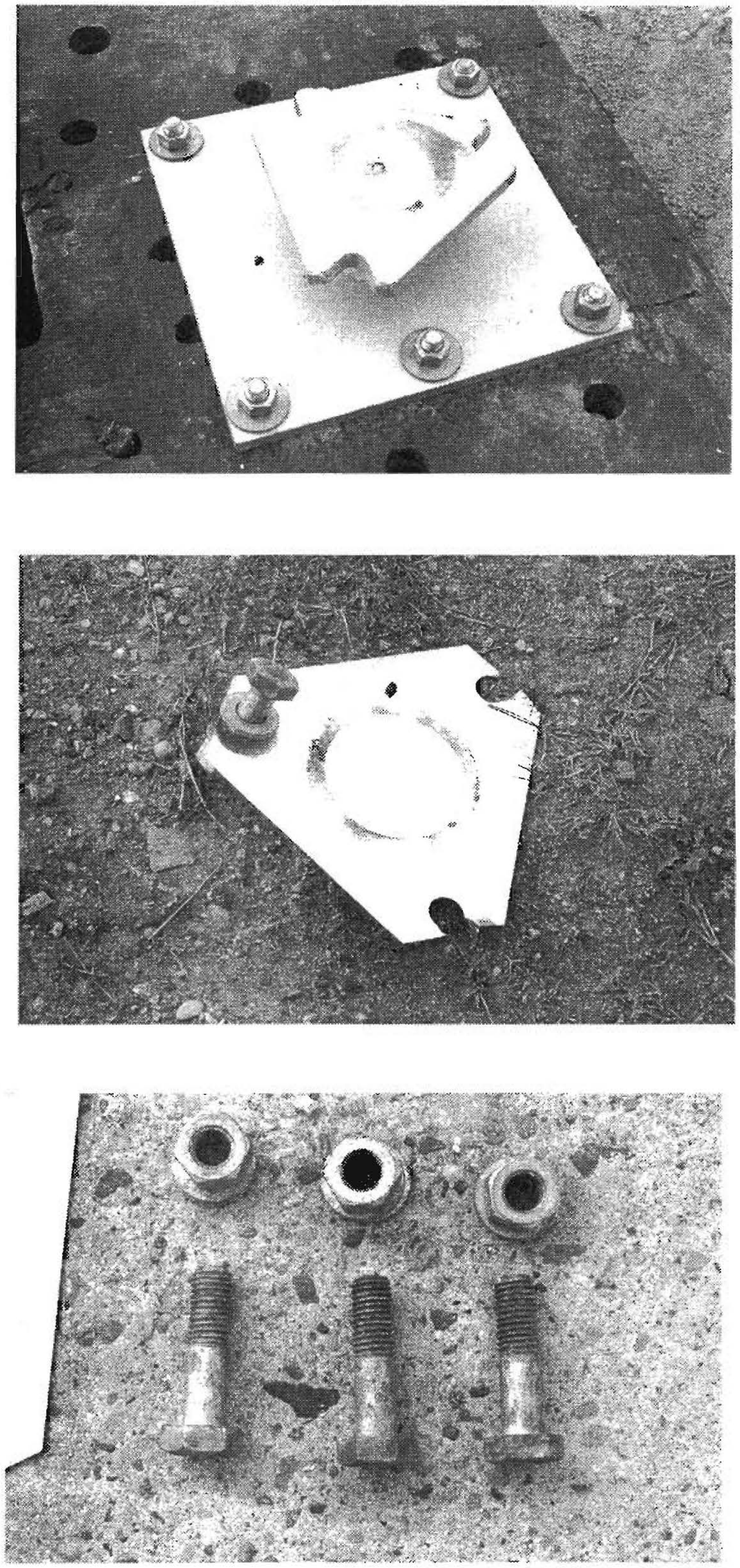
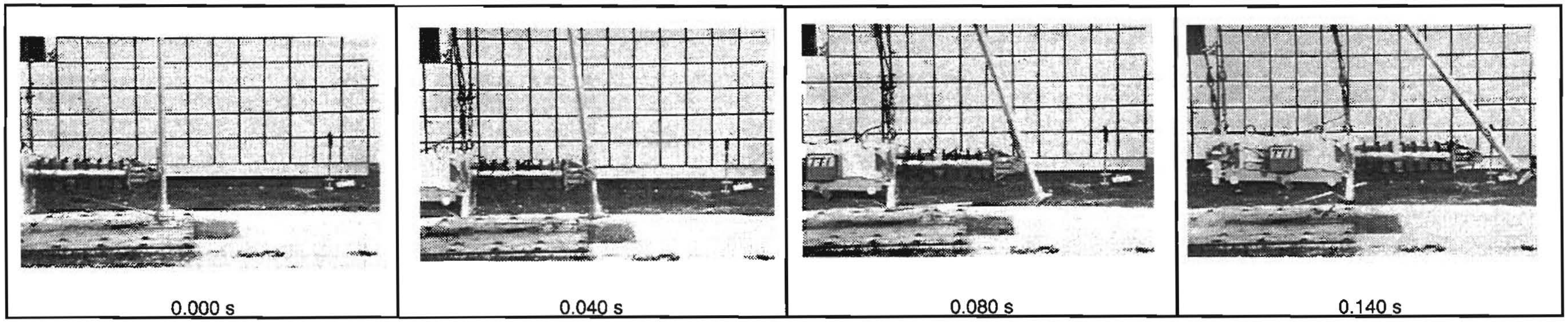


Figure 34. Slip Base Sign Support after Test 417929-P3.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-P3
Date	03/11/99

Test Article

Type	Sign Support
Name	Slip Base Sign Support
Installation Height (m)	2.1 m (7.0 ft)
Material or Key Elements	Locking ring, torqued to 61 N·m (45 ft·lbs 30 gauge keeper plate, three 16 mm diameter x 102 mm (5/8 in. diameter x 4 in.) grade 5 bolts torqued to 100 N·m (100 ft·lb), w/ a 1.0 m x 1.2 m x 16 mm (3 ft x 4 ft x 5/8 in.) plywood sign panel mounted at 2.1 m (7.0 ft)

Soil Type .... Steel Plate

Test Vehicle

Type	Bogie
Designation	Pendulum
Test Inertial Mass	839 kg

Impact Conditions

Speed (km/h)	36.1 (22.4 mi/h)
Angle (deg)	0

Occupant Risk Values

Occupant Impact Velocity (m/s)	
x-direction	No contact
Ridedown Acceleration (g's)	
x-direction	No contact
Max. 0.050-s Average (g's)	
x-direction	-1.0
Max. Change in Velocity (m/s)	0.4 (1.3 ft/s)

Figure 35. Summary of Results for Test 417929-P3.

Test No. 417929-P4

Test Article

The slip base installation used for the final pendulum test incorporated a lifting cone on the lower slip base foundation plate and a spacer cap between the upper and lower slip plates. The purpose of the test was to evaluate the performance of the lifting cone retrofit with the higher slip bolt torque. The slip base foundation had a 25 mm (1 in.) tall lifting cone stamped into the center of the triangular base plate. The slip base plate and a short section of a pipe stub were welded to a steel base plate that was bolted to a steel reaction plate in the pendulum test area. The distance from the ground surface to the top face of the permanent lower triangular slip plate was 76 mm (3 in.). The slip base was oriented such that the direction of impact was perpendicular to one of the flat faces of the triangular plate.

A molded polycarbonate plastic cap was placed over the lifting cone. The 37 mm (1.44 in.) thick cap was molded in a triangular shape that matched the geometry of the slip base plate. A 29 mm (1.13 in.) deep triangular-shaped recess was molded in the center of the cap to accept the lifting cone. The triangular configuration provides support for the corners of the keeper plate and slip base plates and minimizes the potential for rotation of the upper slip plate during tightening of the slip bolts. The 8 mm (0.31 in.) thick top surface of the cap provided a flat, hard surface against which the split-ring collar on the end of the support post can bear during the bolt tightening procedure. The three 16 mm (0.63 in.) diameter × 102 mm (4 in.) long A325 bolts were torqued to 136 N·m (100 ft·lb). High-strength washers were used under both the head and nut of each bolt.

Other details of the sign support installation were similar to those used in Tests 417929-P1 and 417929-P2. A 914 mm (36 in.) wide × 1219 mm (48 in.) tall × 16 mm (5/8 in.) thick plywood sign panel was attached to a 73 mm (2.875 in.) O.D. schedule 10 post at a mounting height of 2.1 m (7.0 ft) using two pipe mounting clamps. These and other details of the sign support installation for this test are shown in figure 36. Photographs of the completed sign support installation are shown in figure 37.

Test Results

The test was performed the morning of March 11, 1999. The pendulum bogie, shown in figure 38, impacted the sign support at a speed of 36.4 km/h (22.6 mi/h) at a height of 468 mm (18.4 in.). Shortly after impact, the first section of the honeycomb began to crush. The pendulum nose plate contacted the pole at 0.010 s. At 0.012 s, the rear sections of the honeycomb began to crush and the pole began to slip away from the base. By 0.030 s, the pole had completely separated from the base. The pendulum bogie was traveling at a speed of 34.2 km/h (21.3 mi/h) at 0.076 s as the sign support exited the test site. Sequential photographs from high-speed film are presented in Appendix D, figure 95.

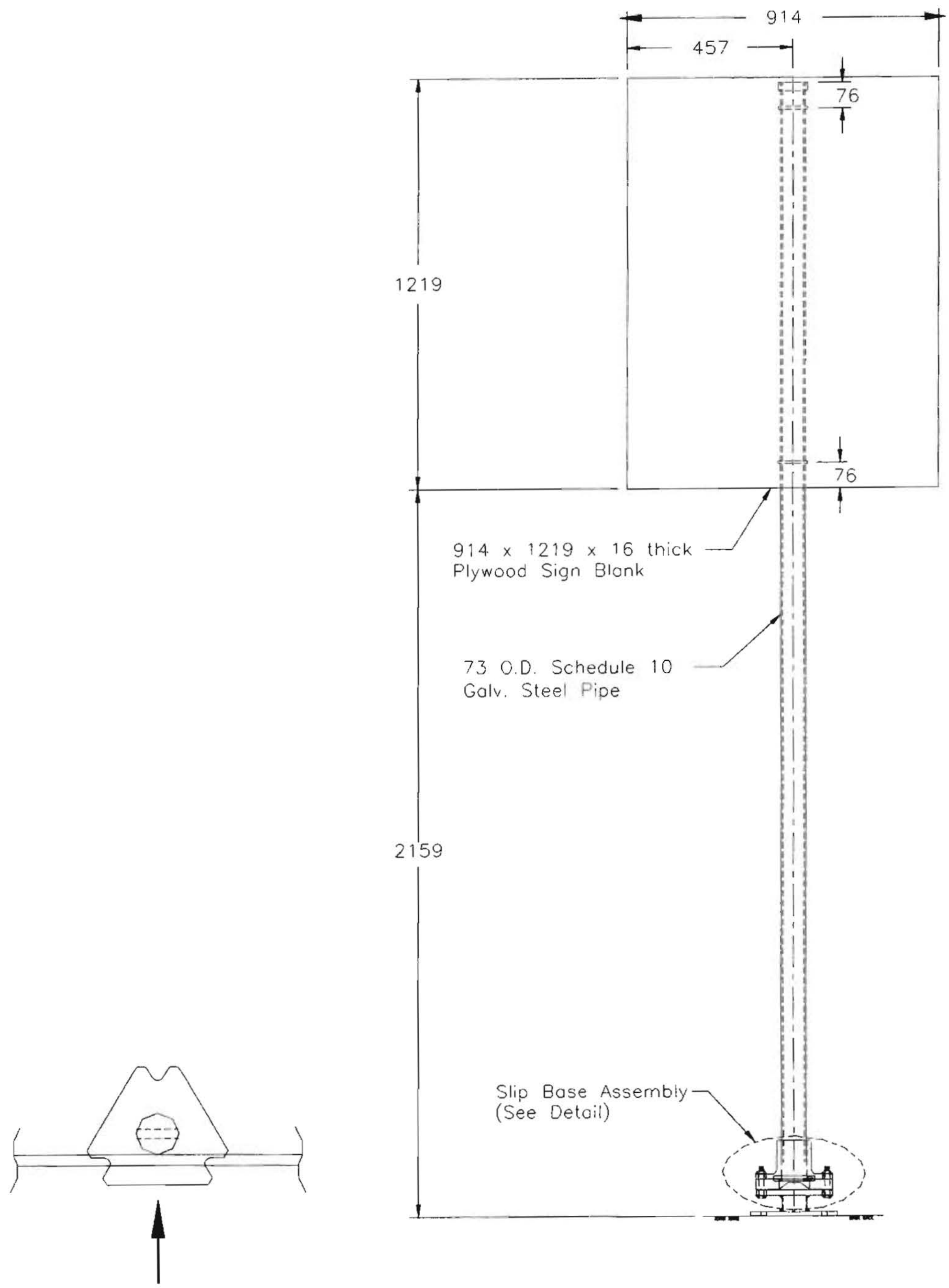


Figure 36. Details of Test Installation for 417929-P4.

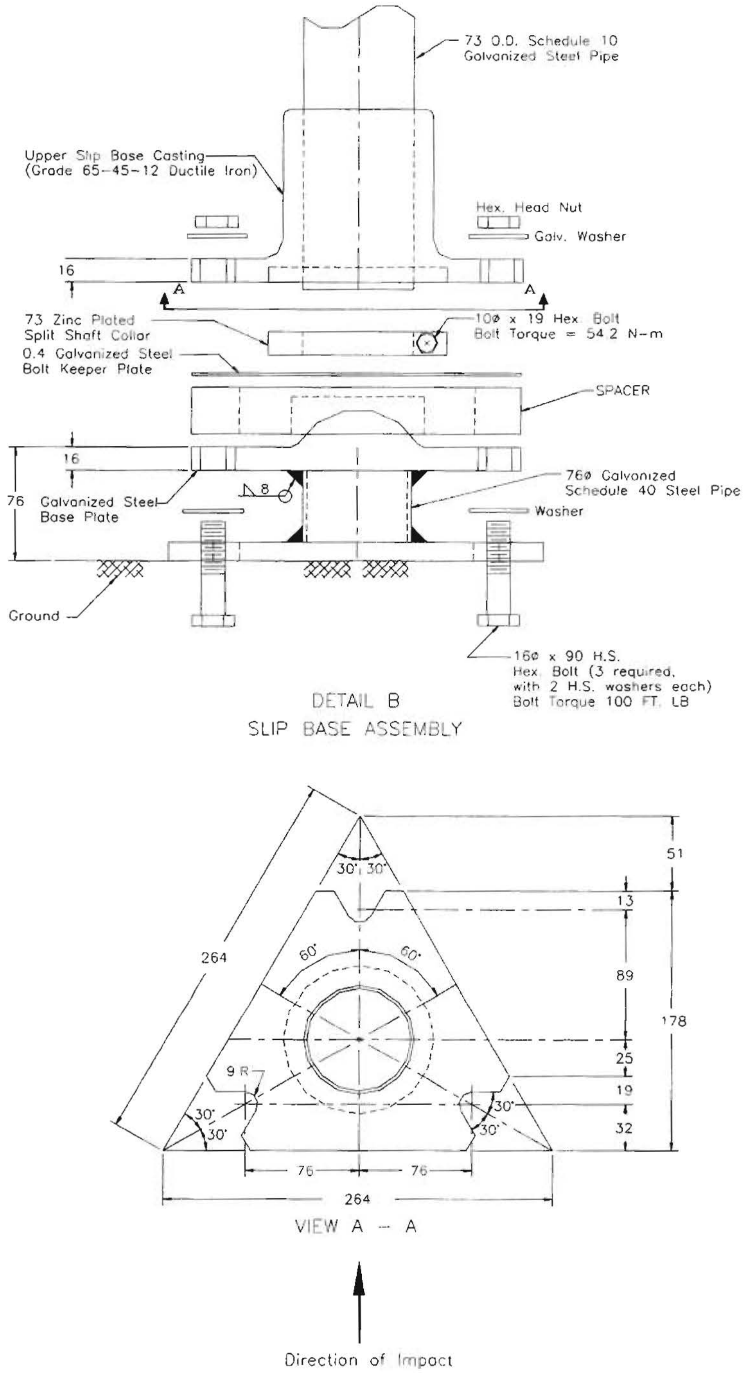
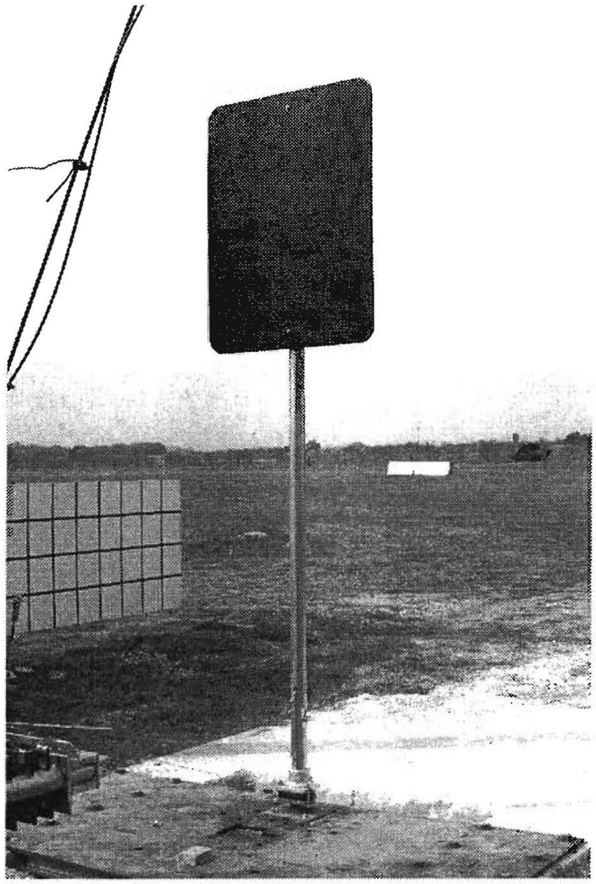


Figure 36. Details of Test Installation for 417929-P4 (Continued).



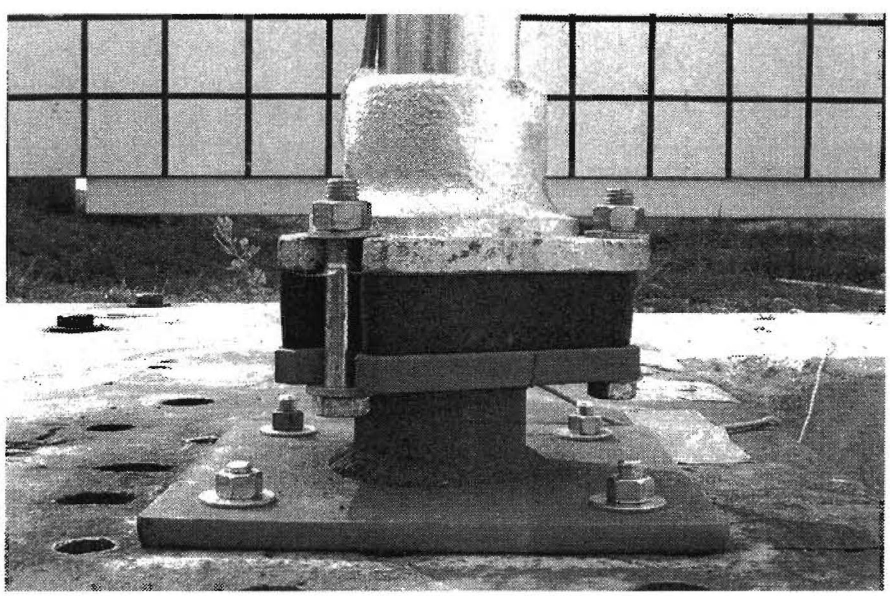
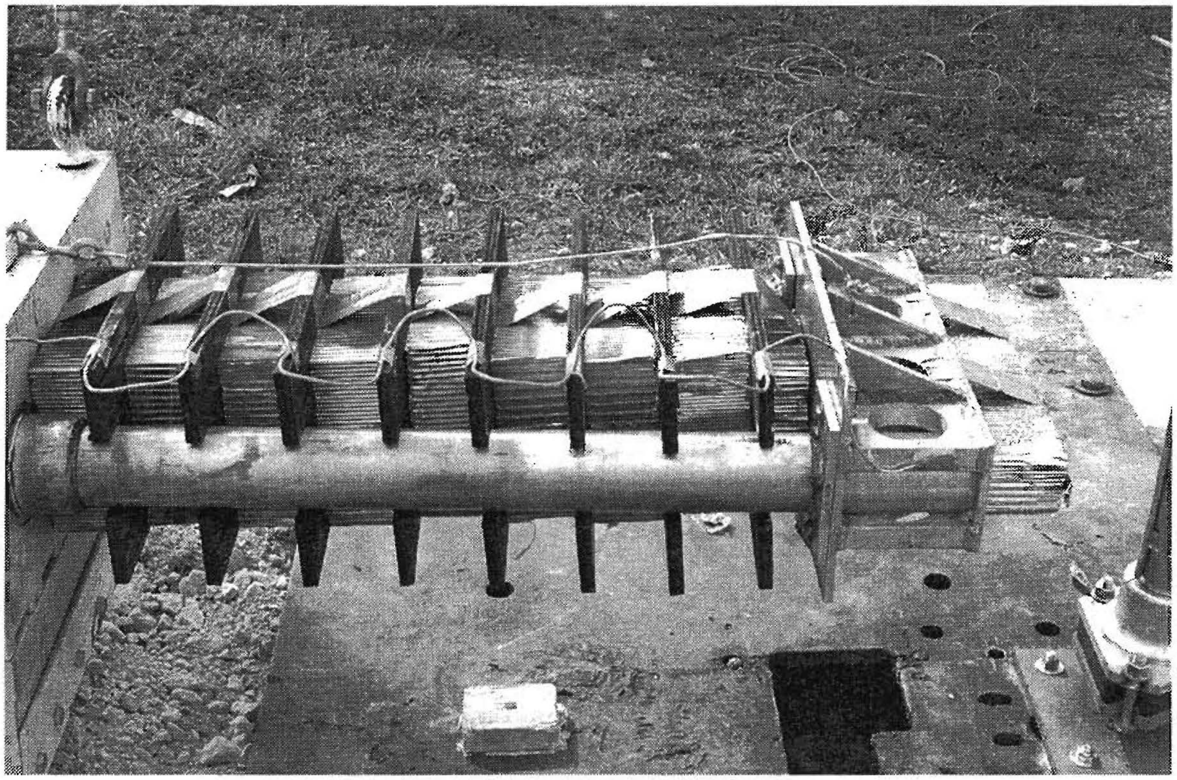
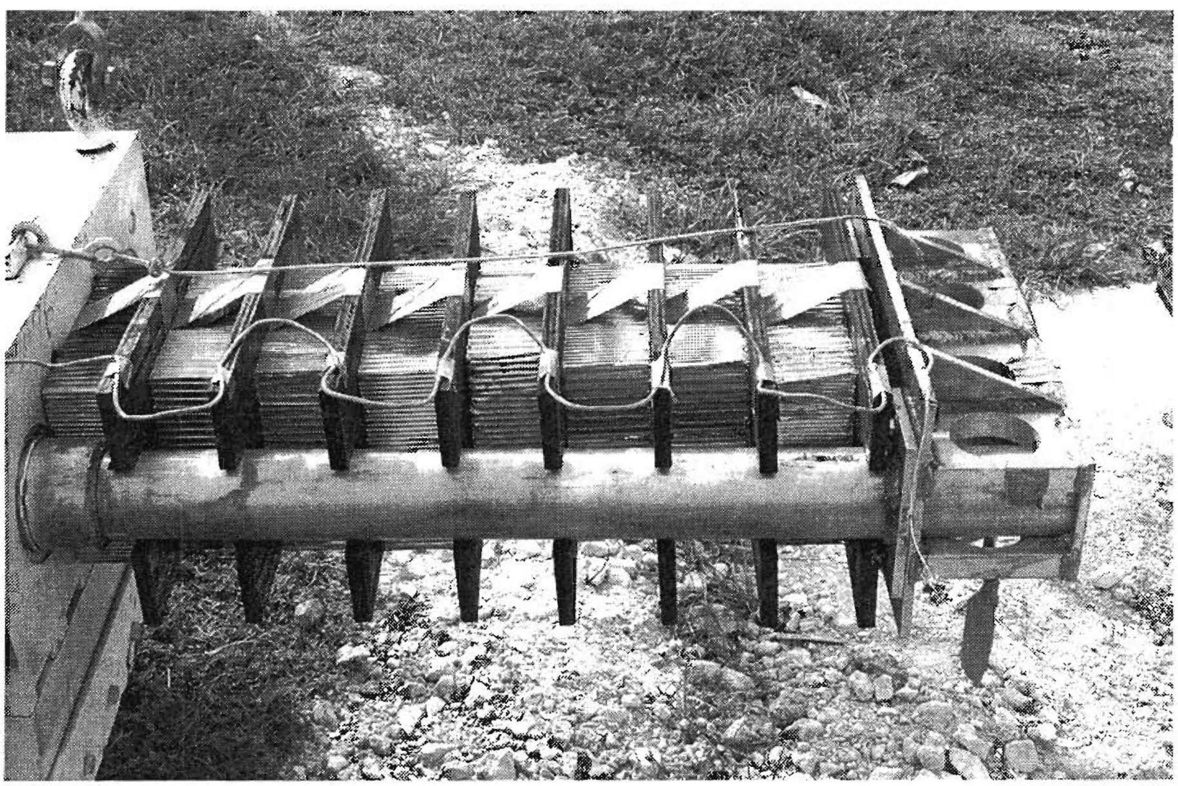


Figure 37. Slip Base Sign Support before Test 417929-P4.



(a) before test



(b) after test

Figure 38. Pendulum Bogie for Test 417929-P4.

Photographs of the test installation after the test are shown in figures 39 through 41. The triangular spacer cap was found 0.8 m (2.6 ft) in front of the test installation. The locking ring and upper slip base casting stayed attached to the pole. There was no observable permanent deformation to the schedule 10 support post, and it was considered reusable. The bolt keeper plate, with one bolt still attached, came to rest adjacent to the bottom end of the support post 12.9 m (42.3 ft) down from the point of impact. The plywood sign panel detached from the support post during the impact and came to rest adjacent to the support 13.7 m (44.9 ft) down from the impact point. Maximum crush of the honeycomb nose was 45 mm (1.8 in.).

No occupant contact occurred, and the maximum 0.050 s longitudinal average was -0.8 g's. These data and other information pertinent to the test are summarized in figure 42. The maximum change in velocity was 0.6 m/s (2.0 ft/s). The longitudinal accelerometer trace is shown in Appendix C, figure 91.

In summary, the performance of the schedule 10 support with the retrofit lifting cone spacer cap and slip base bolts torqued to 136 N·m (100 ft·lb) was considered acceptable. Neither the higher bolt torque nor the presence of the spacer cap hindered the activation of the slip base. Contrary to the results of Test No. 417929-P2 with the schedule 10 support, there was no occupant contact and the maximum crush of the honeycomb pendulum nose was only 45 mm (1.8 in.).

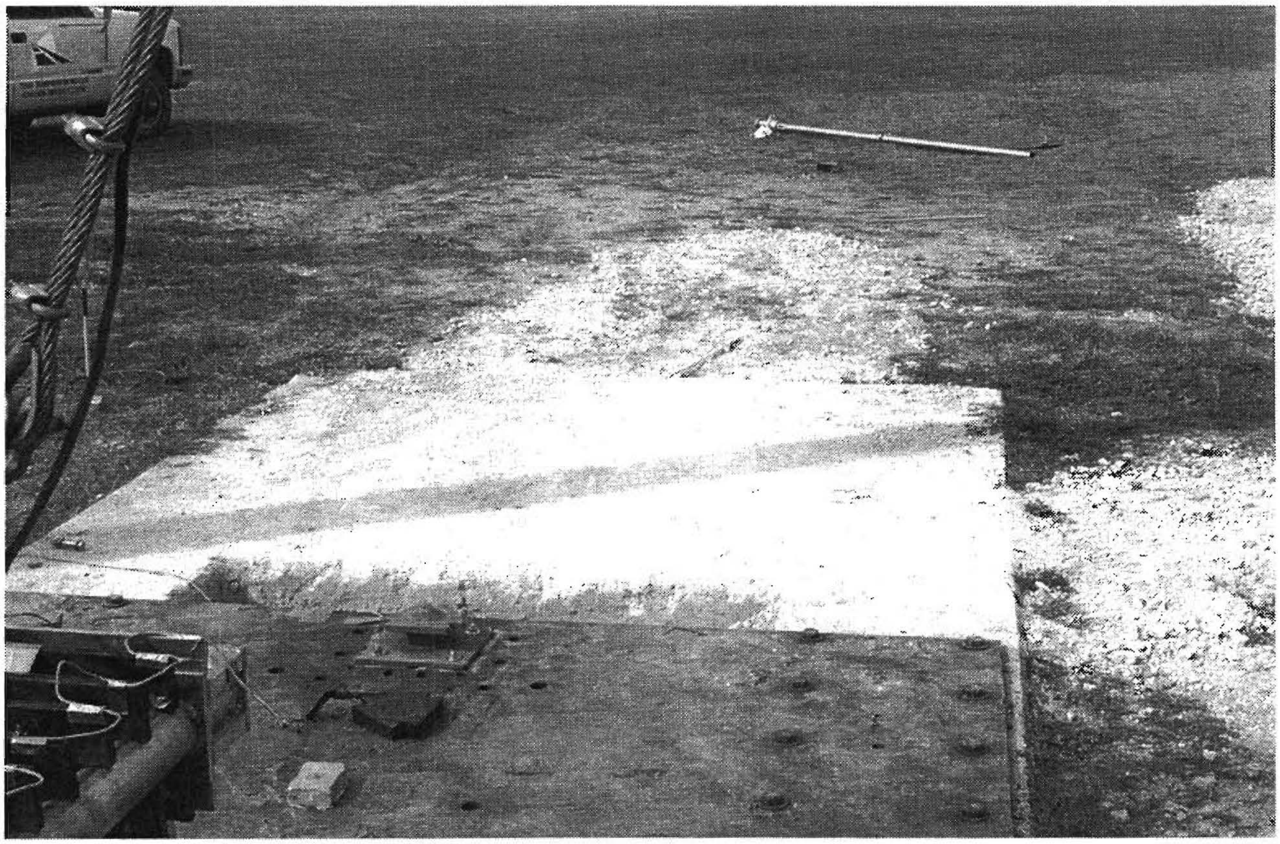


Figure 39. After Impact Trajectory for Test 417929-P4.

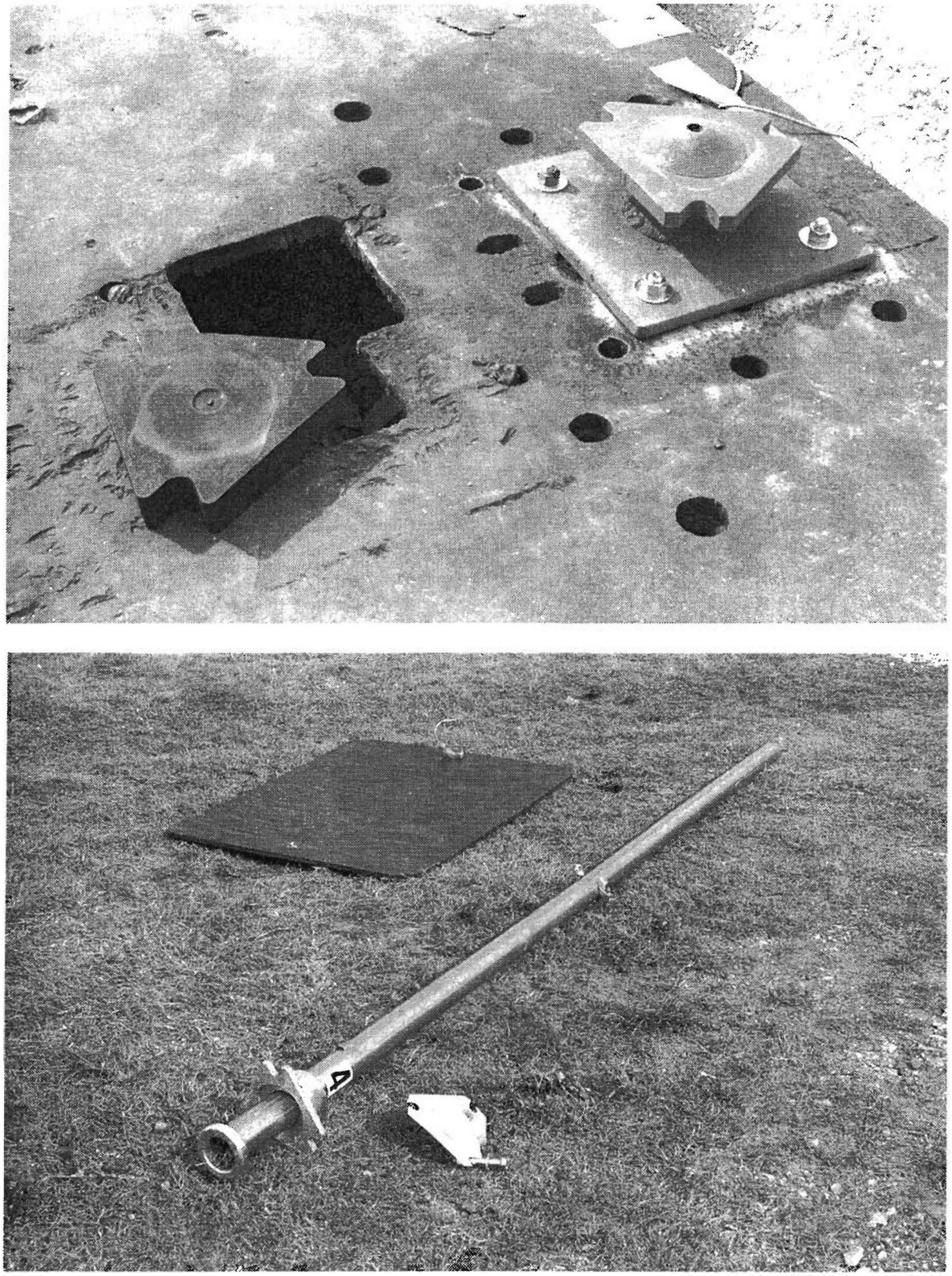
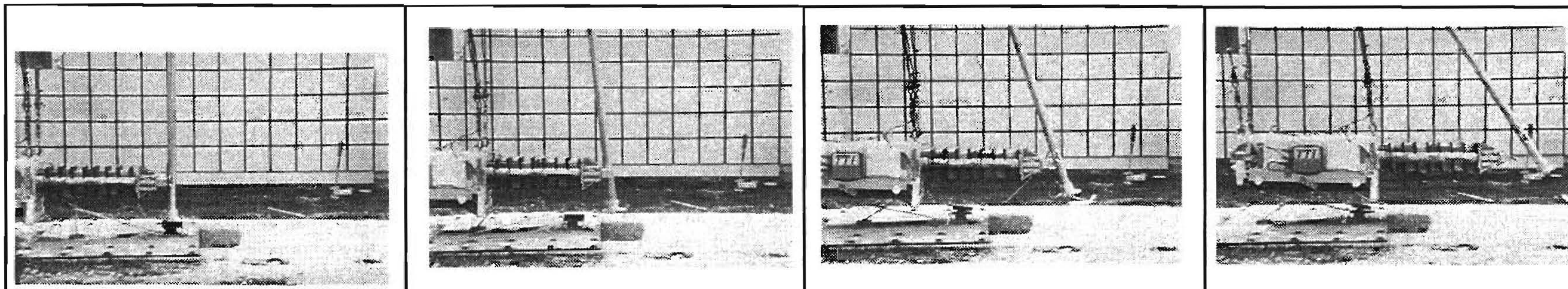


Figure 40. Slip Base Sign Support after Test 417929-P4.

Figure 41. Bolts and Keeper Plate Damage after Test 417929-P4.



0.000 s | 0.040 s | 0.080 s | 0.130 s

General Information

Test Agency	Texas Transportation Institute
Test No.	417929-P4
Date	03/11/99

Test Article

Type	Sign Support
Name	Slip Base Sign Support
Installation Height (m)	2.1 m (7.0 ft)
Material or Key Elements	Lifting cone with plastic spacer, with a black, six-sided one-piece open locking ring, torqued to 61 N·m (45 ft·lb) 30 gauge keeper plate, three 16 mm diameter x 102 mm (5/8 in. diameter x 4 in.) grade 5 bolts torqued to 136 N·m (100 ft·lbs, w/ a 1.0 m x 1.2 m x 16 mm (3 ft x 4 ft x 5/8 in.) plywood sign panel mounted at 2.1 m (7.0 ft)

Soil Type	Steel Plate

Test Vehicle

Type	Bogie
Designation	Pendulum
Test Inertial Mass	839 kg

Impact Conditions

Speed (km/h)	36.4 (22.6 mi/h)
Angle (deg)	0

Occupant Risk Values

Occupant Impact Velocity (m/s)	
x-direction	No contact
Ridedown Acceleration (g's)	
x-direction	No contact
Max. 0.050-s Average (g's)	
x-direction	-0.8
Max. Change in Velocity (m/s)	0.6 (2.0 ft/s)

Figure 42. Summary of Results for Test 417929-P4.

FULL-SCALE CRASH TESTING

Given the favorable results of the pendulum tests, the impact performance of a slip base sign support with higher slip bolt torque was further evaluated through full-scale crash testing. All test and evaluation procedures were in accordance with the recommended guidelines contained in *NCHRP Report 350*.[2] For breakaway support structures, *NCHRP Report 350* recommends a low-speed (35 km/h) and high-speed (100 km/h) test with an 820 kg (1800 lb) passenger car. Further details of the crash test procedures are provided in Appendix B. Details of the evaluation criteria used to assess the results of the tests are described in Chapter II.

Low-Speed Test (Test No. 417929-6, *NCHRP Report 350* Test No. 3-60)

The purpose of this test was to verify the dynamic impact performance of the standard TxDOT slip base system with the slip bolts tightened to a torque of 136 N·m (100 ft·lbs). A secondary objective was to investigate the crashworthiness and reusability of a new plastic substrate for stop signs that TxDOT was evaluating.

Test Article

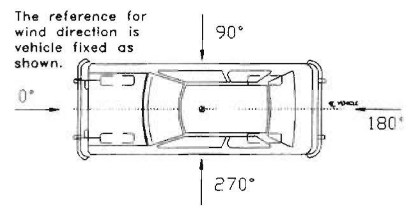
The test installation for the full-scale crash tests was similar to that used in the pendulum tests and conformed to a TxDOT Type A sign installation as shown on the standard sign mounting details for small roadside signs (SMD (1-1)-98). The support post was a 73 mm (2.875 in.) O.D. schedule 10 steel tube, which was cold formed from high strength steel sheet having a yield strength of 379 MPa (55,000 psi). This support was considered to be more discerning in terms of evaluating the activation of the slip base than the schedule 80 pipe due to the potential for the thin-wall support to collapse or buckle during impact if the activation forces are excessive. A 762 mm (30 in.) x 762 mm (30 in.) plastic octagon-shaped stop sign was attached to the schedule 10 support post at a mounting height of 2.1 m (7 ft) using two standard pipe mounting clamps.

The sign support installation was mounted on a triangular slip base. The upper slip base assembly consisted of an integral collar and triangular base plate cast from ASTM A536 Grade 65-45-12 ductile iron. The collar was slipped on to the end of the schedule 10 support. To prevent the casting from slipping off during an impact, a 73 mm (2.875 in.) diameter zinc-plated, split-ring shaft collar was attached flush with the end of the support post and tightened to a torque of 61 N·m (45 ft·lb).

The flat, lower slip base plate was welded to a 76 mm (3 in.) diameter pipe stub that was embedded in a 305 mm (12 in.) diameter by 1.07 m (42 in.) deep concrete footing installed in *NCHRP Report 350* standard soil. The distance from the ground surface to the top face of the permanent lower triangular slip plate was 76 mm (3 in.). The triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. A 30 ga. galvanized steel keeper plate was placed between the upper and lower slip plates. The three 16 mm (0.63 in.) diameter x 64 mm (2.5 in.) long A325 bolts were then torqued to 136 N·m (100 ft·lbs). High-strength washers were used under both the head and nut of each bolt. Additional details of the installation are shown in figure 43. Photographs of the completed sign support installation are shown in figure 44.

Test Description

The test was performed the morning of April 27, 1999. A total of 28 mm (1.1 in.) of rain was recorded one day prior to the test. No other rainfall occurred within 10 days prior to the test. The *NCHRP Report 350* standard soil in which the sign support was installed was moistened slightly just prior to the test to settle the dust and ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 8 km/h (5 mi/h); wind direction: 190 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 23 °C (74 °F); relative humidity: 69 percent.



A 1994 Geo Metro, shown in figures 45 and 46, was used for the crash test. 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 370 mm (14.6 in.), and it was 450 mm (17.7 in.) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, figure 100. 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.

The vehicle impacted the sign support head-on at a speed of 34.7 km/h (21.6 mi/h). Movement of the support post was observed shortly after impact. At 0.017 s, the slip base began to activate, and by 0.030 s, the post had lost contact with the lower slip base foundation plate. The vehicle was traveling at 33.2 km/h (20.6 mi/h) as it initially lost contact with the post at 0.047 s. The sign panel on the rotating support post impacted the upper portion of the windshield at 0.241 s and subsequently shattered the windshield. By 0.310 s, the post rebounded off the vehicle, leaving the reflective portion of the sign panel in contact with the windshield. Brakes on the vehicle were applied at 3.1 s, and the vehicle came to rest 29.7 m (97.4 ft) downstream from the impact point. Sequential photographs of the test are presented in Appendix D, figure 96.

Damage to Test Installation

Damage to the test installation is shown in figures 47 and 48. The upper slip base casting and split ring locking collar remained attached to the support post as intended. There was no observable deformation to the support post and the slip base assembly and post were considered reusable. The plastic sign substrate separated into several pieces as shown in figures 49 and 50. The reflective portion of the sign panel separated from the backing and was broken. The top edge of the backing of the sign panel was cracked. The post and sign panel backing came to rest 33.5 m (109.9 ft) downstream from the point of impact. The remaining debris was scattered 4.6 m (15.1 ft) to the left and 4.6 m (15.1 ft) to the right of the impact point.

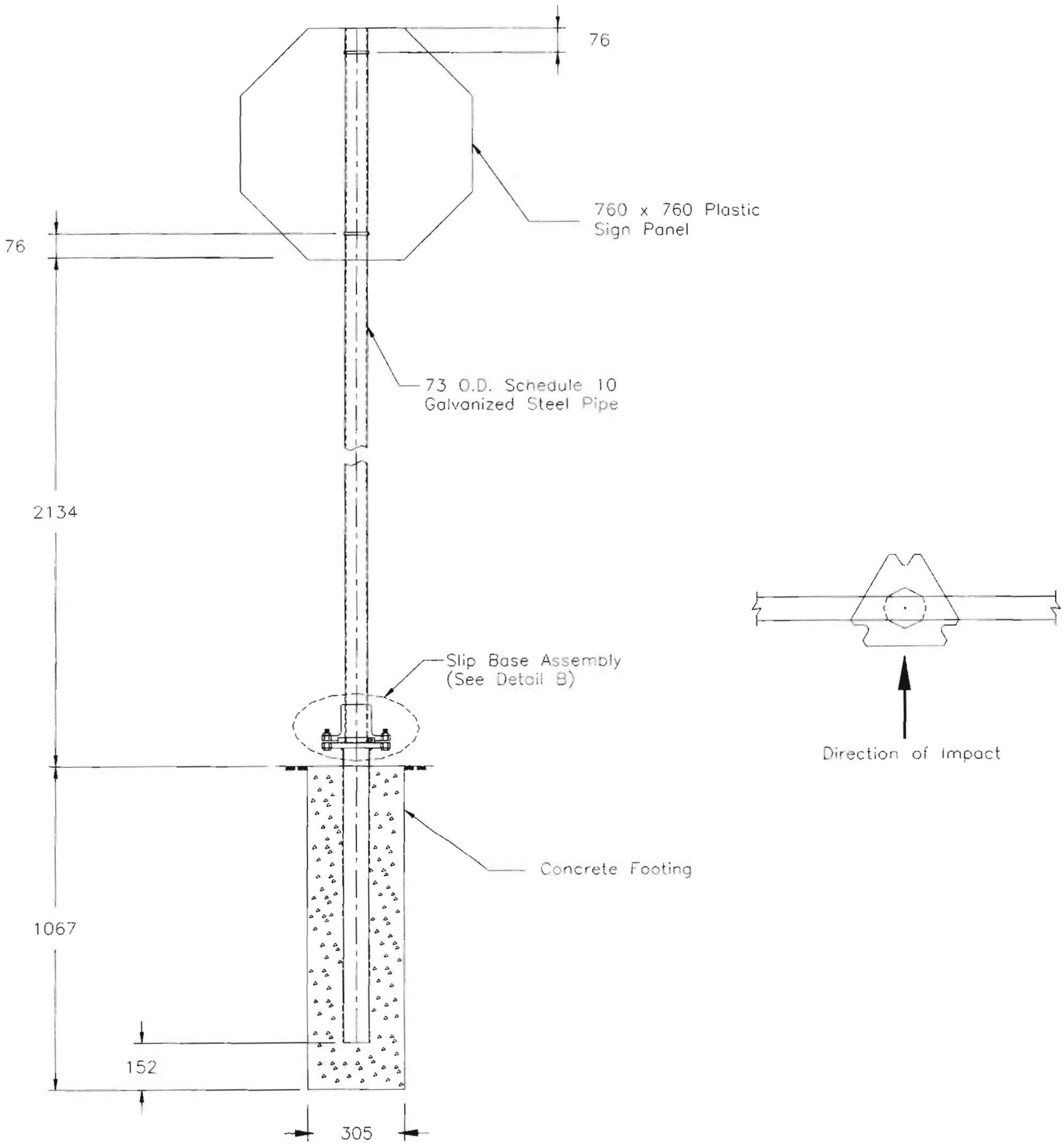


Figure 43. Details of Installation for Test 417929-6.

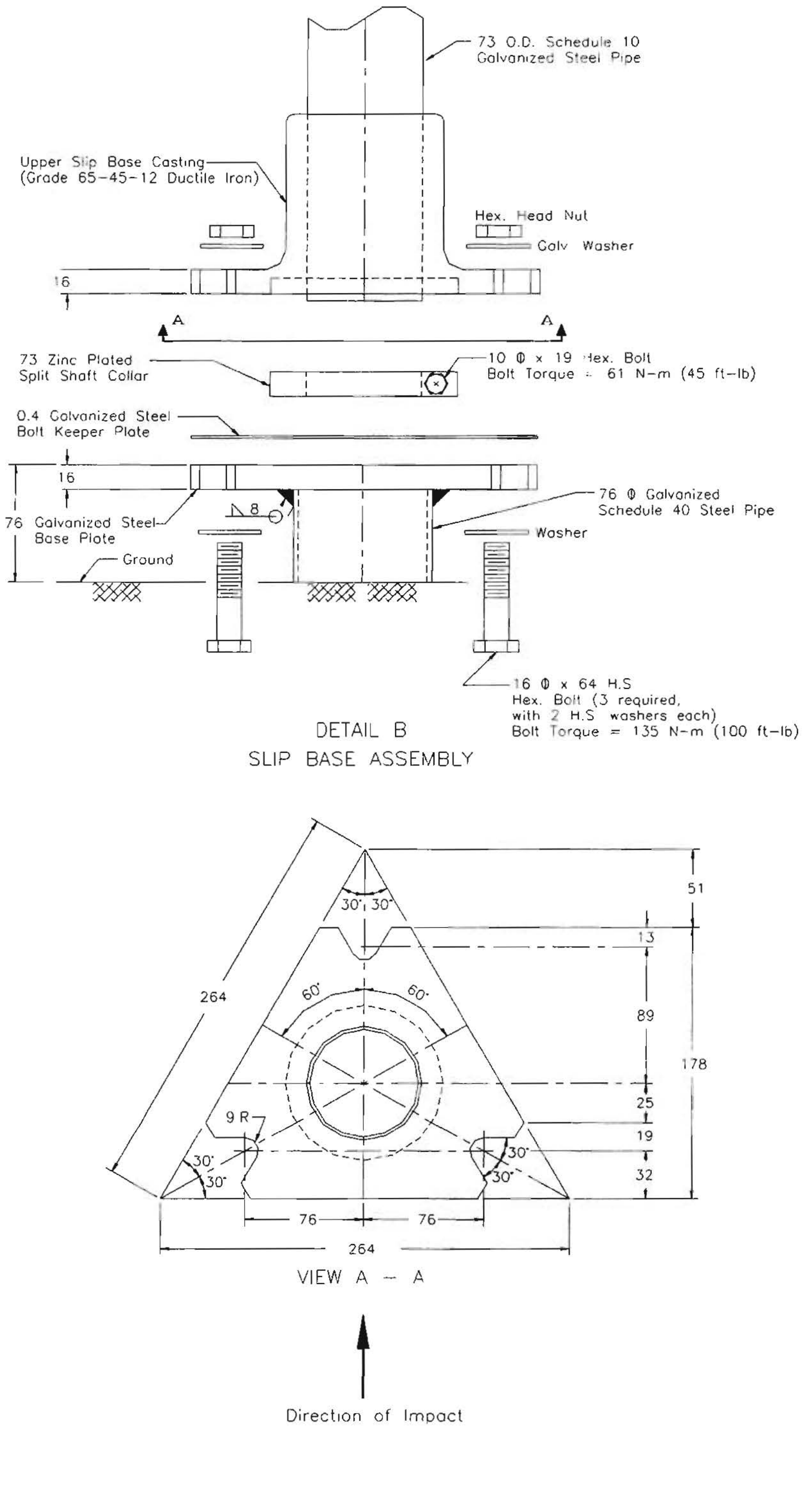


Figure 43. Details of Installation for Test 417929-6 (Continued).

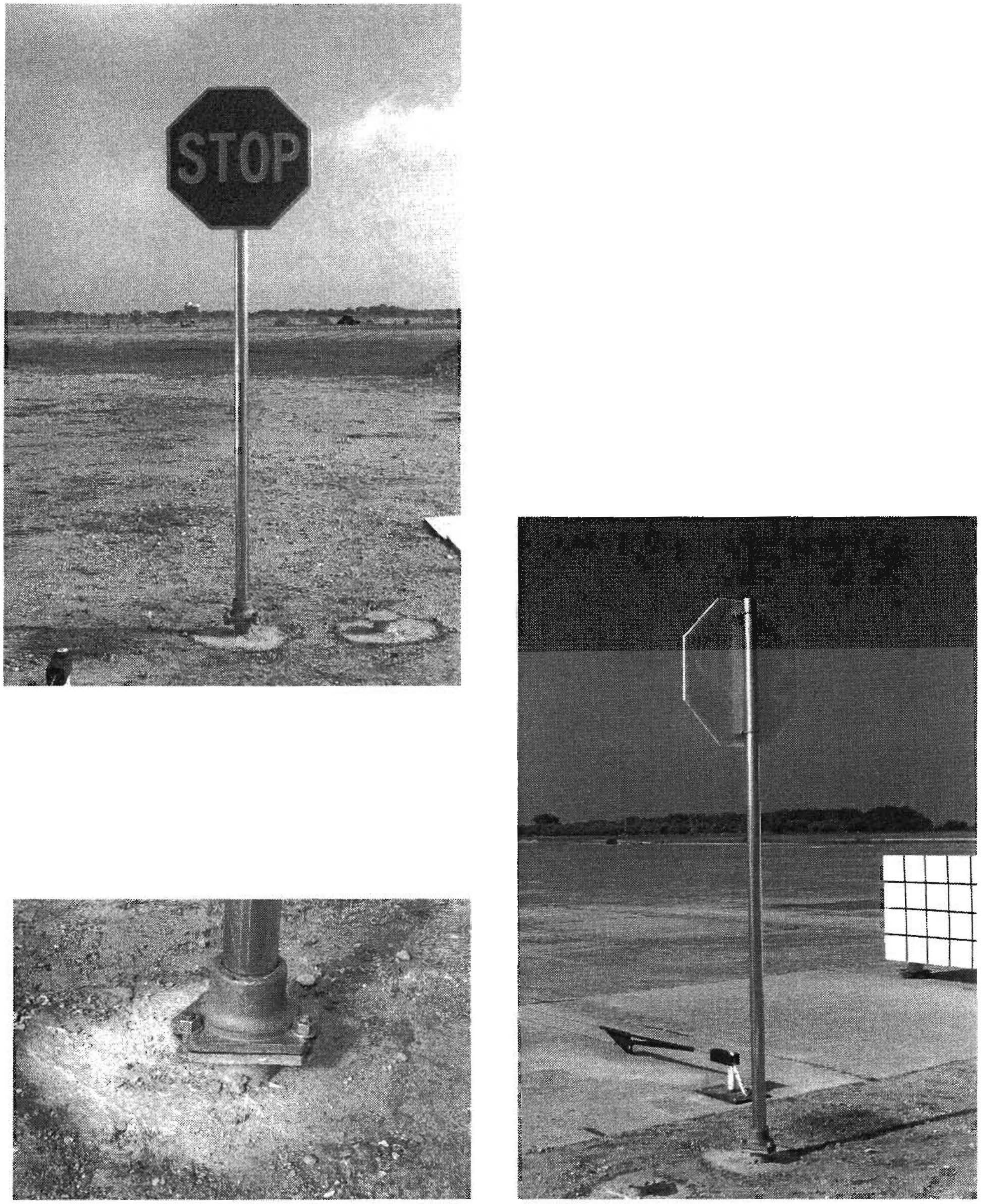


Figure 44. Single Slip Base Steel Sign Support with Concrete Footing before Test 417929-6.

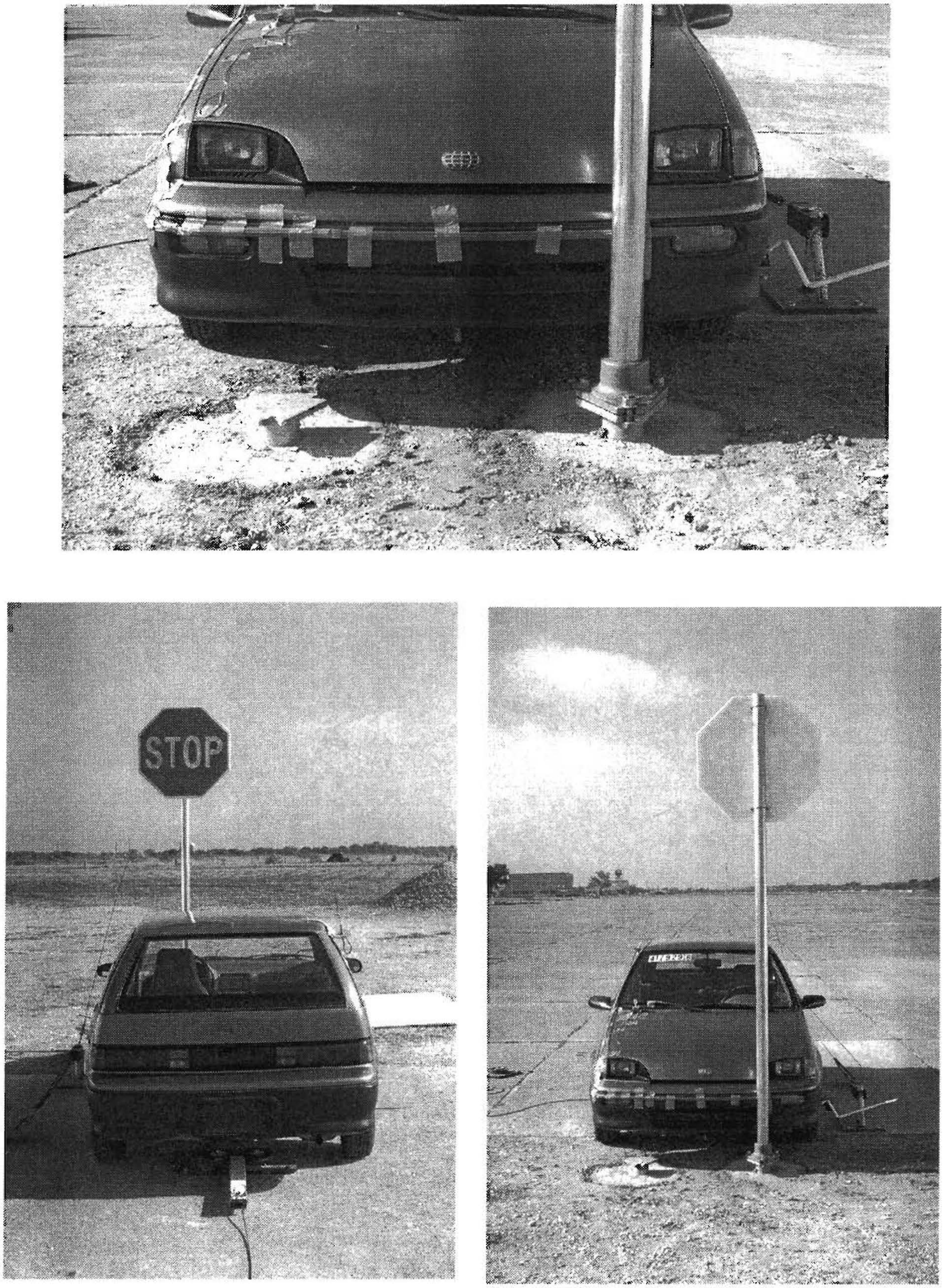


Figure 45. Vehicle/Installation Geometrics for Test 417929-6.

Figure 46. Vehicle before Test 417929-6.

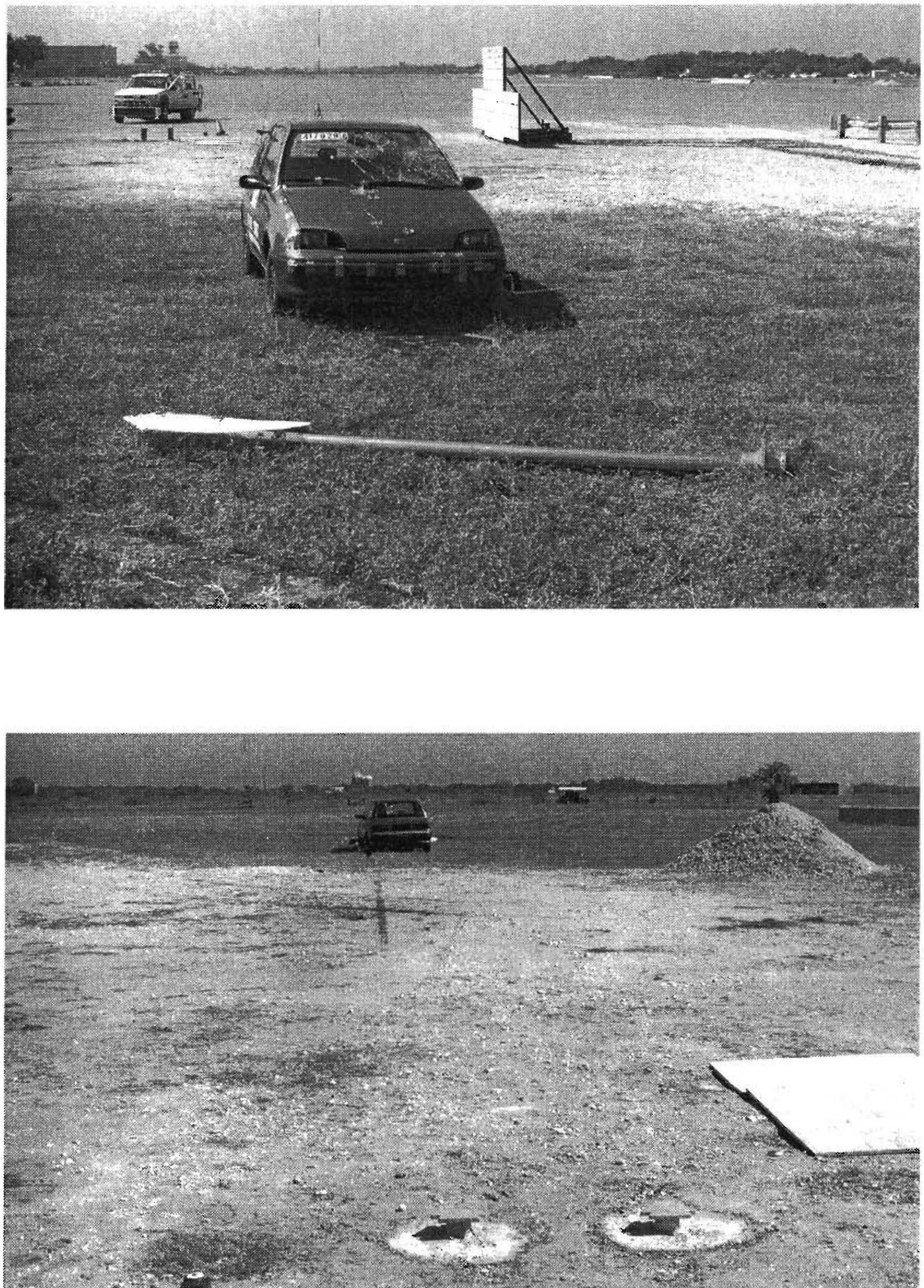


Figure 47. After Impact Trajectory for Test 417929-6.

Figure 48. Installation after Test 417929-6.

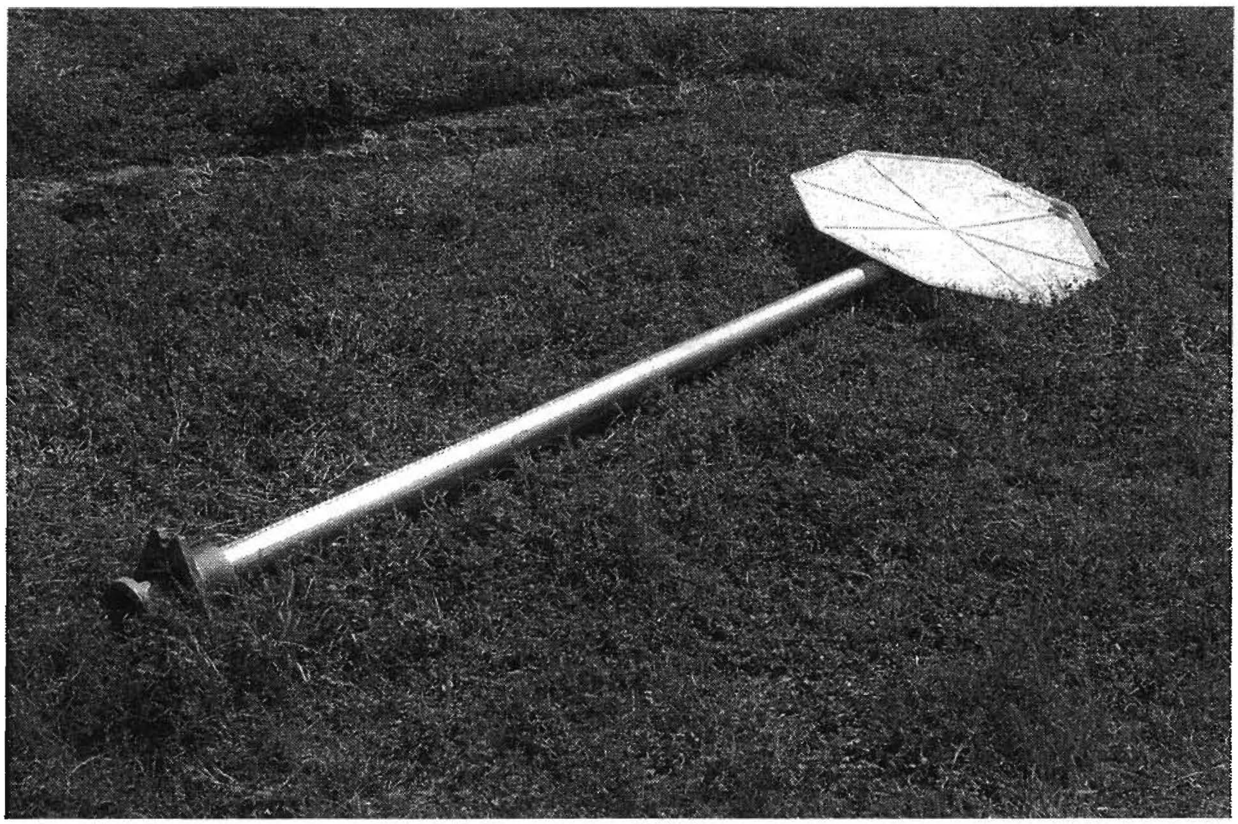


Figure 49. Damage to Plastic Sign Substrate.

Figure 50. Separation of Plastic Sign Substrate.

Vehicle Damage

Damage to the vehicle is shown in figure 51. The vehicle received minimal damage to the front end and bumper. The windshield was shattered and deformed inward by the sign panel and schedule 10 support post. Glass was sprayed into the occupant compartment. The interior of the vehicle is shown in figure 52.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, no occupant contact occurred and the maximum 0.050 s average acceleration was -1.1 g's between -0.011 and 0.039 s. In the lateral direction, no occupant contact occurred and the maximum 0.050 s average was -0.4 g's between 0.053 and 0.103 s. These data and other pertinent information from the test are summarized in figure 53. Vehicle angular displacements are shown in Appendix F, figure 102, and vehicle accelerations versus time traces are presented in Appendix G, figures 106 through 108.

Summary

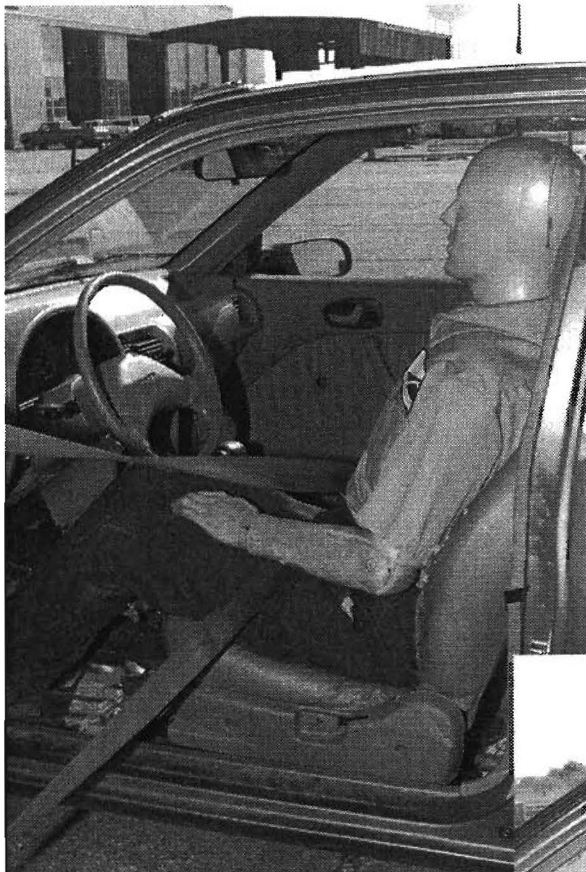
An assessment of the results for Test No. 417929-6 is shown in Table 2. Although the slip base activated, the schedule 10 support and 762 mm (30 in.) x 762 mm (30 in.) plastic octagon-shaped stop sign rotated into the windshield. This contact caused the windshield to shatter and deform inward. Glass shards were sprayed into the occupant compartment. This performance was considered to be marginal. Additional assessment of the test based on the 1994 AASHTO specifications[1] and supplemental evaluation factors that were recommended in an FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features" are presented in Appendix H.

Discussion

As noted above, this low-speed test (Test No. 417929-6) was marginal due to the windshield damage that occurred as a result of the secondary contact of the sign panel and support post with the windshield of the test vehicle. However, this behavior did not appear to be influenced by the activation of the slip base. In fact, there was no occupant contact with the interior passenger compartment, and the schedule 10 sign support did not have any permanent deformation, both of which are indicative of low-level activation forces. It was theorized that the trajectory of the support post may have been affected by the size and mass of the plastic sign substrate used in the test. A decision was made to conduct the planned high-speed test with a more common sign substrate.

Figure 51. Vehicle after Test 417929-6.

Before test



After test

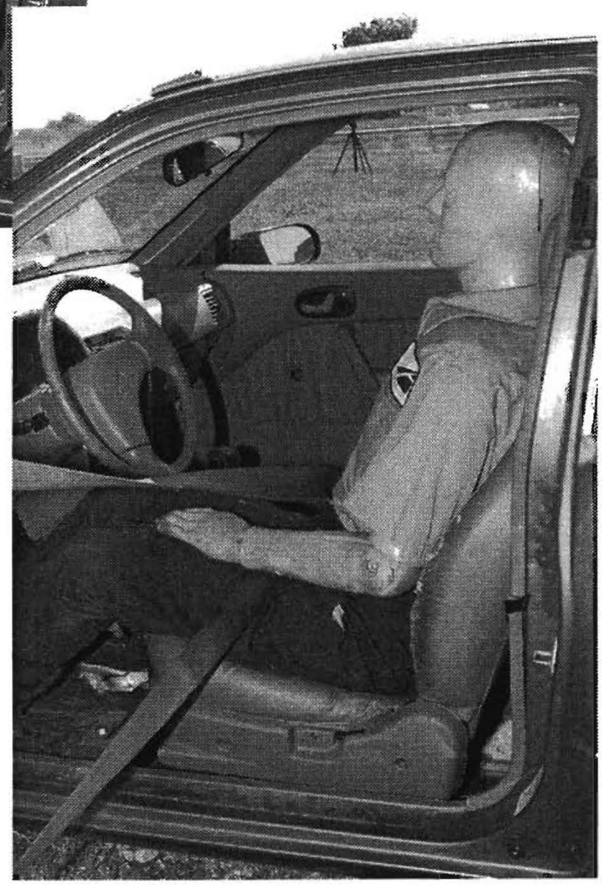
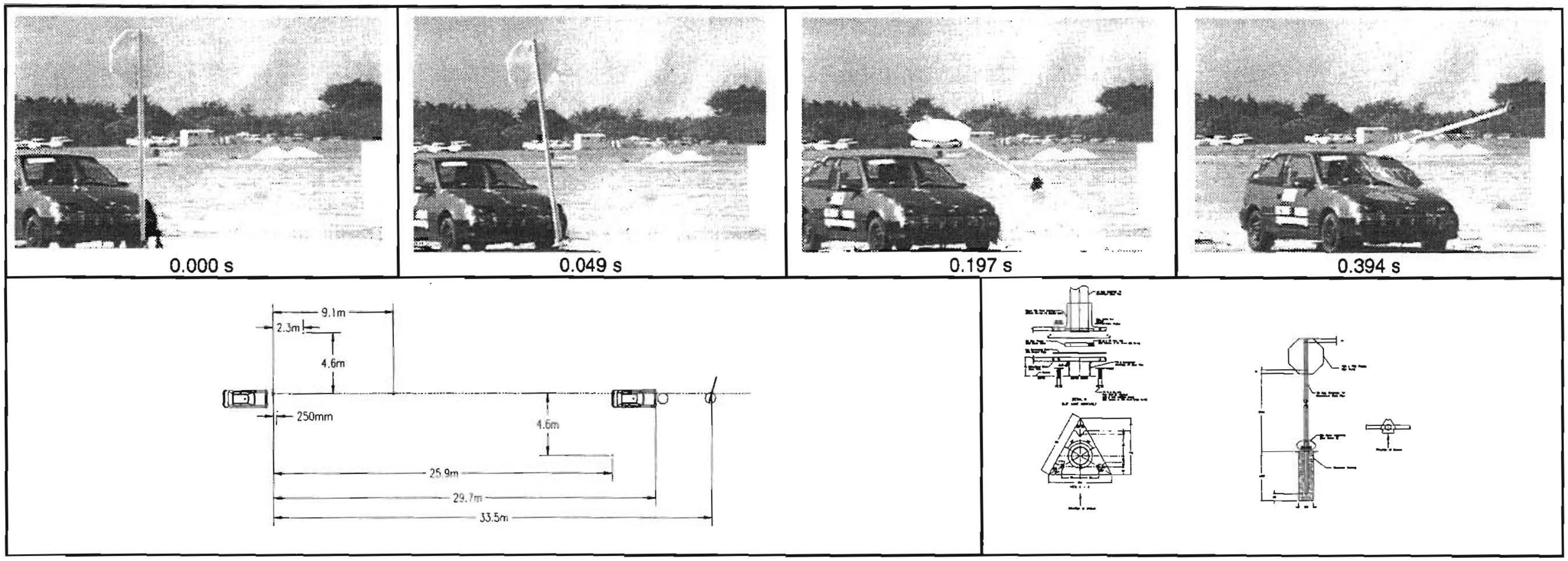


Figure 52. Interior of Vehicle for Test 417929-6.



General Information
Test Agency .... Texas Transportation Institute
Test No. 417929-6
Date 04/27/99
Test Article
Type .... Sign Support
Name .... Single Slip-Base Sign w/Plastic Sign Panel
Installation Height (m) ..... 2.1 (7.0 ft)
Material or Key Elements ... Single Steel Post w/760 x 760 mm (30 in x 30 in.) Plastic Sign, Mounted at 2.1 m (7.0 ft)
Soil Type and Condition .... Concrete Footing, Dry
Test Vehicle
Type .... Production
Designation 820C
Model .... 1994 Geo Metro
Mass (kg)
Curb .... 763 (1682 lb)
Test Inertial .... 820 (1806 lb)
Dummy .... 76 (168 lb)
Gross Static .... 896 (1974 lb)

Impact Conditions
Speed (km/h) .... 34.7 (21.6 mi/h)
Angle (deg) 0
Exit Conditions
Speed (km/h) .... 31.6 (19.6 mi/h)
Angle (deg) 0
Occupant Risk Values
Impact Velocity (m/s)
x-direction .... No contact
y-direction .... No contact
THIV (km/h) .... N/A
Ridedown Accelerations (g's)
x-direction .... N/A
y-direction .... N/A
PHD (g's) .... N/A
ASI 0.09
Max. 0.050 s Average (g's)
x-direction .... -1.0
y-direction .... -0.4
z-direction .... -0.4
Max. Change in Velocity (m/s) 0.9 (3.0 ft/s)

Test Article Deflections (m)
Longitudinal .... 33.5 (109.9 ft)
Lateral .... 4.6 (15.1 ft)
Vehicle Damage
Exterior
VDS 12FD3
CDC .... N/A
Maximum Exterior
Vehicle Crush (mm) ...... nil
Interior
OCDI FS0000000
Max. Occ. Compart.
Deformation (mm) .... nil
Post-Impact Behavior
(during 1.0 s after impact)
Max. Yaw Angle (deg) ...... -1
Max. Pitch Angle (deg) ...... -1
Max. Roll Angle (deg) .... -1

Figure 53. Summary of Results for Test 417929-6, *NCHRP Report 350* Test 3-60.

Table 2. Performance Evaluation Summary for Test 417929-6, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 417929-6 | Test Date: 04/27/99

<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 single slip base sign support with concrete footing slipped away and thereby met the requirements for structural adequacy by yielding to the vehicle.</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 sign panel shattered and deformed the windshield inward (Class 4), but did not penetrate the occupant compartment. Tiny glass shards were found on the interior.</td><td>Marginal 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 period.</td><td>Pass</td></tr>
<tr><td colspan="3">H. Occupant impact velocities should satisfy the following:</td><td rowspan="4">There was no contact in the longitudinal direction.</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">There was no contact in the longitudinal direction.</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</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 traveled in a straightforward manner and came to rest 29.7 m (97.4 ft) directly behind the sign support.</td><td>Pass</td></tr>
<tr><td colspan="3">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>

High-Speed Test (Test No. 417929-7, *NCHRP Report 350* Test No. 3-61)

The purpose of this test was to verify the dynamic impact performance of the standard TxDOT slip base system with a schedule 10 support with the slip bolts tightened to a torque of 136 N·m (100 ft·lb) when impacted at high speed.

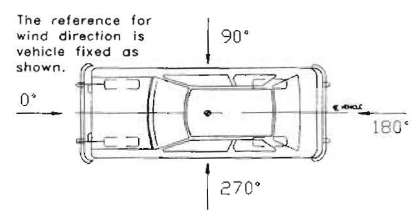
Test Article

The test installation used for this test was identical to that used in the previous test (test 417929-6), except for the sign panel. A 914 mm (36 in.) × 914 mm (36 in.) × 16 mm (5/8 in.) thick plywood sign panel was mounted to the 73 mm (2.875 in.) O.D. schedule 10 steel tube in a diamond configuration using two standard pipe mounting clamps. The mounting height from the ground to the bottom of the sign panel was 2.1 m (7 ft). As in the previous test, the three slip bolts were tightened to a torque of 136 N·m (100 ft·lb).

Additional details of the sign support installation used for this test are shown in figure 54. Photographs of the completed test installation are shown in figure 55.

Test Description

The test was performed the afternoon of April 27, 1999. A total of 28 mm (1.1 in.) of rain was recorded one day prior to the test. No other rainfall occurred during the 10 days preceding the test. The *NCHRP Report 350* standard soil in which the sign support foundation was installed was moistened slightly just prior to the test to settle the dust and ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 10 km/h (6 mi/h); wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 33 °C (92 °F); relative humidity: 30 percent.



A 1994 Geo Metro, shown in figures 56 and 57, was used for the crash test. 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 370 mm (14.6 in.), and it was 450 mm (17.7 in.) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, figure 100. 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.

The vehicle impacted the sign support head-on at a speed of 99.3 km/h (61.7 mi/h). At 0.010 s, the slip base began to activate, and by 0.020 s, the support post had lost contact with the lower slip plate. At 0.030 s, the sign panel began to slide off the post, and by 0.047 s, the upper sign mounting bracket had slipped off the top of the support post. The vehicle lost contact with the support post at 0.054 s while traveling at a speed of 94.1 km/h (58.5 mi/h). At 0.128 s, the lower sign mounting bracket failed and the sign panel separated from the support post. At

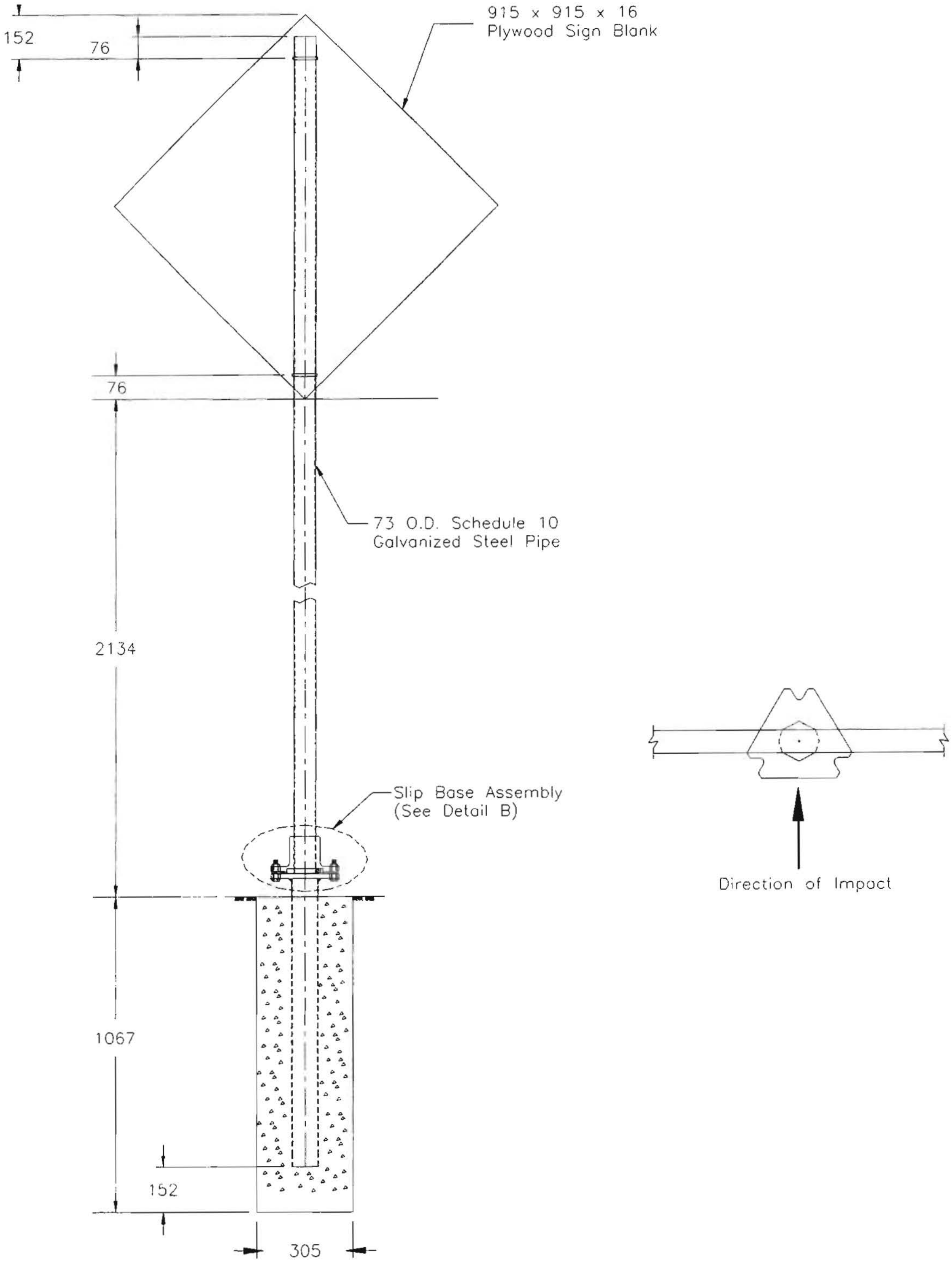


Figure 54. Details of Test Installation for 417929-7.

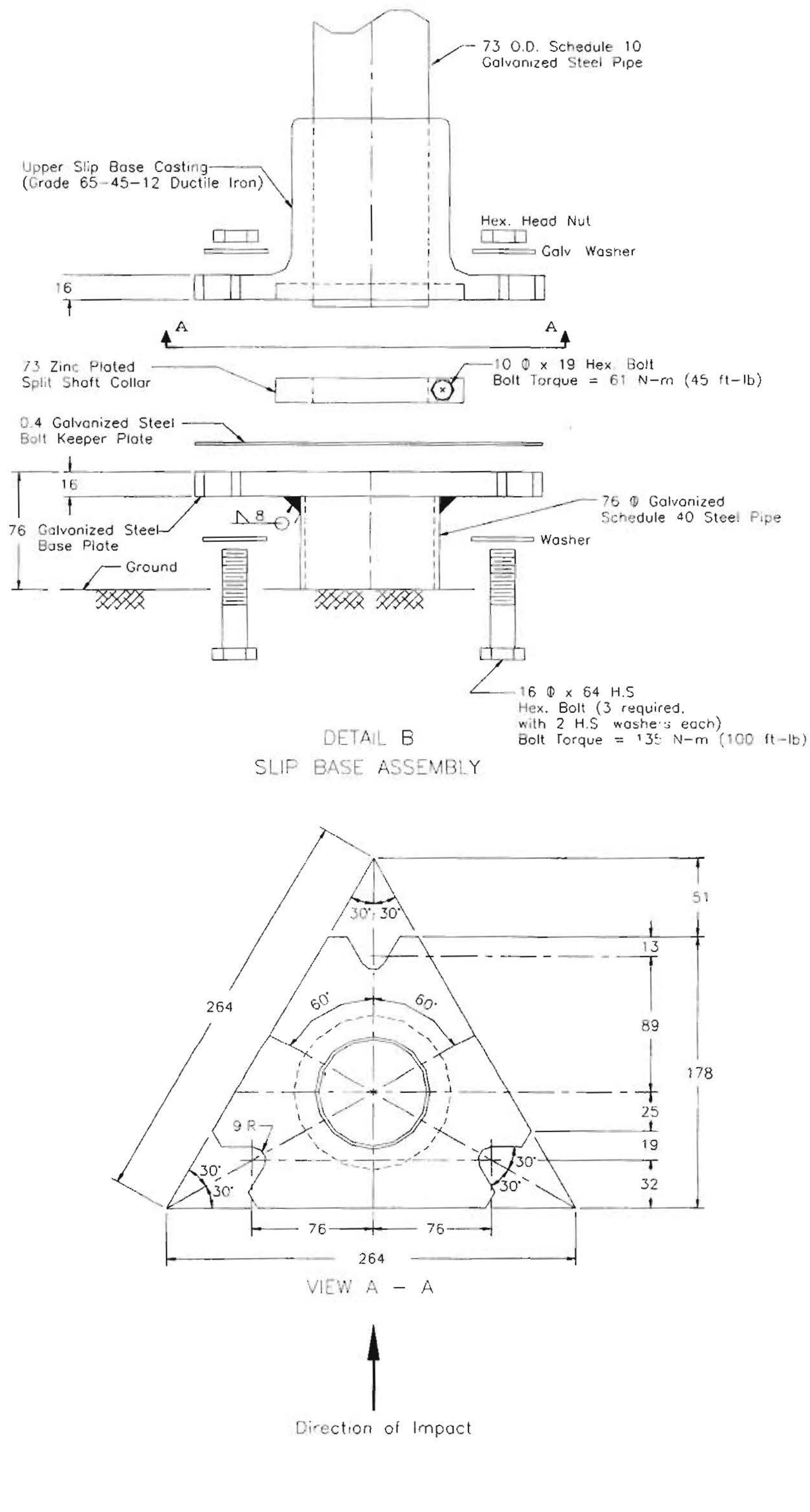


Figure 54. Details of Test Installation for 417929-7 (Continued).

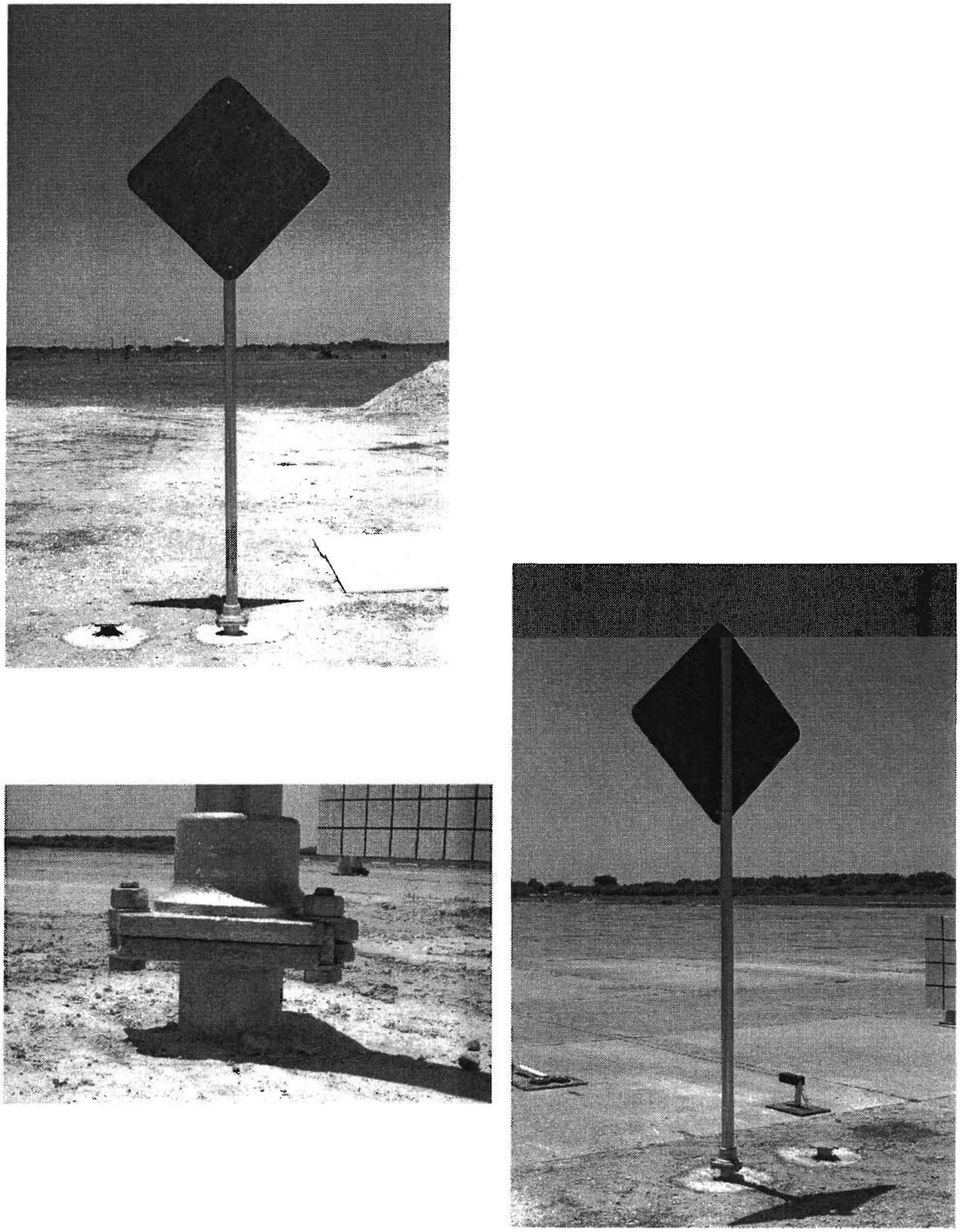


Figure 55. Single Slip Base Steel Sign Support with Concrete Footing before Test 417929-7.

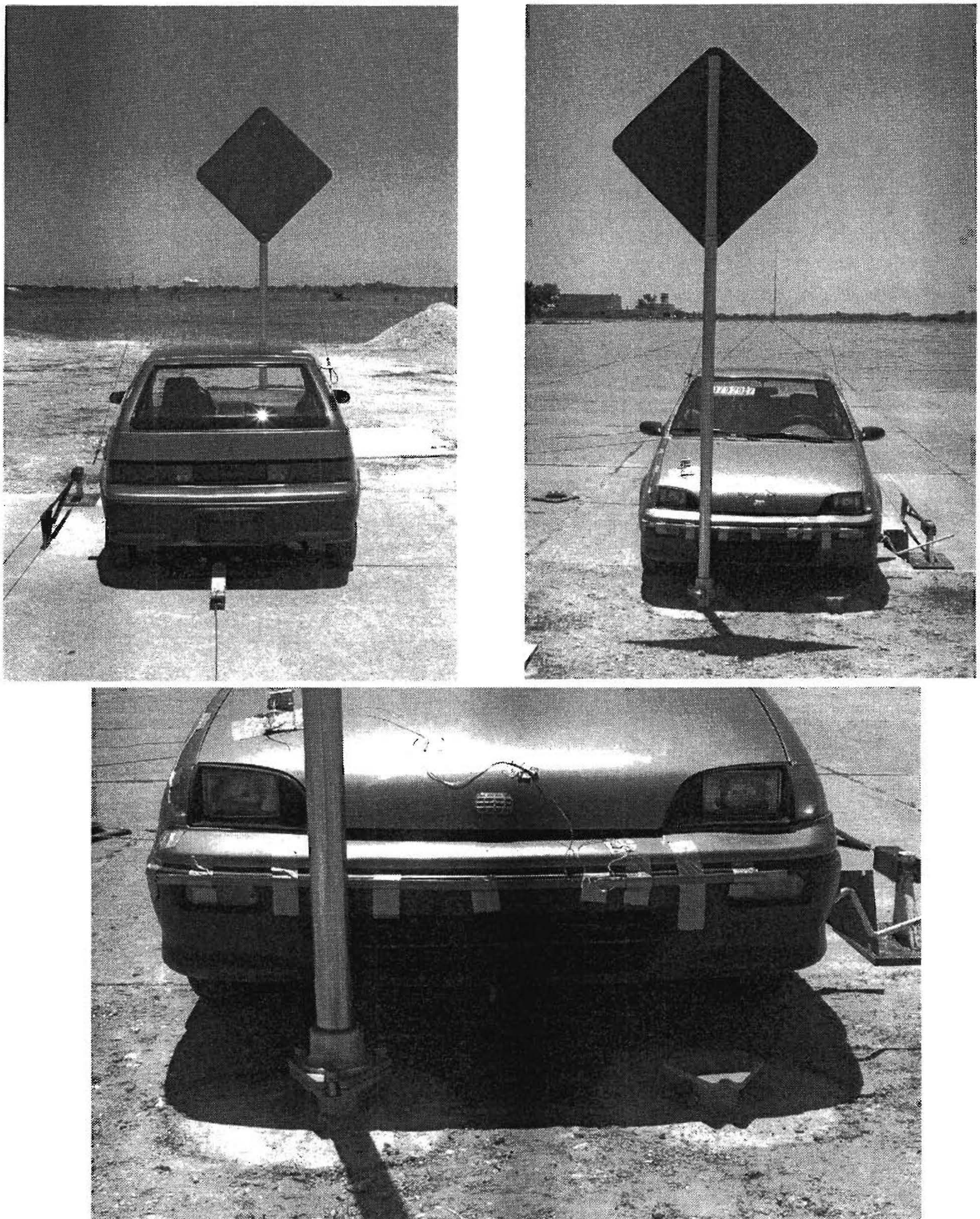


Figure 56. Vehicle/Installation Geometrics for Test 417929-7.

Figure 57. Vehicle before Test 417929-7.

0.148 s, the rotating support post contacted the roof of the vehicle, and at 0.153 s, the post was parallel to the ground. At 0.185 s, the post lost contact with the roof of the vehicle, and the vehicle was traveling at a speed of 93.8 km/h (58.3 mi/h). Brakes on the vehicle were applied at 1.63 s, and the vehicle subsequently came to rest 112.8 m (370.1 ft) downstream from the point of impact. Sequential photographs of the test can be found in Appendix D, figure 97.

Damage to Test Installation

Damage to the sign support installation is shown in figures 58 and 59. The split ring locking collar and upper slip base casting remained on the support post. The support post received a slight amount of permanent deformation. The sign panel separated from the support post and one of the sign mounting clamp castings was broken. The sign panel came to rest at the point of impact, and the remaining debris was scattered 68.6 m (225.1 ft) downstream from impact, 6.1 m (20.0 ft) to the right of impact, and 5.3 m (17.4 ft) to the left of impact.

Vehicle Damage

Damage to the test vehicle is shown in figure 60. The bumper, hood, grill, fan, radiator and radiator support were deformed. The roof was deformed, and the center of the windshield was cracked near the roof edge from the secondary contact of the support post. Maximum exterior crush to the right front inner bumper was 130 mm (5.1 in.), and deformation to the roof of the vehicle consisted of a dent that measured 1.3 m (4.3 ft) in length by 65 mm (2.6 in.) deep. Maximum occupant compartment deformation was 47 mm (2.0 in.) in the center of the roof area. Exterior crush measurements and occupant compartment measurements are shown in Appendix E, tables 6 and 7. The interior of the vehicle is shown in figure 61.

Occupant Risk Factors

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 1.0 m/s (3.3 ft/s) at 0.687 s, the highest 0.010 s occupant ridedown acceleration was -0.2 g's from 0.917 to 0.927 s, and the maximum 0.050 s average acceleration was -1.8 g's between 0.003 and 0.053 s. In the lateral direction, the occupant impact velocity was 0.9 m/s (3.0 ft/s) at 0.687 s, the highest 0.010 s occupant ridedown acceleration was 0.3 g's from 0.955 to 0.965 s, and the maximum 0.050 s average was 0.3 g's between 0.225 and 0.275 s. These data and other pertinent information from the test are summarized in figure 62. Vehicle angular displacements are shown in Appendix F, figure 103, and vehicle accelerations versus time traces are presented in Appendix G, figures 109 through 111.

Summary

An assessment of the results for Test No. 417929-7 is shown in Table 3. The slip base with the slip bolts tightened to a torque of 136 N·m (100 ft·lb) activated as designed. Although the sign support contacted the roof of the vehicle, the resulting deformation and occupant

Figure 58. After Impact Trajectory for Test 417929-7.

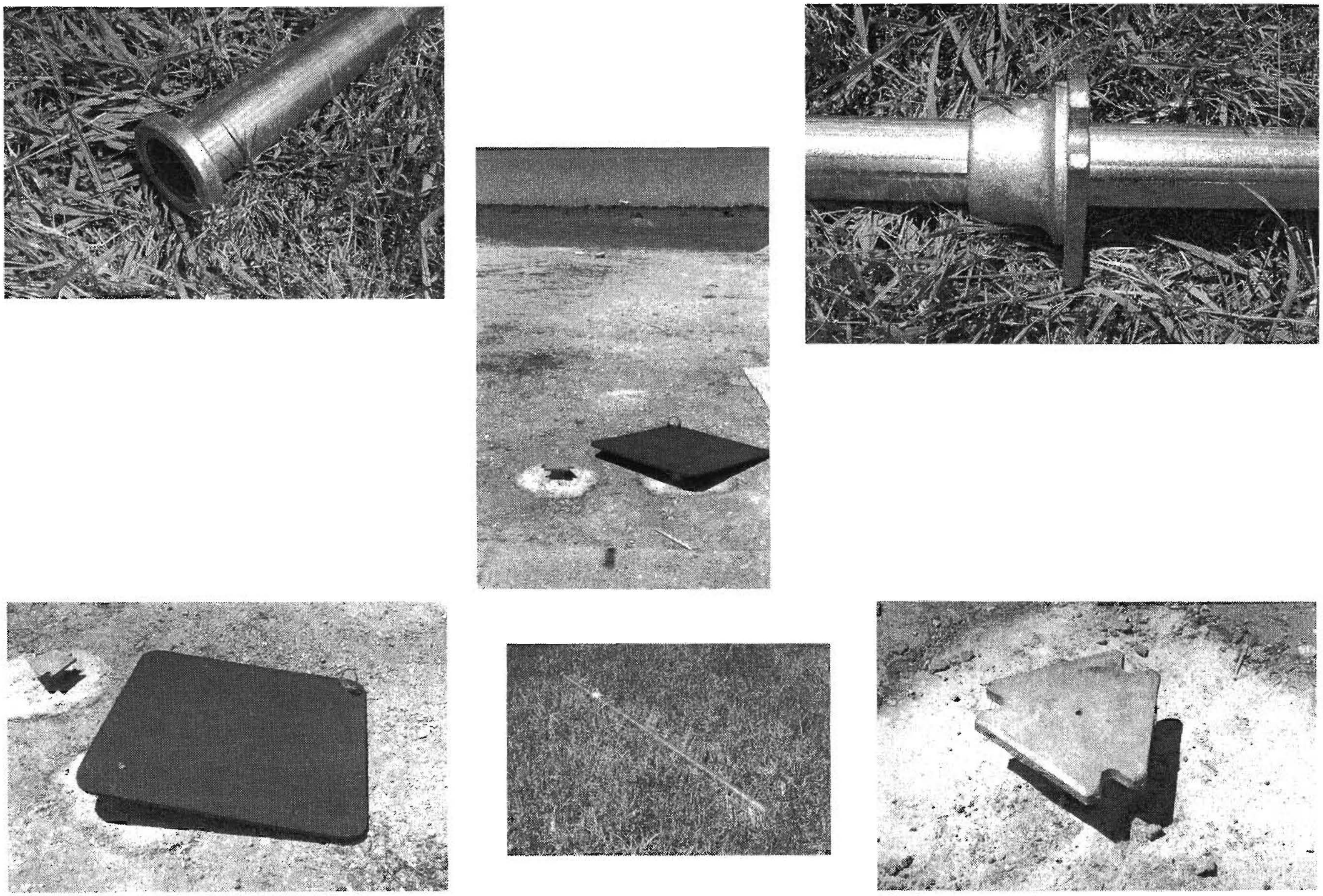
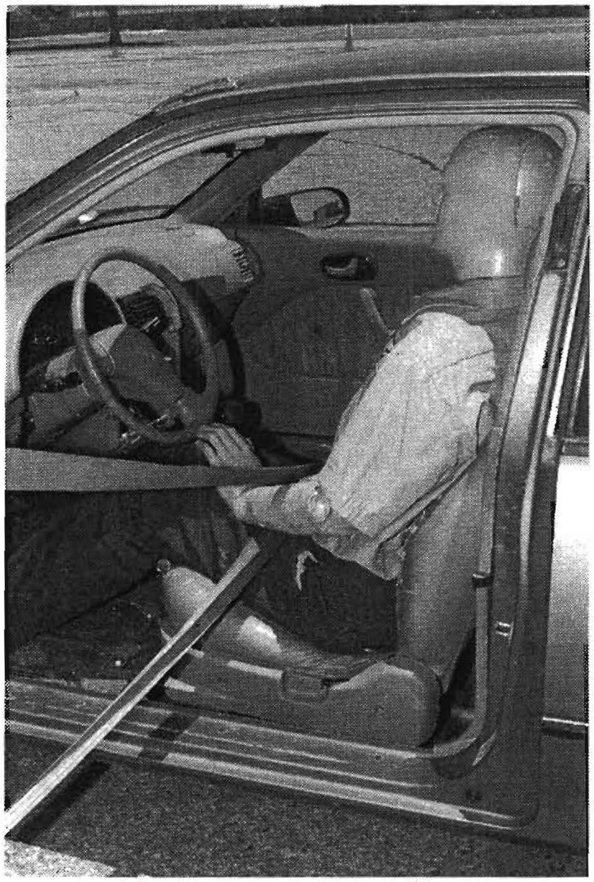
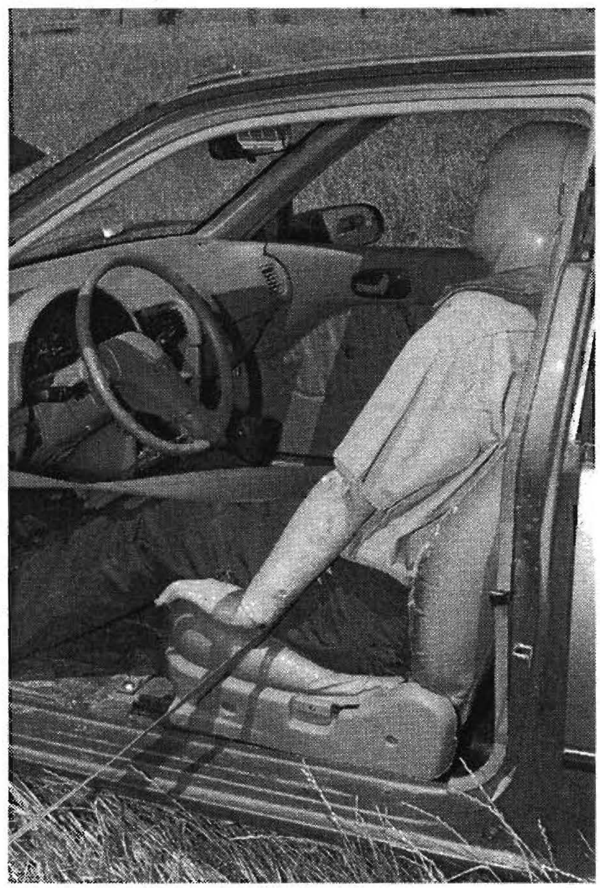


Figure 59. Installation after Test 417929-7.

Figure 60. Vehicle after Test 417929-7.

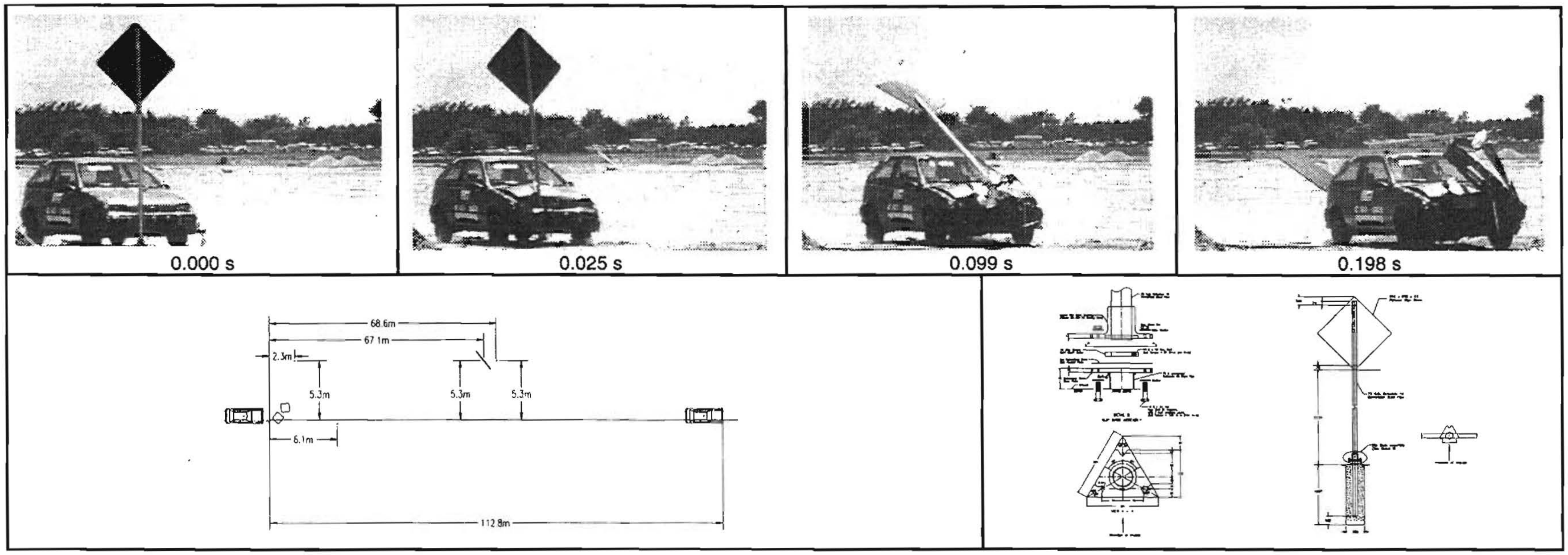


Before test



After test

Figure 61. Interior of Vehicle for Test 417929-7.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-7
Date	04/27/99
Test Article	
Type	Sign Support
Name	Single Slip-Base Sign Support
Installation Height (m)	2.1 (7.0 ft)
Material or Key Elements	Single Steel Post w/ 1225 x 1225 mm (48 x 48 in.) Plywood Sign, Mounted at 2.1 m (7.0 ft)
Soil Type and Condition	Concrete Footing, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (kg)	
Curb	763 (1682 lb)
Test Inertial	820 (1806 lb)
Dummy	76 (168 lb)
Gross Static	896 (1974 lb)

Impact Conditions

Speed (km/h)	99.3 (61.7 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	93.8 (58.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.0 (3.3 ft/s)
y-direction	0.9 (3.0 ft/s)
THIV (km/h)	4.9 (3 mi/h)
Ridedown Accelerations (g's)	
x-direction	-0.2
y-direction	0.3
PHD (g's)	0.5
ASI	0.16
Max. 0.050 s Average (g's)	
x-direction	-1.8
y-direction	0.3
z-direction	-1.0

Test Article Scatter (m)

Longitudinal	68.6 (225.1 ft)
Lateral	6.1 (20.0 ft)
Vehicle Damage	
Exterior	
VDS	12FD3
CDC	12FDEW3
Maximum Exterior Vehicle Crush (mm)	130 (5.1 in.)
Interior	
OCDI	FS0100000
Max. Occ. Compart. Deformation (mm)	47 (2.0 in.)
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	2
Max. Pitch Angle (deg)	7
Max. Roll Angle (deg)	3

Figure 62. Summary of Results for Test 417929-7, *NCHRP Report 350* Test 3-61.

Table 3. Performance Evaluation Summary for Test 417929-7, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 417929-7 | Test Date: 04/27/99

<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 single slip base sign support with concrete footing slipped away and thereby met the requirements for structural adequacy by yielding 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 impact from the post near the roof edge at the center shattered the windshield (Class 6), but did not penetrate the occupant compartment, nor did it present undue hazard to others in the area. Maximum occupant compartment deformation was 47 mm (2.0 in.) (5 percent reduction in space) in the center of the roof 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</td><td>5</td></tr>
</table></td><td>Longitudinal occupant impact velocity was 1.0 m/s (3.3 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 -0.2 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 112.8 m (370.1 ft) directly behind the sign support.</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>

compartment intrusion was not judged to have potential for causing serious injury. The schedule 10 support with 914 mm (36 in.) x 914 mm (36 in.) x 16 mm (5/8 in.) thick plywood sign panel mounted in a diamond configuration passed all *NCHRP Report 350* evaluation criteria for Test Designation 3-61. Additional assessment of the test based on the 1994 AASHTO specifications[1] and supplemental evaluation factors that were recommended in an FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features" are presented in Appendix H.

Discussion

Although the results of the high-speed test (Test No. 417929-7) of the slip base were acceptable for a 914 mm (36 in.) x 914 mm (36 in.) x 16 mm (5/8 in.) thick plywood sign panel, there was concern regarding the marginal performance of the low-speed test. Based on the computed occupant risk indices and damage to the test article, the windshield contact in the test did not appear to be influenced by the higher bolt torque used for the slip bolts. It was theorized that the trajectory of the support post was influenced by the small size and light weight of the plastic sign substrate used in the low-speed test. Traditionally, primarily due to economic considerations, slip base sign supports have only been used for larger signs (e.g., area greater than 1.5 m^2 (16 ft^2)) and their performance for smaller signs is not known. Therefore, an effort was undertaken to examine the performance limits of slip base sign supports in terms of sign panel size and mass.

To analyze the impact response and post-impact trajectory of various slip base sign support configurations, an engineering model was developed based on conservation of energy and conservation of linear and angular momentum principles. The model is used to estimate the change in vehicular velocity resulting from impact with the support and activation of the slip 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.

Input to the model included information on the sign support components (e.g., sign blank, support post, upper slip base assembly, etc.) from which the system properties (e.g., total mass, center of mass location, moment of inertia, etc.) could be calculated. The change in vehicle velocity is computed through consideration of vehicle crush, activation of the slip 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 impact between the sign support and vehicle is detected or the vehicle has passed beneath the sign support.

A graphical analysis was used to determine the point of impact of the sign support on the vehicle. Measurements from an 820 kg (1800 lb) 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 on the vehicle profile.

The analytical methodology was validated by comparing predicted outcomes from the model with results from previous full-scale crash tests including the low-speed test (Test No. 417929-6) and high-speed test (Test No. 417929-7) conducted under this project. High-speed film from these 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 of different sign panel configurations.

Based on input from TxDOT personnel and a review of TxDOT's standard sign mounting details, the smallest practical rectangular sign blank for the slip base was taken to be 0.84 m^2 (9 ft^2). The two support post types currently used by the Department with the new slip base system have the same outside diameter of 73 mm (2.875 in.) but vary in terms of thickness (schedule 10 vs. schedule 80) and, therefore, weight. The standard mounting height of 2.1 m (7 ft) is defined to be the distance from the paved surface to the bottom of the sign blank. Different ground mounting heights were investigated in recognition of the fact that most sign supports are installed on some degree of sideslope, which increases the effective distance from the ground surface to the bottom of the sign. Therefore, in the parametric investigation, the variables included: sign blank size (ranging from 0.84 to 1.5 m^2 (9 to 16 ft^2)), sign substrate type (aluminum and plywood), sign blank aspect ratio, support post type (73 mm (2.875 in.) O.D. schedule 10 and schedule 80 pipe), and ground mounting height (2.1, 2.4, and 2.7 m (7, 8, and 9 ft).

With an increase in the size of the sign panel, there is a corresponding increase in the sign panel weight and the length of the support post, both of which tend to increase the height of the center of mass and mass moment of inertia. This increases the height of the point of rotation and decreases the rate of rotation of the support. Consequently, the top of the sign and support are predicted to impact the roof further rearward of the windshield, thus increasing the probability of success in a crash test. For example, a slip base sign support with a 1067 mm (42 in.) × 1067 mm (42 in.) sign blank having an area of 1.14 m^2 (12.25 ft^2) was predicted to impact approximately 230 mm (9 in.) further rearward on the roof than the same installation with a 914 mm (36 in.) × 914 mm (36 in.) sign blank having an area of 0.84 m^2 (9 ft^2).

For a given sign panel size and support post type, the location of impact on the vehicle moves further rearward on the roof as the mounting height is increased. For example, for an increase in mounting height of 305 mm (12 in.) to 2.4 m (8 ft), there is a corresponding increase in the distance from the front of the roof at which the support will impact. It was observed that the top of the support post will impact approximately 305 mm (12 in.) further rearward on the vehicle for every 305 mm (12 in.) increase in mounting height.

The type of support post also has a significant influence on the trajectory and behavior of the sign support system. A small sign installation with a 914 mm (36 in.) × 914 mm (36 in.) sign panel mounted on a schedule 80 support at a height of 2.1 m (7 ft) is predicted to impact approximately 406 mm (16 in.) further rearward on the roof than the same configuration mounted on a lighter schedule 10 support.

The most critical configuration analyzed was a 457 mm (18 in.) tall × 2.49 m (8 ft) wide × 16 mm (5/8 in.) thick plywood panel mounted on a schedule 10 support post at a height of 2.1 m (7 ft). This would correspond to a Type D-1 sign installation as shown on standard SMD (1-1)-98. For this configuration, the analytical model predicted that the top of the sign panel would contact the middle of the windshield, which made the probability for success in a low-speed crash test questionable.

The most critical configuration investigated for a square sign panel was a 914 mm (36 in.) × 914 mm (36 in.) aluminum sign panel mounted on a schedule 10 support at a height of 2.1 m (7 ft). This would correspond to a Type A sign installation as shown on standard SMD (1-1)-98. For this system, the top of the sign and support were predicted to hit the front of the roof at the intersection with the windshield, which made its probability of success in a low-speed crash test questionable.

To validate the results of the analytical model, examine the extent of interaction between the vehicle and sign support systems, and verify the crashworthiness of the TxDOT slip base system when used with small signs, two additional low-speed crash tests were conducted on the critical configurations identified above. Details of these tests are provided in the following sections of this report.

Low-Speed Test (Test No. 417929-8, *NCHRP Report 350* Test No. 3-60)

The purpose of this test was to verify the dynamic impact performance of the standard TxDOT slip base system when used with a small sign. A secondary objective was to investigate the effect of increased bolt torque on the activation of the slip base.

Test Article

The sign support installation used for this test conformed to a TxDOT Type A sign installation as shown on the standard sign mounting details for small roadside signs (SMD (1-1)-98). The support post was a 73 mm (2.875 in.) O.D. schedule 10 steel tube, which was cold formed from high-strength steel sheet having a yield strength of 379 MPa (55,000 psi). A 914 mm (36 in.) x 914 mm (36 in.) x 2.5 mm (0.10 in.) thick aluminum sign panel was attached to the schedule 10 support post at a mounting height of 2.1 m (7 ft) using two standard pipe mounting clamps. The sign panel was mounted in a square configuration such that the bottom of the sign panel was parallel to the ground.

The sign support was mounted on a triangular slip base. The upper slip base assembly consisted of an integral collar and triangular base plate cast from ASTM A536 Grade 65-45-12 ductile iron. The collar was slipped on to the end of the schedule 10 support. To prevent the casting from slipping off during an impact, a 73 mm (2.875 in.) diameter zinc-plated, split-ring shaft collar was attached flush with the end of the support post and tightened to a torque of 61 N·m (45 ft·lb).

The flat, lower slip base plate was welded to a 76 mm (3 in.) diameter pipe stub, which was embedded in a 305 mm (12 in.) diameter by 1.07 m (42 in.) deep concrete footing installed in *NCHRP Report 350* standard soil. The distance from the ground surface to the top face of the permanent lower triangular slip plate was 76 mm (3 in.). The triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. A 30 ga. galvanized steel keeper plate was placed between the upper and lower slip plates. The three 16 mm (0.63 in.) diameter x 64 mm (2.5 in.) long A325 bolts were torqued to 109 N·m (80 ft·lb). High-strength washers were used under both the head and nut of each bolt. Additional details of the installation are shown in figure 63. Photographs of the completed sign support installation are shown in figure 64.

Test Description

The test was performed the morning of July 29, 1999. A total of 23 mm (0.9 in.) of rain was recorded 10 days prior to the test. No other rainfall occurred during the 10 days preceding the test. The *NCHRP Report 350* standard soil in which the sign support was placed was moistened slightly just prior to the test to settle the dust and ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 7 km/h (4 mi/h); wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 29 °C (85 °F); relative humidity: 62 percent.

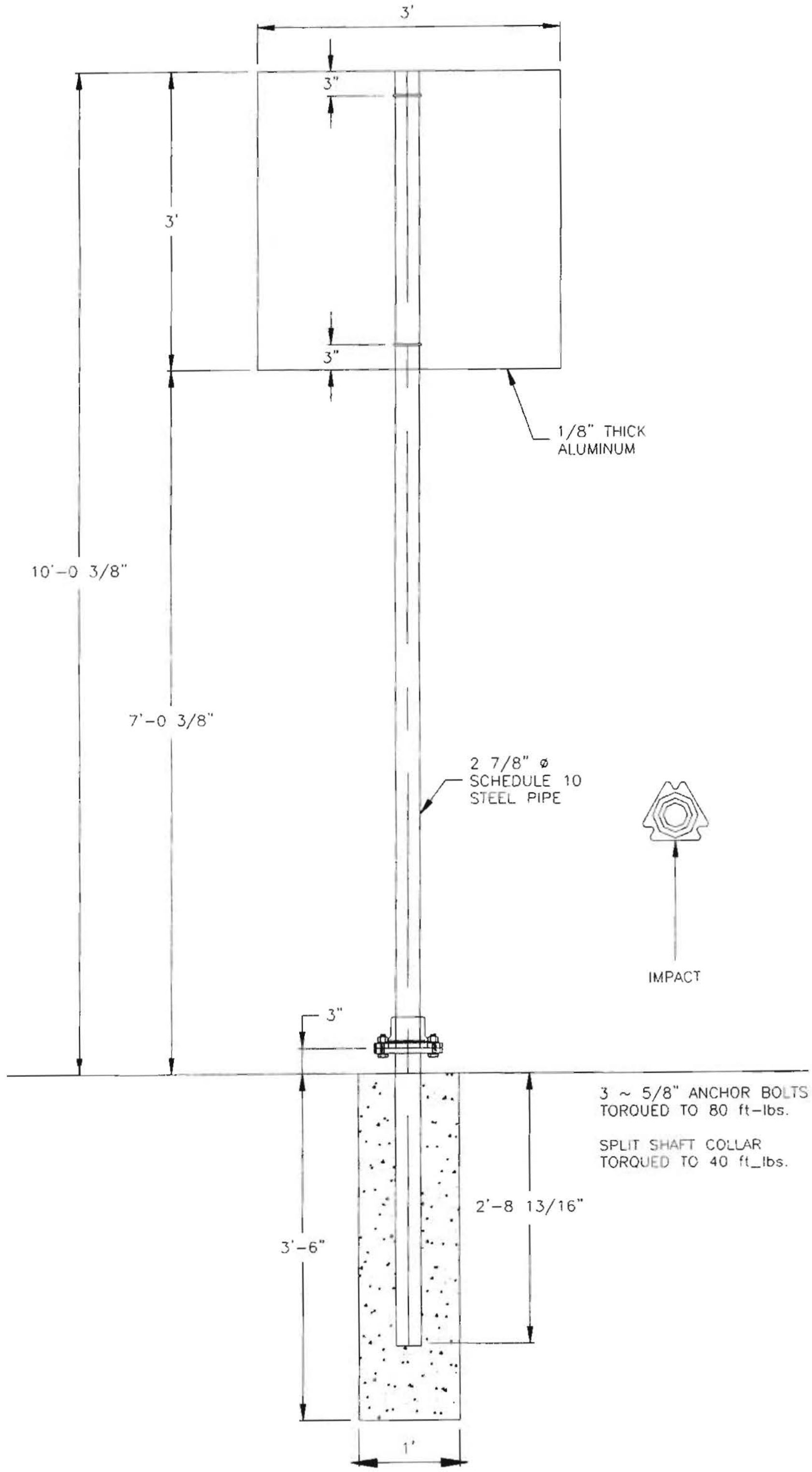


Figure 63. Details of Test Installation for 417929-8.

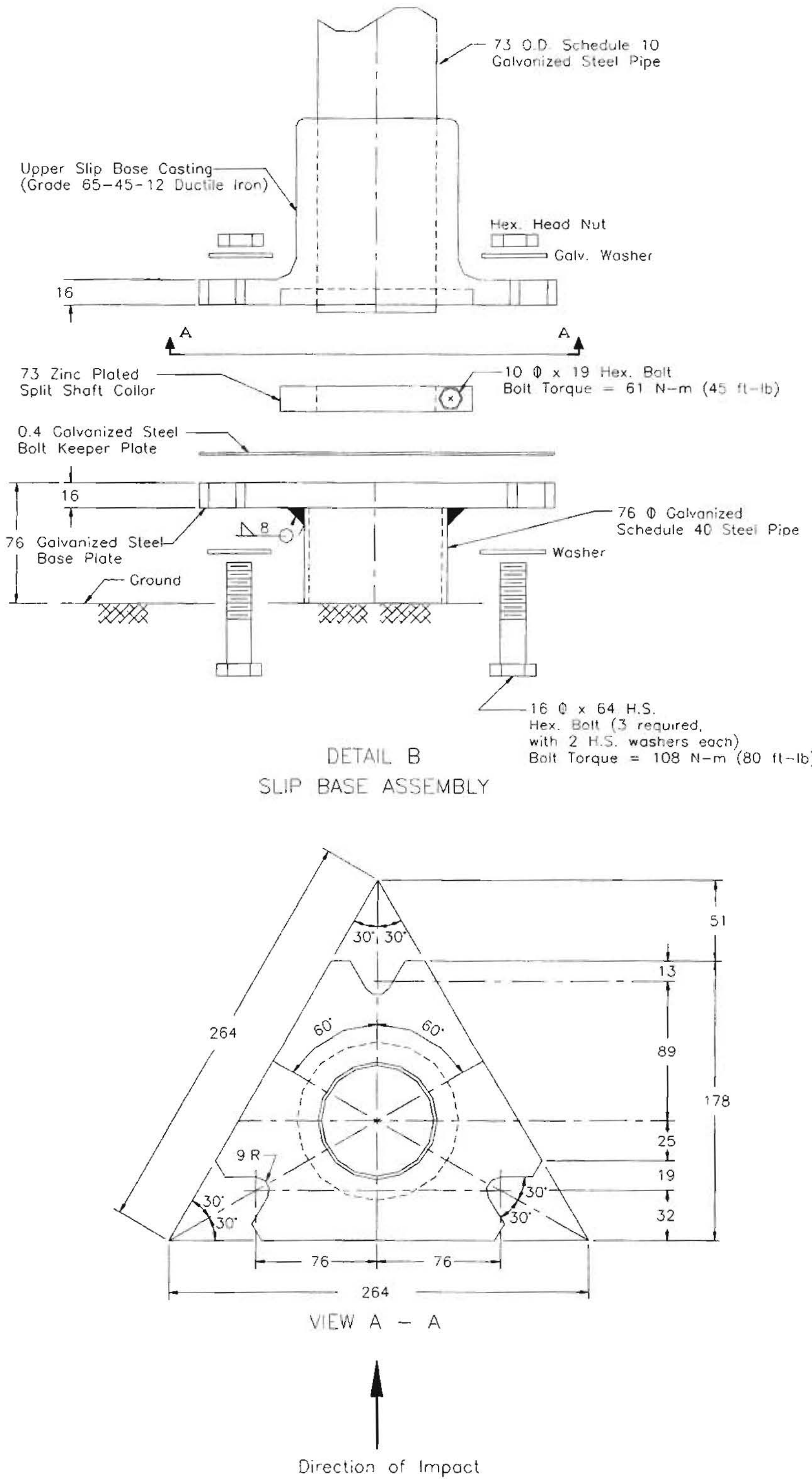


Figure 63. Details of Test Installation for 417929-8 (Continued).

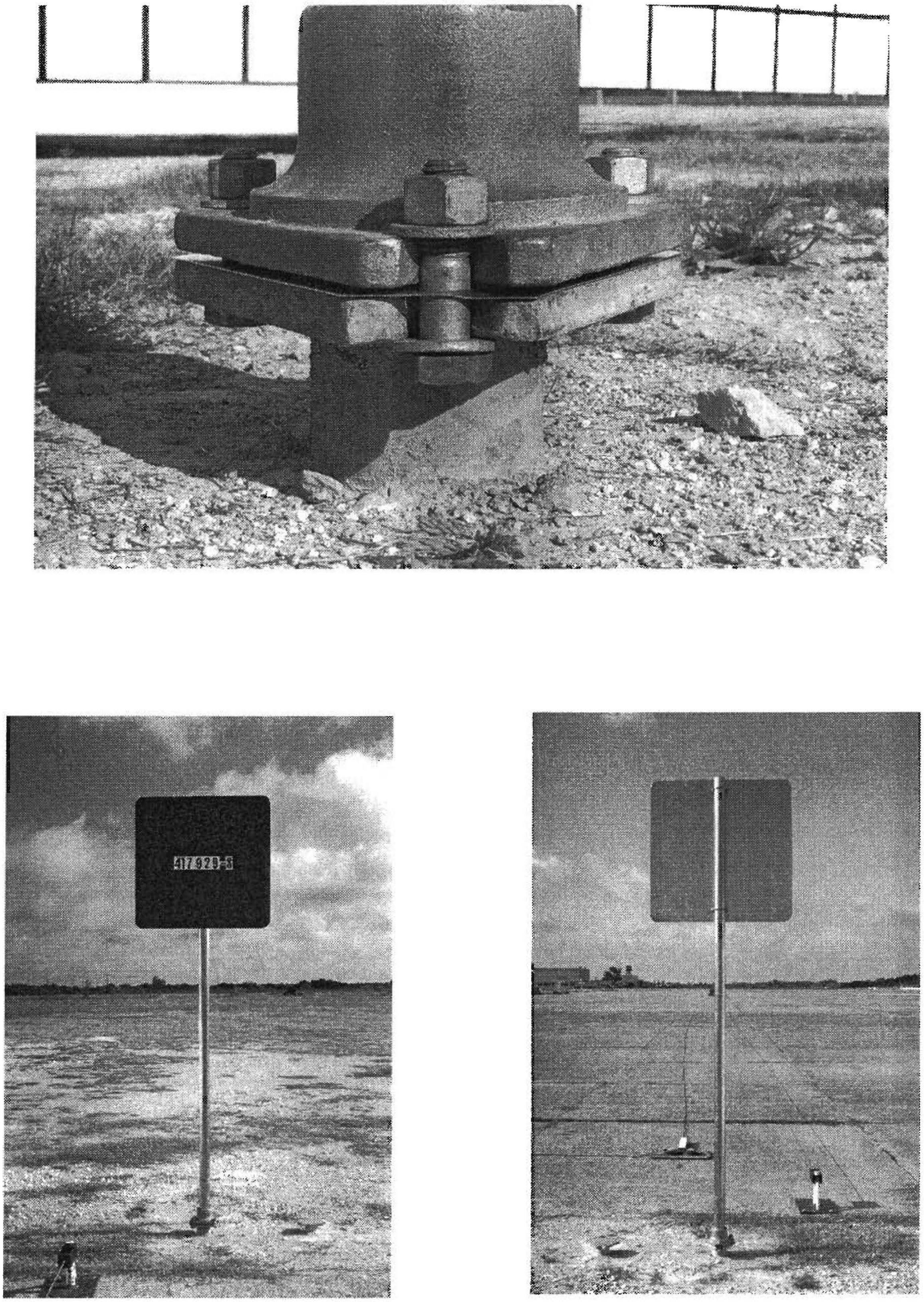


Figure 64. Poz-Loc Slip Base Sign Support before Test 417929-8.

A 1994 Geo Metro, shown in figures 65 and 66, was used for the crash test. 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 375 mm (14.8 in.) and it was 460 mm (18.1 in.) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, figure 101. 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.

The vehicle impacted the sign support head-on at a speed of 33.0 km/h (20.4 mi/h). The support post flexed slightly before activation of the slip base occurred. At 0.024 s the slip base began to activate, and by 0.034 s the post had lost contact with the lower slip plate and begun to rotate away from the vehicle. The vehicle lost contact with the post at 0.066 s while traveling 31.3 km/h (19.4 mi/h). By 0.292 s, the upper right corner of the sign panel contacted the vehicle's roof approximately 152 mm (6 in.) rearward of the windshield, and by 0.305 s the support post was parallel to the ground. The top edge of the sign panel was in full contact with the front of the roof at 0.329 s. The contact with the vehicle stopped the rotation of the support, and the sign panel began to roll off the driver's side of the vehicle. By 0.453 s, the sign panel had lost contact with the vehicle, and the vehicle was traveling at a speed of 29.5 km/h (18.3 mi/h). At 0.870 s, the left side of the sign panel contacted the driver's side mirror as it was falling to the ground, and at 0.963 s the mirror separated from the vehicle. Brakes on the vehicle were applied at 3.0 s as the vehicle exited the test site. The vehicle came to rest 29.0 m (95.1 ft) down from the impact point. Sequential photographs of the test can be found in Appendix D, figure 98.

Damage to Test Installation

Damage to the sign support installation is shown in figures 67 and 68. The split-ring locking collar and upper slip base casting remained on the support post and the sign support installation remained in one piece. The support post received a slight amount of permanent deformation. The sign panel remained attached to the support post and was considered to be reusable. The sign support system came to rest 27.0 m (88.6 ft) downstream from the impact point.

Vehicle Damage

The damage sustained by the vehicle is shown in figure 69. The inner and outer bumper, left corner of the hood, and the driver side mirror were damaged. Maximum exterior crush to the vehicle was 80 mm (3.1 in.) to the left front corner at bumper height. The top mounting bolt for the sign panel left a small hole in the roof of the vehicle. The interior of the vehicle is shown in figure 70. Exterior crush measurements and occupant compartment measurements are shown in Appendix E, tables 8 and 9.

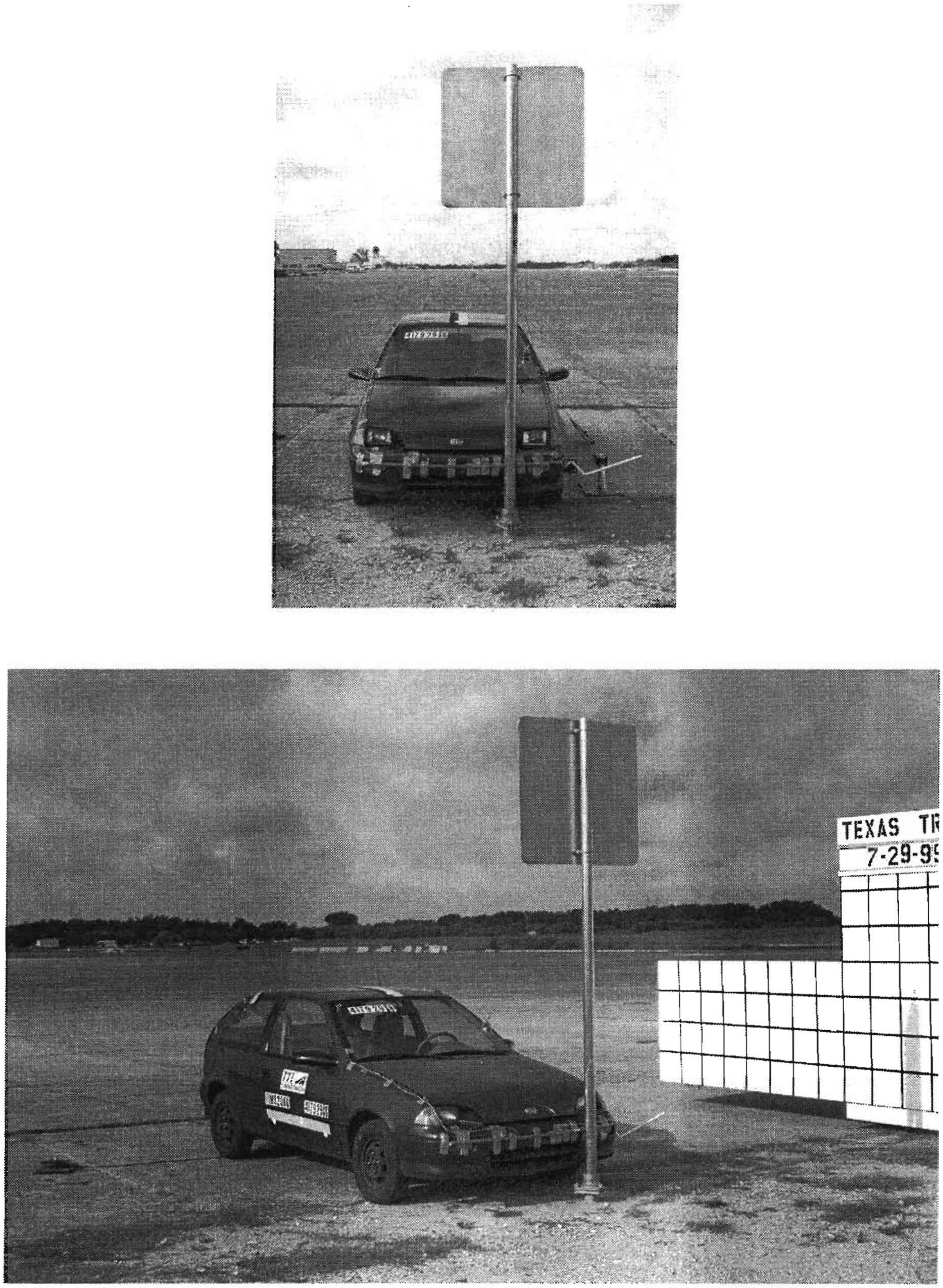


Figure 65. Vehicle/Installation Geometrics for Test 417929-8.

Figure 66. Vehicle before Test 417929-8.

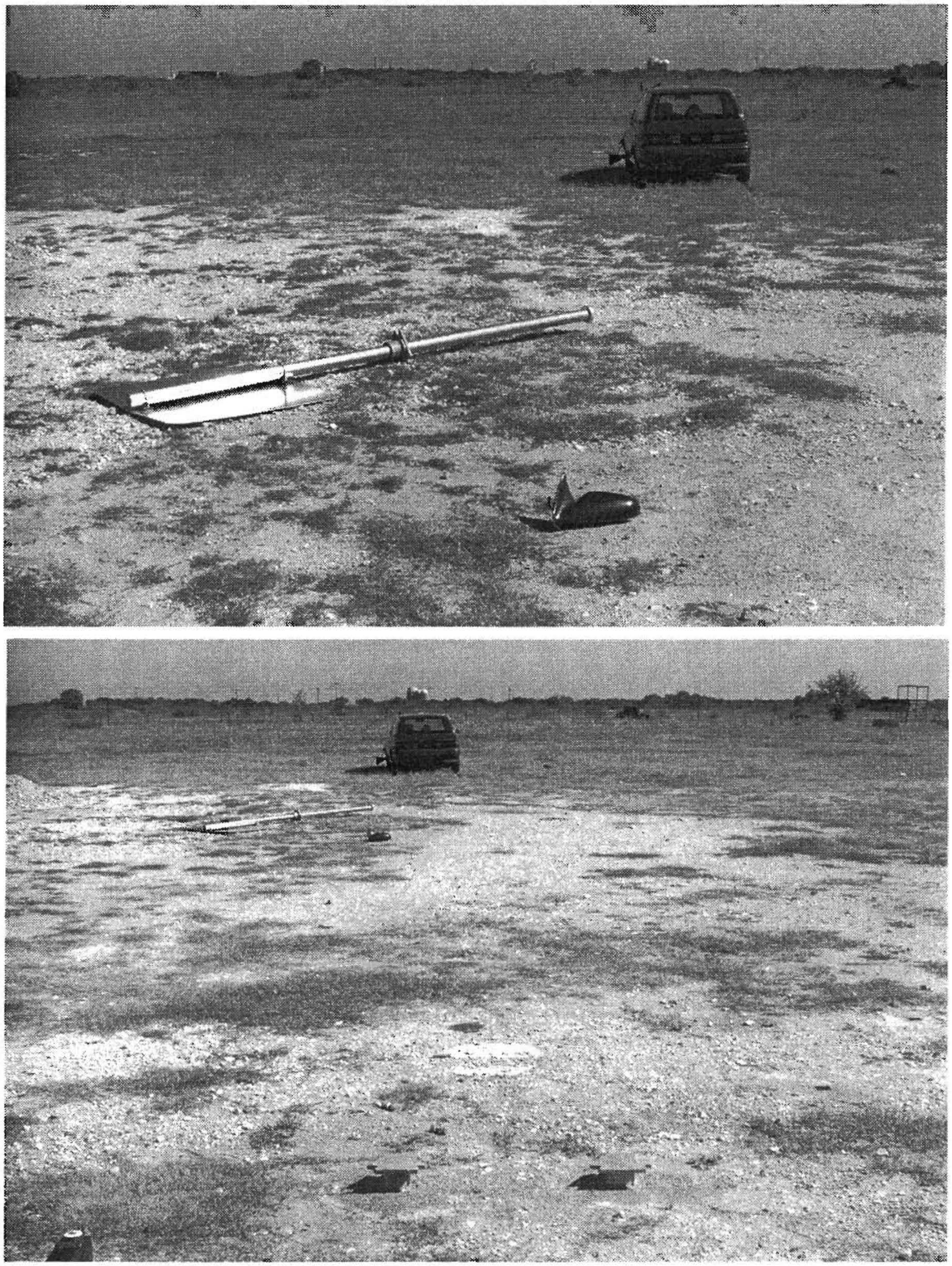


Figure 67. After Impact Trajectory for Test 417929-8.

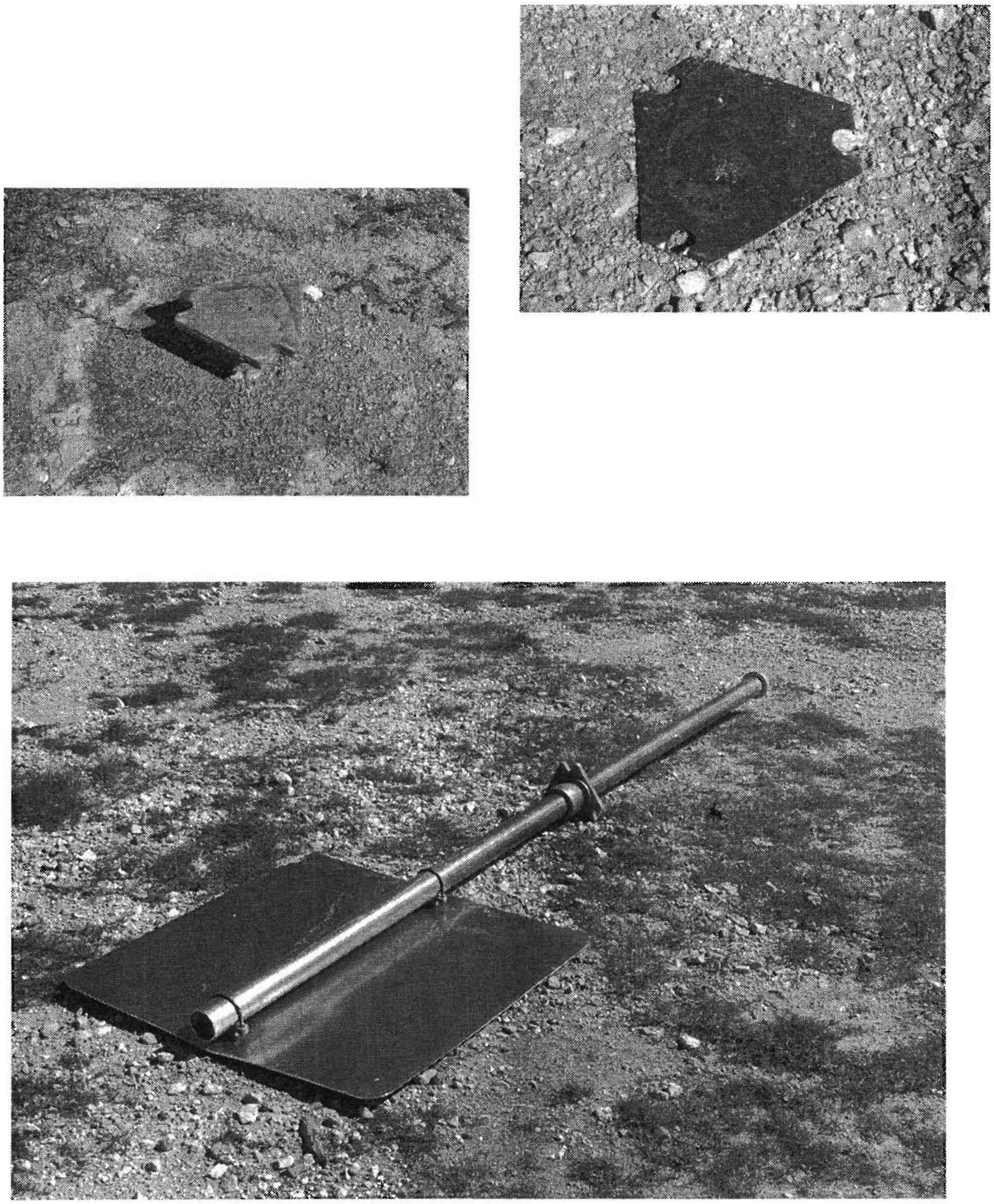


Figure 68. Installation after Test 417929-8.

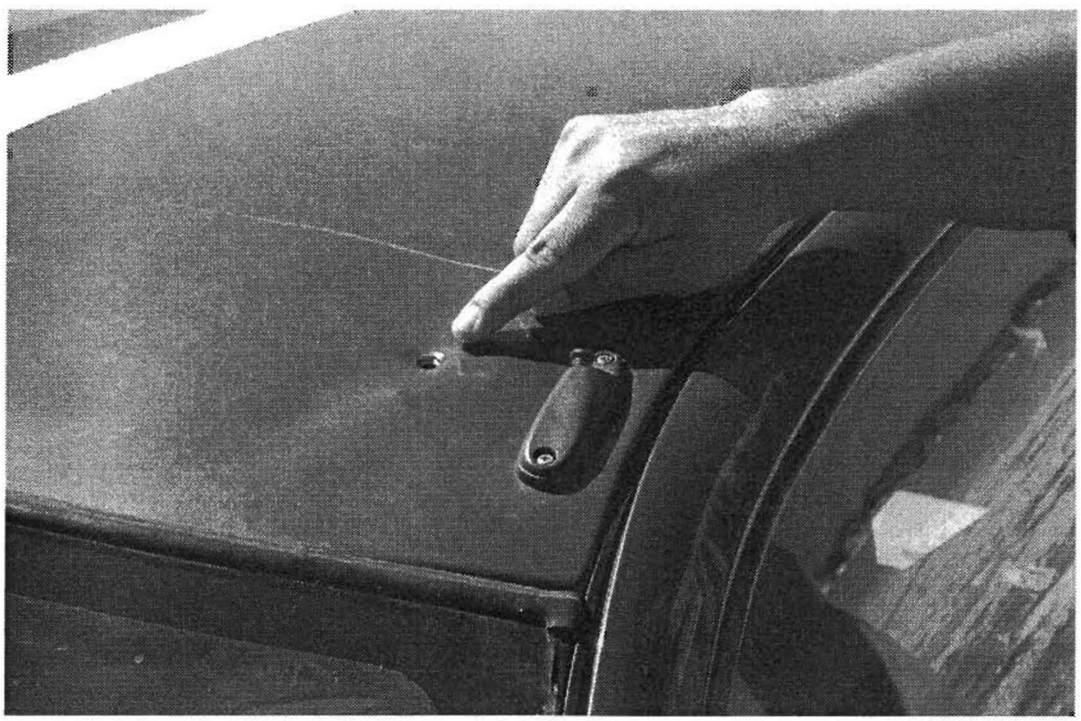


Figure 69. Vehicle after Test 417929-8.

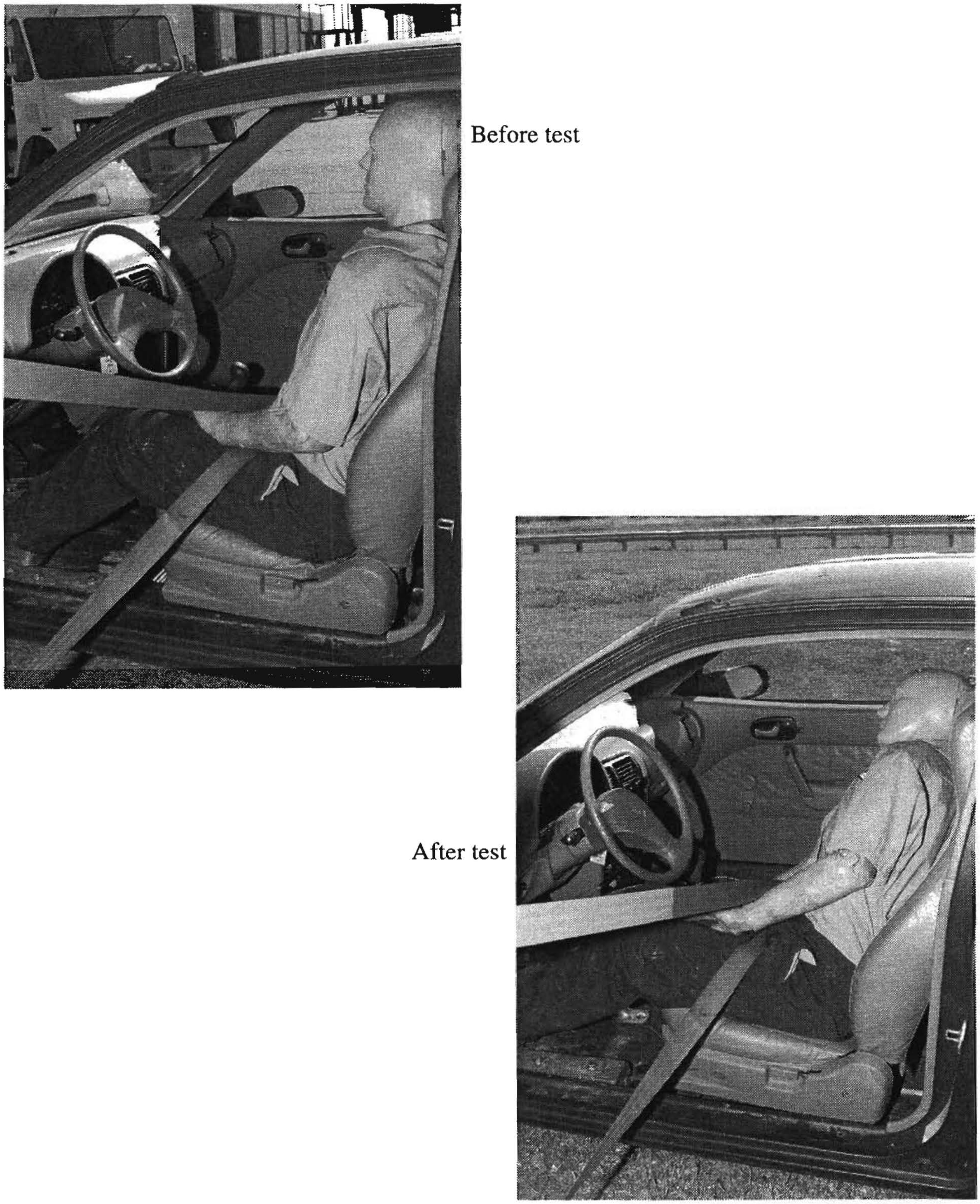


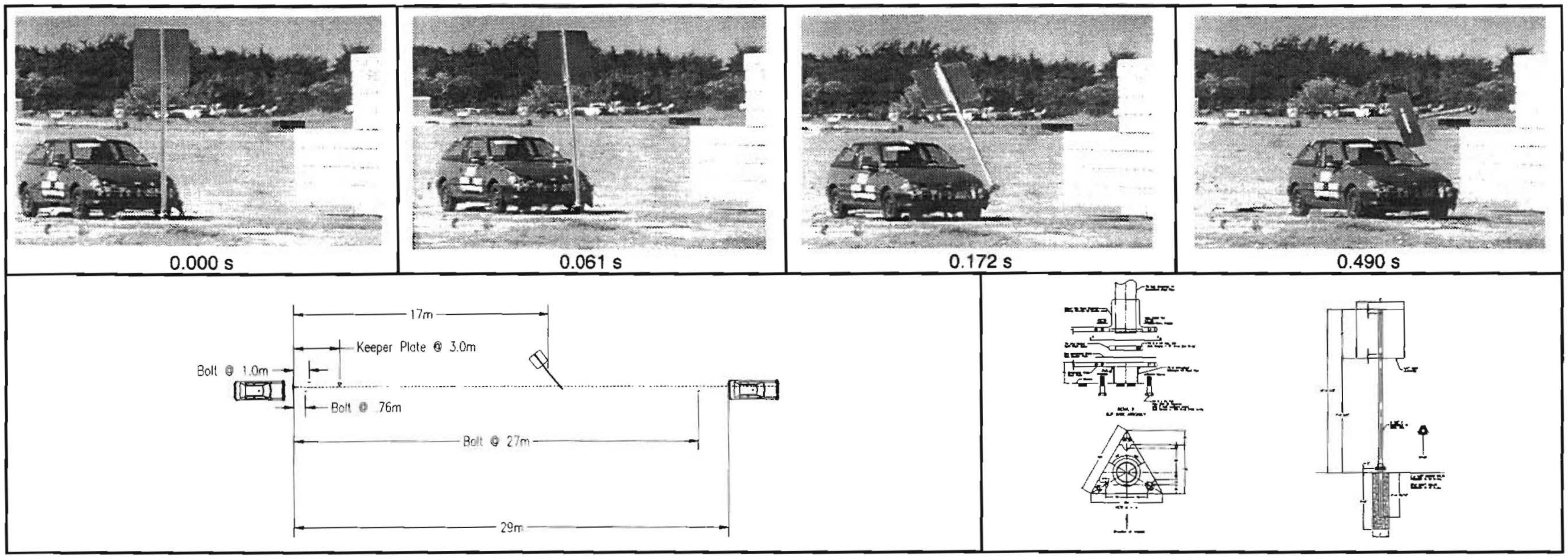
Figure 70. Interior of Vehicle for Test 417929-8.

Occupant Risk Factors

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 0.6 m/s at 0.916 s, the highest 0.010 s occupant ridedown acceleration was -0.2 g's from 0.985 to 0.995 s, and the maximum 0.050 s average acceleration was -1.6 g's between 0.022 and 0.028 s. In the lateral direction, the occupant impact velocity was 0.2 m/s at 0.916 s, the highest 0.010 s occupant ridedown acceleration was 0.1 g's from 0.939 to 0.949 s, and the maximum 0.050 s average was -0.3 g's between 0.039 and 0.089 s. These data and other pertinent information from the test are summarized in figure 71. Vehicle angular displacements are shown in Appendix F, figure 104, and vehicle accelerations versus time traces are presented in Appendix G, figures 112 through 114.

Summary

An assessment of the results for Test No. 417929-8 is shown in Table 4. The slip base with the slip bolts tightened to a torque of 109 N·m (80 ft·lb) activated as designed. Although the top of the sign support and sign panel contacted the roof, the resulting occupant compartment intrusion was not judged to have potential for causing serious injury. The schedule 10 support with 914 mm (36 in.) × 914 mm (36 in.) × 2.5 mm (0.10 in.) thick aluminum sign panel mounted in a square configuration passed all *NCHRP Report 350* evaluation criteria for Test Designation 3-60. Additional assessment of the test based on the 1994 AASHTO specifications[1] and supplemental evaluation factors that were recommended in an FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features" are presented in Appendix H.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-8
Date	07/29/99

Test Article

Type	Sign Support
Name	Poz-Loc Slip Base Sign Support
Installation Height (m)	2.1 (7.0 ft)
Material or Key Elements	Single Steel Post w/914 x 914 x 2 mm (36 x 36 x 0.1 in.) Aluminum Sign, Mounted at 2.1 m (7.0 ft), in Concrete Footing

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

Test Vehicle

Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (kg)	
Curb	749 (1651 lb)
Test Inertial	820 (1806 lb)
Dummy	76 (168 lb)
Gross Static	896 (1974 lb)

Impact Conditions

Speed (km/h)	33.0 (20.4 mi/h)
Angle (deg)	0

Exit Conditions

Speed (km/h)	31.3 (19.4 mi/h)
Angle (deg)	0

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	0.6 (2.0 ft/s)
y-direction	0.2 (0.7 ft/s)
THIV (km/h)	2.2 (1.4 mi/h)
Ridedown Accelerations (g's)	
x-direction	-0.2
y-direction	0.1
PHD (g's)	0.3
ASI	0.13
Max. 0.050 s Average (g's)	
x-direction	-1.6
y-direction	-0.3
z-direction	0.4

Test Article Deflections (m)

Longitudinal	27 (88.6 ft)
Lateral	n/a

Vehicle Damage

Exterior	
VDS	12FL1
CDC	12FLEN1
Maximum Exterior Vehicle Crush (mm)	80 (3.1 in.)
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	nil

Post-Impact Behavior
(during 1.0 s after impact)

Max. Yaw Angle (deg)	-1
Max. Pitch Angle (deg)	-3
Max. Roll Angle (deg)	-1

Figure 71. Summary of Results for Test 417929-8, *NCHRP Report 350* Test 3-60.

Table 4. Performance Evaluation Summary for Test 417929-8, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute   Test No.: 417929-8   Test Date: 07/29/99

<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 Poz-Loc slip base sign support, met the requirements for structural adequacy by yielding 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 bolt from the sign support made a small hole in the roof of the vehicle, but did not penetrate or show potential to penetrate the occupant compartment, or present undue hazard 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 0.6 m/s (2.0 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 -0.2 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 29.0 m (95.1 ft) directly behind the sign support.</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>

Low-Speed Test (Test No. 417929-9, *NCHRP Report 350* Test No. 3-60)

The purpose of this test was to verify the dynamic impact performance of the standard TxDOT slip base system when used with a small sign. A secondary objective was to investigate the effect of increased bolt torque on the activation of the slip base.

Test Article

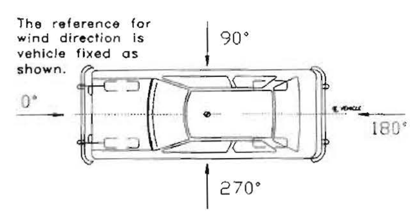
The sign support installation used for this test conformed to a TxDOT Type D-1 sign installation as shown on the standard sign mounting details for small roadside signs (SMD (1-1)-98). A prefabricated T-shaped bracket with a 52 mm (2 in.) diameter, 1600 mm (63 in.) long thin wall horizontal member was attached to a 73 mm (2.875 in.) O.D. schedule 10 steel tube using a 16 mm (5/8 in.) diameter A307 bolt. A 457 mm (18 in.) tall × 2.49 m (8 ft) wide × 16 mm (5/8 in.) thick plywood panel was attached to the T-shaped bracket at four locations using standard pipe mounting clamps. The mounting height from the ground to the bottom of the sign panel was 2.1 m (7 ft).

The details of the slip base assembly were identical to those used in the previous test (Test No. 417929-8). The slip bolts were tightened to a torque of 109 N·m (80 ft·lbs).

Additional details of the installation are shown in figure 72. Photographs of the completed sign support installation are shown in figure 73.

Test Description

The test was performed the morning of July 30, 1999. A total of 23 mm (0.9 in.) of rain was recorded 10 days prior to the test. No other rainfall occurred during the 10 days preceding the test. The *NCHRP Report 350* standard soil in which the sign support was placed was moistened slightly just prior to the test to settle the dust and ensure an unimpaired view for the high-speed cameras. Weather conditions at the time of testing were as follows: wind speed: 6 km/h (4 mi/h); wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 35 °C (95 °F); relative humidity: 35 percent.



A 1994 Geo Metro, shown in figures 74 and 75, was used for the crash test. 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 375 mm (14.8 in.) and it was 460 mm (18.1 in.) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, figure 101. 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.

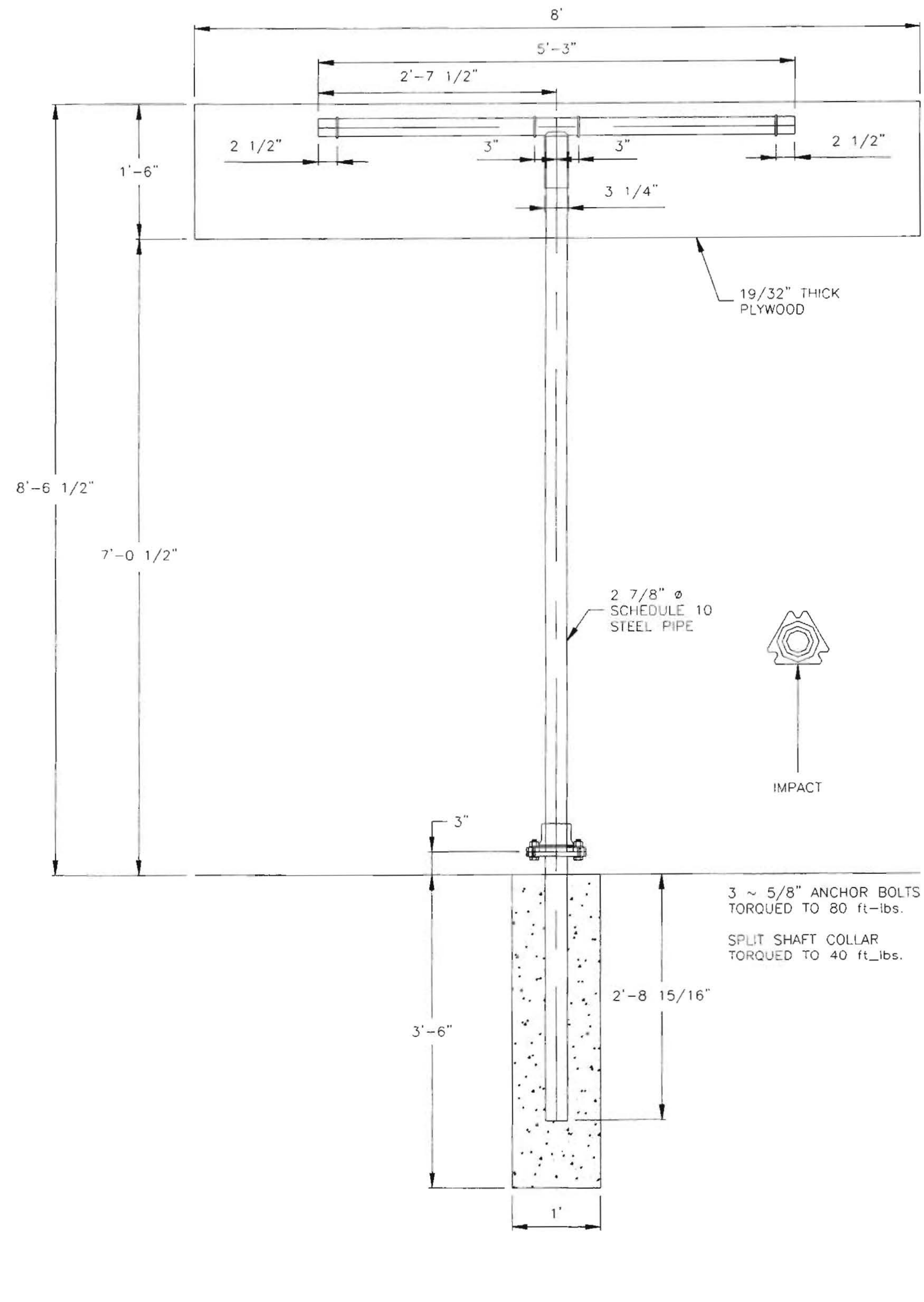
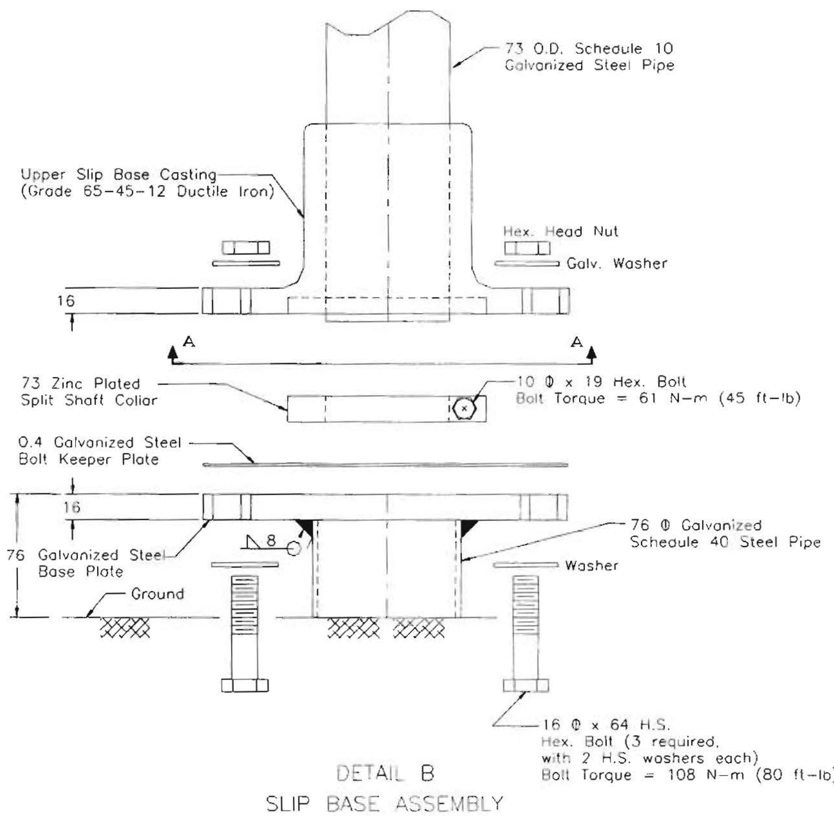


Figure 72. Details of Test Installation for 417929-9.



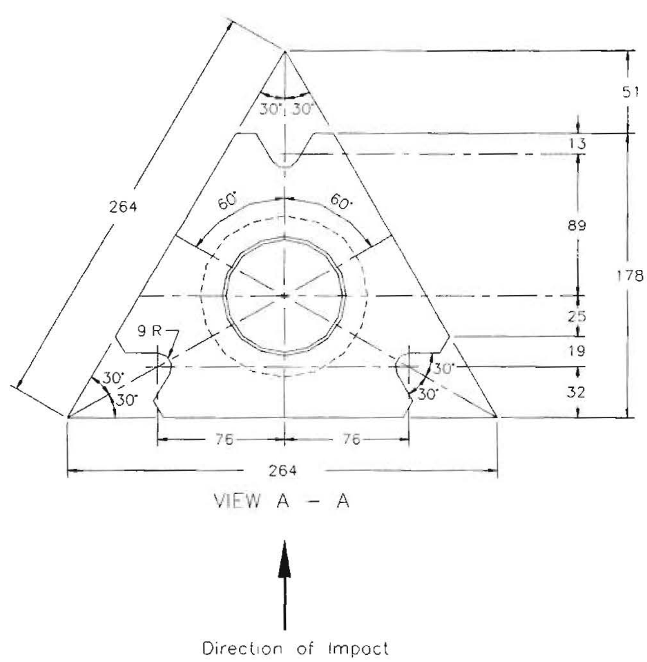


Figure 72. Details of Test Installation for 417929-9 (Continued).

Figure 73. Poz-Loc Slip Base Sign Support before Test 417929-9.

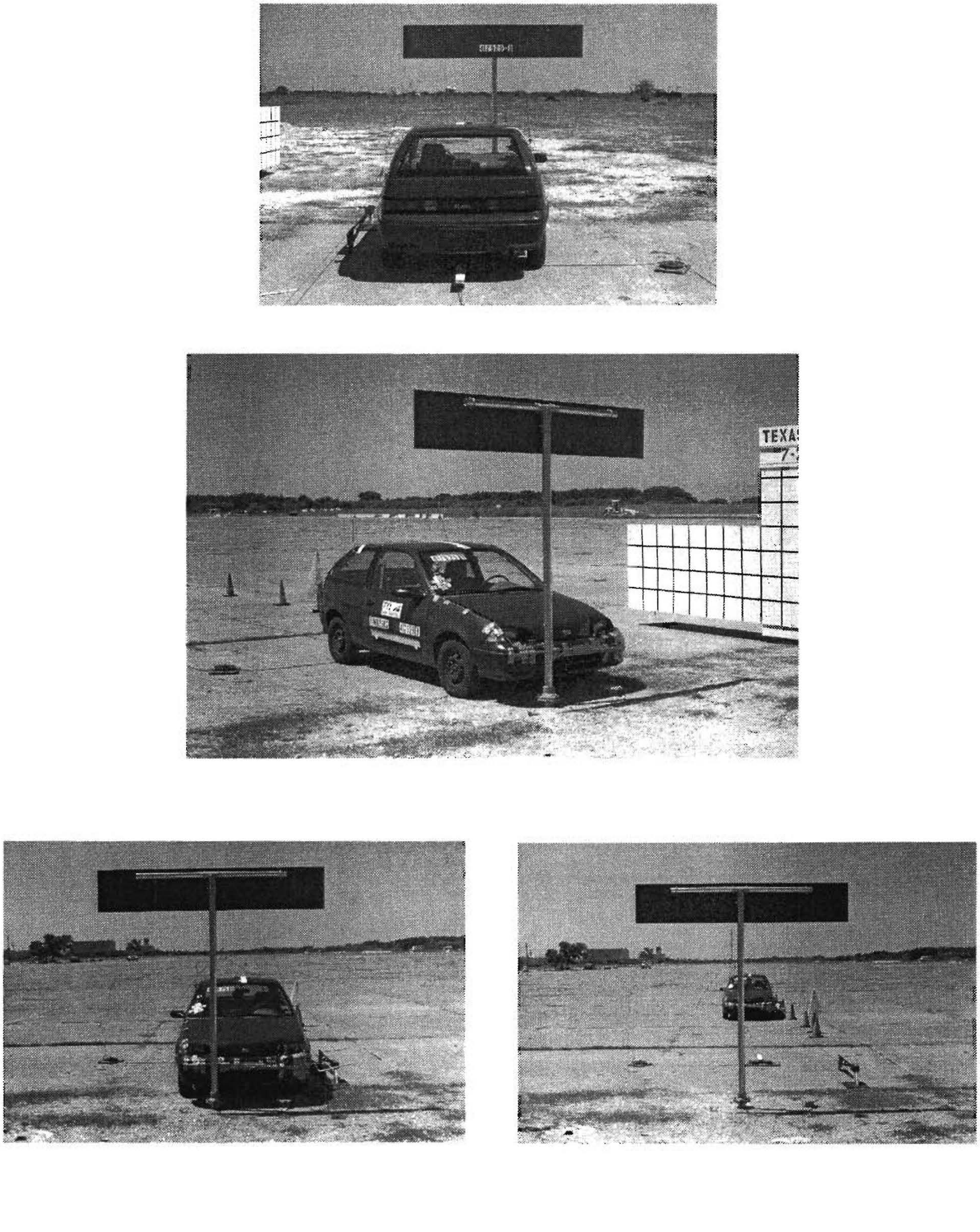


Figure 74. Vehicle/Installation Geometrics for Test 417929-9.

Figure 75. Vehicle before Test 417929-9.

The vehicle impacted the sign support head-on at a speed of 35.3 km/h (21.9 mi/h). The pole flexed appreciably prior to activation of the slip base. At 0.027 s, the slip base began to activate, and by 0.039 s, the post had lost contact with the lower slip plate. The vehicle lost contact with the rotating post at 0.081 s while traveling at a speed of 32.4 km/h (20.1 mi/h). By 0.255 s the post was parallel to the ground surface, and at 0.289 s the top edge of the sign panel contacted the vehicle at the top of the windshield near the edge of the roof. The sign panel contacted the top half of the windshield across the A-pillars. The bottom of the support continued to rotate upward and pivot about the top of the support, which was in contact with the vehicle. At 0.369 s, the sign panel temporarily lost contact with the vehicle while the vehicle was traveling at a speed of 32.3 km/h (20.1 mi/h). At 0.716 s, the sign panel recontacted the windshield, and by 0.836 s the sign panel had again lost contact with the windshield. The top of the support post contacted the vehicle hood at 1.269 s as the base was rotating over the vehicle. At 1.403 s the slip base of the post contacted the ground. Brakes on the vehicle were applied as it exited the test site, and the vehicle came to rest 38.1 m (125.0 ft) from impact point. Sequential photographs of the test can be found in Appendix D, figure 99.

Damage to Test Installation

Damage to the sign support installation is shown in figures 76 and 77. The split-ring locking collar and upper slip base casting remained on the support post, and the sign support installation remained in one piece. The sign panel remained attached to the support post and both the support post and sign panel were considered to be reusable. The sign support system came to rest 26.7 m (87.6 ft) downstream from the impact point.

Vehicle Damage

The vehicle sustained damage to the bumper, hood, radiator support, and windshield as shown in figure 78. A dent in the roof of the vehicle on the passenger side measured 260 mm × 100 mm (10.2 in. × 3.9 in.). Although the sign support rotated into the vehicle and the sign panel contacted the windshield, the windshield damage was minimized by the large surface area of the sign panel and the contact with the A-pillars. The only significant damage to the windshield was induced when a flash bulb bracket attached to the windshield for synchronization of the high speed cameras was pushed into the windshield by the sign panel. There were also some cracks in the windshield near the intersection with the roof from the bolts used to attach the sign to the T-shaped bracket. Maximum exterior crush to the vehicle was 100 mm (3.9 in.) to the right front inner bumper at bumper height. The interior of the vehicle is shown in figure 79. Exterior crush measurements and occupant compartment measurements are shown in Appendix E, tables 9 and 10.

Figure 76. After Impact Trajectory for Test 417929-9.

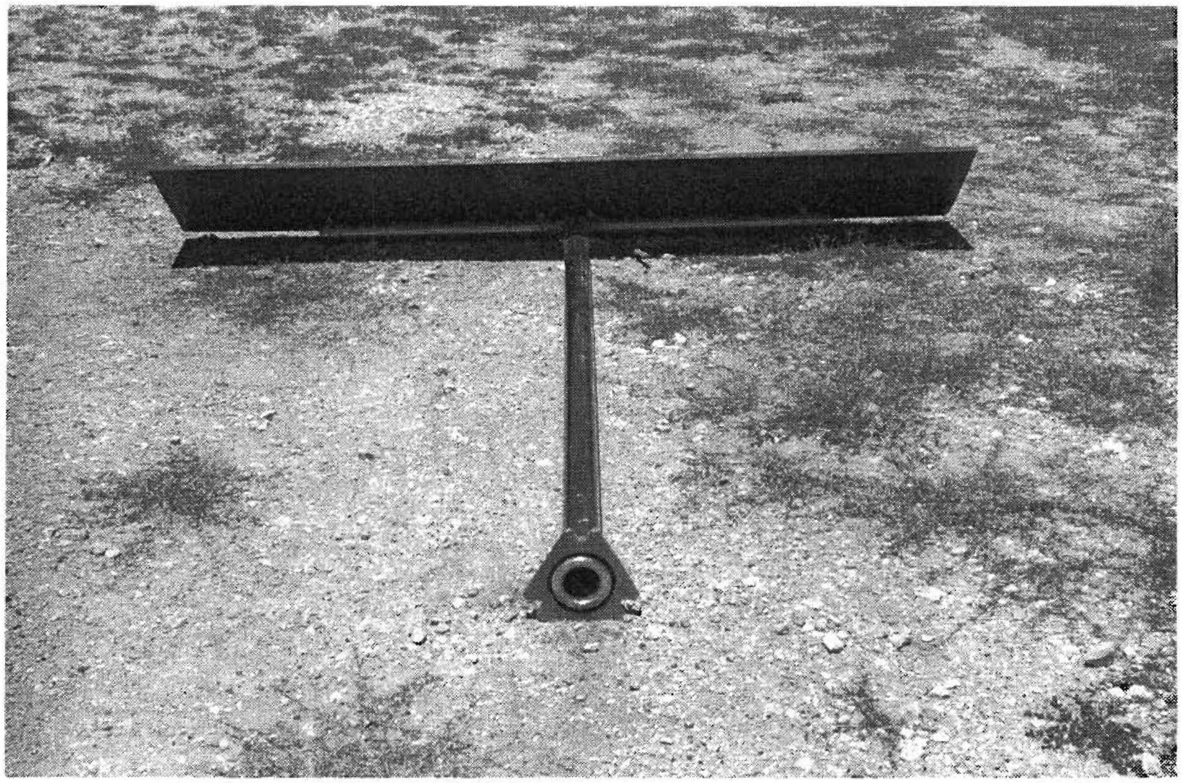
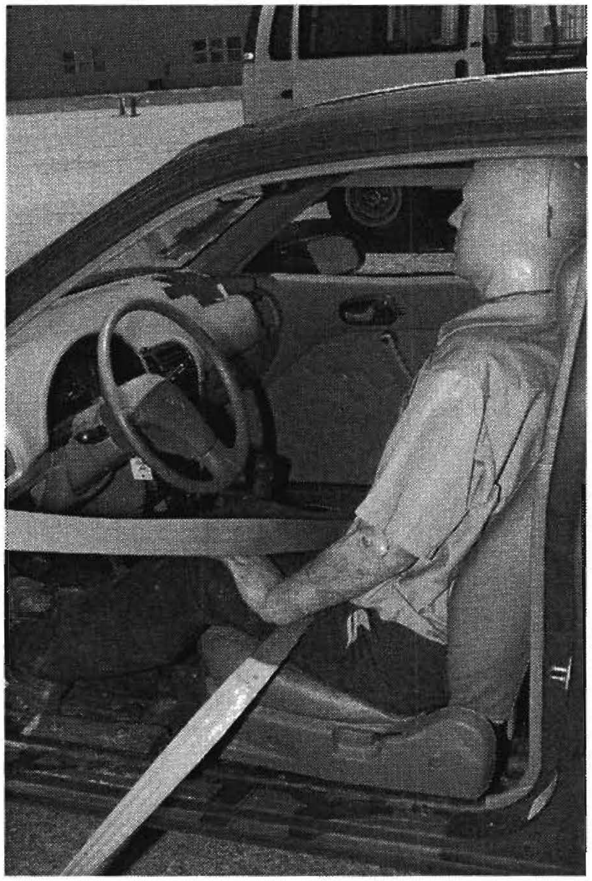


Figure 77. Installation after Test 417929-9.

Figure 78. Vehicle after Test 417929-9.



Before test

After test

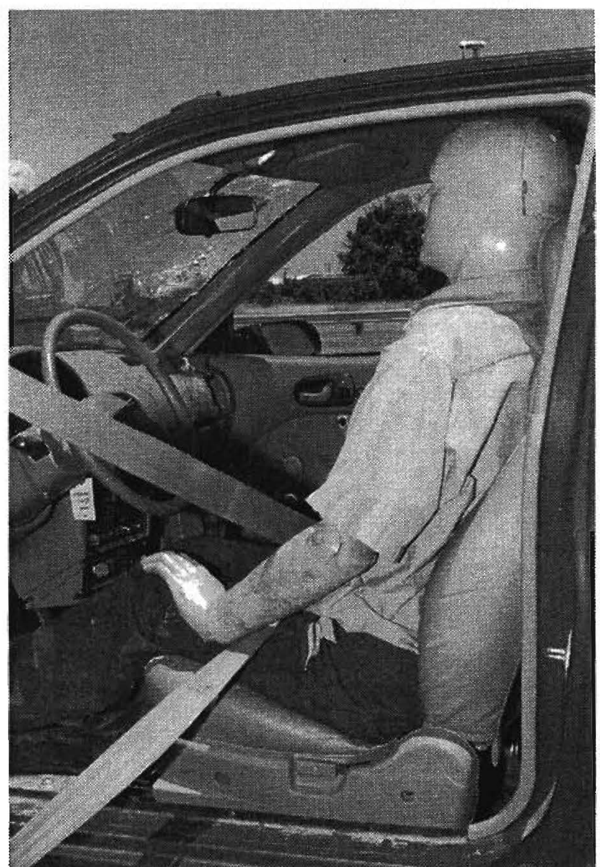


Figure 79. Interior of Vehicle for Test 417929-9.

Occupant Risk Factors

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 0.8 m/s (2.6 ft/s) at 0.808 s, the highest 0.010 s occupant ridedown acceleration was 0.1 g's from 0.852 to 0.862 s, and the maximum 0.050 s average acceleration was -1.7 g's between 0.005 and 0.055 s. In the lateral direction, the occupant impact velocity was 0.5 m/s (1.6 ft/s) at 0.808 s, the highest 0.010 s occupant ridedown acceleration was -0.2 g's from 0.902 to 0.912 s, and the maximum 0.050 s average was 0.5 g's between 0.040 and 0.090 s. These data and other pertinent information from the test are summarized in figure 80. Vehicle angular displacements are shown in Appendix F, figure 105, and vehicle accelerations versus time traces are presented in Appendix G, figures 115 through 117.

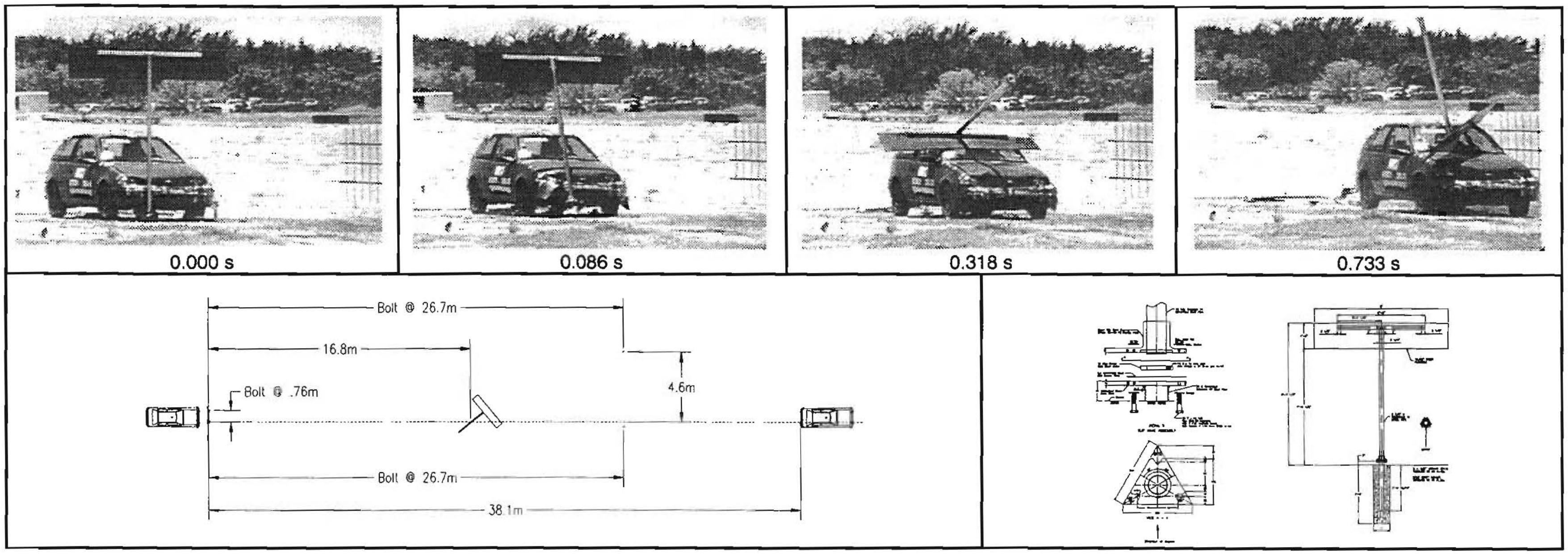
Summary

An assessment of the results for Test No. 417929-9 is shown in Table 5. The slip base with the slip bolts tightened to a torque of 109 N·m (80 ft·lb) activated as designed. Although the top of the sign panel contacted the windshield, the windshield damage was minimized by the large surface area of the sign and the contact with the A-pillars. The resulting occupant compartment intrusion was judged not to have potential for causing serious injury. The schedule 10 support with 457 mm (18 in.) tall × 2.49 m (8 ft) wide × 16 mm (5/8 in.) thick plywood sign panel passed all *NCHRP Report 350* evaluation criteria for Test Designation 3-60. Additional assessment of the test based on the 1994 AASHTO specifications[(2)] and supplemental evaluation factors that were recommended in an FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features" are presented in Appendix H.

SUMMARY OF BOLT TORQUE EVALUATION

Four full-scale crash tests were conducted on slip base sign supports with small signs with higher bolt torques than currently specified in TxDOT's sign mounting detail standards. In the first two tests, the slip bolts were tightened to a torque of 136 N·m (100 ft lb). A bolt torque of 109 N·m (80 ft·lb) was used in the last two tests. In all of the low-speed and high-speed tests, the higher bolt torque did not appear to hinder the activation of the slip base mechanism. This was evidenced by the minimal damage to the support posts and the low occupant risk indices that were computed from the measured vehicle accelerations.

Although the slip base activated as designed, a low-speed crash test with a small, lightweight plastic sign substrate was considered marginal due to significant windshield damage resulting from secondary contact of the sign support with the windshield. In light of this result, an expanded test effort was undertaken to examine the performance limits of slip base sign supports in terms of sign panel size and mass.



General Information

Test Agency	Texas Transportation Institute
Test No.	417929-9
Date	07/29/99
Test Article	
Type	Sign Support
Name	Poz-Loc Slip Base Sign Support
Installation Height (m)	2.1 (7.0 ft)
Material or Key Elements	Single Steel Post w/ 26 x 457 x 15 mm (63 x 18 x 0.5 in.) Wooden Sign, Mounted at 2.1 m (7.0 ft), in Concrete Footing
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1994 Geo Metro
Mass (kg)	
Curb	749 (1651 lb)
Test Inertial	820 (1806 lb)
Dummy	76 (168 lb)
Gross Static	896 (1974 lb)

Impact Conditions

Speed (km/h)	35.3 (21.9 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	32.4 (20.1 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.8 (2.6 ft/s)
y-direction	0.5 (1.6 ft/s)
THIV (km/h)	3.2 (2.0 mi/h)
Ridedown Accelerations (g's)	
x-direction	0.1
y-direction	-0.2
PHD (g's)	0.2
ASI	0.14
Max. 0.050 s Average (g's)	
x-direction	-1.7
y-direction	0.5
z-direction	0.7

Test Article Deflections (m)

Longitudinal	26.7 (87.6 ft)
Lateral	4.6 (15.1 ft)
Vehicle Damage	
Exterior	
VDS	12FR1
CDC	12FREW2
Maximum Exterior Vehicle Crush (mm)	100 (3.9 in.)
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	nil
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	2
Max. Pitch Angle (deg)	-4
Max. Roll Angle (deg)	-1

Figure 80. Summary of Results for Test 417929-9, *NCHRP Report 350* Test 3-60.

Table 5. Performance Evaluation Summary for Test 417929-9, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 417929-9 | Test Date: 07/29/99

<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 Poz-Loc slip base sign support met the requirements for structural adequacy by yielding 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 sign panel shattered the windshield (Class 4) but did not penetrate or show potential to penetrate the occupant compartment, or present undue hazard 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 0.8 m/s (2.6 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 0.1 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 38.1 m (125.0 ft) directly behind the sign support.</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>

The two sign support configurations that were tested in support of this effort were selected with the aid of an engineering model that was developed based on conservation of energy and conservation of linear and angular momentum principles. The model was used to estimate the position of the vehicle, orientation of the support post, and location of secondary impacts between the support post and vehicle for various small sign configurations.

Both of the small slip base sign installations with small signs met all *NCHRP Report 350* evaluation criteria. Although there was secondary contact of the sign support with the roof and/or windshield in both tests, the resulting vehicle deformations were not considered to be a probable cause of serious injury to the occupants. The occupant risk values were all within the preferred limits specified in *NCHRP Report 350.*

Based on these results, the performance of small slip base sign supports using a slip bolt torque in the range of 109 N·m (80 ft·lb) to 136 N·m (100 ft·lb) is considered to be in compliance with *NCHRP Report 350* and suitable for implementation. However, it should be noted that in both the dynamic pendulum and full-scale crash tests, the schedule 10 support flexed appreciably before the slip base activated and had observable permanent deformation after impact. This indicates that while the increased activation force associated with the higher bolt torque did not pose a problem in regard to occupant risk factors, it is approaching the structural capacity of the schedule 10 support. Any higher value of bolt torque could result in the kinking or collapsing of the schedule 10 support, which would hinder the activation of the slip base mechanism. Therefore, if TxDOT elects to implement a higher slip bolt torque, it is recommended that a value on the lower end of the range tested (e.g., 109 N·m (80 ft·lb)) be adopted to maintain some safety factor for slip base activation.

Although slip base sign supports have typically been tested and implemented with sign panels having an area of 1.5 m^2 (16 ft^2) or greater, the crash test results reported herein indicate that slip base sign supports should perform acceptably when used with conventional sign panels having an area of 0.84 m^2 (9 ft^2) or greater. It should be noted that the trajectories of these signs were evaluated in relation to a small, 820 kg (1800 lb) passenger car. The 820 kg (1800 lb) passenger car is generally considered to be critical in regard to the performance of breakaway support structures. The compatibility of the slip base with small signs (e.g., < 1.11 m^2 (12 ft^2)) with other vehicle types was not evaluated.

V. SUMMARY OF FINDINGS AND CONCLUSIONS

TxDOT routinely uses the feedback obtained from field crews to assess the performance of breakaway sign support systems and identify areas in which design improvements can result in reduced installation and maintenance costs or improved impact behavior. Under this project, several issues related to the performance of slip base sign supports were investigated. These issues include: the effect of bolt torque on the impact performance of slip base sign supports, the effect of sign panel size and configuration on the trajectory and impact performance of slip base sign supports, and an evaluation of methods for retrofitting slip base stubs that incorporate a lifting ramp or cone. A summary of the findings and conclusions resulting from these investigations is provided below.

EVALUATION OF SLIP BOLT TORQUE

The use of a higher bolt torque for slip base sign supports is desired to increase the ability to withstand cyclical service loads and reduce the incidence of sign installations blowing down in the field. However, the amount of torque applied to the slip bolts effects the activation force of the slip base. The activation force must be maintained at a level that will result in acceptable deceleration of an impacting vehicle and not exceed the flexural capacity of the support post. Therefore, any change in slip bolt torque must be properly evaluated to ensure that impact performance is not adversely affected.

This issue was investigated through dynamic pendulum testing and full-scale vehicle crash testing. The performance of the schedule 10 support with the slip base bolts torqued to 209 N·m (154 ft·lb) was found to be unacceptable. The activation force was too high, causing the support post to bend and collapse, and the occupant impact velocity exceeded the maximum acceptable value of 5 m/s (16.4 ft/s) specified in *NCHRP Report 350* for breakaway structures.

In subsequent pendulum and full-scale crash tests, small slip base sign supports using slip bolt torques in the range of 109 N·m (80 ft·lb) to 136 N·m (100 ft·lb) were determined to be in compliance with *NCHRP Report 350* and suitable for implementation. The occupant risk indices computed for these tests were all within the preferred limits specified in *NCHRP Report 350*, and portions of the sign support systems were considered reusable in most tests.

EVALUATION OF PERFORMANCE LIMITS FOR SLIP BASE SIGNS

In one of the low-speed crash tests conducted to investigate the effect of bolt torque on impact performance, the performance was marginal due to significant windshield damage resulting from secondary contact of the sign support with the windshield. After examination of the test results, this behavior was attributed not to the higher bolt torque but to the small, lightweight plastic sign substrate used in the test. It was concluded that the small size and light weight of the plastic sign substrate decreased the height of the center of mass and mass moment of inertia of the support, thereby adversely influencing the trajectory of the support post.

Traditionally, slip base sign supports have been tested and implemented with larger signs than those tested under this study. Therefore, the performance of slip base supports with very small signs was unknown. An expanded investigation using engineering modeling and full-scale crash testing was undertaken to examine the performance limits of slip base sign supports in terms of sign panel size and mass.

Two critical sign panel configurations were subjected to a low-speed crash test. Both of the small slip base sign installations met all *NCHRP Report 350* evaluation criteria. Although there was secondary contact of the sign support with the roof and/or windshield in both tests, the resulting vehicle deformations were not considered to be a probable cause of serious injury to the occupants. The occupant risk values were all within the preferred limits specified in *NCHRP Report 350.*

Although slip base sign supports have typically been used for sign panels having an area of 1.5 m^2 (16 ft^2) or greater, these crash test results indicate that slip base sign supports should perform acceptably when used with conventional sign panels having an area of 0.84 m^2 (9 ft^2) or greater. It should be noted that the trajectories of these signs were evaluated in relation to a small, 820 kg (1800 lb) passenger car. The 820 kg (1800 lb) passenger car is generally considered to be critical in regard to the performance of breakaway support structures. The compatibility of the slip base with small signs (e.g., < 1.11 m^2 (12 ft^2)) with other vehicle types was not evaluated.

EVALUATION OF LIFTING DEVICE RETROFIT

For many years, the TxDOT slip base design incorporated a lifting device on the lower base plate. The purpose of the lifting device was to help propel the sign support upward during impact to eliminate or reduce the severity of any secondary impacts of the sign or its support with the windshield or roof of the vehicle. During the development of a new triangular slip base system for TxDOT, it was determined that the lifting cone was unnecessary and, in some instances, detrimental to overall impact performance. Therefore, since the addition of lifting ramps and/or cones can significantly increase fabrication costs, the lifting cone was removed from the new slip base design.

This change in design created a need to develop retrofit alternatives that would enable existing slip base foundations to be utilized when repairing or upgrading existing sign supports. Under TxDOT research project 7-3911, the impact performance of several options was investigated. Subsequent to the completion of project 7-3911, several additional spacer concepts were conceived for retrofitting slip base foundations with lifting devices.

A series of six full-scale pendulum tests was performed to investigate the influence of these new lifting device retrofit alternatives on the dynamic activation response of a triangular slip base small sign support. The impact performance of several types of spacer rings and caps were evaluated. While each option performed acceptably, a triangular-shaped cap manufactured from polycarbonate plastic was considered to be the best alternative. The 37 mm (1.44 in.) thick cap was molded in a triangular shape that matched the geometry of the slip base plate. In addition to providing the required separation between the slip plates to accommodate an existing lifting cone, the triangular geometry provides support for the corners of the keeper plate and slip base plates and minimizes the potential for rotation of the upper slip plate during tightening of the slip bolts. The 8 mm (0.31 in.) thick top surface of the cap also provides a flat, hard surface against which the split-ring collar on the end of the support post can bear during the bolt tightening procedure.

In the pendulum test conducted with impact conditions similar to those of the low-speed test (Test Designation 3-60) recommended in *NCHRP Report 350* for evaluation of breakaway structures, the triangular polycarbonate cap did not impede the activation of the slip base mechanism. The occupant risk indices were within the preferred limits specified in *NCHRP Report 350*, and the change in vehicular velocity was below the preferred value contained in the 1994 AASHTO specifications. Based on these results, the use of a triangular polycarbonate spacer cap for retrofitting existing slip base plates that incorporate a lifting device is considered to be suitable for implementation when circumstances warrant during upgrade and repair operations.

VI. IMPLEMENTATION RECOMMENDATIONS

Under this project, several independent issues related to the performance of small slip base sign supports were investigated. These issues include: the effect of bolt torque on the impact performance of slip base sign supports, the effect of sign panel configuration on the trajectory and impact performance of slip base sign supports, and an evaluation of methods for retrofitting slip base stubs that incorporate a lifting ramp or cone. Recommendations regarding implementation of research results in each of these areas are presented below.

- There have been reports of slip base sign installations blowing down in regions subject to high winds. This occurrence is likely due to the cyclical loading applied to the slip base, which varies the tension in the slip bolts and permits them to "walk" out of their slots. If adequate safety performance is maintained, a higher bolt torque could help alleviate incidences of signs blowing down. Based on the results of pendulum and full-scale crash tests, small slip base sign supports using slip bolt torques in the range of 109 N·m (80 ft·lb) to 136 N·m (100 ft·lb) were determined to be in compliance with *NCHRP Report 350* and suitable for implementation. However, it should be noted that in some of the tests conducted, the schedule 10 support flexed appreciably before the slip base activated and had observable permanent deformation after impact. This result indicates that the increased activation force associated with the higher bolt torque is approaching the structural capacity of the schedule 10 support. Any higher value of bolt torque could result in the kinking or collapsing of the schedule 10 support, which would hinder the activation of the slip base mechanism. Therefore, if TxDOT elects to implement a higher slip bolt torque, it is recommended a value on the lower end of the range tested (e.g., 109 N·m (80 ft·lb)) be adopted to maintain some safety factor for slip base activation. At the discretion of TxDOT, a higher bolt torque can be used in lieu of the standard bolt torque of 55 N·m (40 ft·lb) to help alleviate the reported field problems with slip base sign supports. The implementation of the higher bolt torque can be accomplished through appropriate revisions to TxDOT's SMD standard sheets.

- Previous TxDOT slip base designs incorporated a lifting device on the lower base plate to help propel the sign support upward during impact and eliminate or reduce the severity of any secondary impacts of the support with the windshield or roof of the vehicle. However, TxDOT research determined that the lifting cone was not needed and, in some instances, was detrimental to overall impact performance. The lifting cone was therefore removed from the current slip base design. This change in design created a need to develop a retrofit concept to enable existing slip base foundations with lifting devices to be repaired or upgraded with the new slip base system. A triangular-shaped polycarbonate spacer cap was determined to be the best alternative of the retrofit concepts investigated. In a dynamic pendulum test, the use of the triangular spacer cap for retrofitting existing slip base foundations was determined to comply with *NCHRP Report 350* performance criteria and is considered suitable for implementation when circumstances warrant during upgrade and repair operations. The plastic spacer ring provided the required separation between the slip plates to accommodate an existing lifting cone and did not impede the breakaway performance of the small sign support. The implementation of the plastic retrofit spacer ring has already been accomplished through revisions to TxDOT's SMD standard sheets.

- Due to economic considerations, slip base sign supports have traditionally been used for larger signs (e.g., >1.5 m^2 (16 ft^2)). Many Districts are using the new TxDOT slip base with schedule 10 support post for smaller signs. The marginal performance of a slip base sign support system in a low-speed crash test raised concerns regarding the performance limits of slip base supports with small signs. The use of a small sign can adversely influence the trajectory of the support post by decreasing the height of the center of mass and mass moment of inertia of the support. The performance of slip base supports with small signs was investigated using engineering modeling and full-scale crash testing. Two critical sign panel configurations that were subjected to a low-speed crash test met all *NCHRP Report 350* evaluation criteria. These crash test results indicate that slip base sign supports should perform acceptably when used with conventional sign panels having an area of 0.84 m^2 (9 ft^2) or greater. Therefore, TxDOT does not have to restrict the use of the new slip base for signs having an area of 0.84 m^2 (9 ft^2) or greater. The one test conducted on a slip base support with a sign panel having an area less than 0.84 m^2 (9 ft^2) was marginally acceptable. The compatibility of small sign slip base supports with vehicles other than the small passenger car design test vehicle was not evaluated.

REFERENCES

1. *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.

2. 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.

APPENDIX A. PENDULUM TEST PROCEDURES

The pendulum 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 bogie was instrumented with two accelerometers mounted at the rear of the bogie to measure longitudinal acceleration levels. The accelerometers were strain gage type with a linear millivolt output proportional to acceleration.

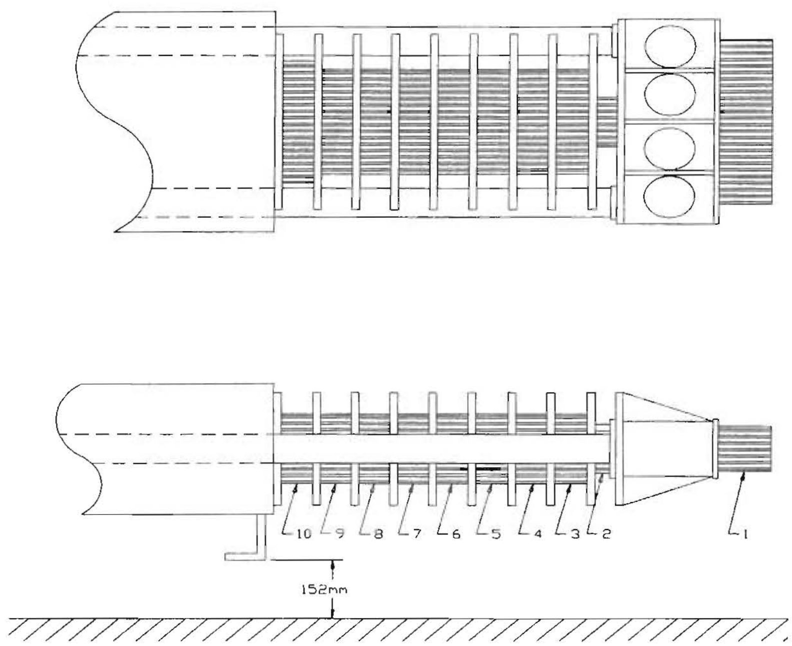
The electronic signals from the accelerometers were amplified and transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test and an accurate time reference signal was simultaneously recorded with the data. Pressure-sensitive switches on the nose of the bogie were actuated by wooden dowel rods and initial contact to produce speed trap and "event" marks on the data record to establish the exact instant of contact with the installation, as well as impact velocity.

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 a computer program called DIGITIZE. The DIGITIZE program uses digitized data from the bogie-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 0.010 s average ridedown acceleration. The DIGITIZE program also calculates an impact velocity and the change in velocity at the end of a given impulse period. In addition, maximum average accelerations over 0.050 s intervals are computed. For reporting purposes, the data from the bogie-mounted accelerometers were then filtered with a 180 Hz digital filter and plotted using Microsoft Excel.

PHOTOGRAPHIC INSTRUMENTATION

A high-speed camera, positioned perpendicular to the path of the pendulum bogie and the post, was used to record the collision period. The film from this high-speed camera was analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain event times, displacement, and angular data. A VHS video camera and still cameras were used to document the crushable pendulum nose and the post before and after the test.



Cartridge Number	Size (mm)	Area effectively Removed by Crushing (mm^2)	Static Crush Strength (kPa)
1	95 x 406 x 76		896.3
2	102 x 127 x 51		172.4
3	203 x 203 x 76	13549	896.3
4	203 x 203 x 76	9678	1585.8
5	203 x 203 x 76	3871	1585.8
6	203 x 203 x 76		1585.8
7	203 x 203 x 76	13549	2757.9
8	203 x 203 x 76	7742	2757.9
9	203 x 203 x 76		2757.9
10	203 x 254 x 76		2757.9

Figure 81. Configuration of Pendulum Nose and Honeycomb.

APPENDIX B. CRASH TEST 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. 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. Angular rate 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 before the test and 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 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 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 and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are 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 are made any time data are suspect.

The digitized data are then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these 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 calculates 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 are then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using 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 plots 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 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, is positioned on the impacting vehicle to indicate the instant of contact with the installation and is visible from each camera. The films from these high-speed cameras are analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain event times, displacement, and angular data. A BetaCam, a VHS video camera, and still cameras are used to document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle is towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle is 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 is 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 so the tow vehicle moves away from the test site. A two-to-one speed ratio between the test and tow vehicle exists with this system. Just prior to impact with the installation, the test vehicle is released to be free-wheeling and unrestrained. The vehicle remains free-wheeling, i.e., no steering or braking inputs, until the vehicle clears the immediate area of the test site, at which time brakes on the vehicle are activated, bringing it to a safe and controlled stop.

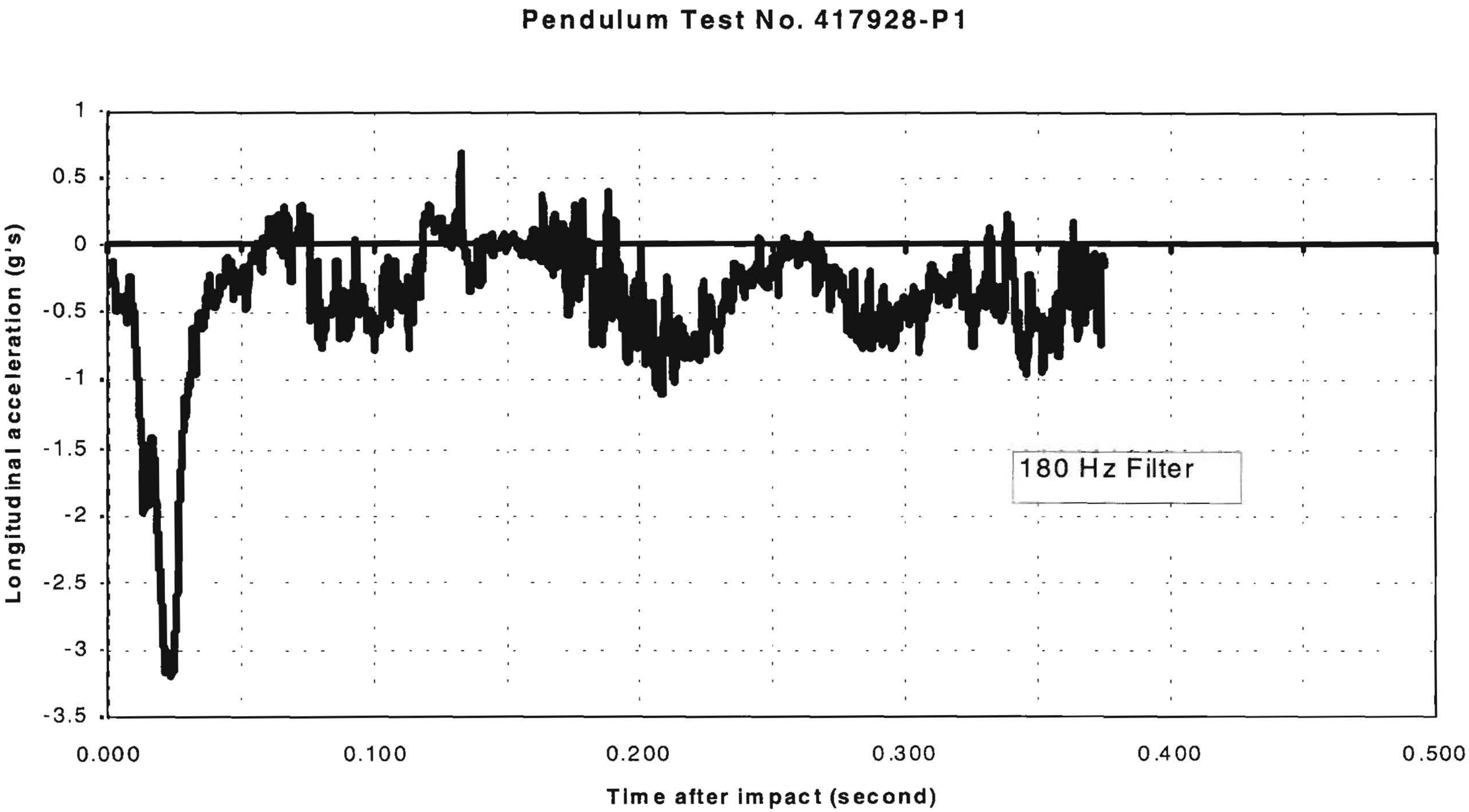


Figure 82. Pendulum Longitudinal Accelerometer Trace for Test 417928-P1.

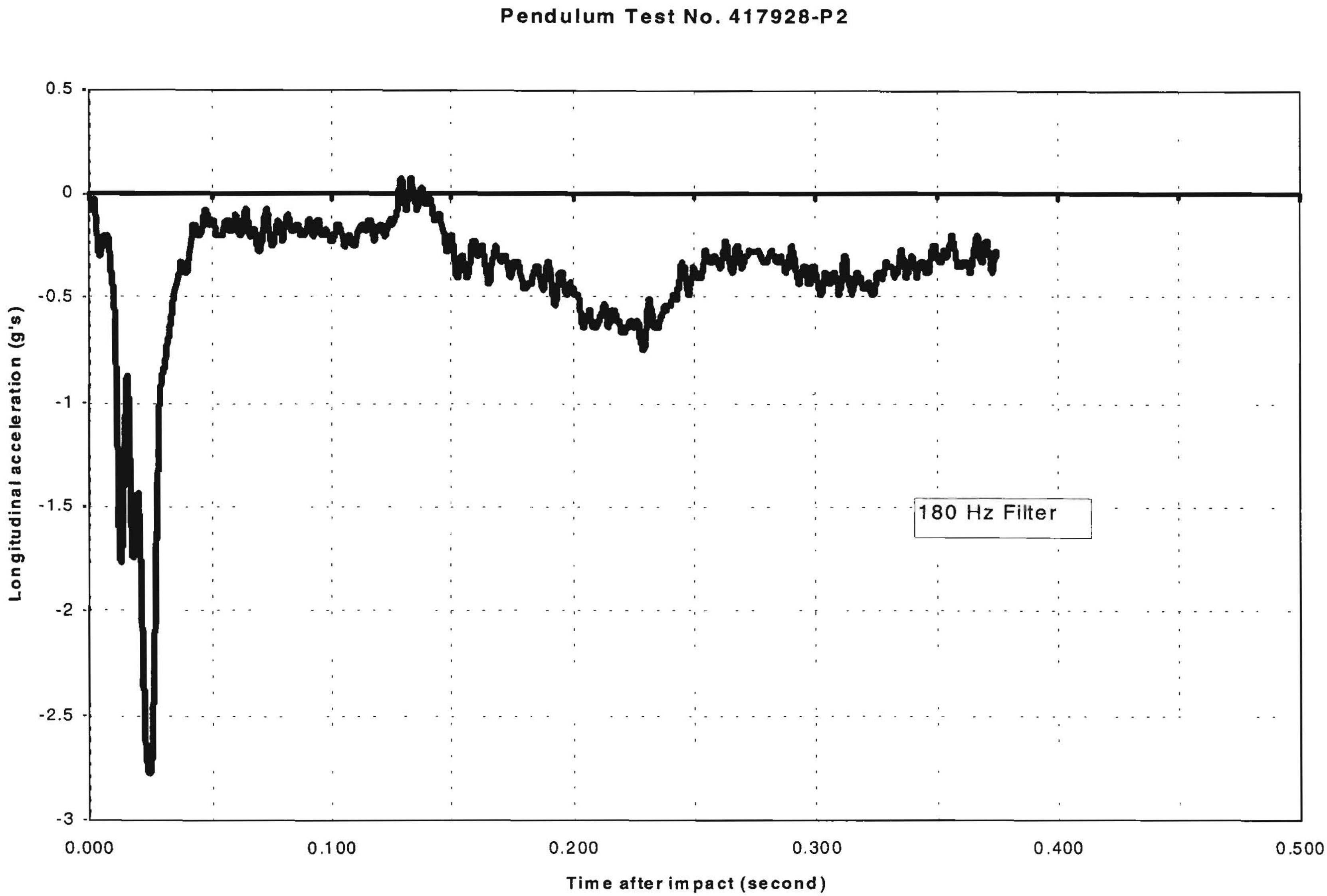


Figure 83. Pendulum Longitudinal Accelerometer Trace for Test 417928-P2.

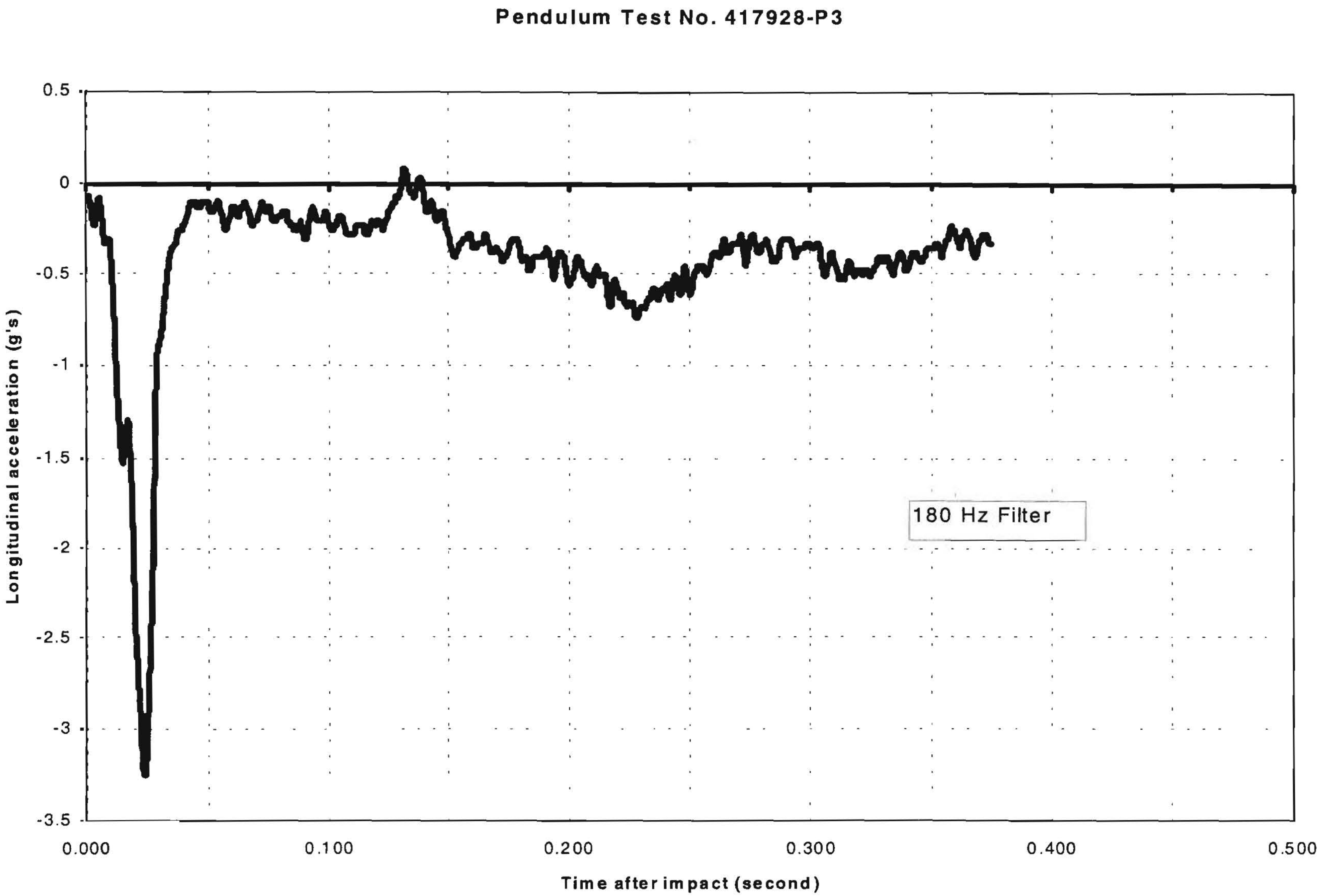


Figure 84. Pendulum Longitudinal Accelerometer Trace for Test 417928-P3.

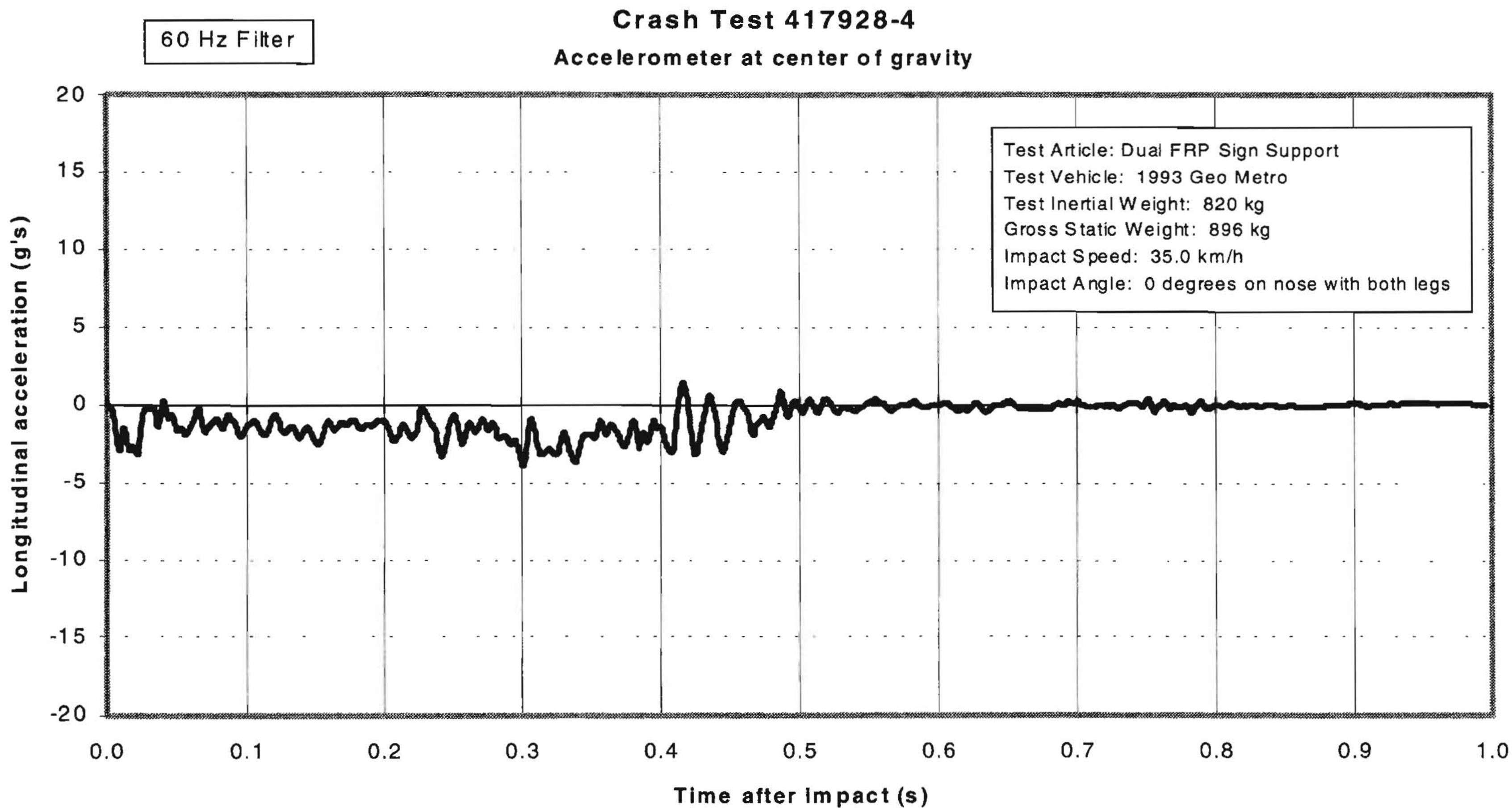


Figure 85. Pendulum Longitudinal Accelerometer Trace for Test 417928-P4.

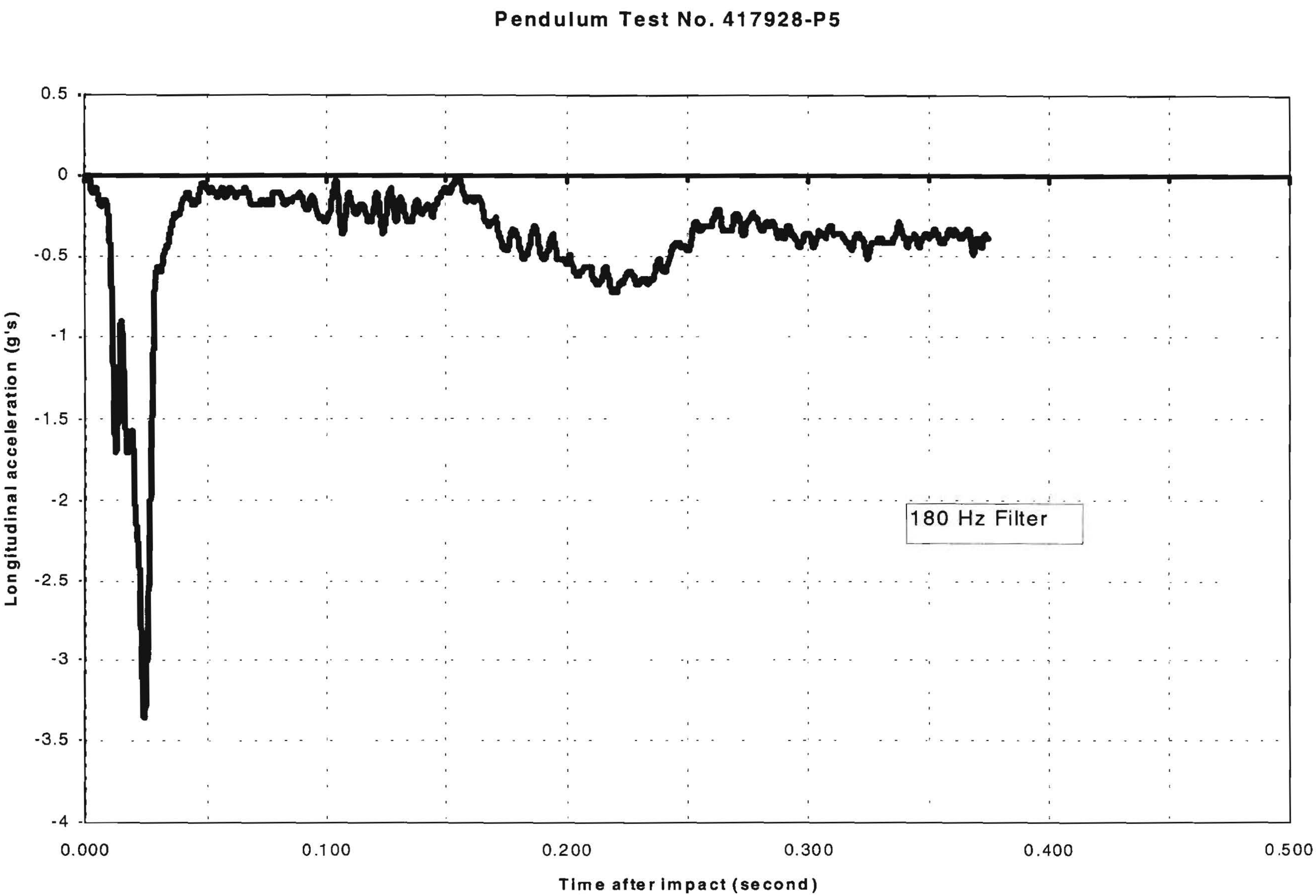


Figure 86. Pendulum Longitudinal Accelerometer Trace for Test 417928-P5.

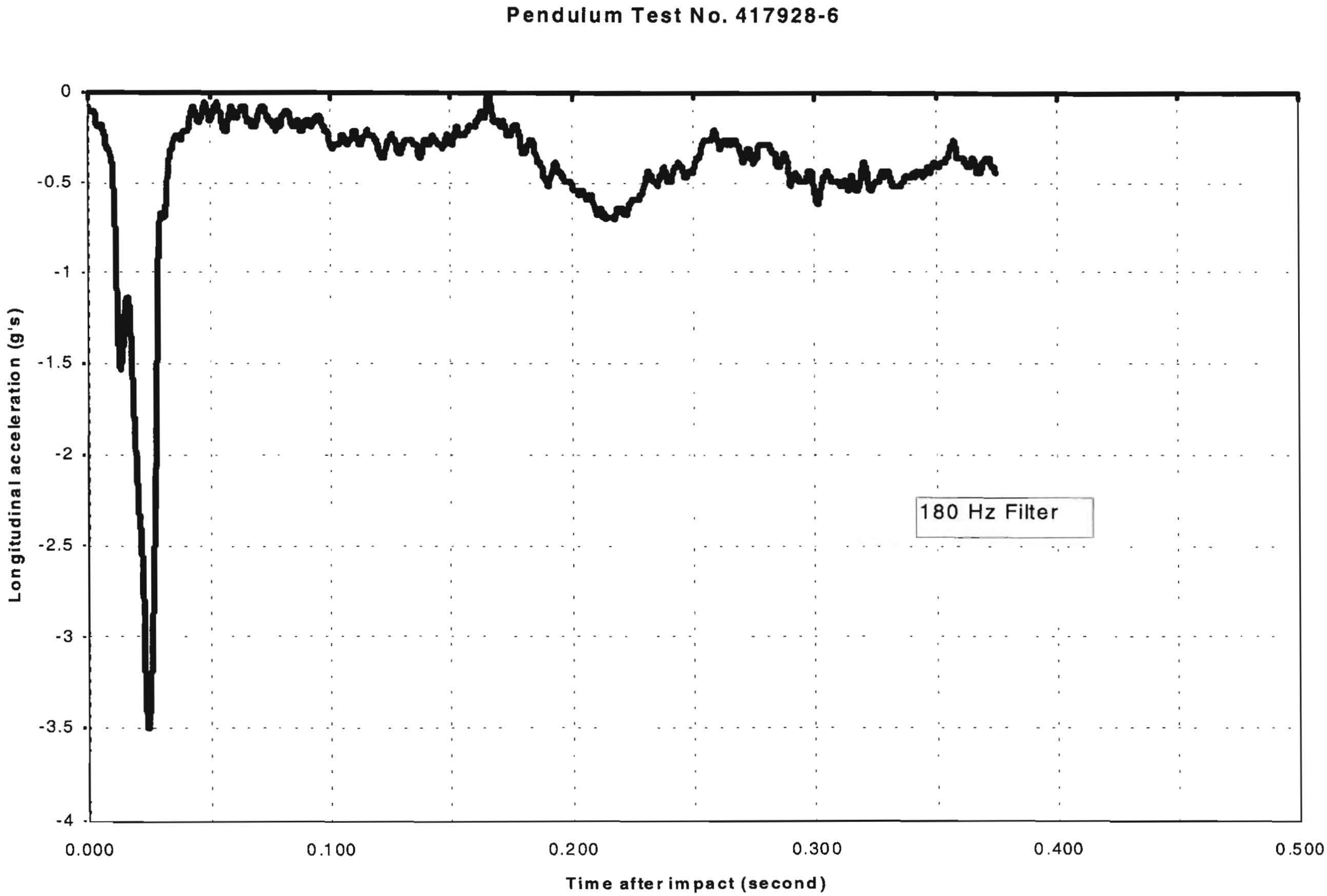


Figure 87. Pendulum Longitudinal Accelerometer Trace for Test 417928-P6.

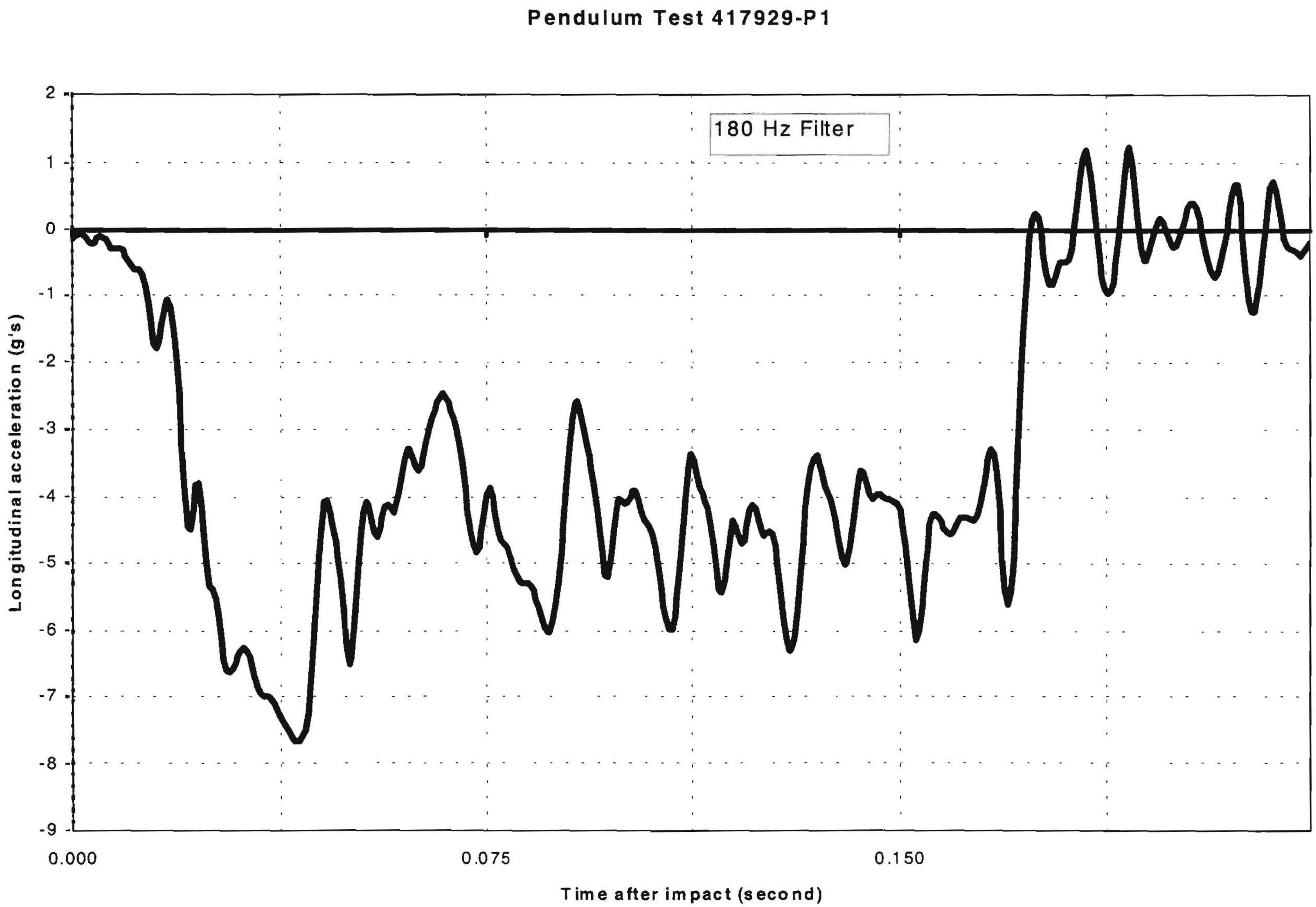


Figure 88. Pendulum Longitudinal Accelerometer Trace for Test 417929-P1.

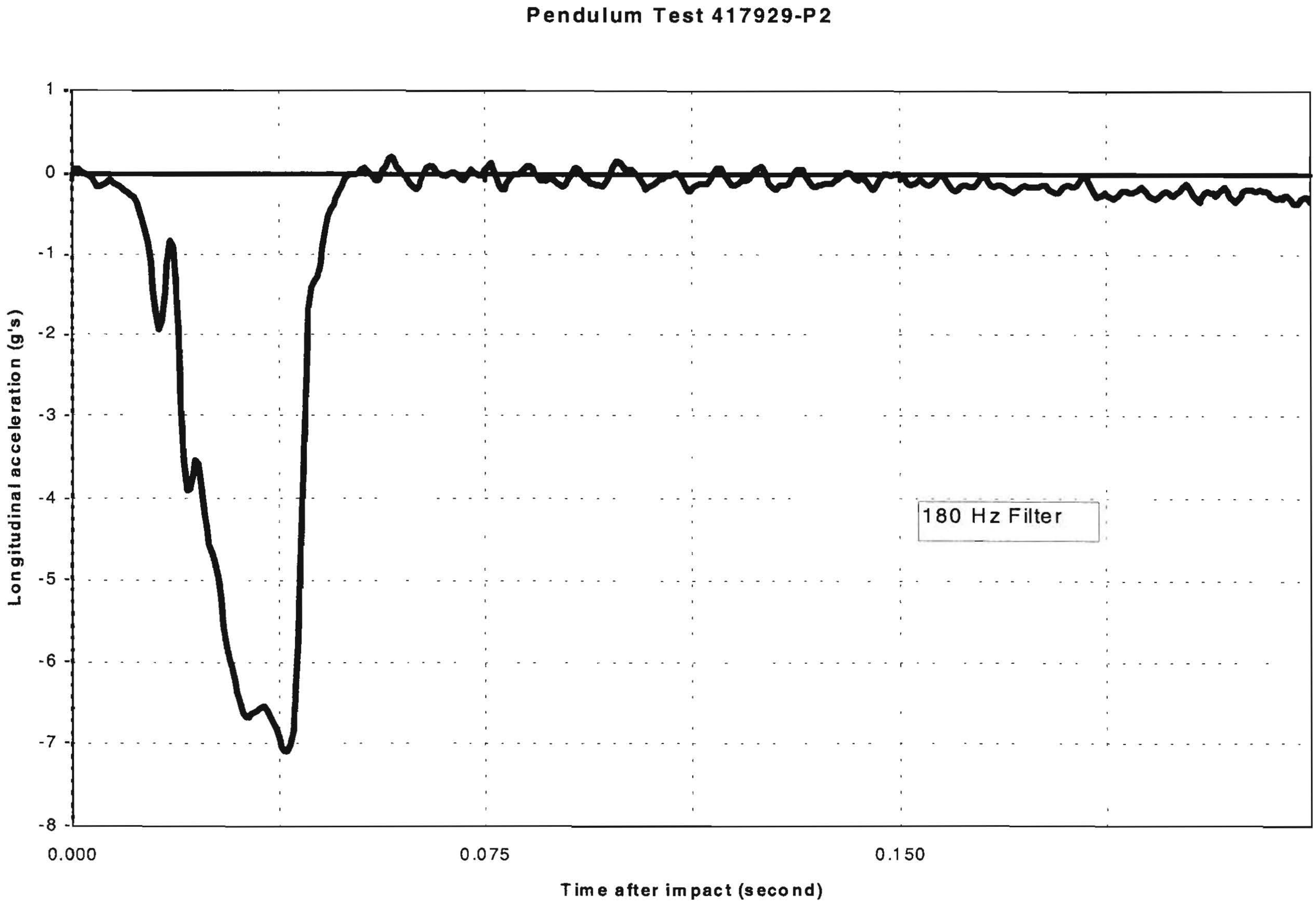


Figure 89. Pendulum Longitudinal Accelerometer Trace for Test 417929-P2.

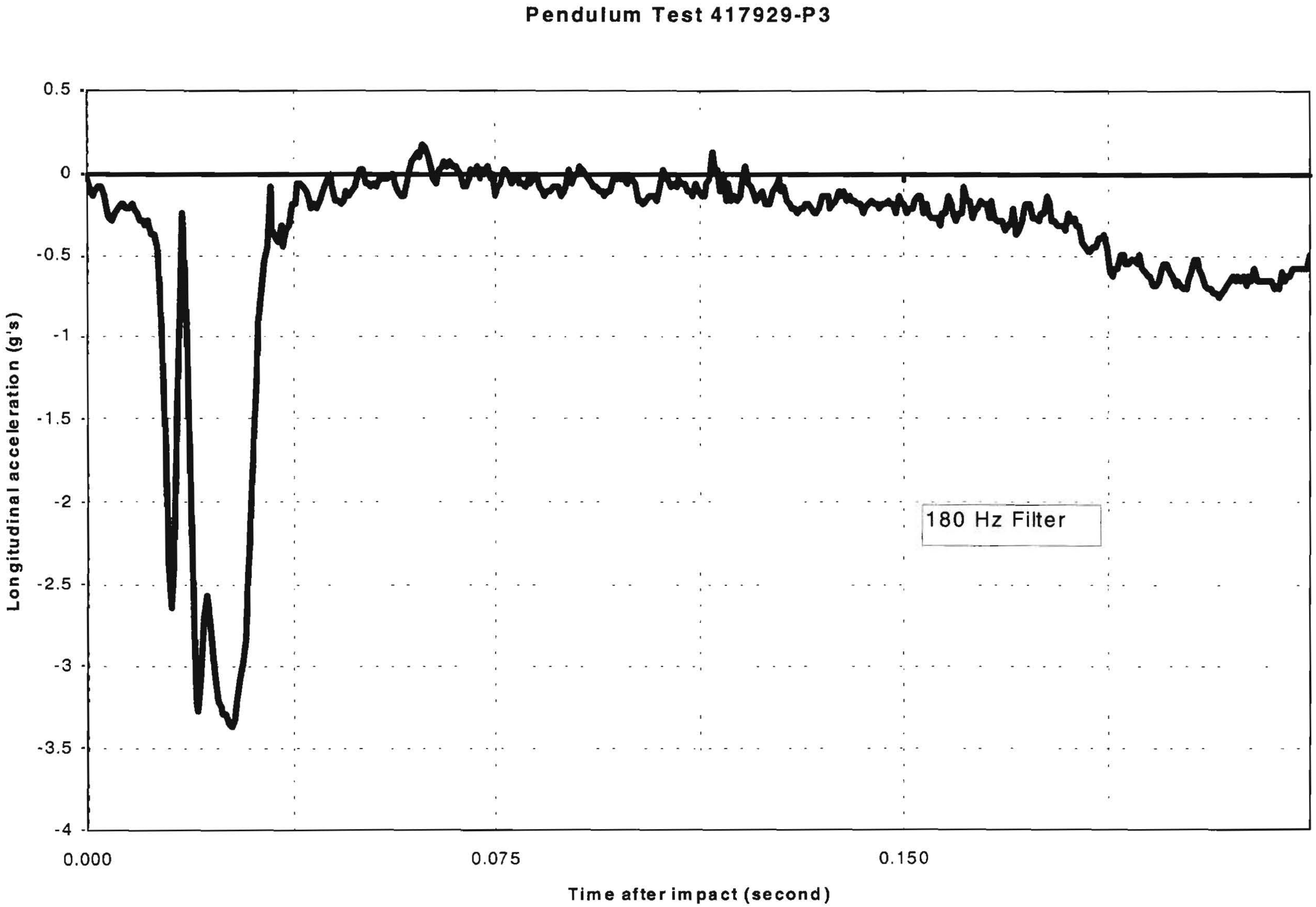


Figure 90. Pendulum Longitudinal Accelerometer Trace for Test 417929-P3.

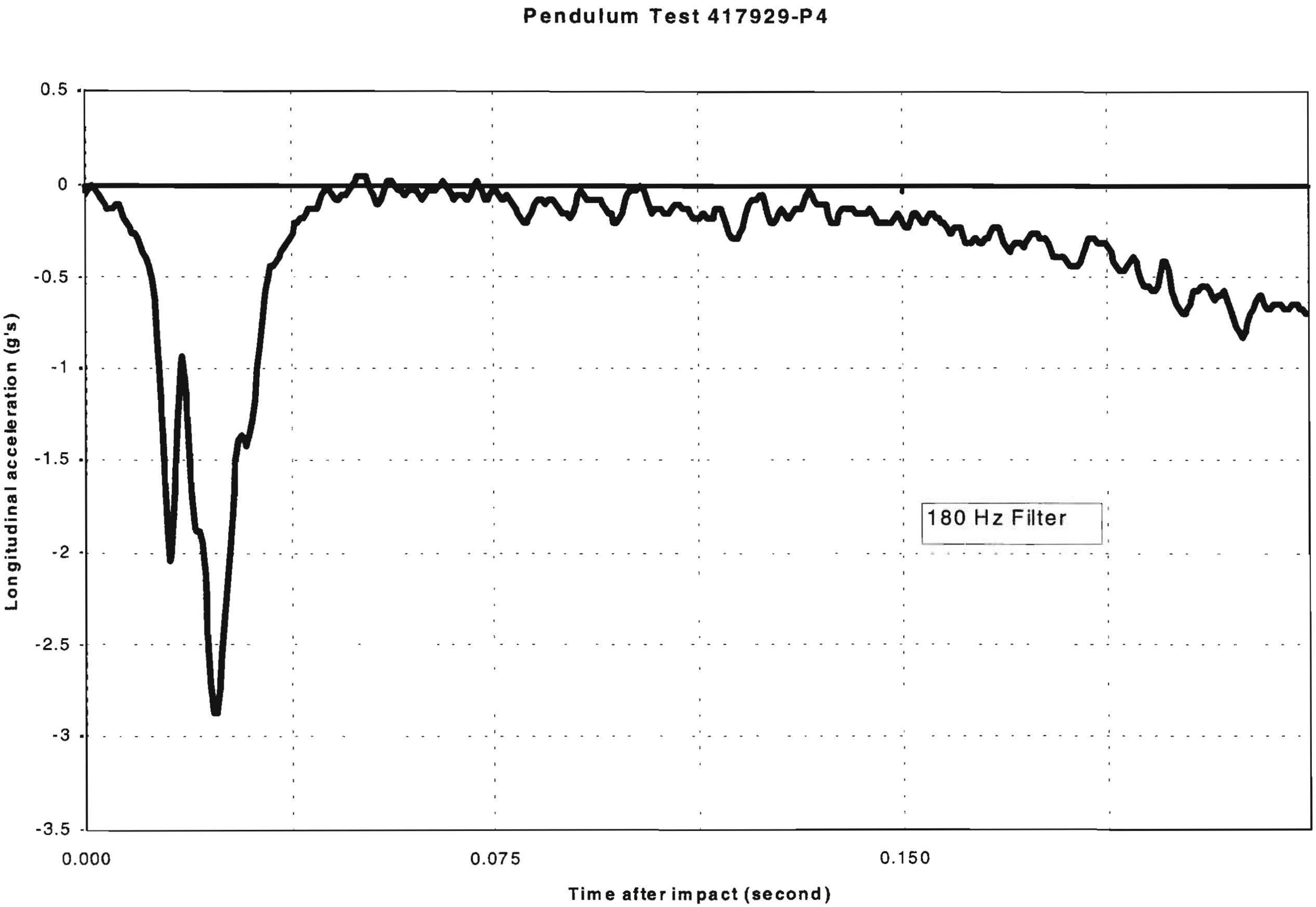
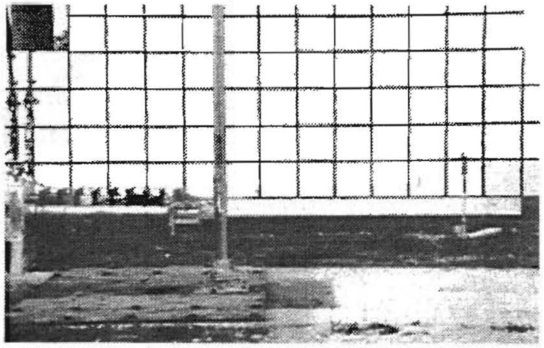
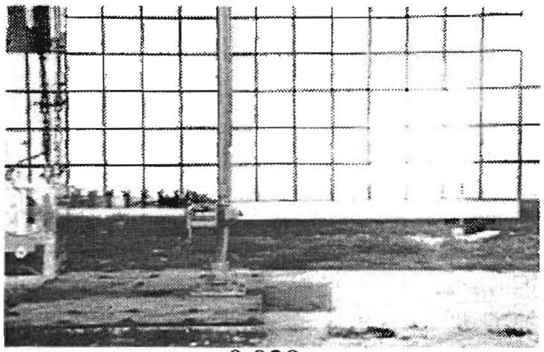


Figure 91. Pendulum Longitudinal Accelerometer Trace for Test 417929-P4.

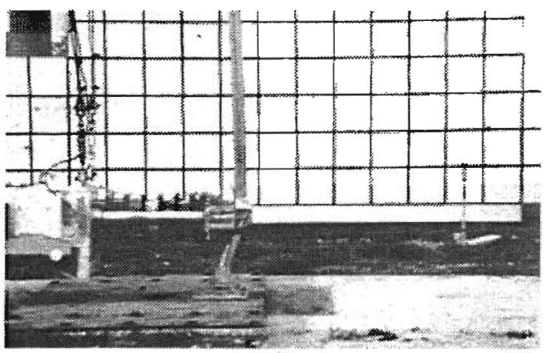
APPENDIX D. SEQUENTIAL PHOTOGRAPHS



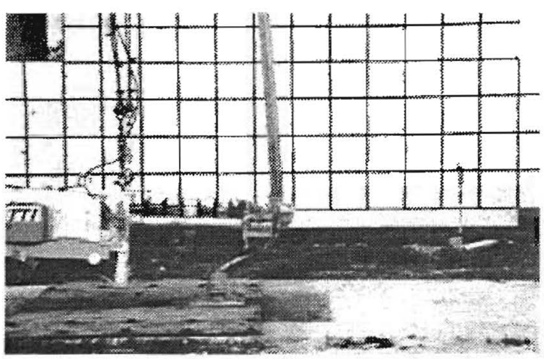
0.000 s



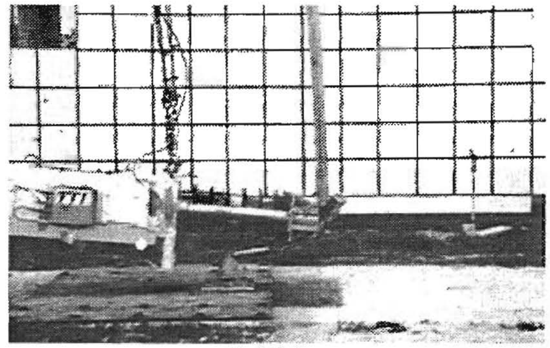
0.020 s



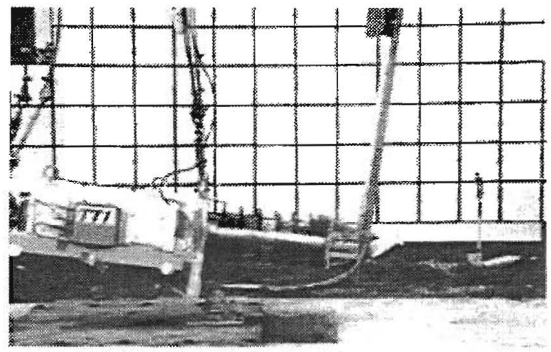
0.040 s



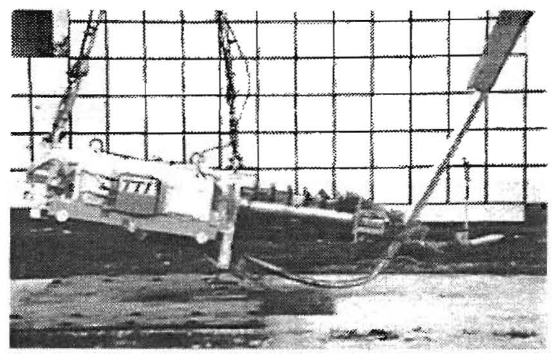
0.070 s



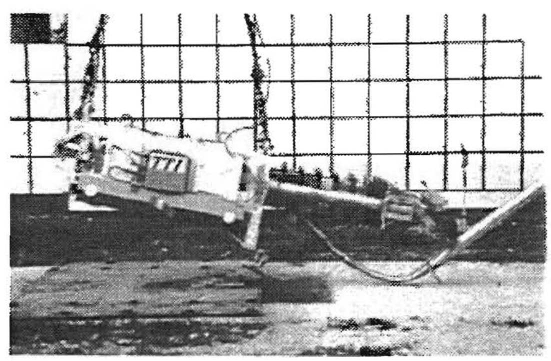
0.100 s



0.150 s

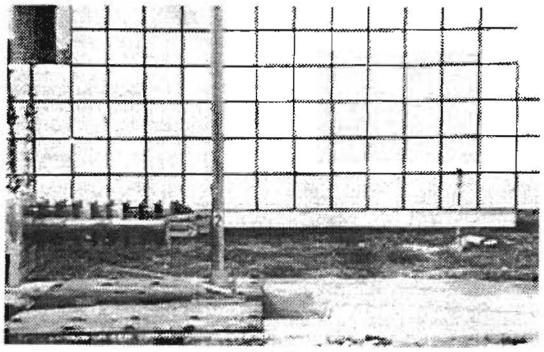


0.200 s

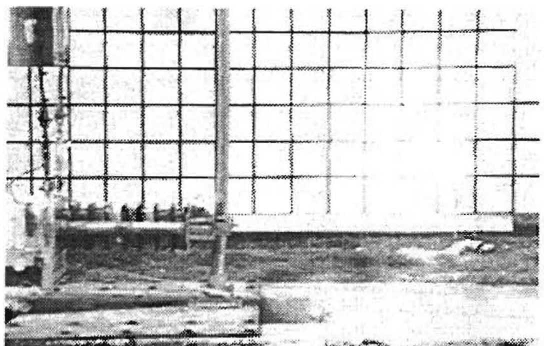


0.260 s

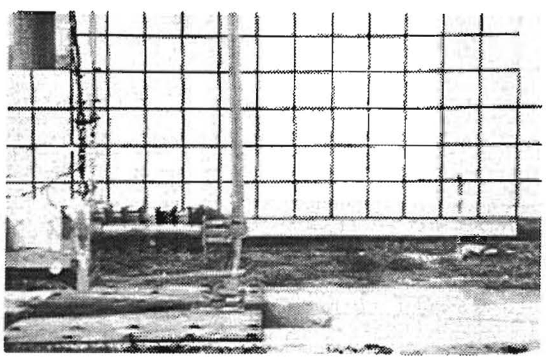
Figure 92. Sequential Photographs for Test 417929-P1 (Perpendicular View).



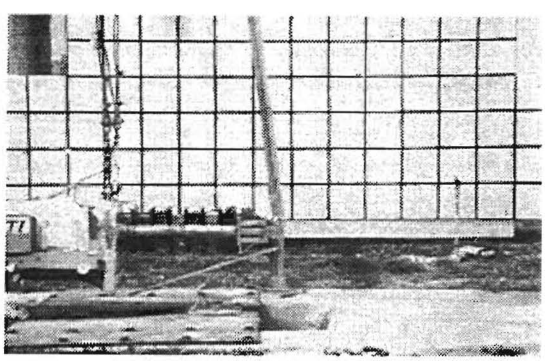
0.000 s



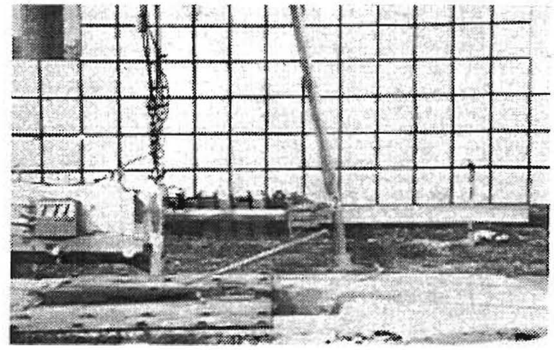
0.020 s



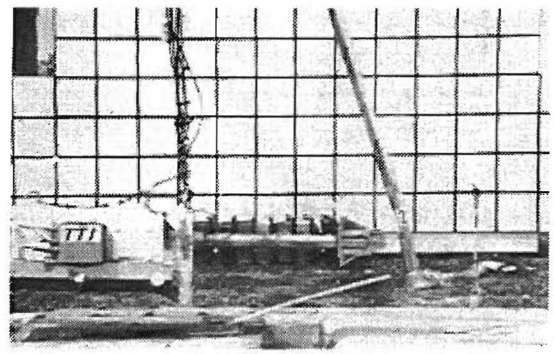
0.040 s



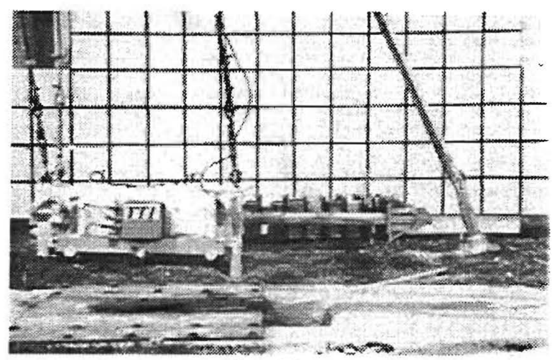
0.060 s



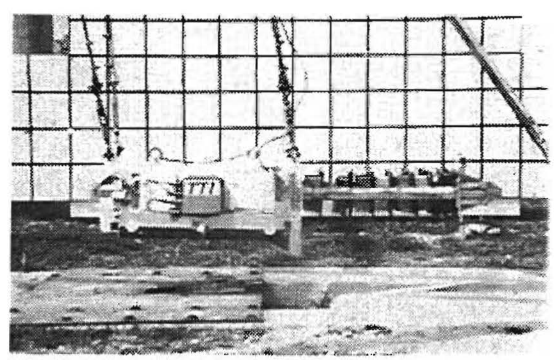
0.080 s



0.110 s

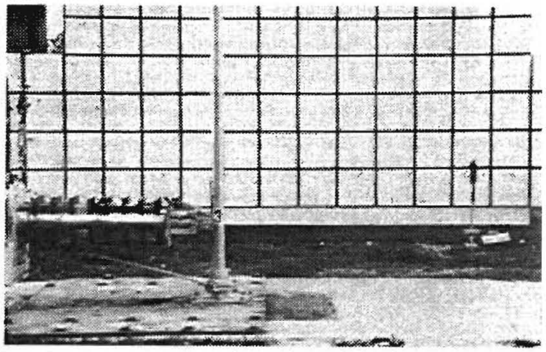


0.140 s

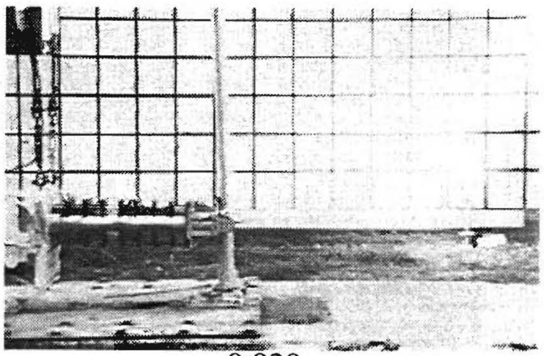


0.180 s

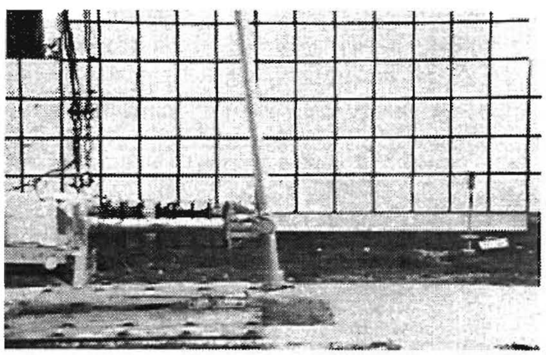
Figure 93. Sequential Photographs for Test 417929-P2 (Perpendicular View).



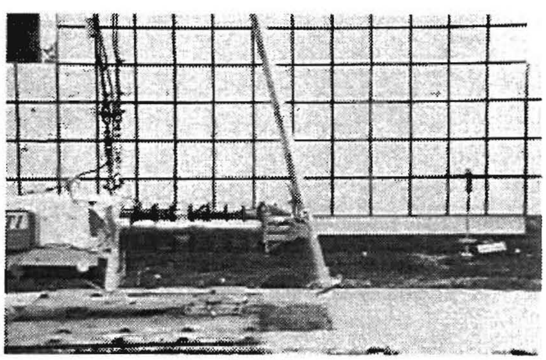
0.000 s



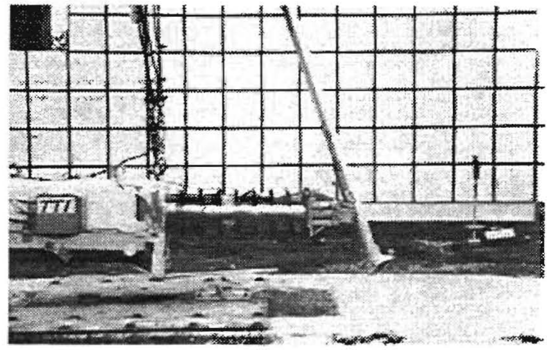
0.020 s



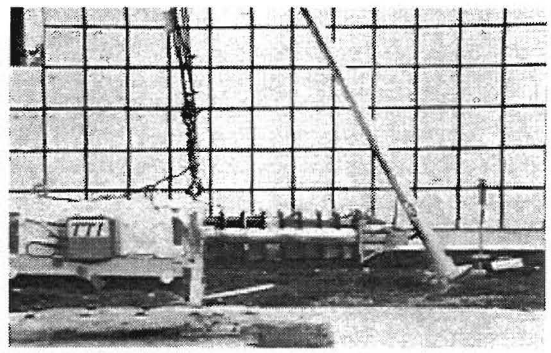
0.040 s



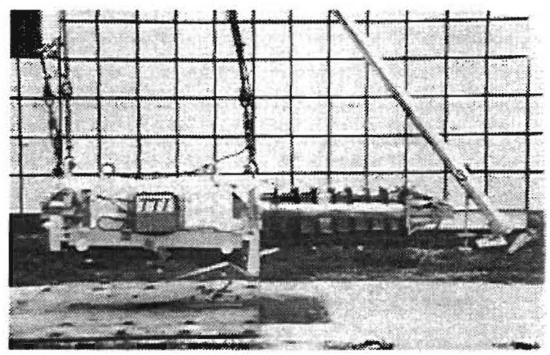
0.060 s



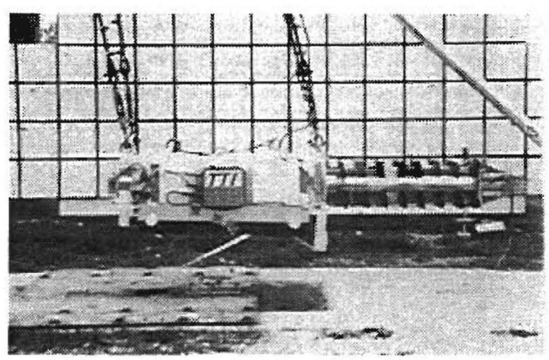
0.080 s



0.110 s

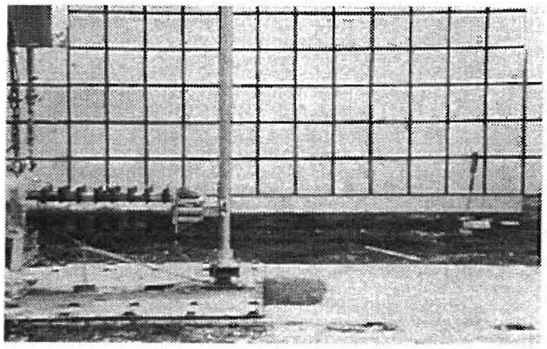


0.140 s

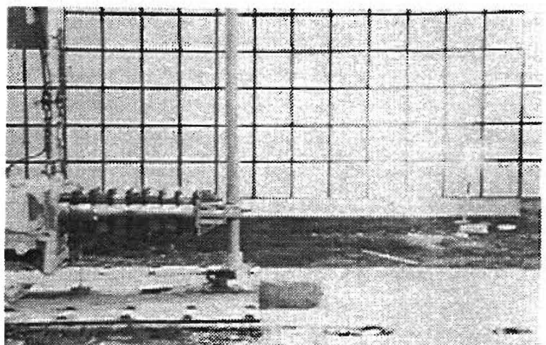


0.180 s

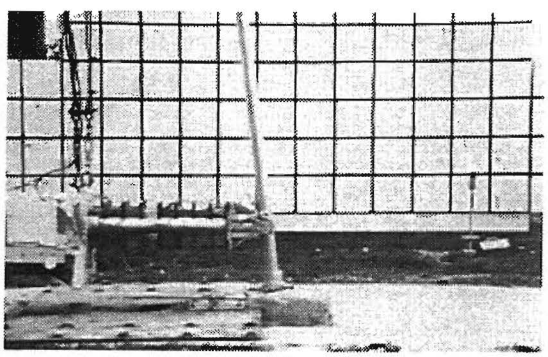
Figure 94. Sequential Photographs for Test 417929-P3 (Perpendicular View).



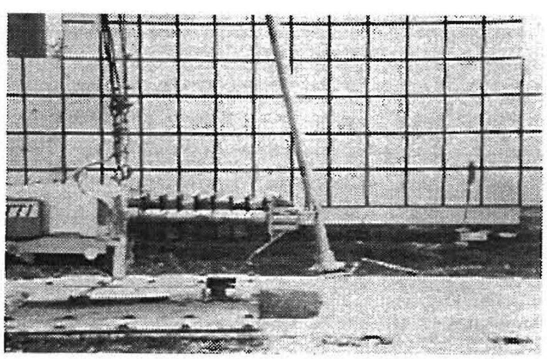
0.000 s



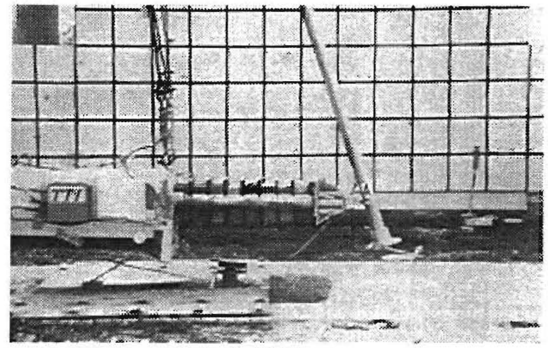
0.020 s



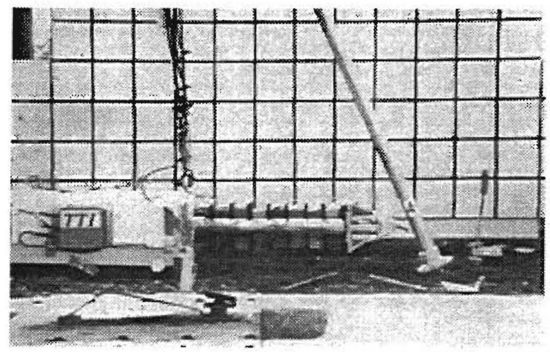
0.040 s



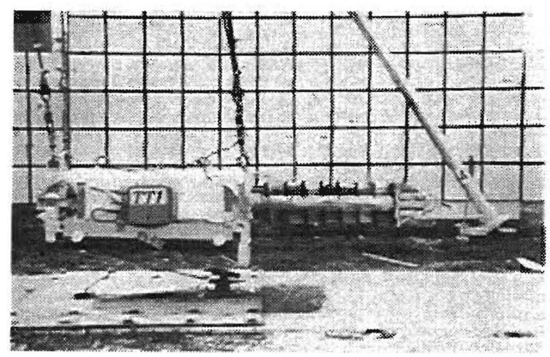
0.060 s



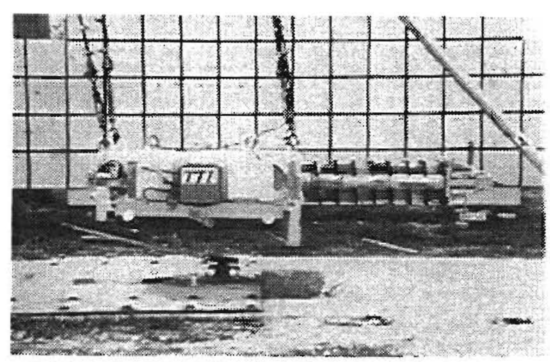
0.080 s



0.100 s



0.130 s



0.160 s

Figure 95. Sequential Photographs for Test 417929-P4 (Perpendicular View).

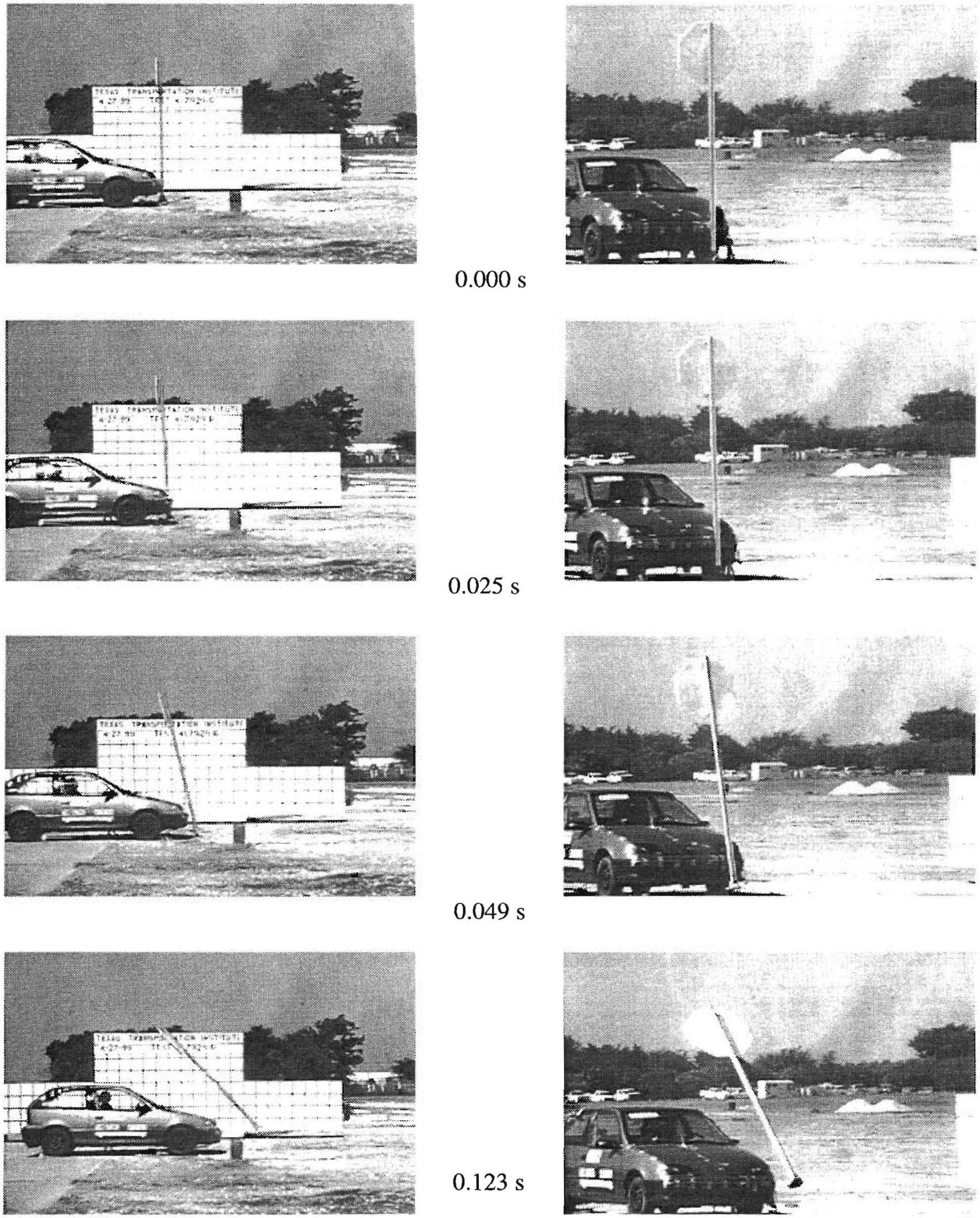
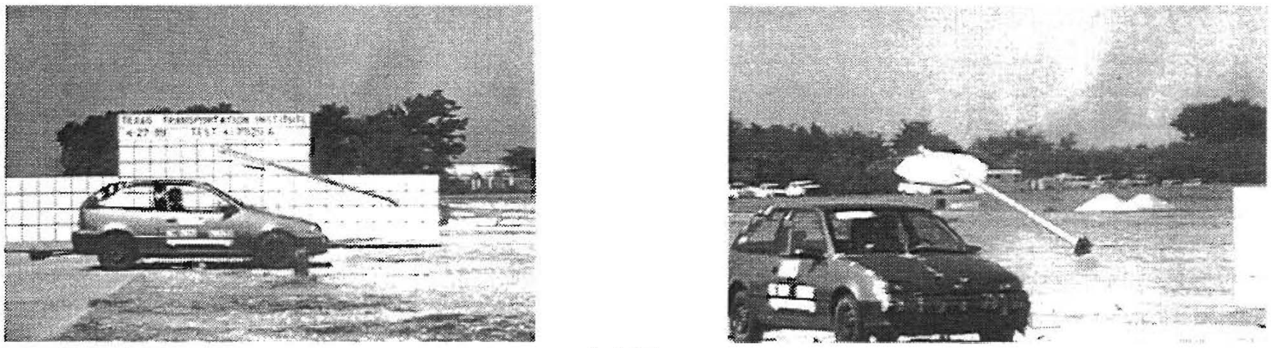
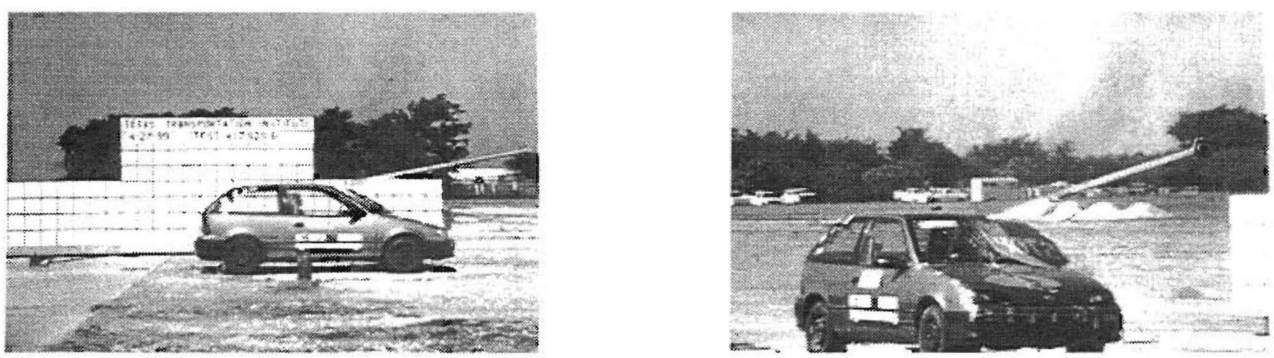


Figure 96. Sequential Photographs for Test 417929-6 (Perpendicular and Frontal Views).

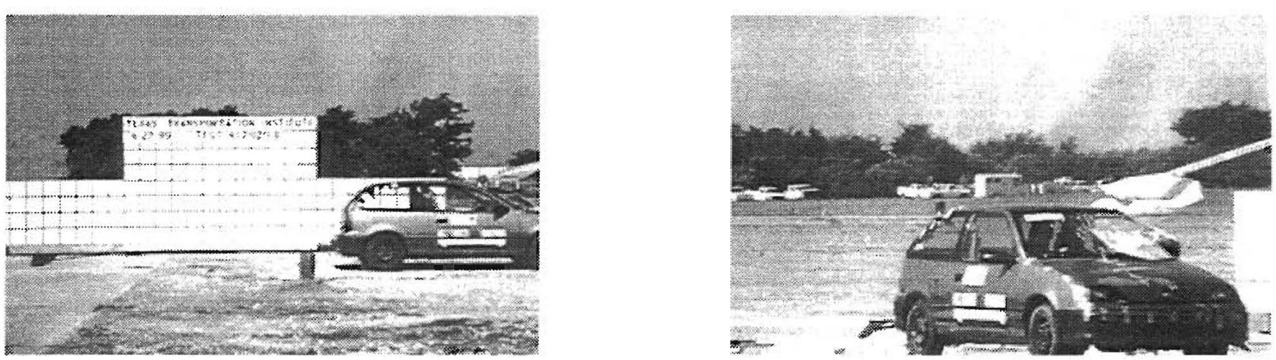


0.197 s

0.295 s

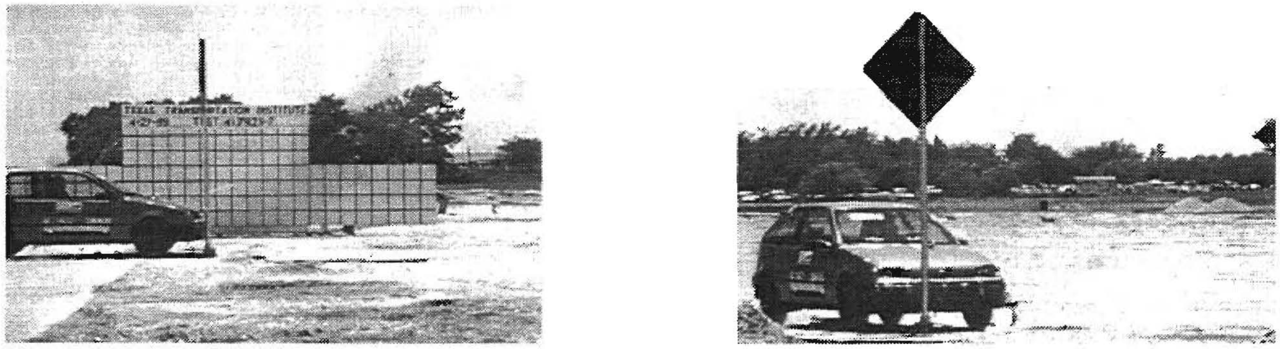


0.394 s

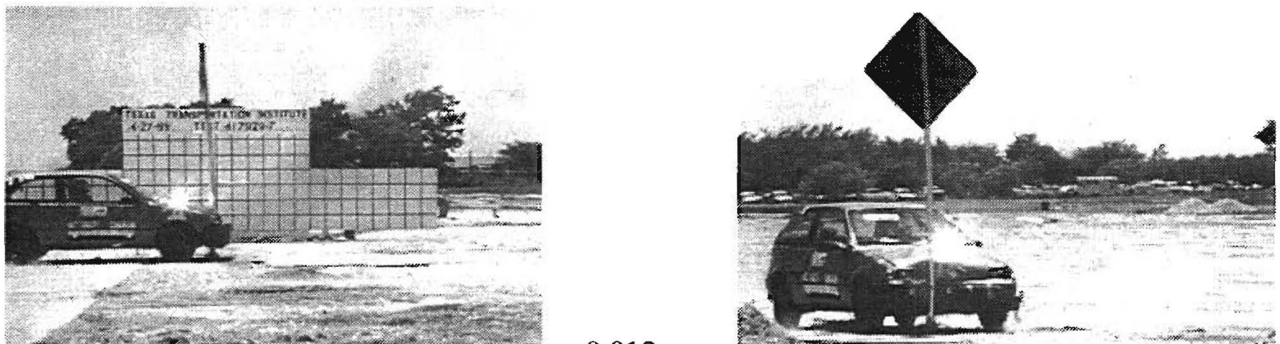


0.615 s

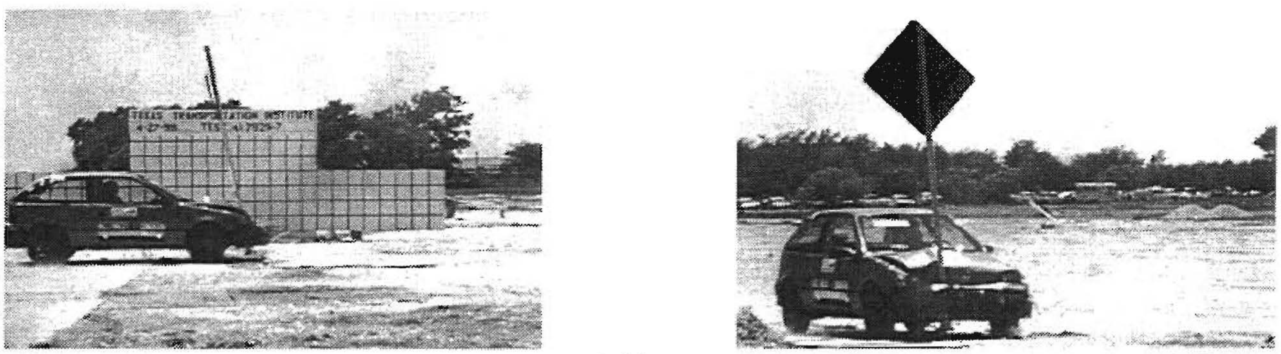
Figure 96. Sequential Photographs for Test 417929-6 (Perpendicular and Frontal Views) (Continued).



0.000 s



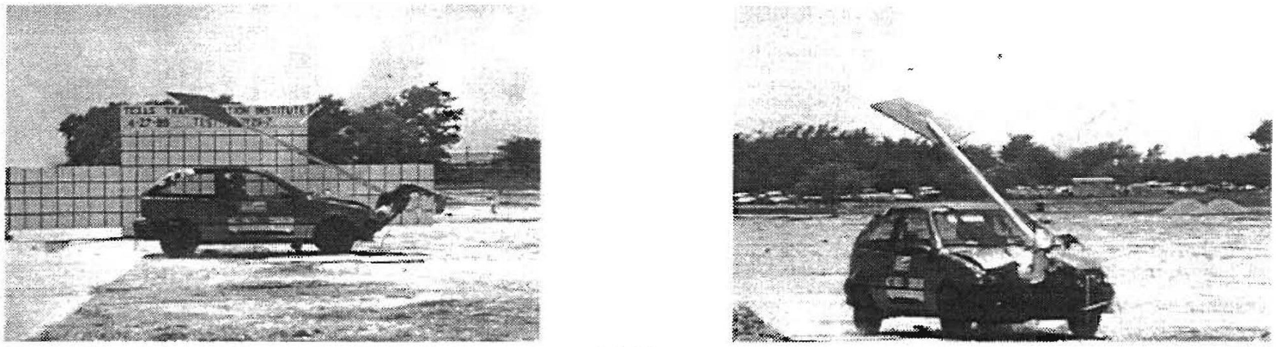
0.012 s



0.025 s

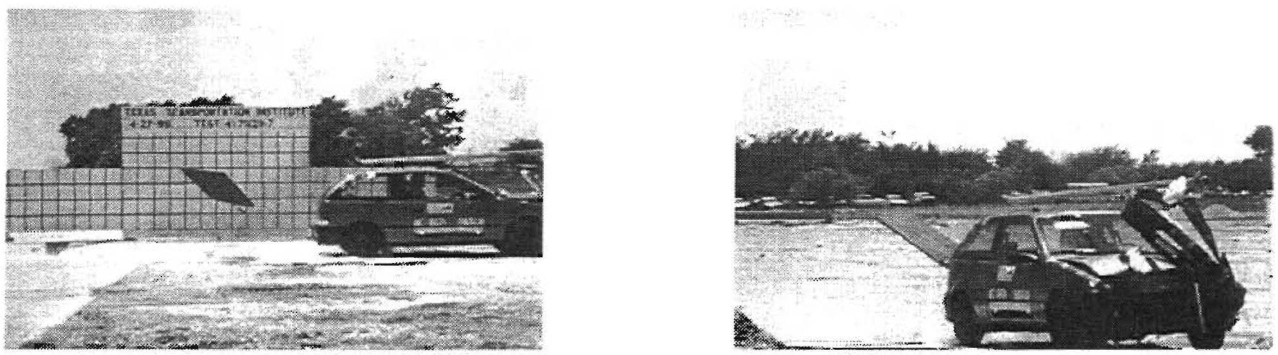
0.049 s

Figure 97. Sequential Photographs for Test 417929-7 (Perpendicular and Frontal Views).

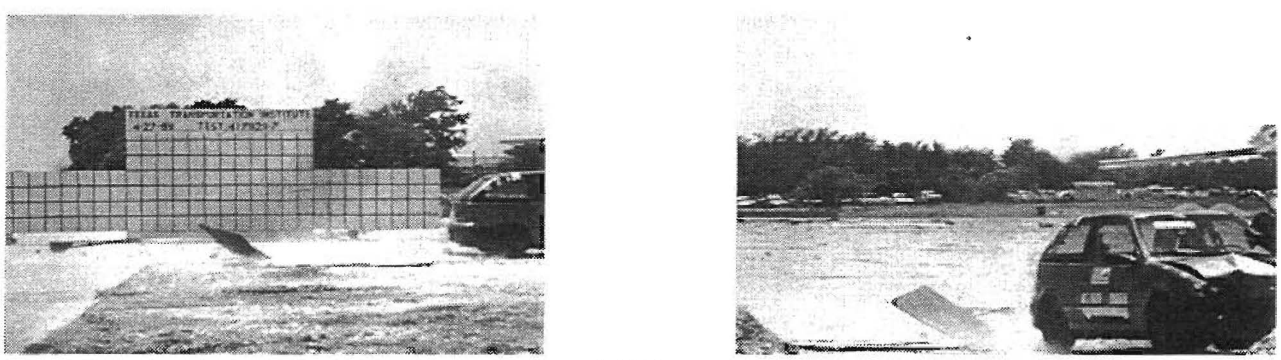


0.099 s

0.148 s



0.198 s



0.272 s

Figure 97. Sequential Photographs for Test 417929-7 (Perpendicular and Frontal Views) (Continued).

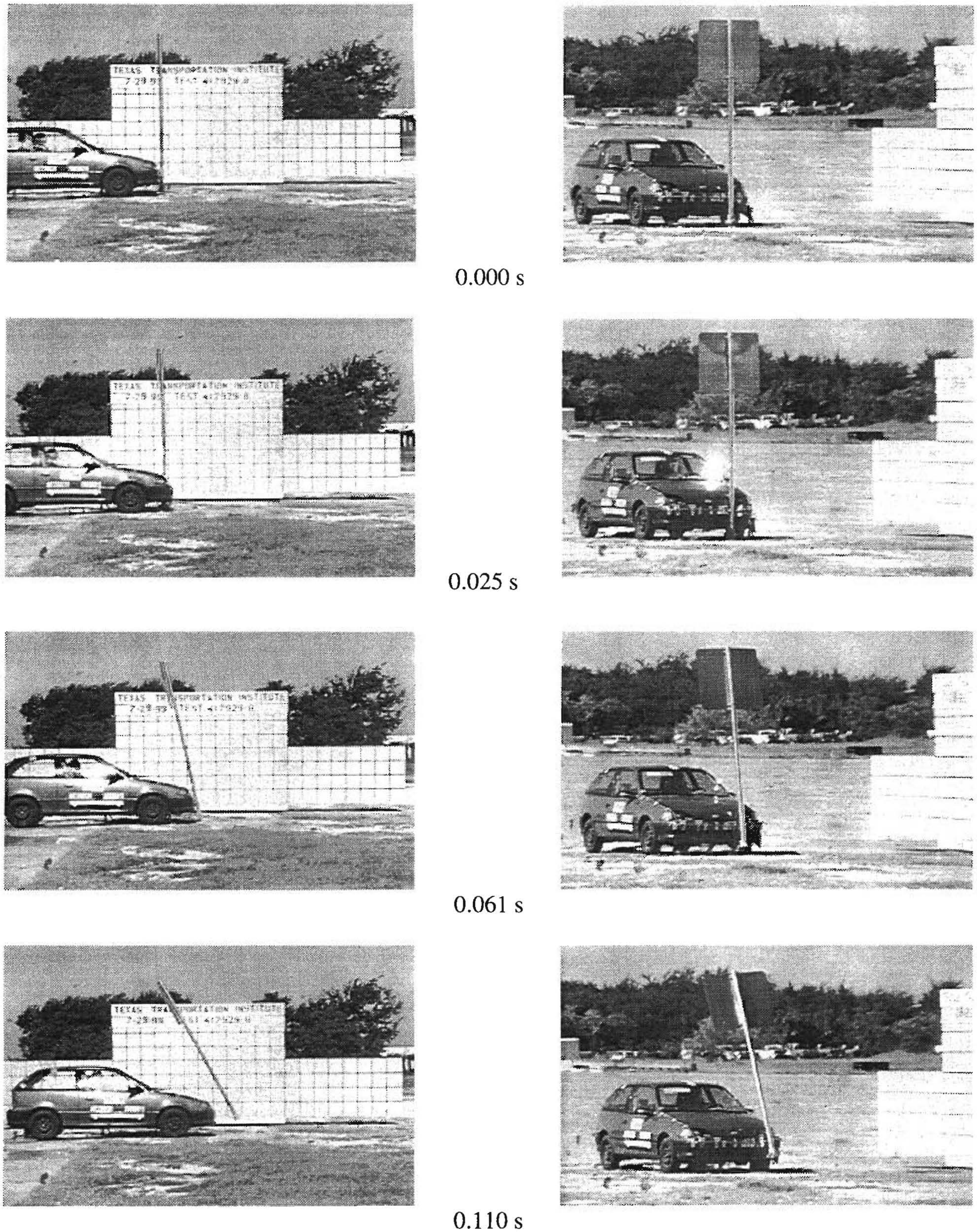


Figure 98. Sequential Photographs for Test 417929-8 (Perpendicular and Frontal Views).

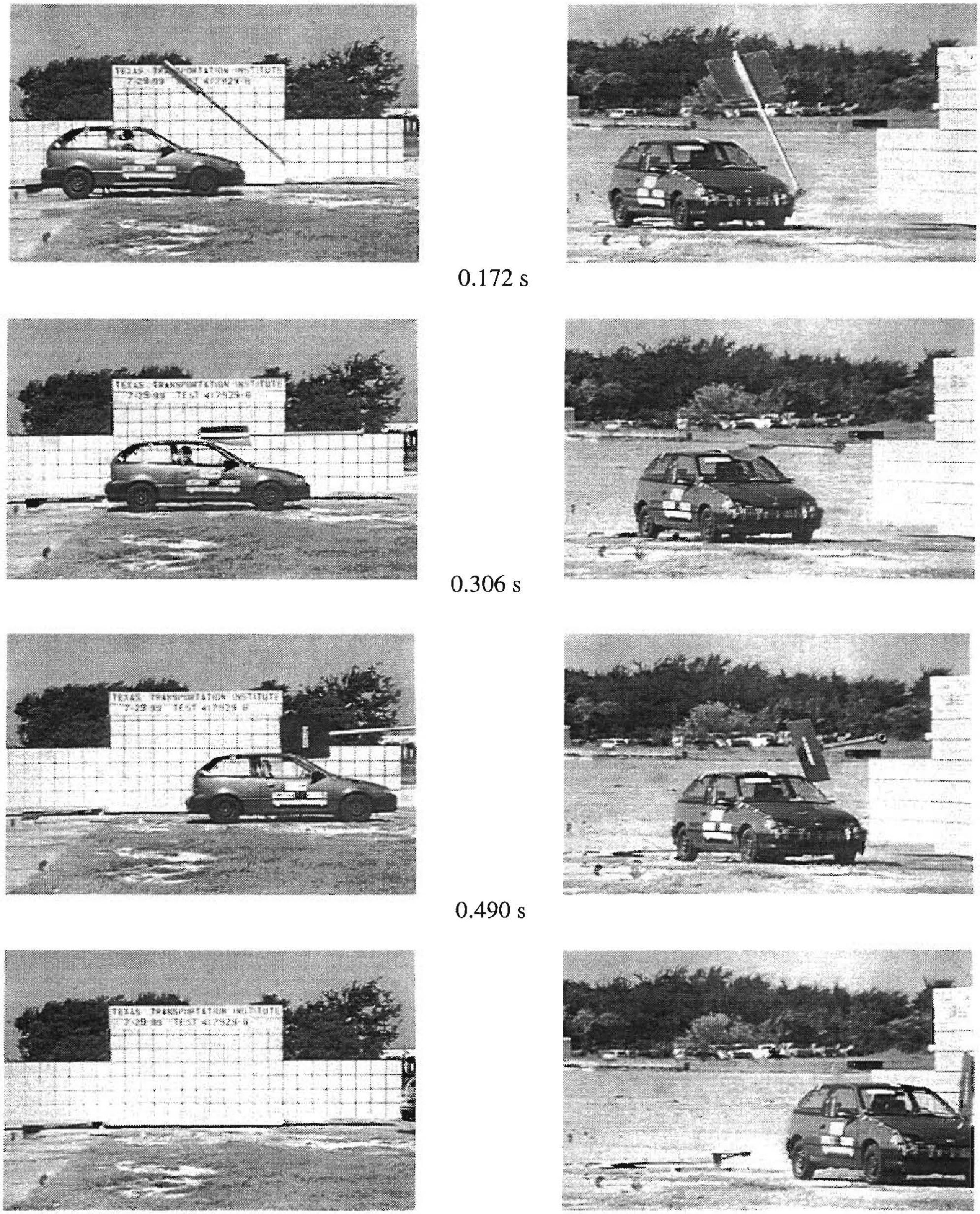
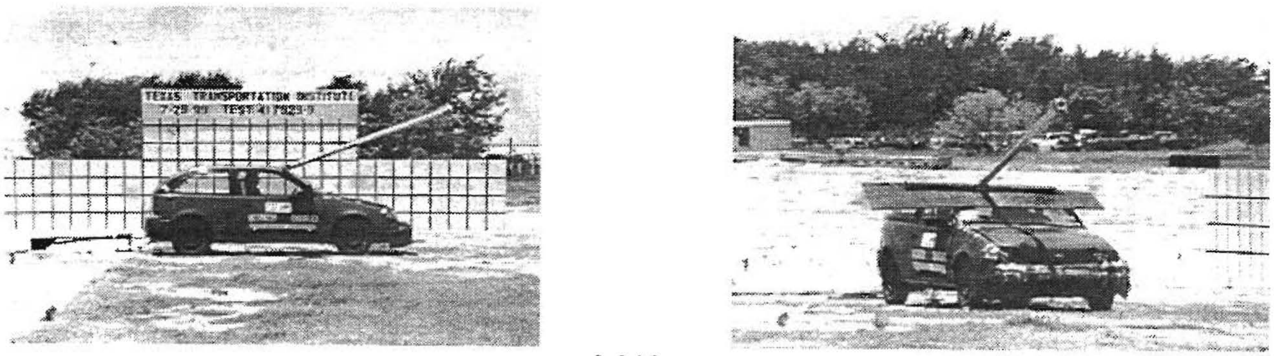
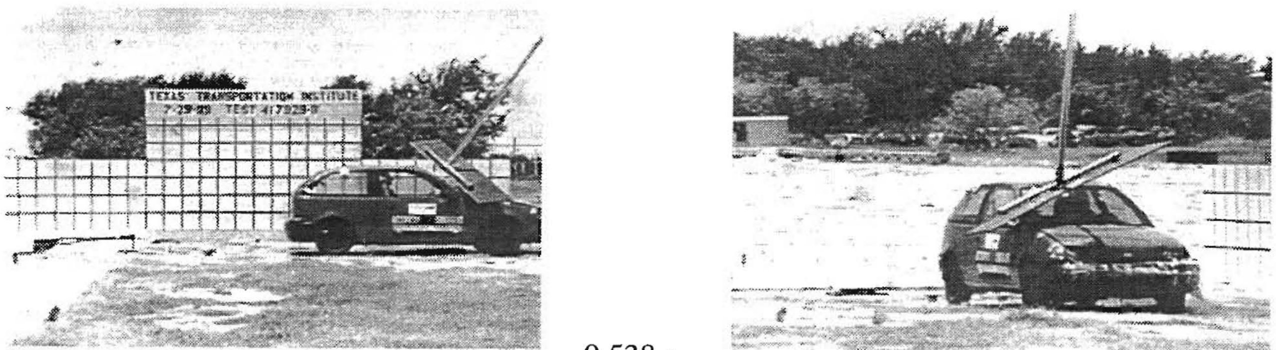


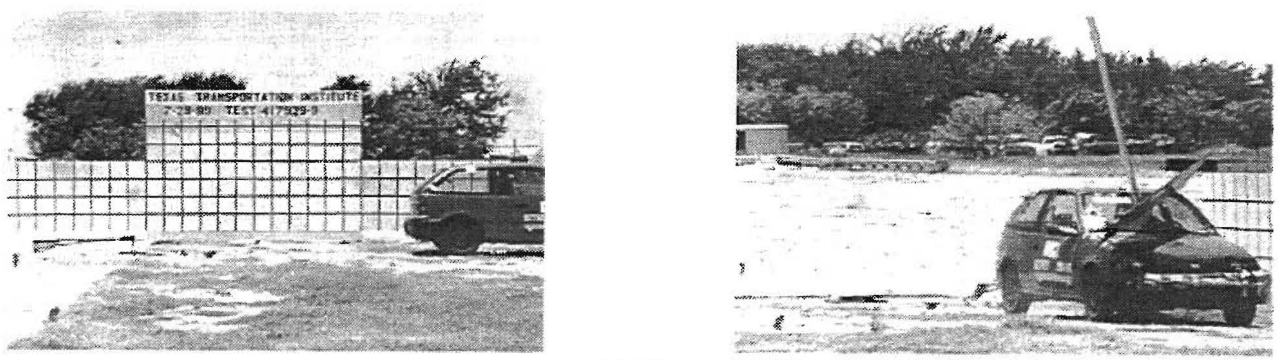
Figure 98. Sequential Photographs for Test 417929-8 (Perpendicular and Frontal Views) (Continued).



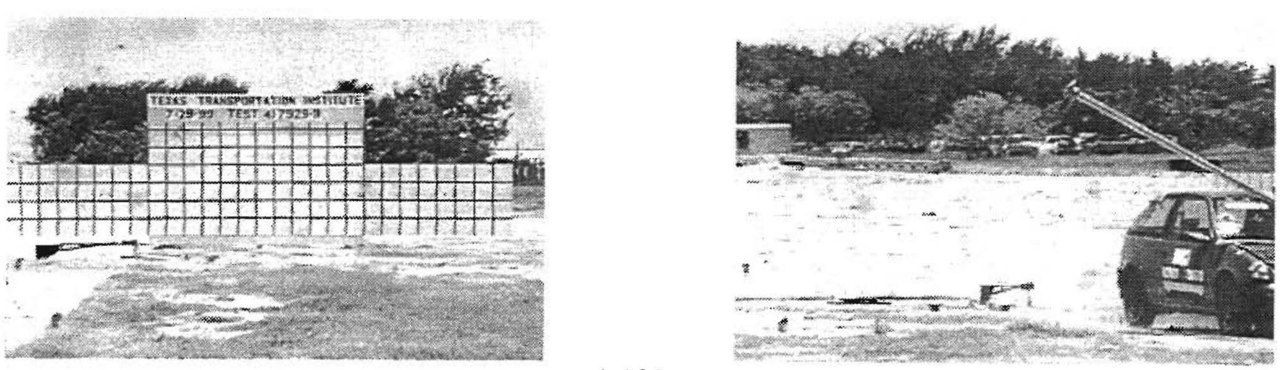
0.318 s



0.538 s



0.733 s



1.100 s

Figure 99. Sequential Photographs for Test 417929-9 (Perpendicular and Frontal Views) (Continued).

APPENDIX E. TEST VEHICLE PROPERTIES AND INFORMATION

DATE: 04-27-99 TEST NO.: 417929-6&7 VIN NO.: 2C1MR2466R6739330

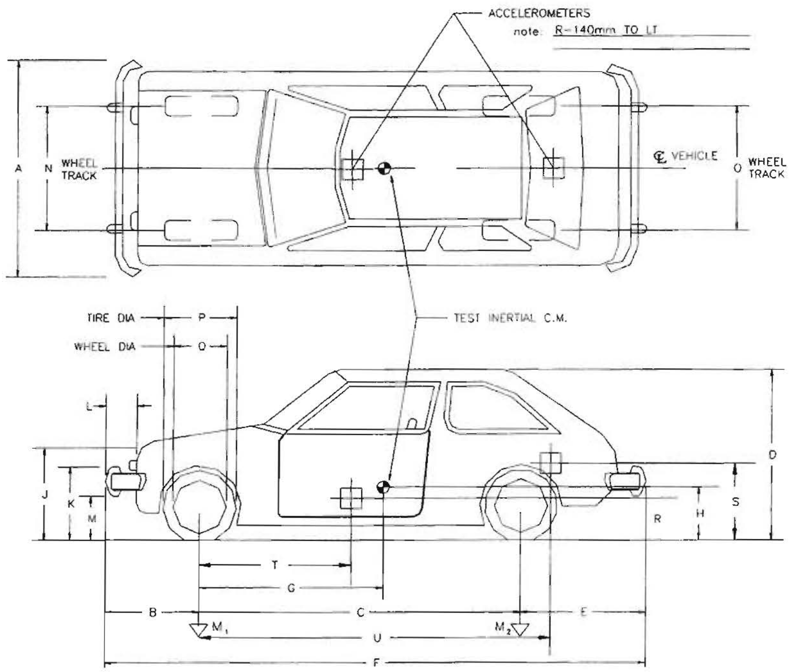
YEAR: 1994 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ______ ODOMETER: 73001 TIRE SIZE: 155R12

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

MASS DISTRIBUTION (kg) LF 252 RF 241 LR 171 RR 156

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 CYL.

ENGINE CID: 1.0L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

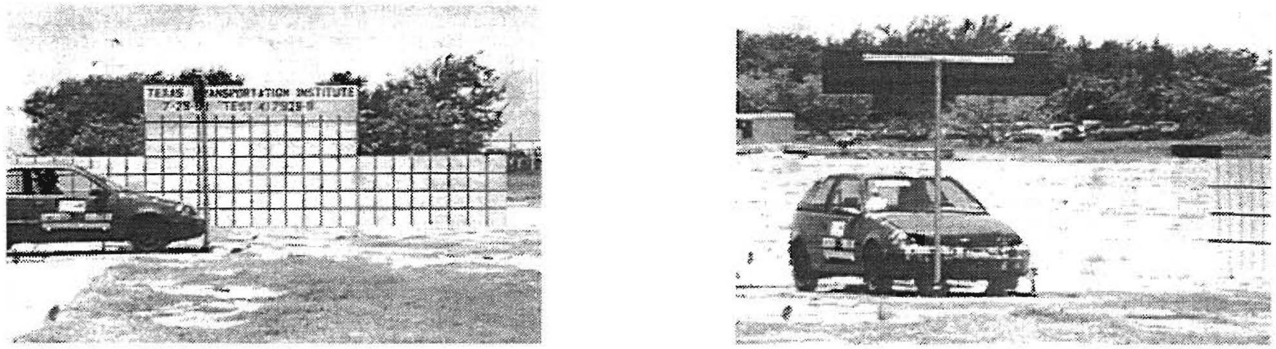
SEAT POSITION: Driver

GEOMETRY – (mm)

A	1410	E	680	J	680	N	1350	R	380
B	770	F	3720	K	450	O	1350	S	560
C	2270	G	905.2	L	950	P	540	T	950
D	1320	H		M	370	Q	335	U	2470

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	475	493	527
M_2	288	327	369
M_T	763	820	896

Figure 100. Vehicle Properties for Test 417929-6 and 417929-7.



0.000 s

0.024 s

0.086 s

0.183 s

Figure 99. Sequential Photographs for Test 417929-9 (Perpendicular and Frontal Views).

Table 6. Exterior Crush Measurements for Test 417929-7.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 ____ X1 ____
Corner shift: A1 ________	B2 ____ X2 ____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	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	Inner Bumper	700	130	880	0	-35	-80	-120	0	80	

[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).

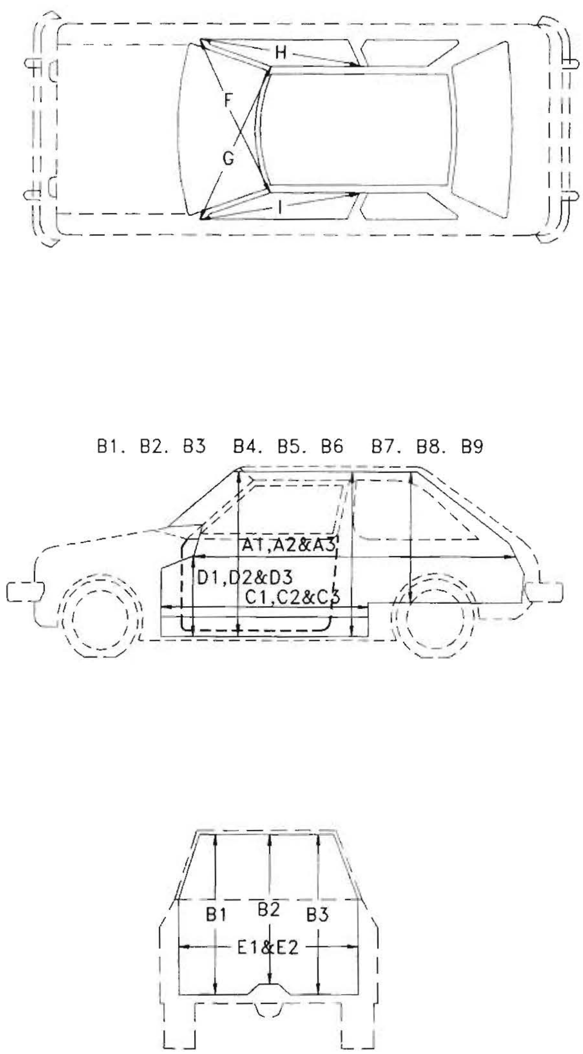
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 7. Occupant Compartment Measurements for Test 417929-7.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1505	-
A2	2087	-
A3	1505	-
B1	983	-
B2	937	911
B3	982	-
B4	965	955
B5	860	813
B6	963	955
B7	660	655
B8	670	640
B9	645	625
C1	707	-
C2	710	-
C3	709	-
D1	300	-
D2	105	-
D3	298	-
E1	1247	-
E2	1249	-
F	1205	-
G	1205	-
H	900	-
I	900	-

DATE: 07/29/99 TEST NO.: 417929-8 & 9 VIN NO.: 2C1MR2464R6770415

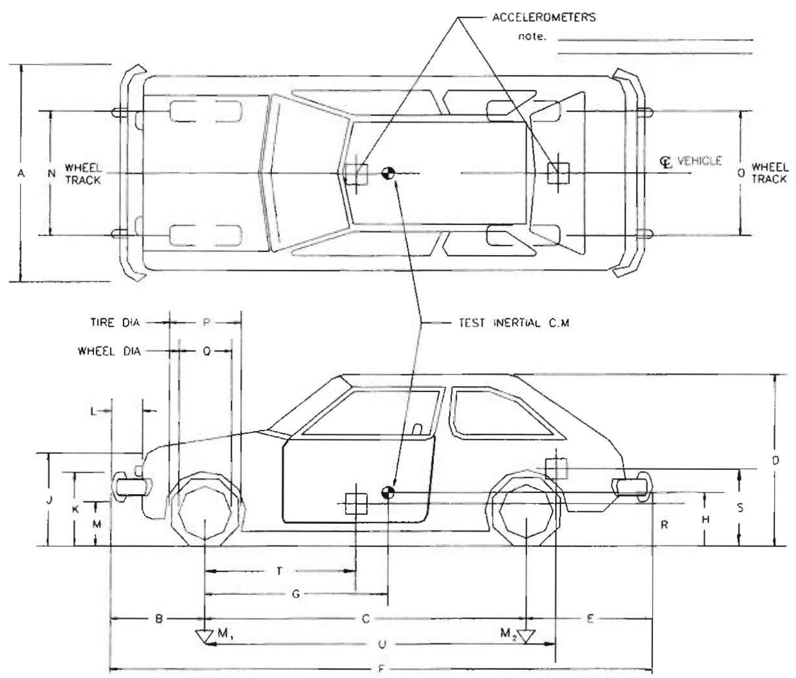
YEAR: 1994 MAKE: GEO MODEL: METRO

TIRE INFLATION PRESSURE: ________ ODOMETER: 73361 TIRE SIZE: 155R12

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

MASS DISTRIBUTION (kg) LF 245 RF 232 LR 177 RR 166

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	1400	E	630	J	690	N	1380	R	360
B	765	F		K	460	O	1360	S	525
C	2265	G		L	95	P	540	T	940
D	1340	H		M	375	Q	335	U	2455

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	452	477	515
M_2	297	343	381
M_T	749	820	896

Figure 101. Vehicle Properties for Tests 417929-8 and 417929-9.

Table 8. Exterior Crush Measurements for Test 417929-8.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 ____ X1 ____
Corner shift: A1 ________	B2 ____ X2 ____
A2 ________	
End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	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)	Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Bumper	550	80	700	15	70	60	15	10	0	-350

[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).

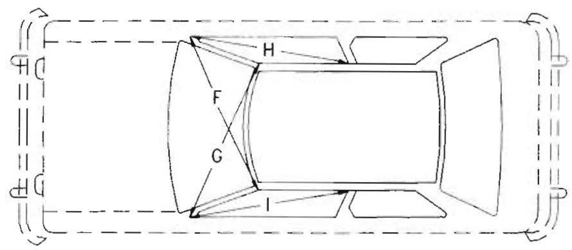
***Measure and document on the vehicle diagram the location of the maximum crush.

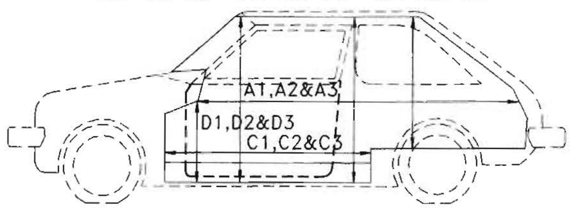
Note: Use as many lines/columns as necessary to describe each damage profile.

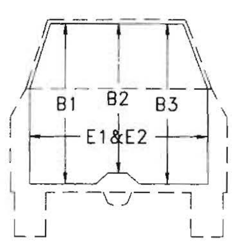
Table 9. Occupant Compartment Measurements for Tests 417929-8 and 417929-9.

Small Car

Occupant Compartment Deformation







	BEFORE	AFTER
A1	1505	-
A2	2067	-
A3	1550	-
B1	971	-
B2	920	-
B3	986	-
B4	960	-
B5	853	-
B6	952	-
B7	650	-
B8	670	-
B9	646	-
C1	705	-
C2	705	-
C3	723	-
D1	288	-
D2	100	-
D3	282	-
E1	1237	-
E2	1235	-
F	1210	-
G	1210	-
H	900	-
I	900	-

Table 10. Exterior Crush Measurements for Tests 417929-9.

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 Inner Bumper	500	100	650	0	-5	-15	-40	-100	80	325

[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.

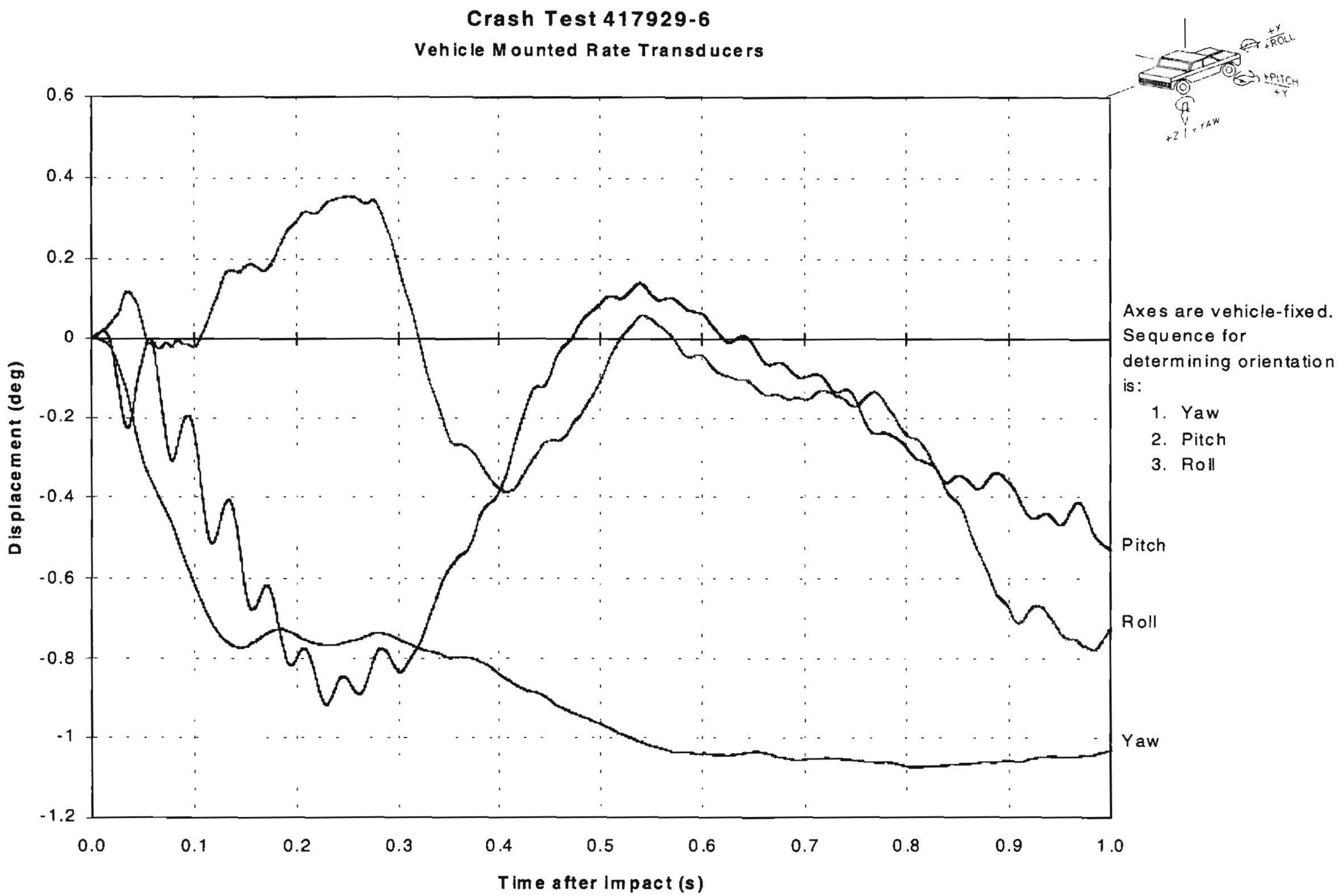


Figure 102. Vehicular Angular Displacements for Test 417929-6.

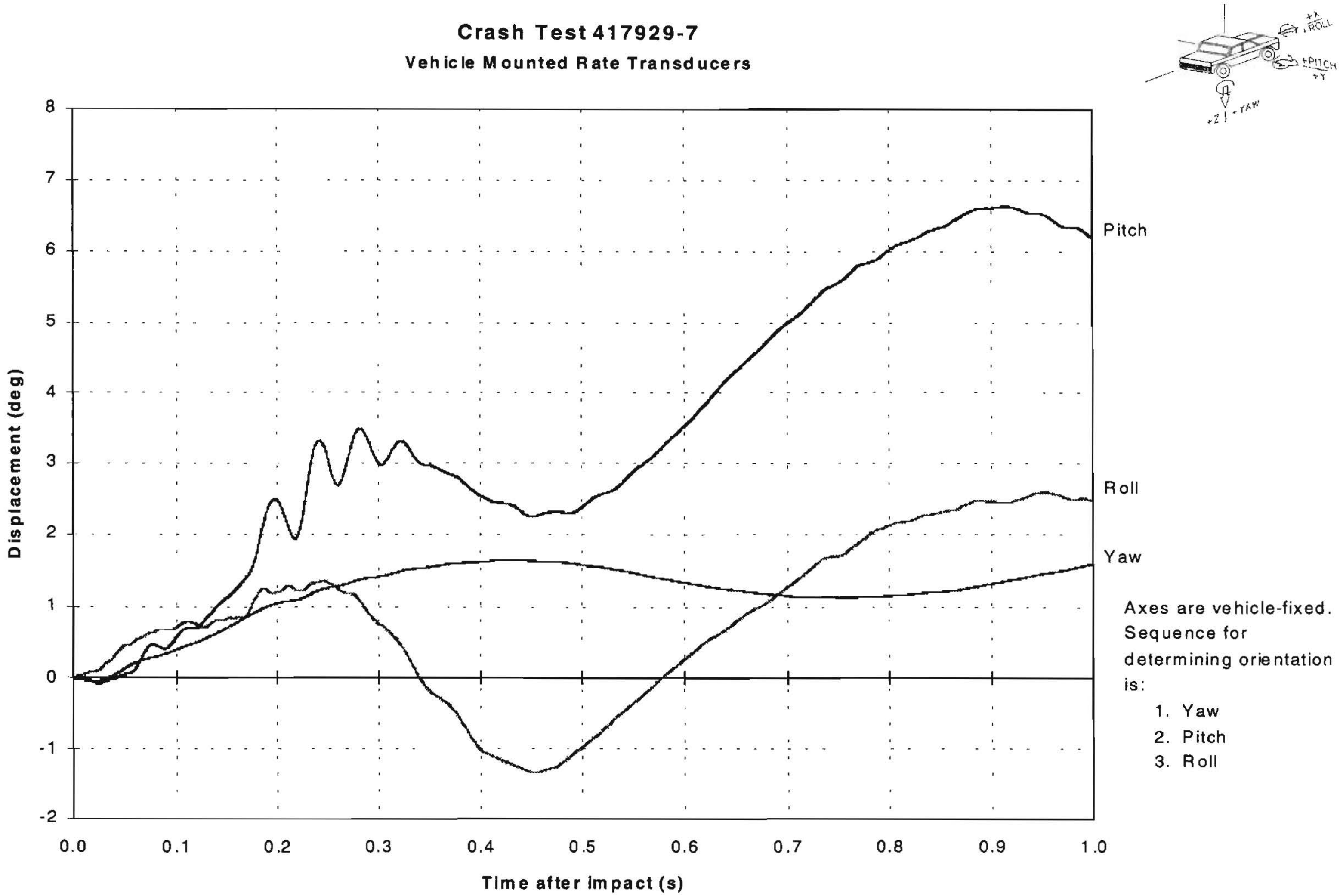


Figure 103. Vehicular Angular Displacements for Test 417929-7.

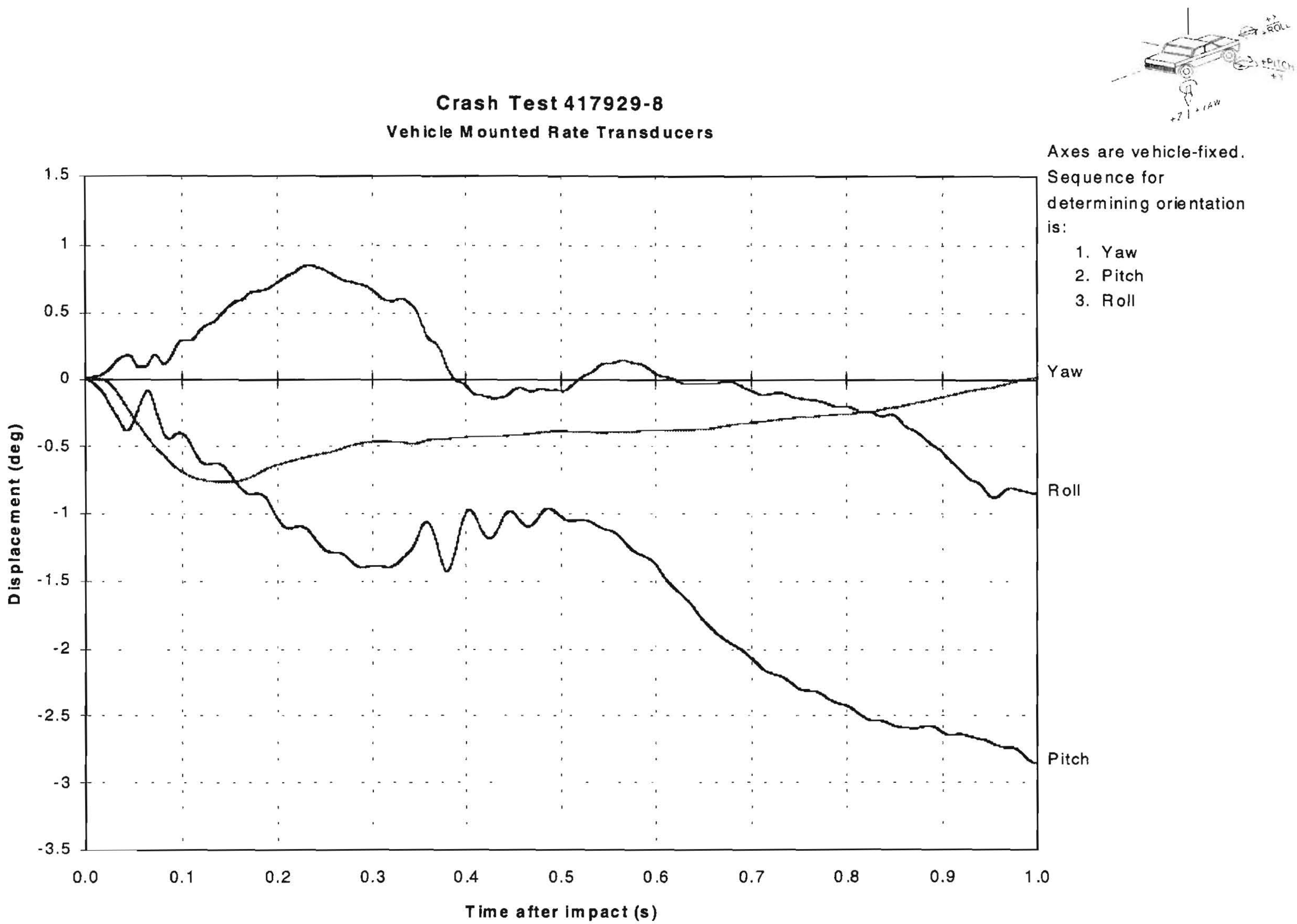


Figure 104. Vehicular Angular Displacements for Test 417929-8.

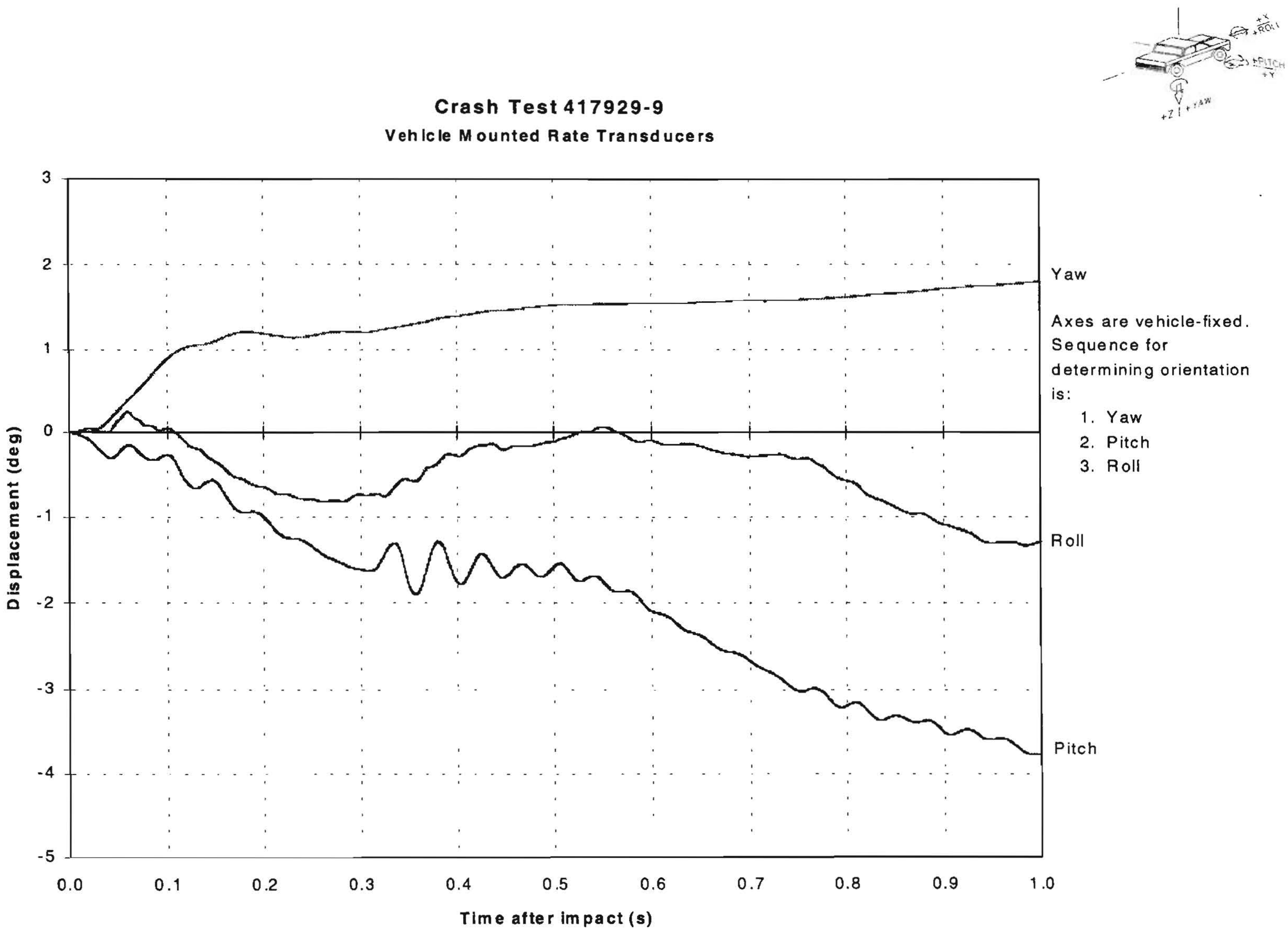


Figure 105. Vehicular Angular Displacements for Test 417929-9.

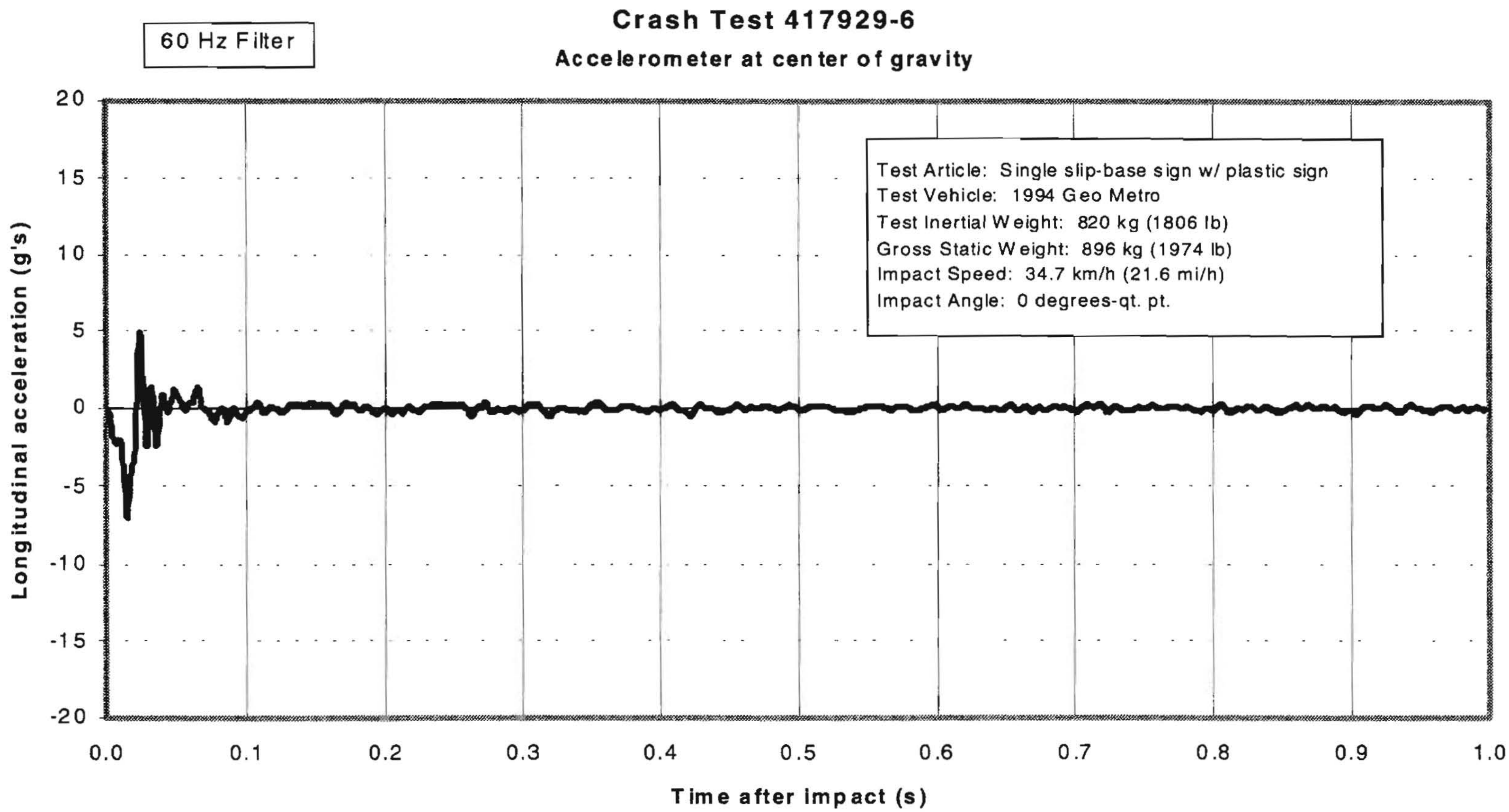


Figure 106. Vehicle Longitudinal Accelerometer Trace for Test 417929-6.

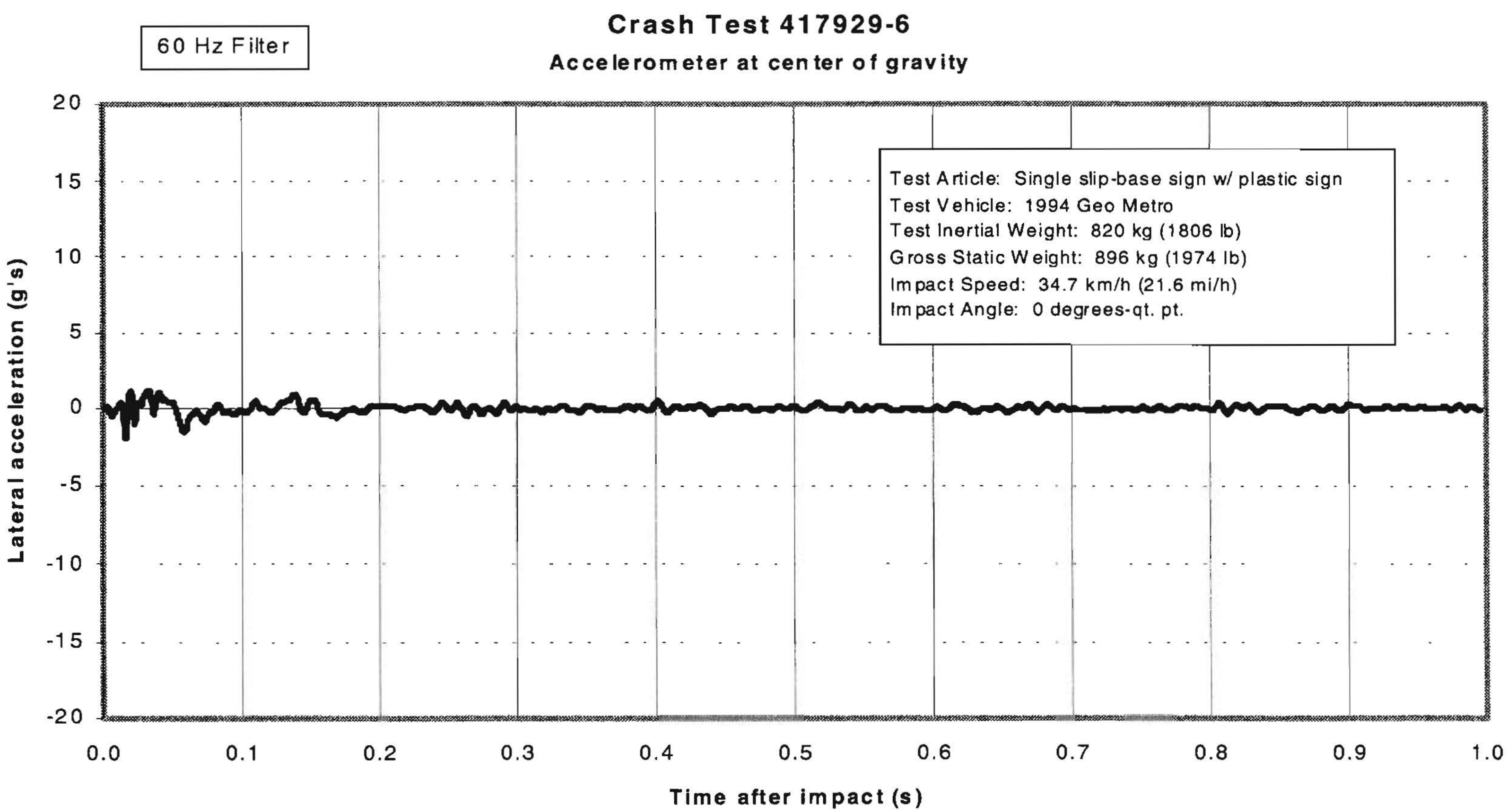


Figure 107. Vehicle Lateral Accelerometer Trace for Test 417929-6.

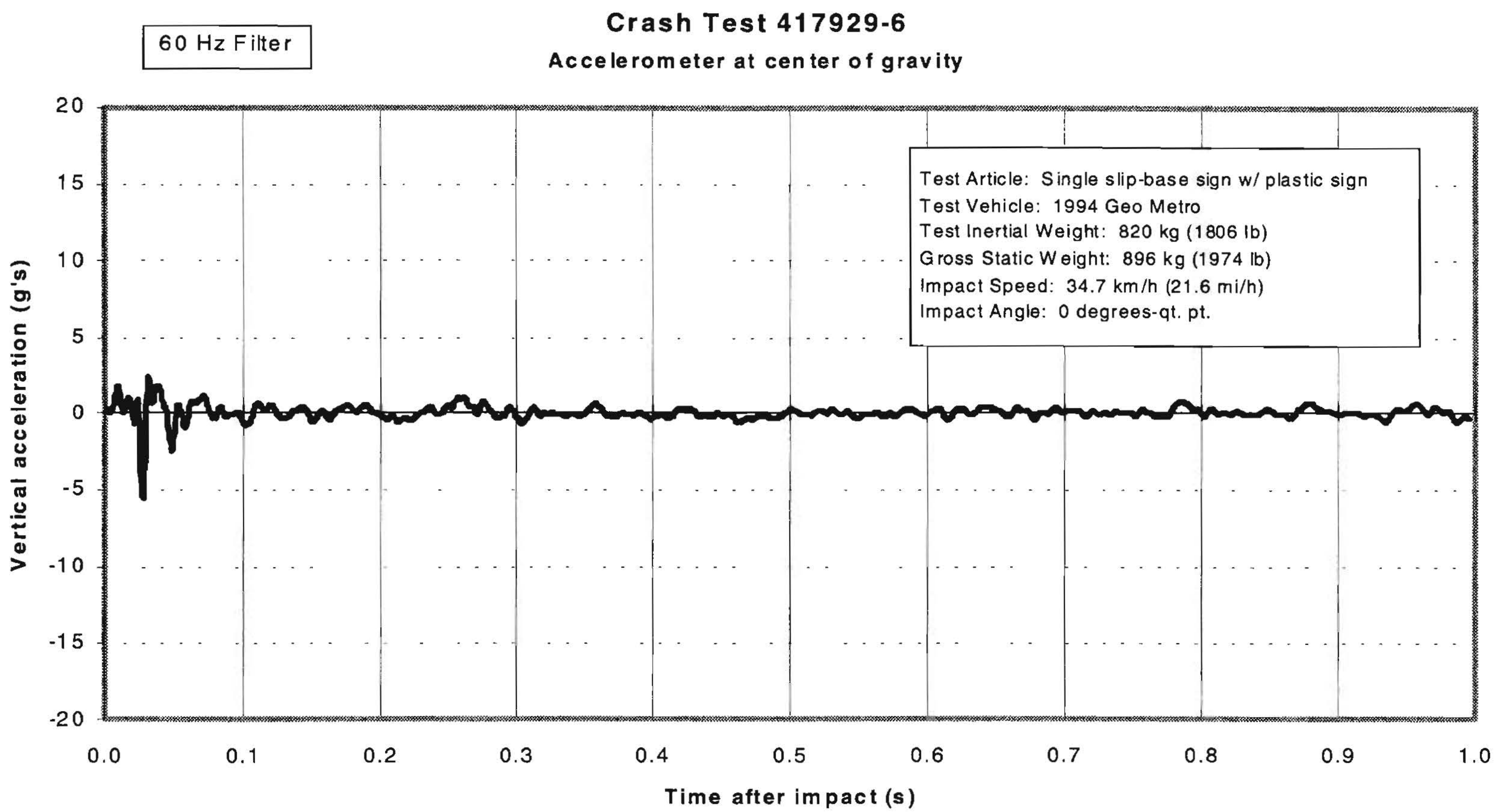


Figure 108. Vehicle Vertical Accelerometer Trace for Test 417929-6.

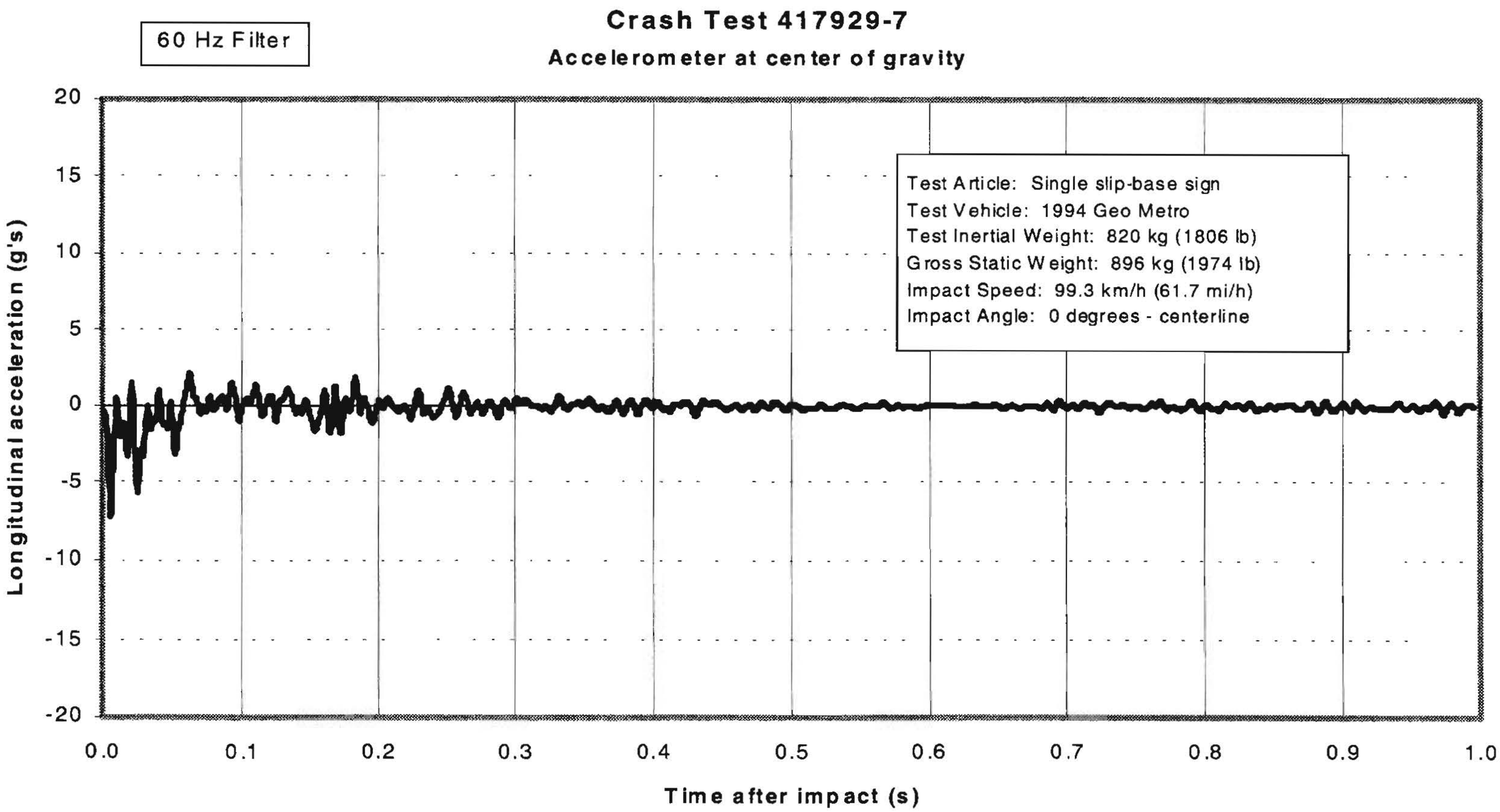


Figure 109. Vehicle Longitudinal Accelerometer Trace for Test 417929-7.

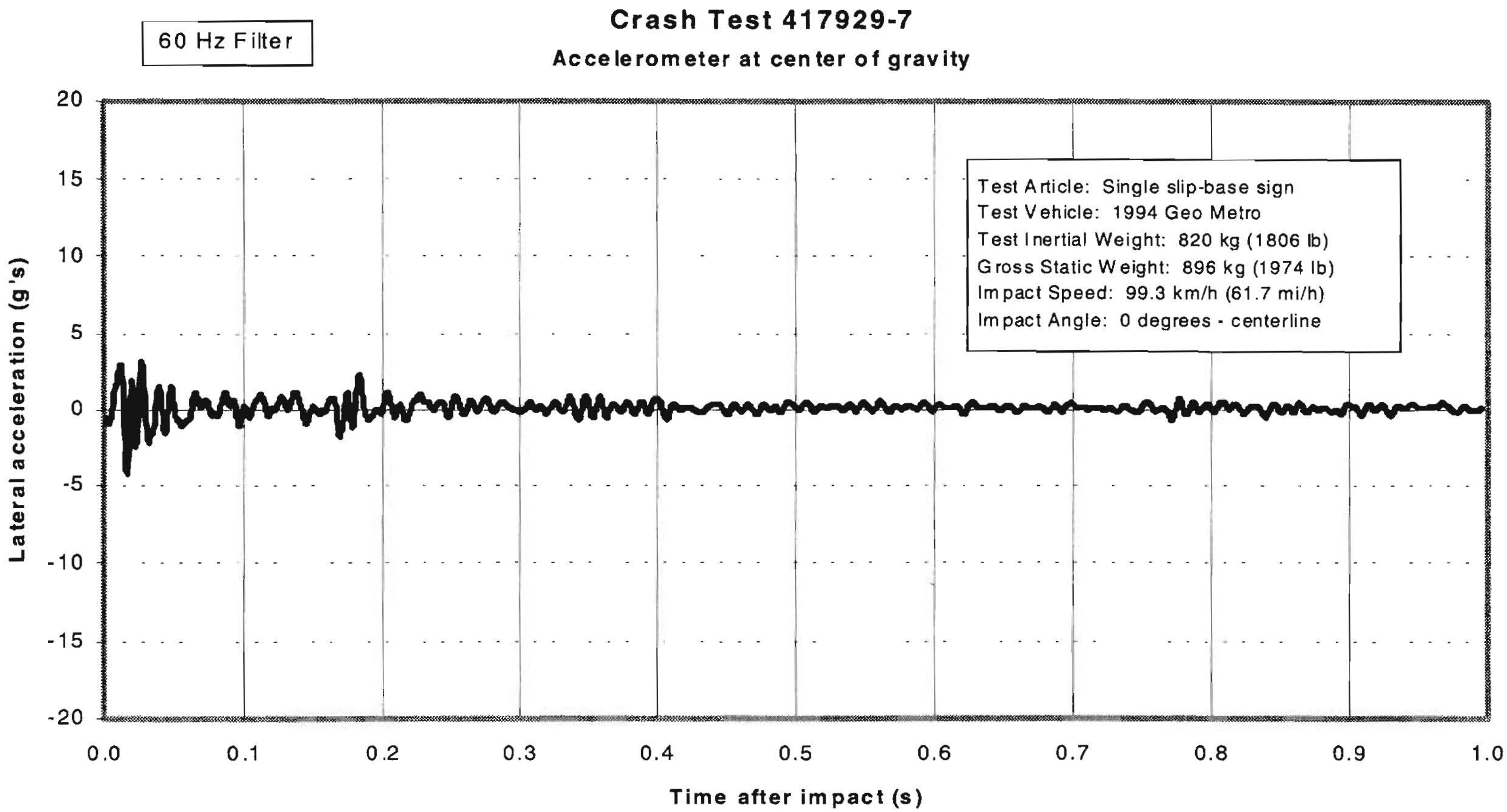


Figure 110. Vehicle Lateral Accelerometer Trace for Test 417929-7.

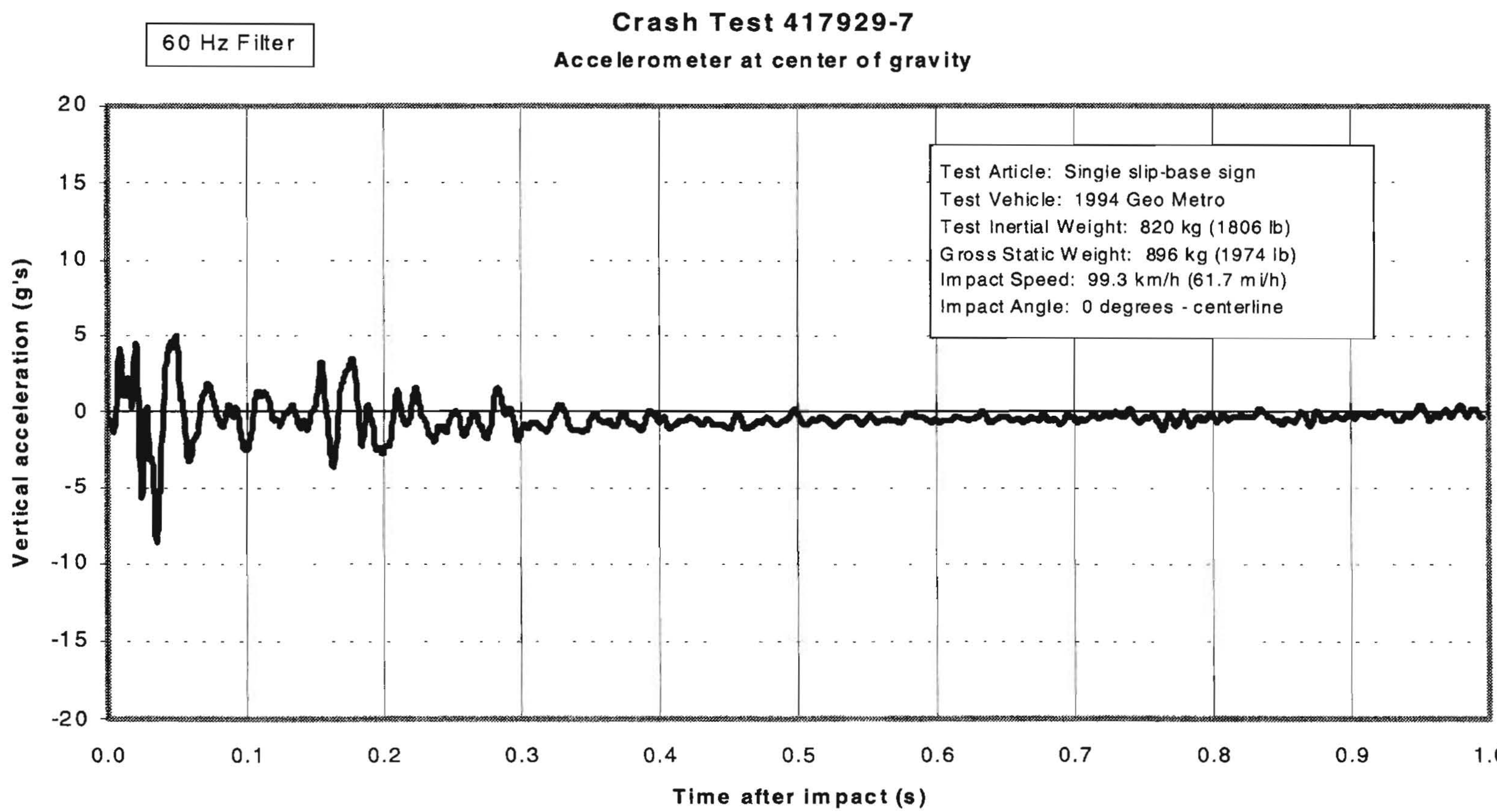


Figure 111. Vehicle Vertical Accelerometer Trace for Test 417929-7.

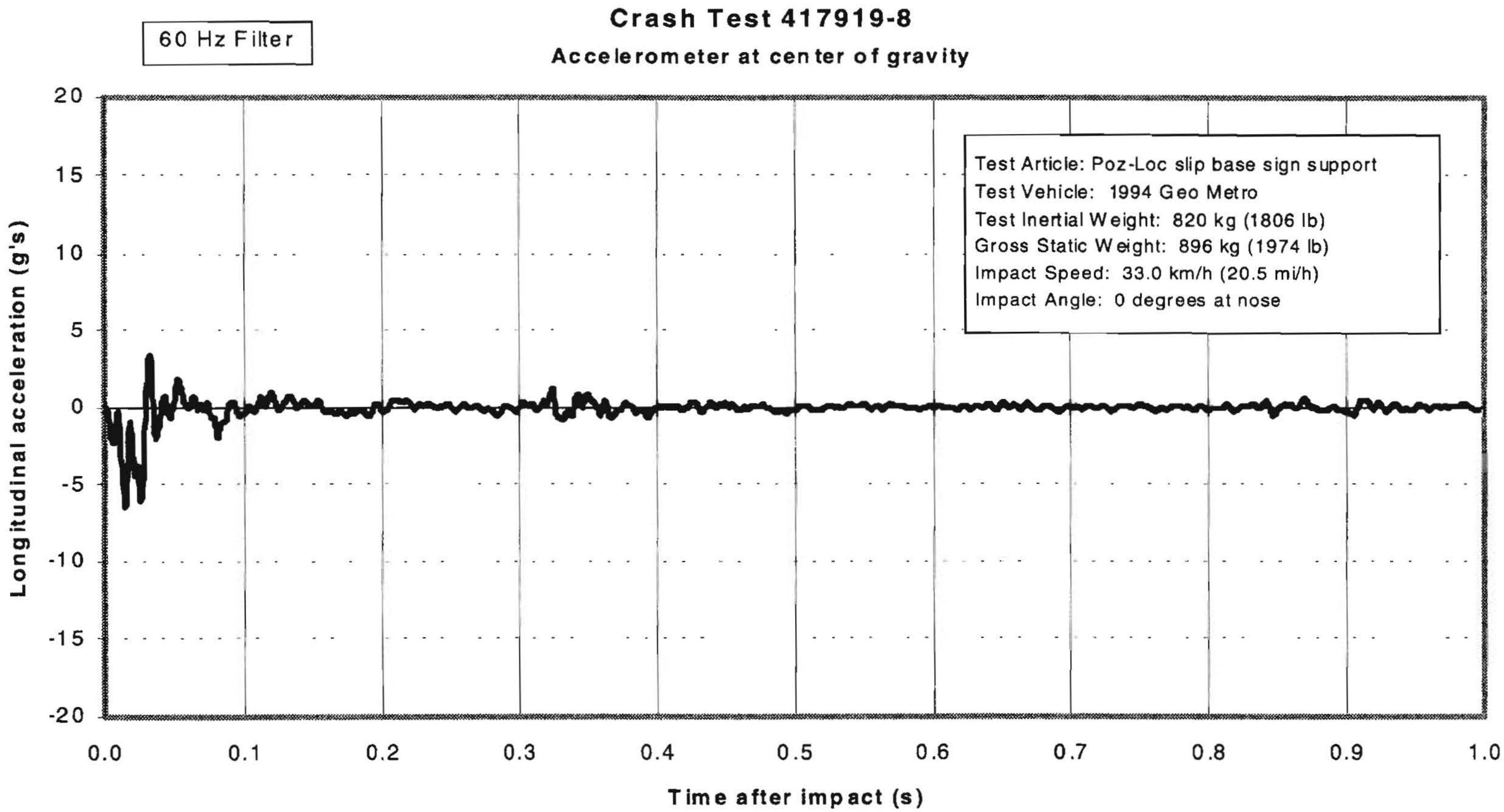


Figure 112. Vehicle Longitudinal Accelerometer Trace for Test 417929-8.

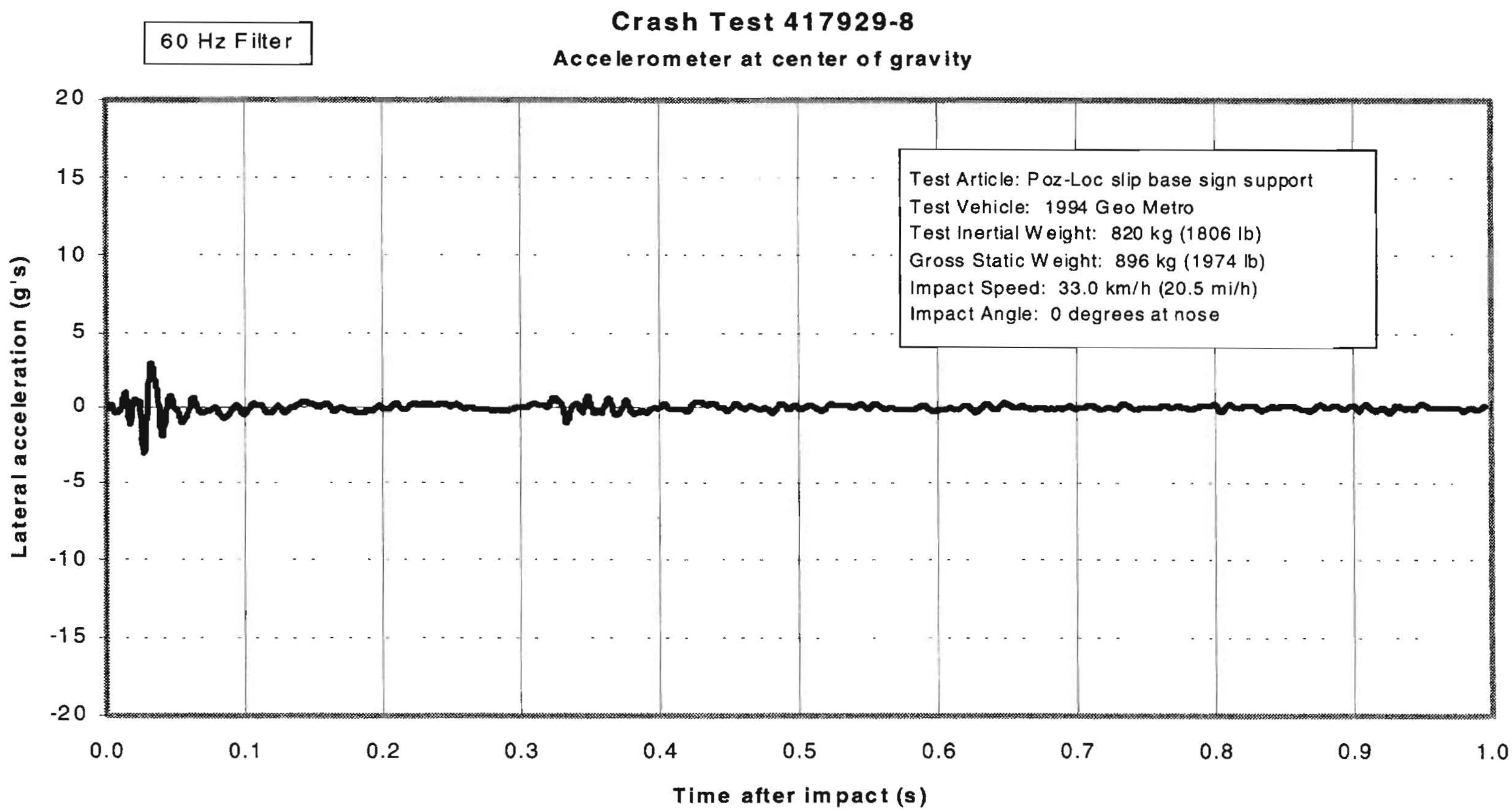


Figure 113. Vehicle Lateral Accelerometer Trace for Test 417929-8.

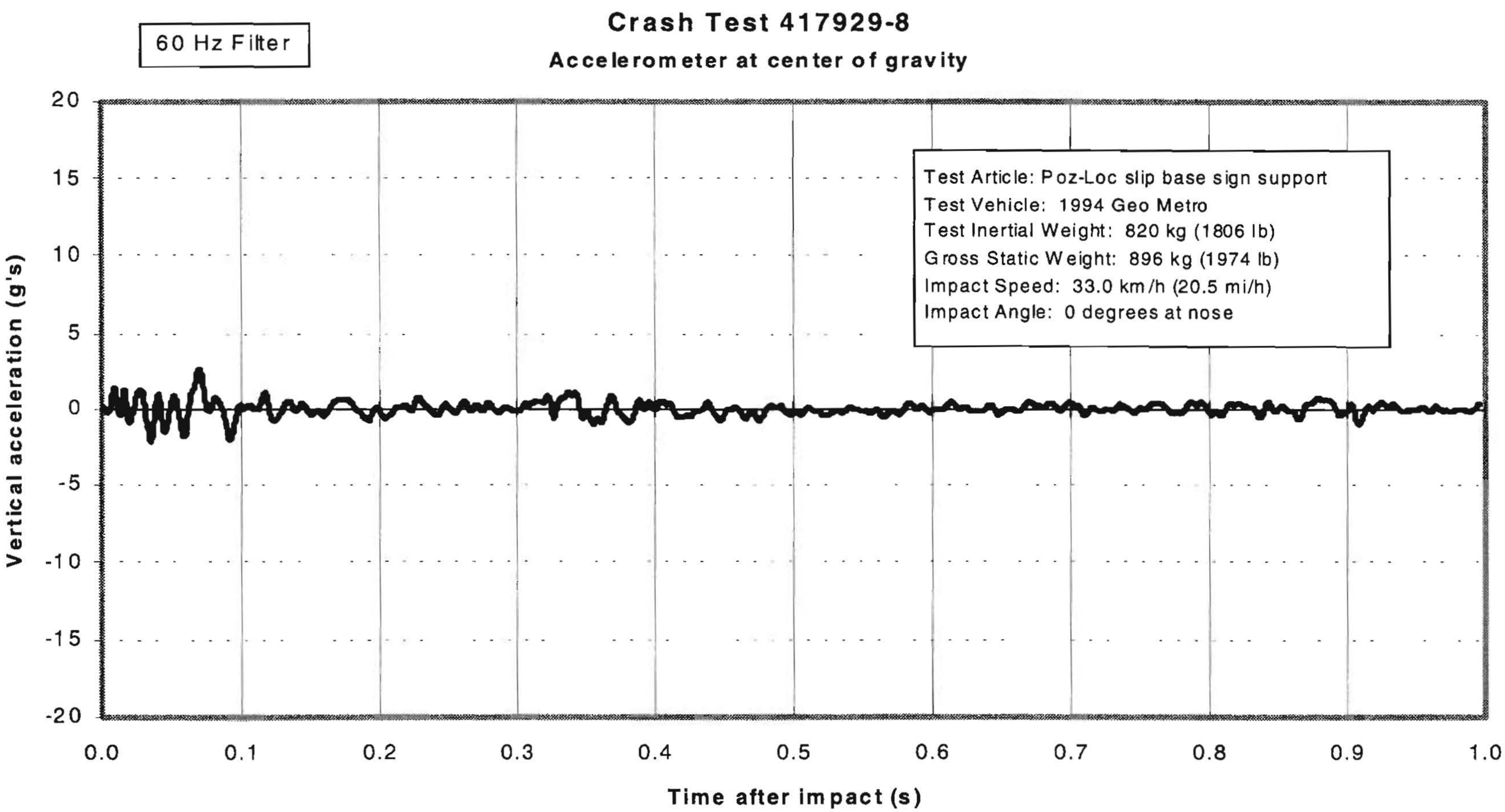


Figure 114. Vehicle Vertical Accelerometer Trace for Test 417929-8.

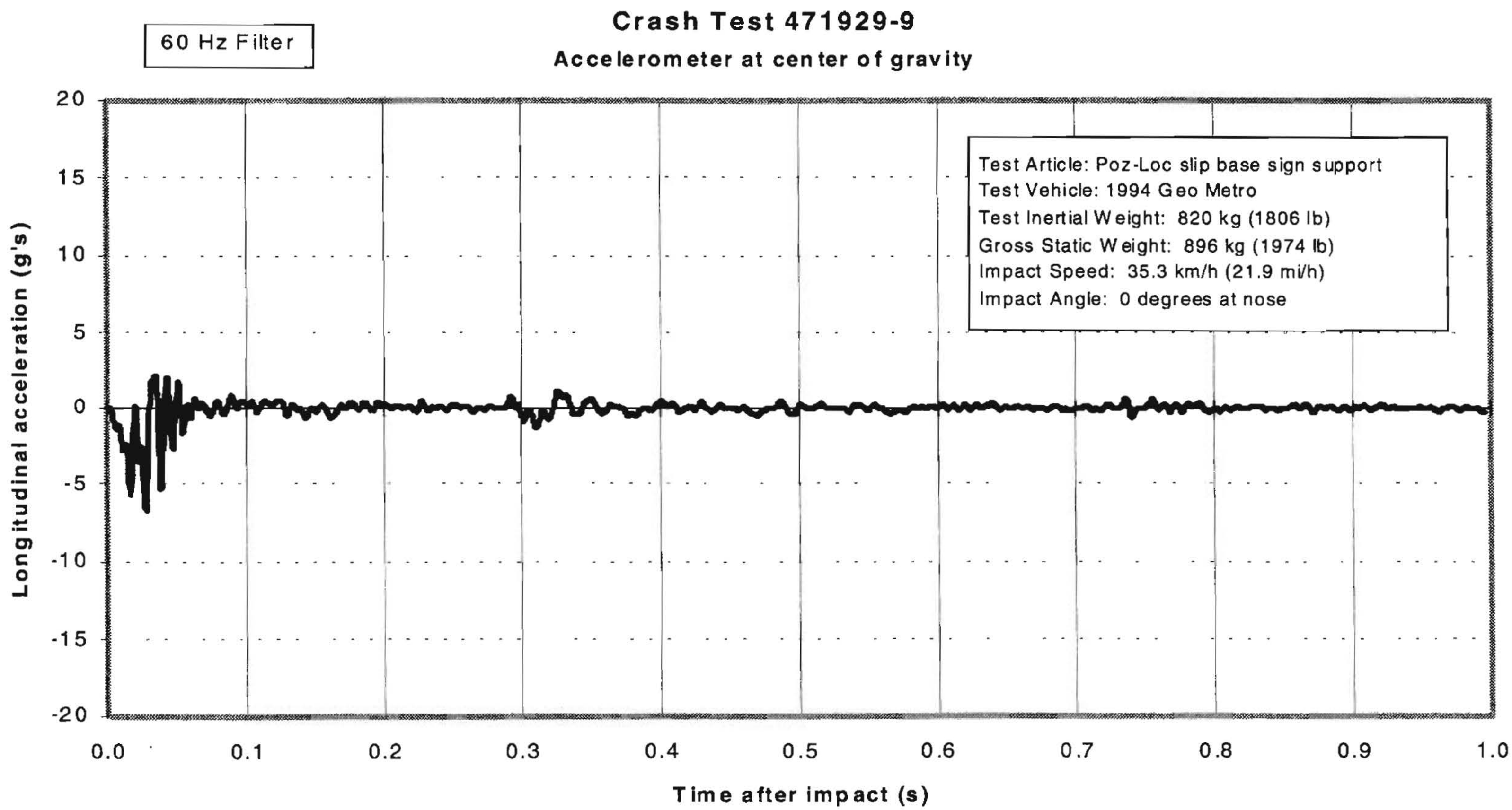


Figure 115. Vehicle Longitudinal Accelerometer Trace for Test 417929-9.

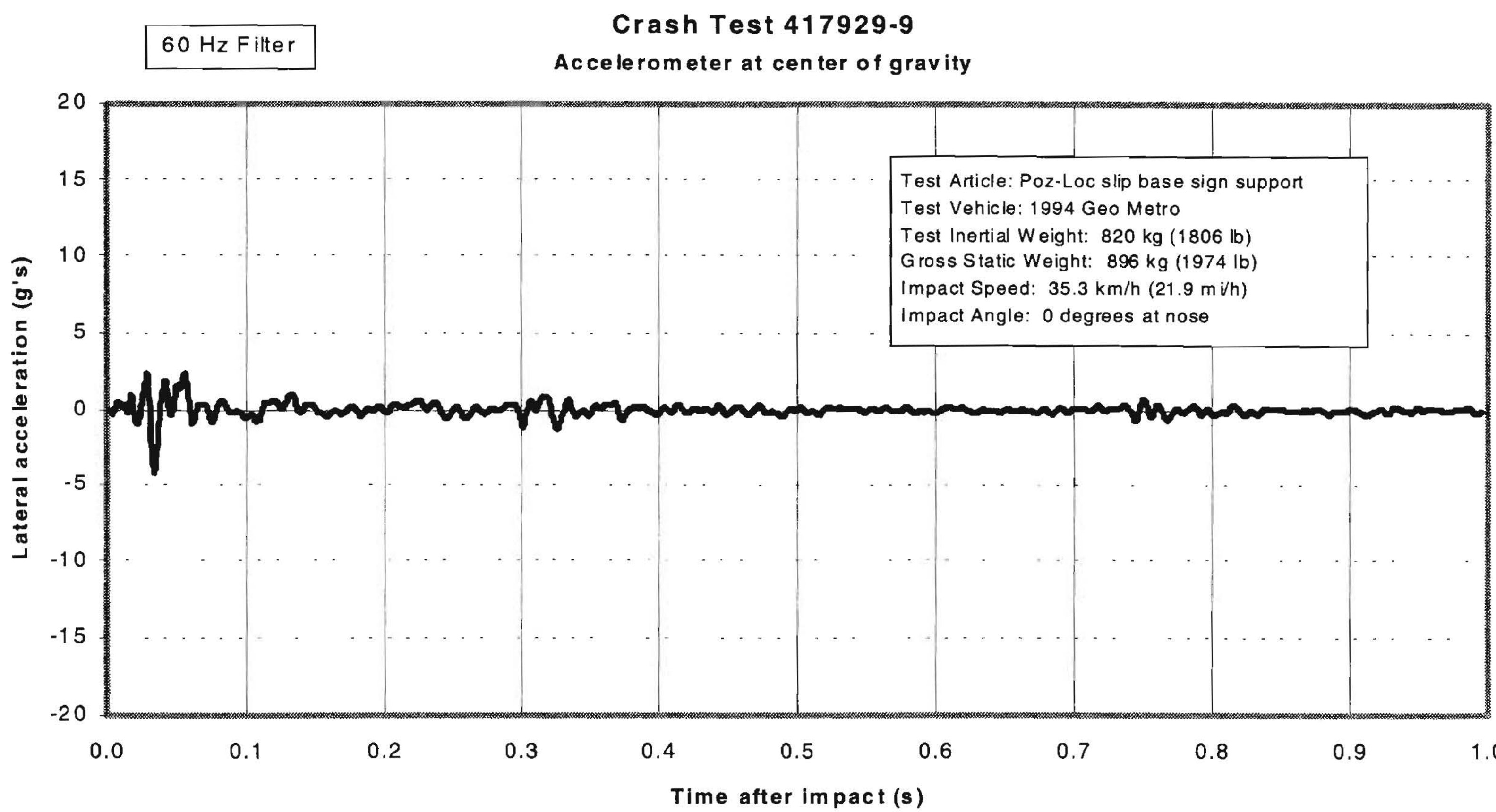


Figure 116. Vehicle Lateral Accelerometer Trace for Test 417929-9.

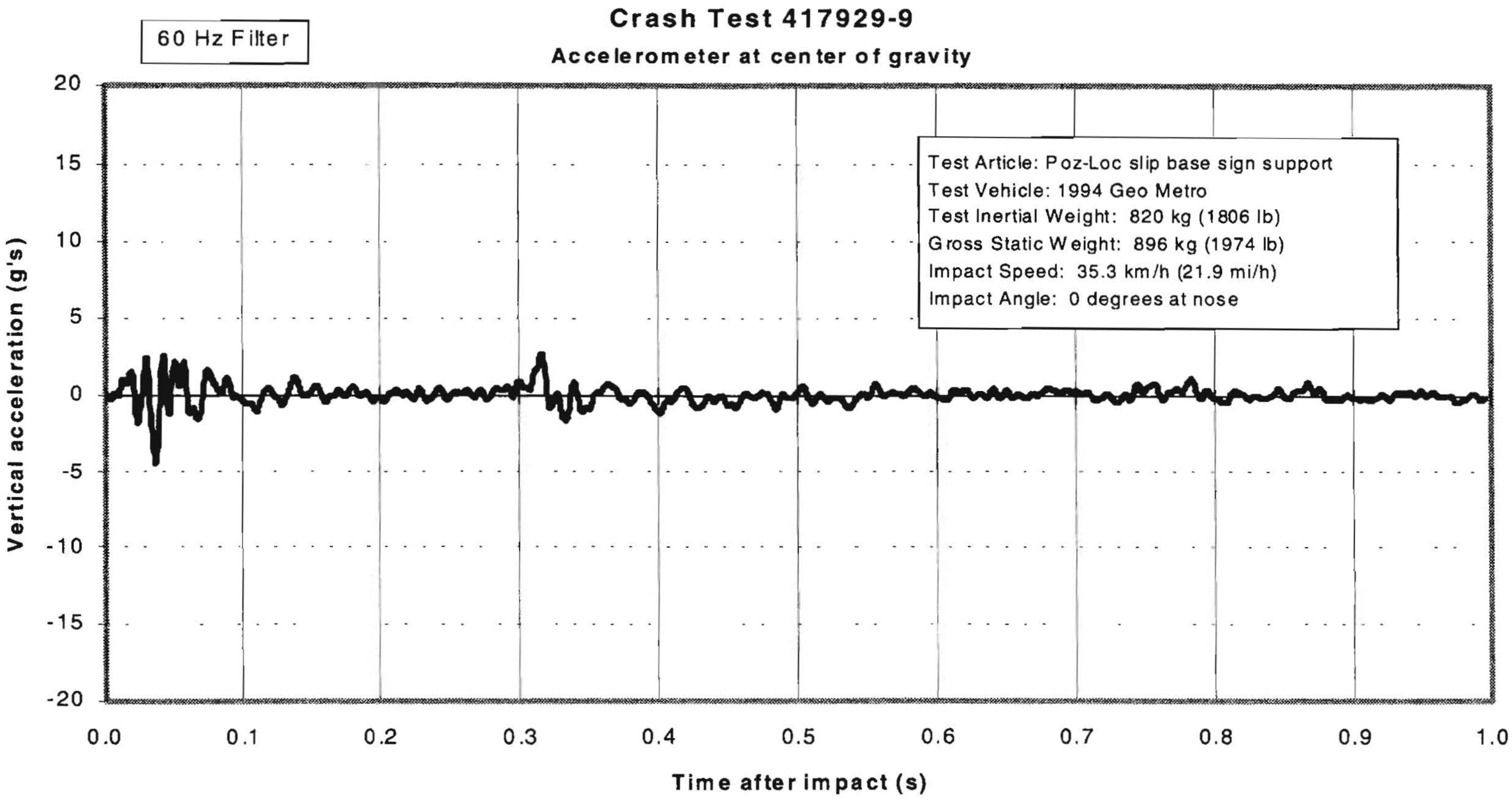


Figure 117. Vehicle Vertical Accelerometer Trace for Test 417929-9.

APPENDIX H. SUPPLEMENTAL CRASH TEST EVALUATION

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 the crash test results reported herein.

<u>**Test 417929-6**</u>

- **PASSENGER COMPARTMENT INTRUSION**

  1. **Windshield Intrusion**

     a. No windshield contact
     b. Windshield contact, no damage
     <u>c. Windshield contact, no intrusion</u>
     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 <u>no</u>

- **LOSS OF VEHICLE CONTROL**

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

- **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**

  The sign support slipped away at the base, rode along in front the vehicle, and did not pose a threat to others.

- **VEHICLE AND DEVICE CONDITION**

  1. **Vehicle Damage**

     a. None
     <u>b. Minor scrapes, scratches or dents</u>
     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. <u>Broken, no interference with visibility (Class 4)</u>
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. <u>Superficial</u>
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 [817 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 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.*

<u>Results</u>: Maximum change in velocity for this test was 0.9 m/s (3.0 ft/s).

<u>Test 417929-7</u>

◆ **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

a. No windshield contact
b. Windshield contact, no damage
c. <u>Windshield contact, no intrusion</u>
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 <u>no</u>

◆ **LOSS OF VEHICLE CONTROL**

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

◆ **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

The sign support slipped away from the base, rose up and over the vehicle, and did not pose a threat to others.

◆ **VEHICLE AND DEVICE CONDITION**

1. Vehicle Damage

a. None
<u>b. Minor scrapes, scratches or dents</u>
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
<u>c. Broken, no interference with visibility (Class 6)</u>
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
<u>b. Superficial</u>
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 [817 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 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.*

<u>Results:</u> Maximum change in velocity for this test was 1.5 m/s (5.0 ft/s).

Test 417929-8

- **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

     Bolt from the sign bracket poked a hole in the roof above the driver.

- **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**

  The sign support slipped away at the base, rode along in front the vehicle, and did not pose a threat 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 [817 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 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.*

Results: Maximum change in velocity for this test was 0.5 m/s (1.6 ft/s).

Test 417929-9

◆ **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**

  The sign support slipped away at the base, rose up and over the vehicle, and did not pose a threat 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 (Class 4)
     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 [817 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mi/h to 60 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.*

Results: Maximum change in velocity for this test was 0.8 m/s (2.6 ft/s).