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16. Abstract

In response to feedback obtained from field crews, TxDOT routinely assesses the performance of its breakaway sign support systems and identifies areas in which design improvements can result in reduced installation and maintenance costs or improved impact behavior. This project investigated several independent issues related to the performance of small sign supports. These issues include: the effect of keeper plate thickness on the impact performance of slip-base sign supports, an evaluation of methods for retrofitting slip-base stubs which incorporate a lifting ramp or cone, and investigation of a bolt-down anchor design for direct attachment of small signs to concrete pavement or median islands.

Tests determined that a 26-gauge keeper plate can be used in place of the standard 30-gauge keeper plate to help alleviate reported field problems with slip-base sign supports. Use of a 26-gauge keeper plate in a triangular slip-base small sign support system did not impede the breakaway performance and was determined to comply with National Cooperative Highway Research Program *(NCHRP) Report 350* performance criteria.

A plastic spacer ring was determined to be the most cost-effective alternative for retrofitting existing slip-base foundations to permit their use with the new TxDOT slip-base system. The plastic spacer ring provides the required separation between the slip plates to accommodate an existing lifting cone and does not impede the breakaway performance of the small sign support.

Various configurations of a bolt-down base for small sign supports were tested in an attempt to achieve an anchor system that would accommodate design wind loads, be crashworthy in a vehicular collision, and have a high degree of reusability after an impact. Although the system met all *NCHRP Report 350* performance criteria, further strengthening is needed to increase reusability and decrease maintenance after an impact.

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EVALUATION OF DESIGN AND RETROFIT CONCEPTS FOR SLIP-BASE SIGN SUPPORT SYSTEMS

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Report 3911-S
Project Number 7-3911
Research Project Title: Design and Testing
of New Sign Support Systems

Sponsored by the
Texas Department of Transportation

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ACKNOWLEDGMENTS

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IMPLEMENTATION RECOMMENDATIONS

Under this project, several independent issues related to the performance of small sign supports were investigated. These issues include: the effect of keeper plate thickness on the impact performance of slip base sign supports, an evaluation of methods for retrofitting slip base stubs which incorporate a lifting ramp or cone, and investigation of a bolt down anchor design for direct attachment of small signs to concrete pavement or median islands. Recommendation regarding implementation of research results in each of these areas is presented below.

- Based on the results of full-scale crash tests, the use of a 26-gauge keeper plate in conjunction with a triangular slip base small sign support system was determined to comply with *NCHRP Report 350* performance criteria and is considered suitable for implementation. The keeper plate serves as a retainer which keeps the slip bolts in their proper position 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, which is precipitated by the slip bolts "walking" out of their slots, is preceded by a failure of the keeper plate. Feedback received from sign crews also indicates a high incidence of keeper plate tear out during the installation and tightening of the slip bolts. There is not much tolerance provided in the keeper plate to accommodate misalignment of the slip bolts and slip bases during the bolt tightening process. The 26-gauge keeper plate can be used in place of the standard 30-gauge keeper plate to help alleviate these reported field problems with slip base sign supports. The implementation of the thicker keeper plate can be accomplished through appropriate revisions to TxDOT's Sign Mounting Detail (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 acting as intended 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 cones to be repaired or upgraded with the new slip base system. A plastic spacer ring was determined to be the most cost-effective alternative of the retrofit concepts investigated. The use of a plastic spacer ring 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 it 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 Sign Mounting Detail (SMD) standard sheets.

- Various configurations of a bolt-down base for small sign supports were tested in an attempt to achieve an anchor system that would accommodate design wind loads, be crashworthy in a vehicular collision, and have a high degree of reusability after an impact. As conceived, the steel base assembly bolts directly to a concrete pavement or island and the sign post is then secured to the base. By eliminating the construction of an independent concrete footing, the entire sign installation can be completed in a single trip. This reduces installation cost by decreasing labor time and improves safety by minimizing the exposure of the sign crew to traffic. When crash tested, the bolt down base met all *NCHRP Report 350* evaluation criteria. However, the anchor plate assembly experienced some damage and was not completely reusable after impact. Although the system was acceptable from a crashworthiness standpoint, it is recommended that the base be further strengthened to increase reusability and decrease maintenance after an impact.

I. INTRODUCTION

Through their research program, the Texas Department of Transportation continues to be proactive in its ongoing commitment to providing safer roadsides for the traveling public. TxDOT-sponsored projects have 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 a one-year project under which several issues related to the performance of small sign supports were investigated. These issues include: the effect of keeper plate thickness on the impact performance of slip-base sign supports, an evaluation of methods for retrofitting slip-base stubs which incorporate a lifting ramp or cone, and investigation of a bolt-down anchor design for direct attachment of small signs to concrete pavement or median islands. The evaluation of keeper plate thickness is summarized in Chapter II. Chapter III presents the analysis and testing of lifting cone retrofit options for small, slip-base sign supports. An investigation of bolt-down bases for small sign supports is summarized in Chapter IV. Project conclusions and recommendations are presented in Chapter V.

II. EVALUATION OF BOLT KEEPER PLATE THICKNESS

By design, the slip bolts in a slip-base sign support are intended to slip during impact thus permitting relative motion of the two baseplates they connect. The keeper plate serves as a retainer which keeps the slip bolts in their proper position to resist wind loads applied to the sign. In the absence of a keeper plate, the slip bolts can "walk" out of the slots in which they are installed due to cyclical wind loads which vary the amount of tension in the bolts. Because tear out of the keeper plate is necessary to permit the breakaway mechanism to function, it is typically fabricated from very thin gauge sheet metal. The current TxDOT Sign Mounting Detail (SMD) standards specify the use of 30 gauge material for the keeper plate. Testing has shown that this material will readily tear out during a vehicular impact. However, feedback from sign crews also indicates a high incidence of keeper plate tear out during the installation and tightening of the slip bolts. This is likely caused by improper alignment of the bolt and slip bases during tightening. There is not much tolerance provided in the keeper plate to accommodate misalignment of the slip bolts and slip bases during the bolt tightening process.

There have also been reports of slip-base sign installations blowing down in regions subject to high winds. Such behavior, which is precipitated by the walking of the slip bolts out of their slots, must be preceded by a failure of the keeper plate which retains the bolts. The use of a thicker keeper plate is desired to reduce the occurrence of these problems without adversely affecting impact performance. This issue was investigated through dynamic pendulum testing and full-scale vehicle crash testing as described below.

PENDULUM TESTING

The effect of keeper plate thickness on the dynamic breakaway response of slip-base small sign supports was initially investigated through a series of 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 (31.9 ft/s). Thus, the pendulum mass and impact speed were comparable to the low-speed crash test with a small car which is recommended in National Cooperative Highway Research Program *(NCHRP) Report 350* for the evaluation of breakaway devices. Additional details regarding the pendulum testing procedures are presented in Appendix A.

Test Articles

Installations for the four pendulum tests were identical except for thickness of keeper plates. A single, 51 mm diameter pipe support with a 0.91 m wide by 1.22 m tall aluminum sign blank was mounted on a triangular slip base as shown in Figure 1. The pipe support was American Society for Testing and Materials (ASTM) A53, grade A, type F (furnace butt welded) pipe with a yield strength of 270 MPa. The lower slip-base plate and pipe stub were welded to a base plate which was bolted to a steel reaction plate in the pendulum pit. The upper slip-base plate assembly consisted of a cast ductile iron triangular slip base plate with a 305 mm tall stub which fit inside the 51 mm diameter pipe support. The triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. The three 16 mm diameter, high-strength bolts were tightened to a prescribed torque of 51.5 N-m. Keeper plate thickness was 30 (standard), 28, 26, and 24 gauge for tests P3, P4, P5, and P6, respectively. Photographs of the typical sign support installation used in the pendulum tests are shown in Figure 2.

Test Results

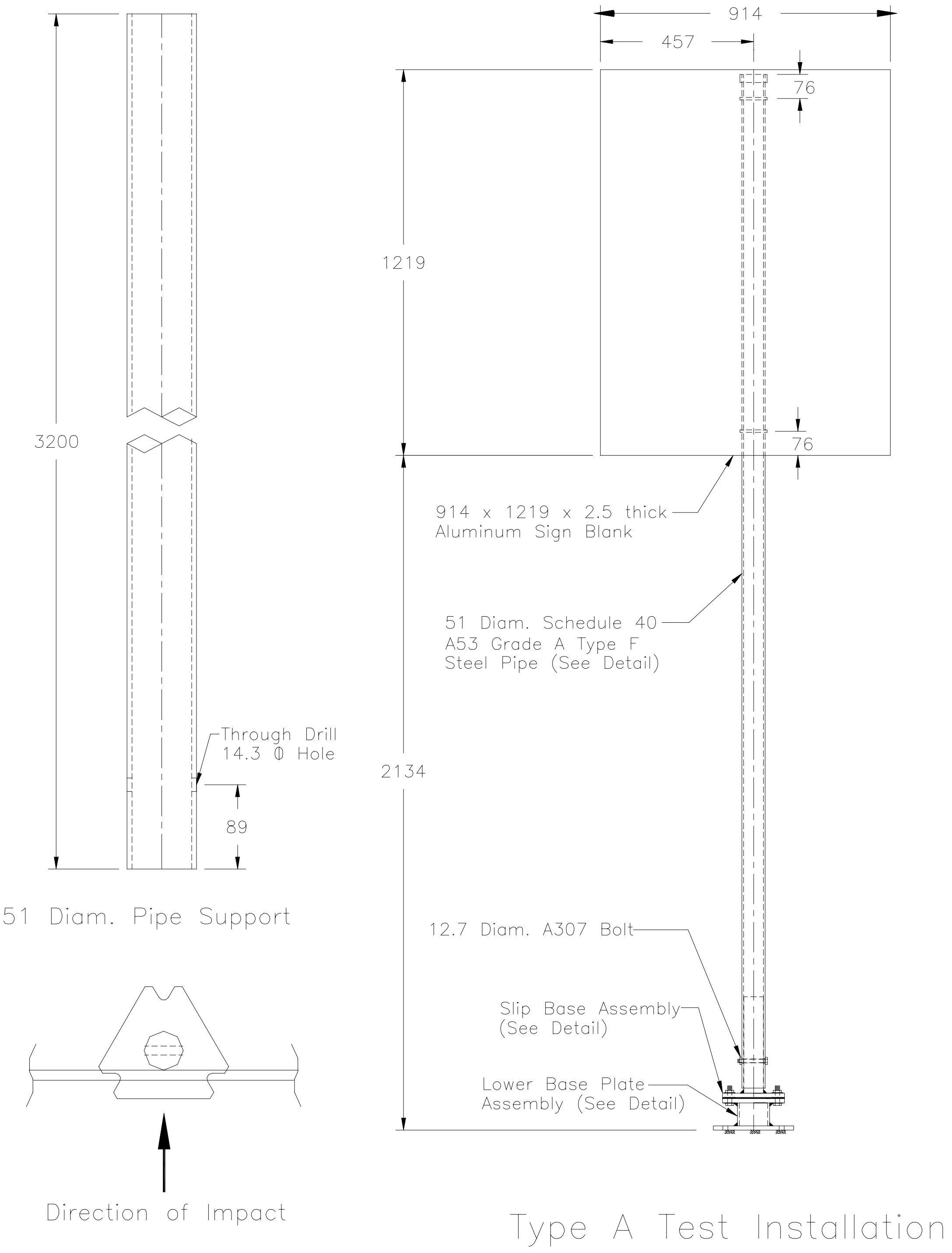
During test P3, the 30 gauge keeper plate remained with the fixed lower slip-base plate. All three slip bolts tore out of the keeper plate. Two of the slip bolts remained near the base while the remaining bolt came to rest with the sign post and panel approximately 18.3 m downstream from the point of impact. Maximum crush to the nose of the pendulum was 122 mm.

In test P4, the 28 gauge keeper plate separated from the base with the sign support and came to rest 0.9 m down from the point of impact. All three slip bolts remained near the base. The sign post and panel came to rest 20.1 m downstream from the fixed lower base. Maximum crush to the pendulum nose was 115 mm.

The 26 gauge keeper plate used in test P5 separated with the sign support and came to rest 15.5 m from the base with one slip bolt still attached. One bolt remained near the base and the third came to rest near the sign support and panel approximately 17.4 m down from the point of impact. Maximum crush to the nose of the pendulum was 117 mm.

The 24 gauge keeper plate used in test P6 separated from the base and came to rest near the base with one bolt still attached and another nearby. The third slip bolt came to rest in the vicinity of the sign post and panel approximately 11.0 m down and 12.8 m to the right of the point of impact. Maximum crush to the pendulum nose was 123 mm.

The acceleration-time histories for these pendulum impacts are presented in Appendix B. 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, and the occupant impact velocity which is an occupant risk evaluation criteria specified in *NCHRP Report 350*. A summary of these results is shown in Table 1. As expected, the peak accelerations increased as the keeper plate thickness increased. A 27 percent increase in peak acceleration was observed between the 30 gauge and 24 gauge keeper plates. With the exception of the 24 gauge keeper plate, increasing keeper plate thickness also caused an increase in the maximum force required to activate the slip base. The difference in maximum force between the 30 gauge and 26 gauge tests



51 Diam. Pipe Support

Type A Test Installation

Figure 1. Details of Sign Support Installation Used for Evaluation of Keeper Plate Thickness.

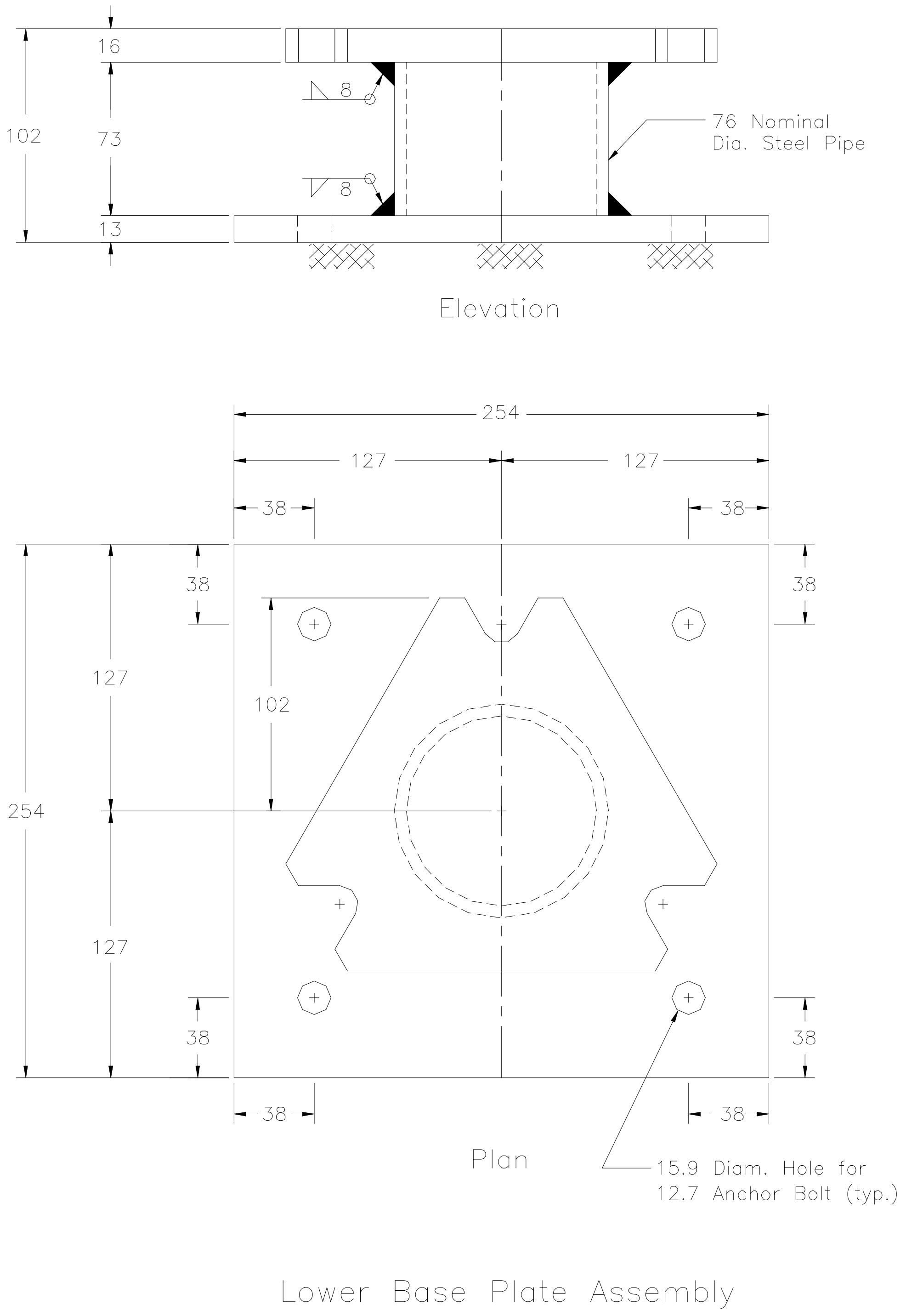


Figure 1. Details of Sign Support Installation Used for Evaluation of Keeper Plate Thickness (Continued).

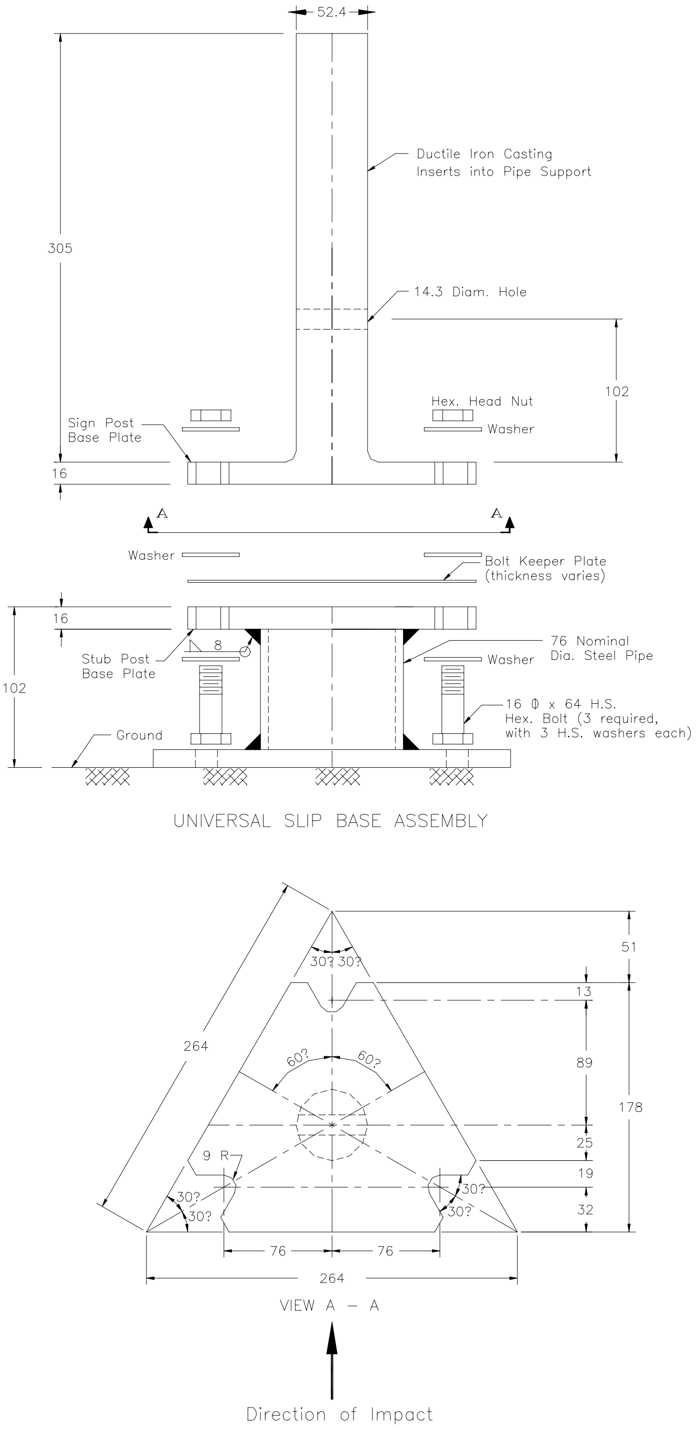


Figure 1. Details of Sign Support Installation Used for Evaluation of Keeper Plate Thickness (Continued).

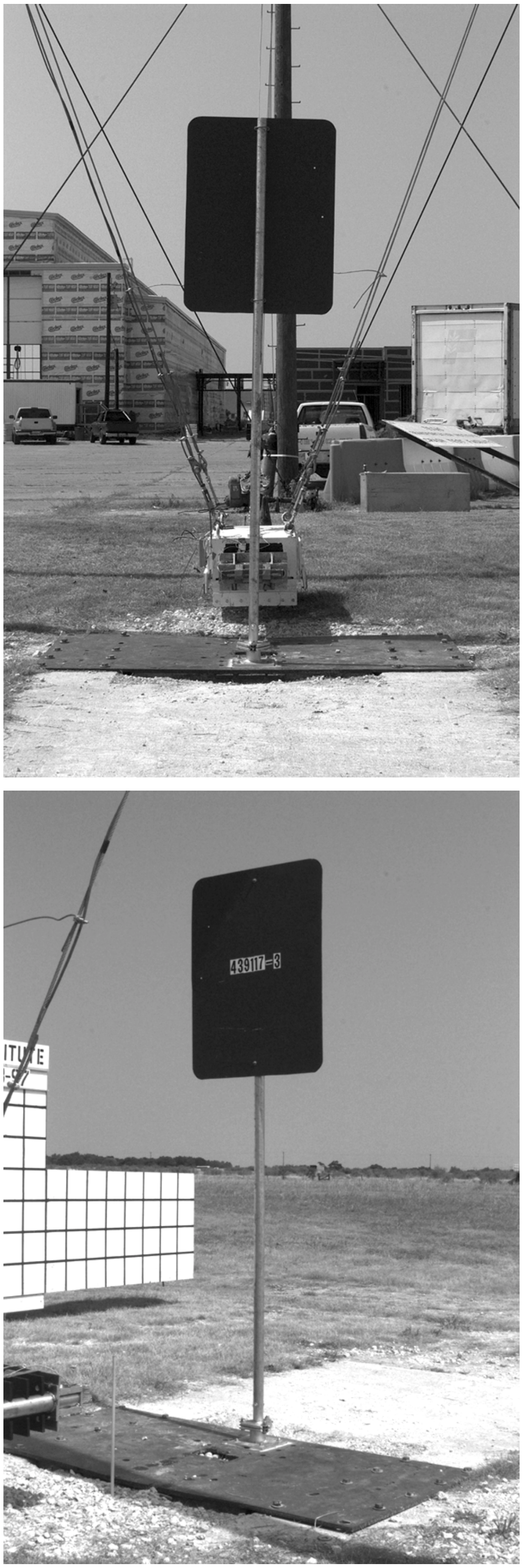


Figure 2. Typical Sign Support Installation before Pendulum Testing of Keeper Plates.

Table 1. Results of Pendulum Testing on Keeper Plates.

Test No.	Keeper Plate Thickness (ga.)	Impact Speed (km/h)	Max. Nose Crush (mm)	Peak Acceleration (g's)	Max. 10 ms Force (kN)	Kinetic Energy (N-m)	Occupant Impact Vel. (m/s)
P3	30	35.1	122	-2.2	14.90	3161	No contact
P4	28	35.3	115	-2.7	17.08	3252	No contact
P5	26	35.1	117	-2.8	18.33	3243	No contact
P6	24	35.0	123	-3.0	16.99	3157	No contact

was 17 percent. However, in the test of the 24 gauge keeper plate, the maximum force was equivalent to that measured for the 28 gauge keeper plate, which was lower than expected. There was no clear trend observed in the amount of energy dissipated. The values computed for the different keeper plate thicknesses were all within 3 percent of each other.

These tests indicated that all of the keeper plates should demonstrate acceptable crashworthiness. This result was evidenced by the fact that even with the increase in acceleration produced by the increase in keeper plate thickness, there was no occupant contact computed. In other words, the levels of acceleration imparted by the sign support on the impacting pendulum were not sufficient to cause an unrestrained occupant to contact the interior surface of a vehicle. *NCHRP Report 350* permits an occupant impact velocity of 5 m/s for breakaway devices.

After reviewing the results of the pendulum tests, TxDOT personnel chose to use a 26 gauge keeper plate in full-scale vehicle crash tests to further validate its performance. These tests are reported in the following section of this report.

FULL-SCALE CRASH TESTING

Given the favorable results of the pendulum tests, the impact performance of a slip-base sign support with 26 gauge bolt keeper plate 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*.(1) 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 passenger car. Details of the crash test procedures and evaluation criteria are provided in Appendix B.

Low-Speed Test (Test 439117-3, *NCHRP Report 350* Test No. 3-60)

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)-95). A 0.91 m wide by 1.22 m tall aluminum sign blank was attached to a single, 51 mm diameter pipe support which was mounted on a triangular slip base. The pipe support was ASTM A53, type F (furnace butt welded) pipe with a yield strength of 52.7 MPa. The upper slip-base plate assembly consisted of a cast ductile iron triangular slip base plate with a 305 mm tall stub that fit inside the 51 mm diameter pipe support. The lower slip base plate was welded to a 76 mm diameter pipe stub, which was embedded in a 305 mm diameter by 1.07 m deep high-density polyurethane foam footing.

The triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. The three 16 mm diameter, high-strength bolts were tightened to a prescribed torque of 51.5 N-m. A 26 gauge bolt keeper plate was used in place of the standard 30 gauge plate. Additional details of the installation are shown in Figure 3. Photographs of the sign support installation used in the low-speed crash test are shown in Figure 4.

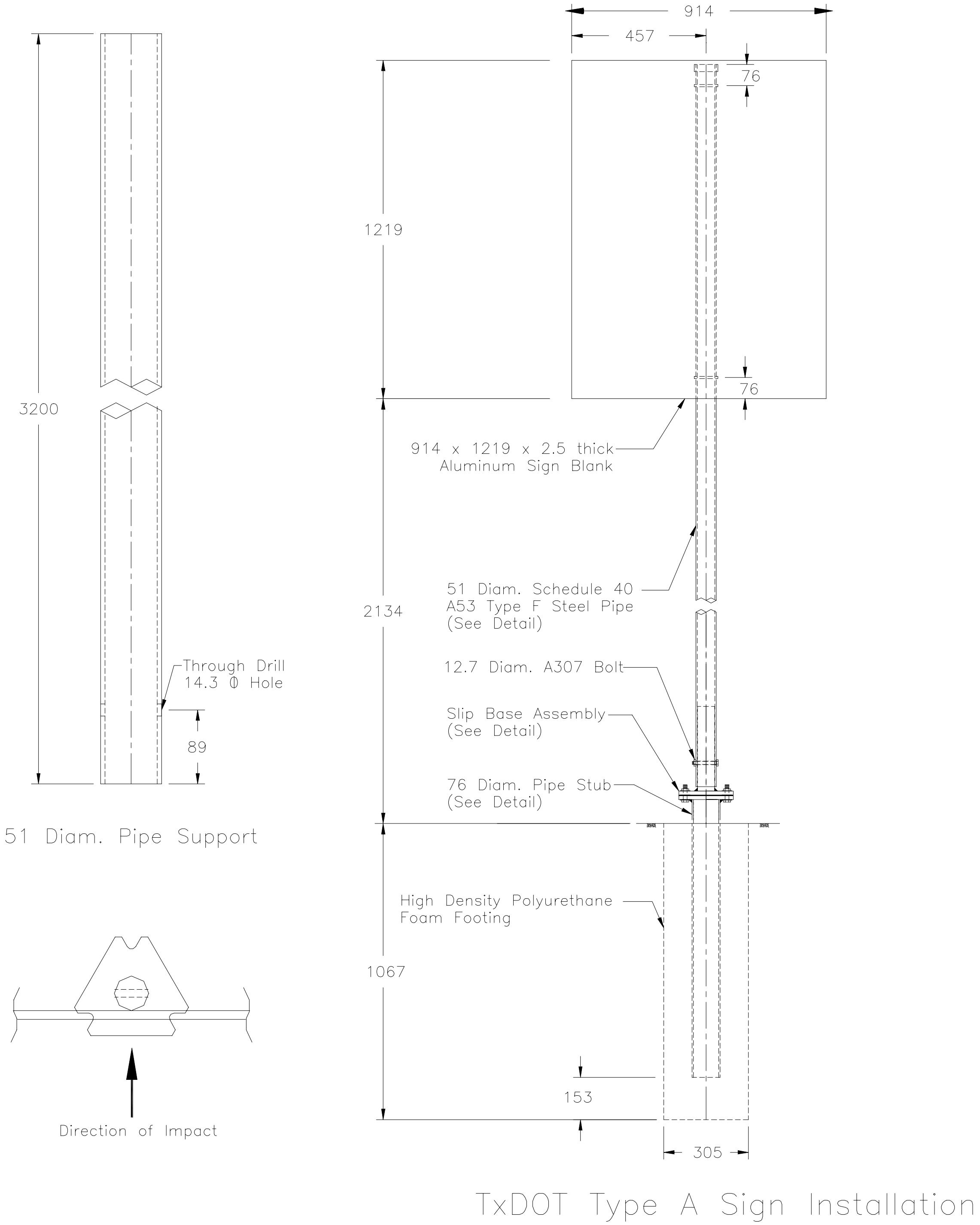


Figure 3. Details of the Sign Support Installation Used for Evaluation of Keeper Plates in Vehicle Crash Testing.

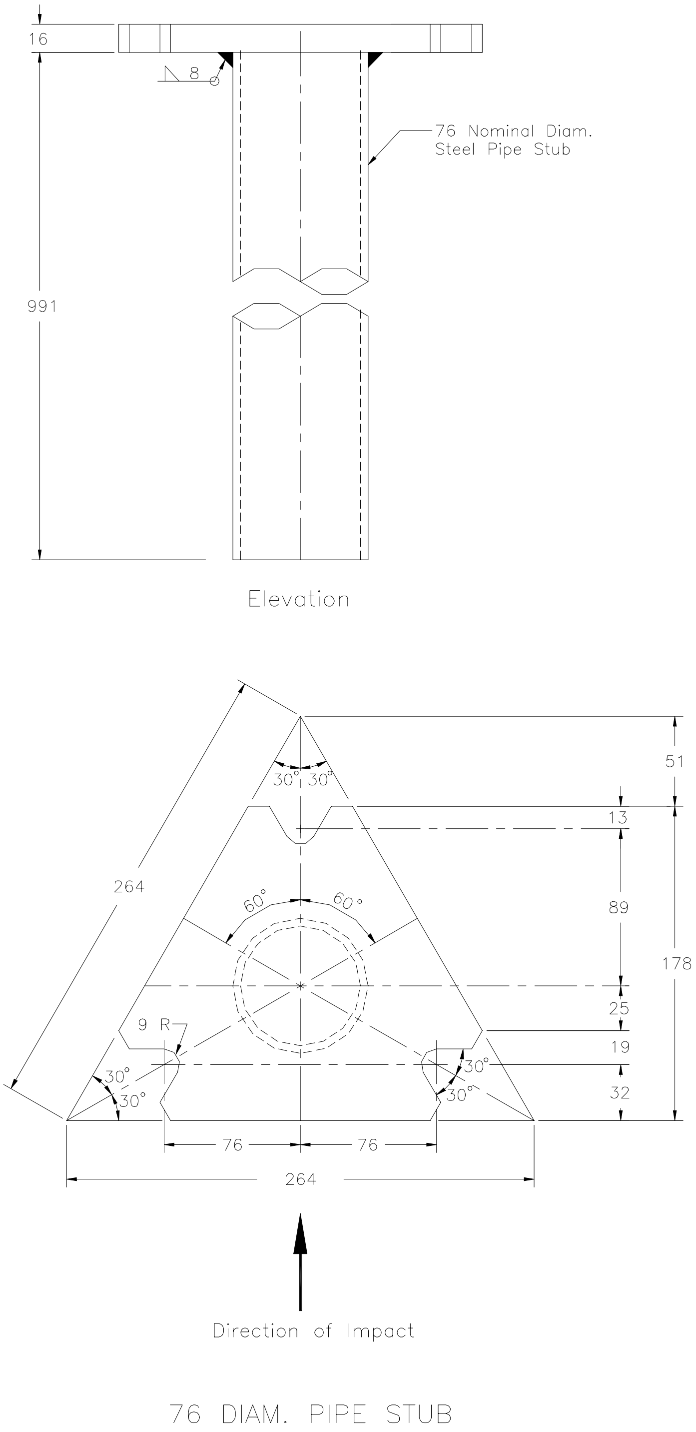


Figure 3. Details of the Sign Support Installation Used for Evaluation of Keeper Plates in Vehicle Crash Testing (Continued).

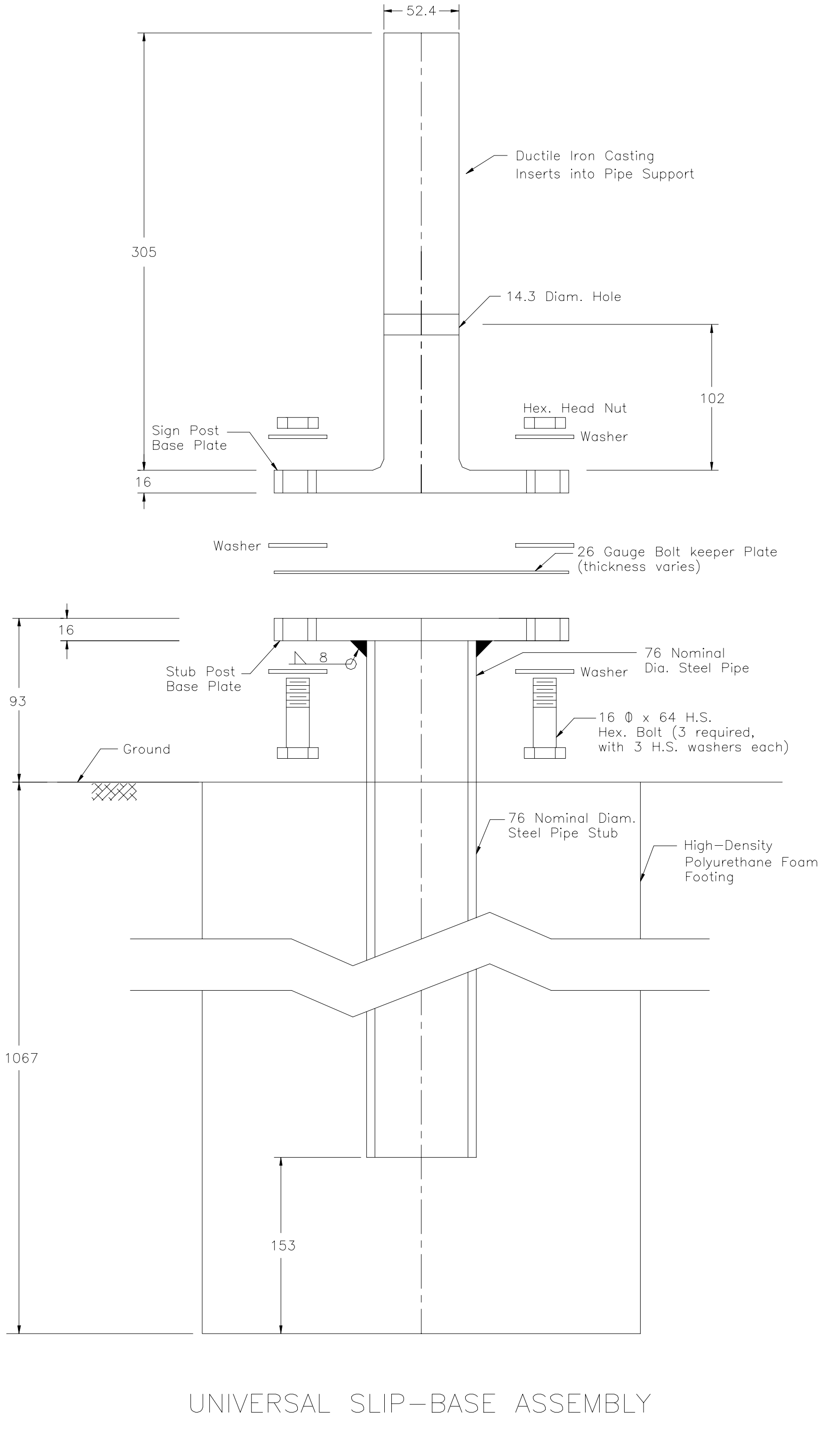


Figure 3. Details of the Sign Support Installation Used for Evaluation of Keeper Plates in Vehicle Crash Testing (Continued).

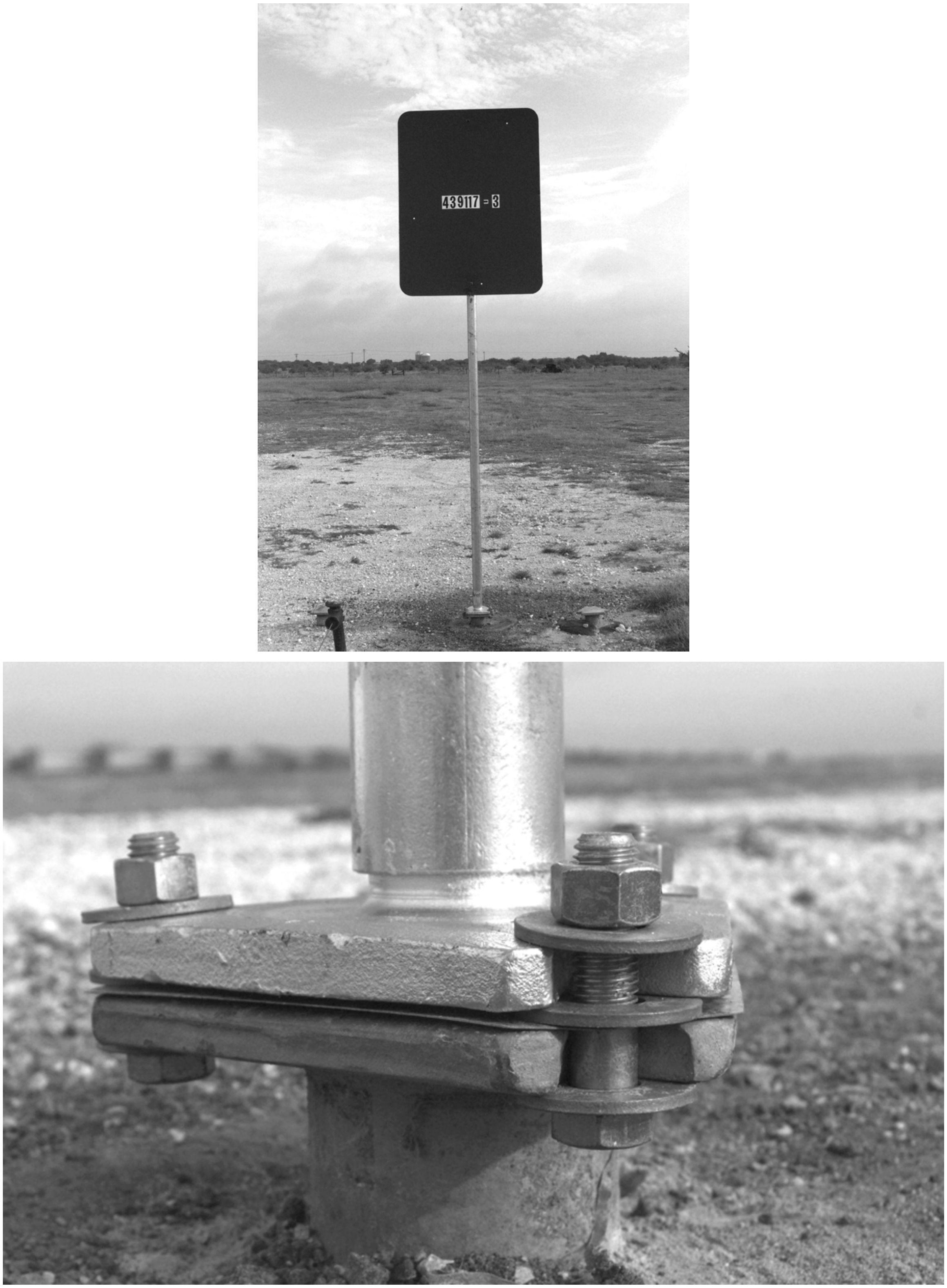


Figure 4. Sign Support Installation before Test 439117-3.

Test Description

A 1993 Ford Festiva, shown in Figures 5 and 6, was used for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 380 mm, and it was 525 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix C, Figure 61. 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, traveling at 37.35 km/h, impacted the sign support at 0 degrees with the left quarter point of the vehicle aligned with the sign support. The support began to slip away from the base at 0.009 s and lost contact with the base at 0.024 s. At 0.034 s the support lost contact with the vehicle at which time the vehicle was traveling at 34.00 km/h. The middle and upper portions of the sign came in contact with the frontal and mid sections of the vehicle's roof at 0.257 s. The sign, with the support still attached, bounced off the roof at 0.330 s. The vehicle was traveling at 33.41 km/h at loss of contact with the sign support. The support, with sign panel still attached, came to rest 22.9 m downstream and 1.8 m to the left of the point of impact. Brakes on the vehicle were applied 2.0 s after impact, and the vehicle subsequently came to rest 45.8 m downstream from the impact point. Sequential photographs of the test period are shown in Appendix D, Figure 64.

Damage to Test Installation

The triangular slip base activated as designed. The support received minor damage during the impact as shown in Figures 7 and 8. Two of the holes in the 26 gauge bolt keeper plate tore out, and one slip bolt was still attached. The keeper plate and slip bolts came to rest near the base plate. No movement of the base in the high-density polyurethane foam was observed. The support, with the sign panel still attached but loosened, came to rest 22.9 m down and 1.8 m to the left of the base. All parts except for the keeper plate were considered reusable.

Vehicle Damage

Damage to the vehicle was relatively minor as shown in Figure 9. A small scrape was noted on the left front hood. A 17 mm deep indention was found in the roof 500 mm rearward of the windshield. The indention, which was caused by the sign panel and support slapping the roof, was 890 mm wide. There was no other measurable exterior crush to the vehicle. Maximum deformation into the occupant compartment was 10 mm in the roof area near the rear of the vehicle.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk criteria. In the longitudinal direction, the occupant impact velocity was 1.51 m/s at 0.790 s, the highest 0.010-s occupant ridedown acceleration was -0.99 g's from

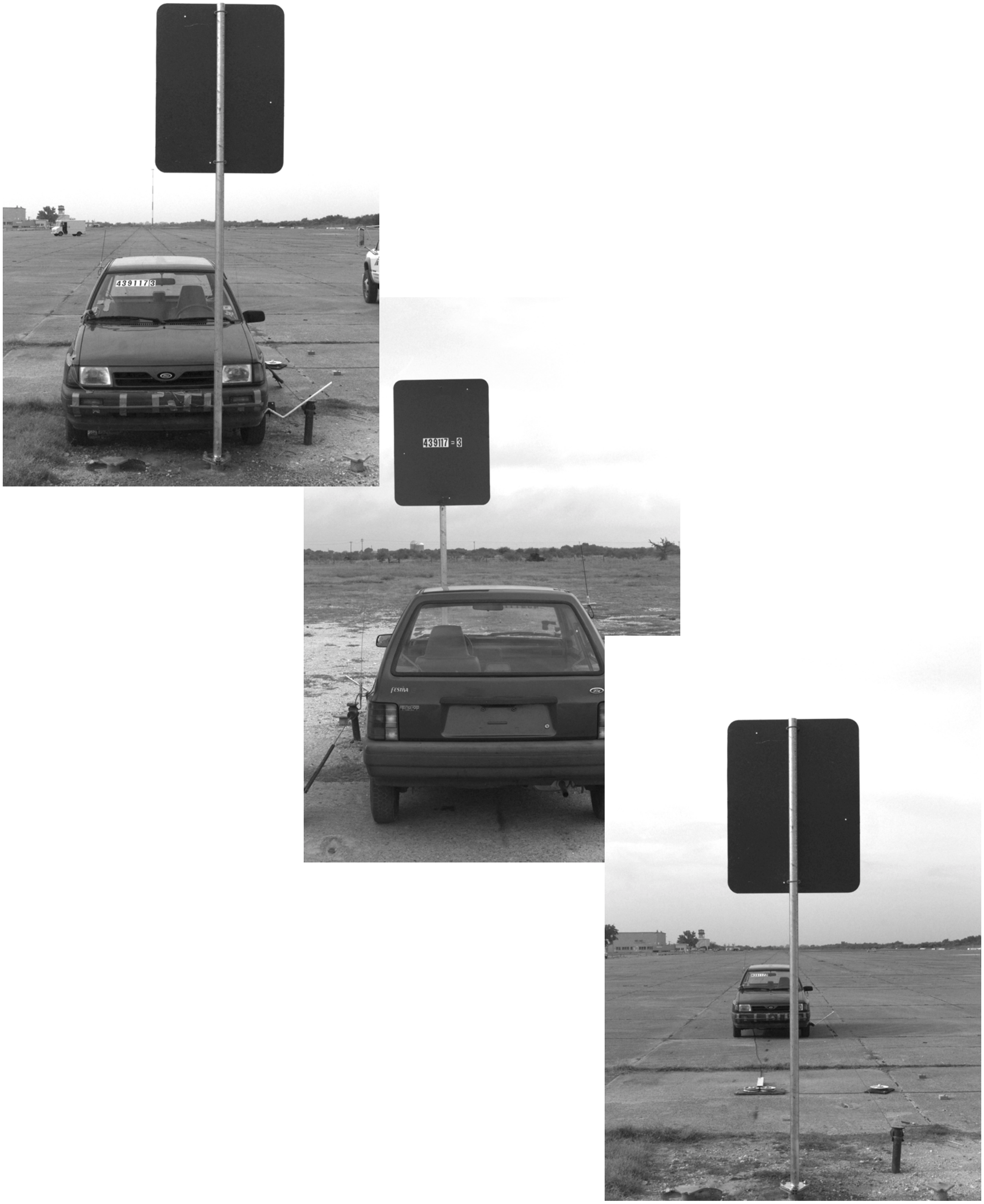


Figure 5. Vehicle/Installation Geometrics for Test 439117-3.

Figure 6. Vehicle before Test 439117-3.

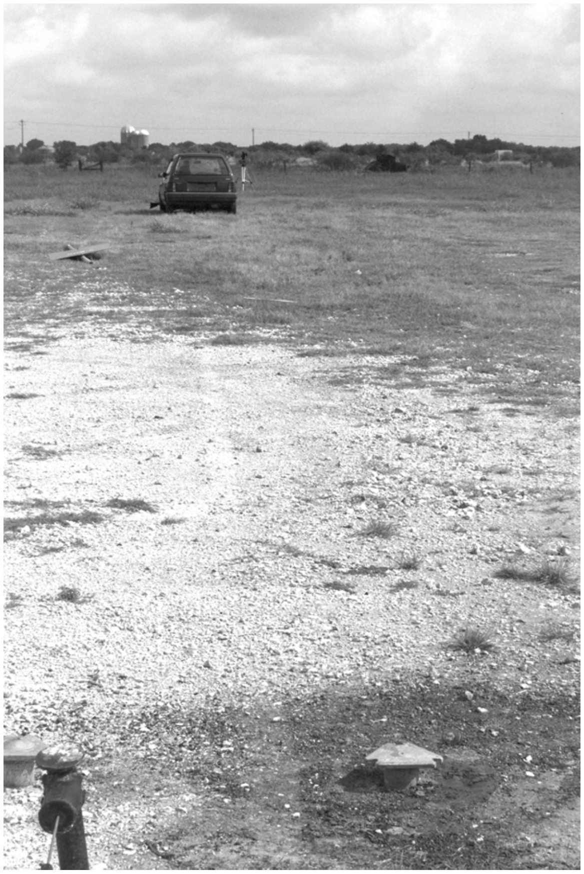


Figure 7. After Impact Trajectory for Test 439117-3.

Figure 8. Installation after Test 439117-3.

Figure 9. Vehicle after Test 439117-3.

0.876 to 0.886 s, and the maximum 0.050-s average acceleration was -0.74 g's between 0.001 and 0.051 s. In the lateral direction, the occupant impact velocity was 0.92 m/s at 0.600 s, the highest 0.010-s occupant ridedown acceleration was 0.89 g's from 0.833 to 0.843 s, and the maximum 0.050-s average was 0.55 g's between 0.836 and 0.886 s. The change in vehicular velocity during impact was 1.09 m/s. These data and other pertinent information from the test are summarized in Figure 10. Vehicle angular displacements are displayed in Appendix E, Figure 71. Vehicular accelerations versus time traces are presented in Appendix F, Figures 78 through 80.

High-Speed Test (Test 439117-4, *NCHRP Report 350* Test No. 3-61)

Test Article

The test installation was identical to that impacted in the previous test (test 439117-3), except for the type of pipe used. In this test, the 51 mm diameter support was type F (furnace butt weld) pipe fabricated from ASTM A501 material. The yield strength of the pipe was 262 MPa, and the percent elongation was 40 percent. Photographs of the completed sign support system are shown in Figure 11.

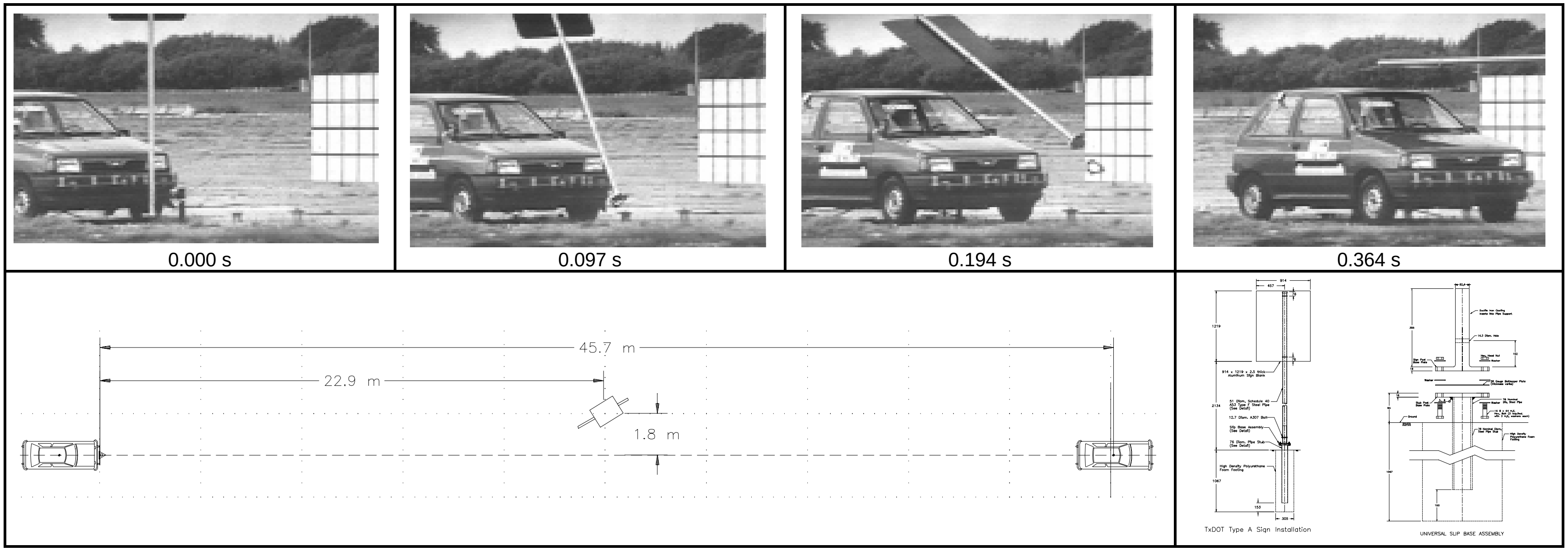
Test Description

The same 1993 Ford Festiva used in the low-speed test (test 439117-3) was reused in this crash test. The condition of the vehicle prior to the test is shown in Figures 12 and 13. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in Appendix C, Figure 61. 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, traveling at 99.83 km/h, impacted the slip-base sign support at 0 degrees with the right quarter point of the vehicle aligned with the support. Upon impact, the two slip bolts on the impact side of the slip base tore through the 26 gauge keeper plate, allowing the sign support to break away from its base. After initially losing contact with the vehicle, the sign support contacted the front of the vehicle a second time at 0.046 s. At 0.119 s, the rotating sign support and sign panel contacted the rear of the vehicle's roof. The sign support lost contact with the vehicle at 0.156 s. At this time, the speed of the vehicle had been reduced to 97.67 km/h. The deformed sign support came to rest approximately 38.1 m downstream and 0.3 m to the right of the point of impact. Brakes on the vehicle were applied 2.0 s after impact, and the vehicle subsequently came to rest 122.6 m downstream and 1.8 m to the right of the point of impact. Sequential photographs of the test period are shown in Appendix D, Figure 65.

Damage to Test Installation

Damage to the support is shown in Figures 14 and 15. Two of the slip bolts tore through the 26 gauge keeper plate and were found to the left and slightly behind the base plate. The


0.000 s

0.097 s

0.194 s

0.364 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-3
Date	08/11/97
Test Article	
Type	Sign Support
Name or Manufacturer	TxDOT Type A Sign Installation
Installation Height (m)	2.14
Size and/or dimension and material of key elements	Single Steel Post w/ aluminum sign blank
Soil Type and Condition	Concrete Footing, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1993 Ford Festiva
Mass (kg) Curb	805
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	37.35
Angle (deg)	0 - lf qtrpt
Exit Conditions	
Speed (km/h)	33.41
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.51
y-direction	0.92
Ridedown Accelerations (g's)	
x-direction	-0.99
y-direction	0.89
Max. 0.050-s Average (g's)	
x-direction	-0.74
y-direction	0.55
z-direction	0.63
Veh. Change in Velocity (m/s)	1.09

Test Article Debris Pattern (m)	
Longitudinal	22.9
Lateral	1.8
Vehicle Damage	
Exterior	
VDS	12FL1
CDC	12FLEN1
Maximum Exterior Vehicle Crush (mm)	17
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	10
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	0.7
Max. Pitch Angle (deg)	-2.7
Max. Yaw Angle (deg)	-0.5

Figure 10. Summary of Results for Test 439117-3.

Figure 11. Sign Support Installation before Test 439117-4.

Figure 12. Vehicle/Installation Geometrics for Test 439117-4.

Figure 13. Vehicle before Test 439117-4.

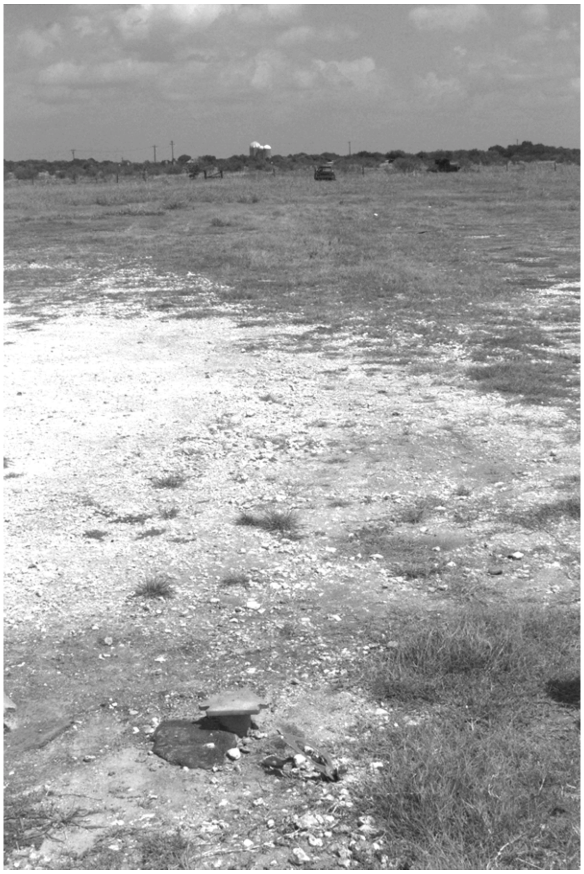


Figure 14. After Impact Trajectory for Test 439117-4.

Figure 15. Installation after Test 439117-4.

keeper plate, with the remaining slip bolt attached, came to rest slightly to the right and behind the base plate. The sign panel detached from the support and was located 23.5 m downstream and 2.4 m to the right of the point of impact. The sign support had some permanent deformation at bumper height and came to rest 38.13 m downstream and 0.30 m to the right of the point of impact. All the components were considered reusable except the support pipe and bolt keeper plate.

Vehicle Damage

Damage to the front bumper, hood, grill, and roof can be seen in Figure 16. A dent in the roof measuring 900 mm wide, 1104 mm long, and 26 mm deep, resulted from secondary contact with the sign support and sign panel. Maximum exterior crush to the front of the vehicle at bumper height was 95 mm. The maximum deformation into the occupant compartment was 50 mm in the rear roof area.

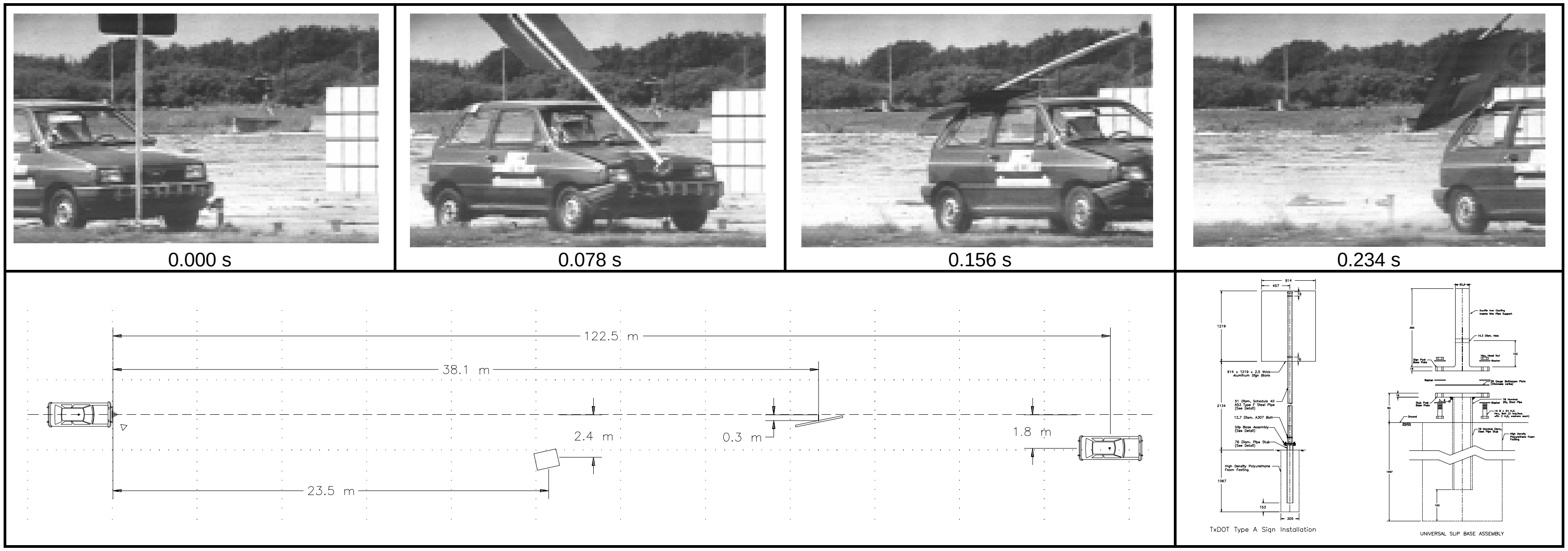
Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk criteria. In the longitudinal direction, the occupant impact velocity was 0.96 m/s at 0.791 s, the highest 0.010-s occupant ridedown acceleration was -2.18 g's from 0.907 to 0.917 s, and the maximum 0.050-s average acceleration was -1.47 g's between and 0.000 and 0.050 s. In the lateral direction, the occupant impact velocity was 1.03 m/s at 0.930 s, the highest 0.010-s occupant ridedown acceleration was 0.71 g's from 0.917 to 0.927 s, and the maximum 0.050-s average was -0.63 g's between 0.109 and 0.159 s. The change in vehicular velocity during impact was 0.60 m/s. These data and other pertinent information from the test are summarized in Figure 17. Vehicle angular displacements are displayed in Appendix E, Figure 72. Vehicular accelerations versus time traces are presented in Appendix F, Figures 81 through 83.

CONCLUSIONS

The 26 gauge keeper plate did not impede the breakaway performance of the small sign support and the slip base activated as designed in both the low-speed and high-speed tests. The detached elements from the sign support did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. In both tests, there was minor deformation (10 - 50 mm) into the occupant compartment at the rear passenger roof area, but given the magnitude and location of the deformation, it was not considered to be a probable cause of serious injury to the occupants of the vehicle. The vehicle remained upright and stable both during and after the impacts. The occupant risk values were all within the preferred limits specified in *NCHRP Report 350*, and the change in vehicular velocity was below the preferred value contained in the 1994 American Association of State Highway and Transportation Officials (AASHTO) specifications.(2) The vehicle did not intrude into adjacent traffic lanes and came to rest behind the test article in each test. Based on these results, the use of a 26 gauge keeper plate in conjunction with a triangular slip base small sign support system is considered to be in compliance with *NCHRP Report 350* and suitable for implementation.

Figure 16. Vehicle after Test 439117-4.



General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-4
Date	08/11/97
Test Article	
Type	Sign Support
Name or Manufacturer	TxDOT Type A Sign Installation
Installation Height (m)	2.11
Size and/or dimension and material of key elements	Single Steel Post with aluminum sign blank
Soil Type and Condition	Concrete Footing, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1993 Ford Festiva
Mass (kg) Curb	805
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	99.83
Angle (deg)	0 - rt qtrpt
Exit Conditions	
Speed (km/h)	97.67
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.96
y-direction	1.03
Ridedown Accelerations (g's)	
x-direction	-2.18
y-direction	0.71
Max. 0.050-s Average (g's)	
x-direction	-1.47
y-direction	-0.63
z-direction	-1.75
Veh. Change in Velocity (m/s)	0.60

Test Article Debris Pattern (m)	
Longitudinal	38.1
Lateral	2.4
Vehicle Damage	
Exterior	
VDS	12FR2
CDC	12FREN1
Maximum Exterior Vehicle Crush (mm)	95
Interior	
OCDI	FL0100000
Max. Occ. Compart. Deformation (mm)	50
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	-3.7
Max. Pitch Angle (deg)	4.8
Max. Yaw Angle (deg)	4.4

Figure 17. Summary of Results for Test 439117-4.

III. EVALUATION OF LIFTING DEVICE RETROFIT

For many years, the TxDOT slip-base design has incorporated a lifting device on the lower base plate. 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 multi-directional slip base. The purpose of the lifting ramp 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.

Under TxDOT research project 7-1971, a new triangular slip-base system for pipe sign supports was developed and successfully crash tested. During the development of this system, 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 repair and upgrade operations to utilize existing slip-base foundations. The basic concept that was investigated was to provide space between the upper and lower plates of the slip-base so that sign supports with the new upper slip base plate could be installed on existing lower base plates that have lifting ramps or cones. Two options, a series of stacked washers and a spacer ring, were investigated. Four pendulum tests and two full-scale vehicle crash tests were performed to evaluate the impact performance of the proposed options.

PENDULUM TESTING

The effect of lifting cone retrofit alternatives on the dynamic breakaway response of a triangular slip-base small sign support was initially investigated through a series of full-scale pendulum tests. As in the keeper plate investigation, 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 the crashworthiness of the lifting cone retrofit alternatives 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 A.

Test Articles

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)-95). A 1.22 m wide by 1.52 m tall plywood sign panel was attached to a single, schedule 40, 76 mm diameter pipe support which was mounted on a triangular slip base. The support was ASTM A53, grade B, type E (electric resistance welded) pipe with a yield strength of 241 MPa. The upper slip-base plate assembly consisted of a cast ductile iron triangular slip-base plate with a 305 mm tall stub which fit inside the 76 mm diameter pipe support. The lower slip-base plate and pipe stub were welded to a base plate which was bolted to a steel reaction plate in the pendulum pit. A 25 mm tall cone was stamped into the center of the lower slip-base plate as shown in Figure 16. The bolt keeper plate was fabricated with a 108 mm diameter hole (as shown on standard drawing SMD (1-3)-95) to fit over the lifting cone and rest flat against the lower base plate. Separation between the upper and lower slip plates was provided either by stacking a sufficient number of standard washers at each of the three slip-bolt locations or by using a spacer ring fabricated from steel or plastic. Photographs of the stacked washer and spacer ring options are shown in Figure 18(a) and 18(b), respectively.

In each test, the triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. The three 16 mm diameter, high-strength bolts were tightened to a prescribed torque of 51.5 N-m. Details of the sign support installation with the different lifting cone retrofit options are shown in Figure 18. Photographs of the typical sign support installation used in the pendulum tests are shown in Figure 19.

Test Results

The stacked washers alternative was evaluated in the first pendulum test (test P1). During the test, the 30 gauge keeper plate separated from the base with one slip bolt and set of washers still attached and came to rest 4.6 m down and 1.2 m to the right of the base. One set of slip bolt and washers came to rest 4.6 m down and 1.2 m to the left of the base, and the third set of slip bolt and washers was found 12.8 m down and 2.1 m to the right of the base. The sign post and panel hung on the pendulum body and eventually slid off behind the base. Maximum crush to the nose of the pendulum was 143 mm.

In test P2, a steel spacer ring was used to separate the two triangular slip plates. The slip base activated and the sign support released as designed. The 30 gauge keeper plate, with one slip bolt still attached, came to rest 5.5 m down and 0.9 m to the right of the base. The other two slip bolts remained near the base. The sign post and sign panel came to rest 15.5 m down and 1.2 m to the right of the base. The steel spacer ring was found 21.9 m down and 7.3 m to the left of the base. Maximum crush to the pendulum nose was 133 mm.

The installation used in the third pendulum test in this series (test P7) was identical to test P2 with the exception that the steel spacer ring was replaced by a plastic spacer ring of the same

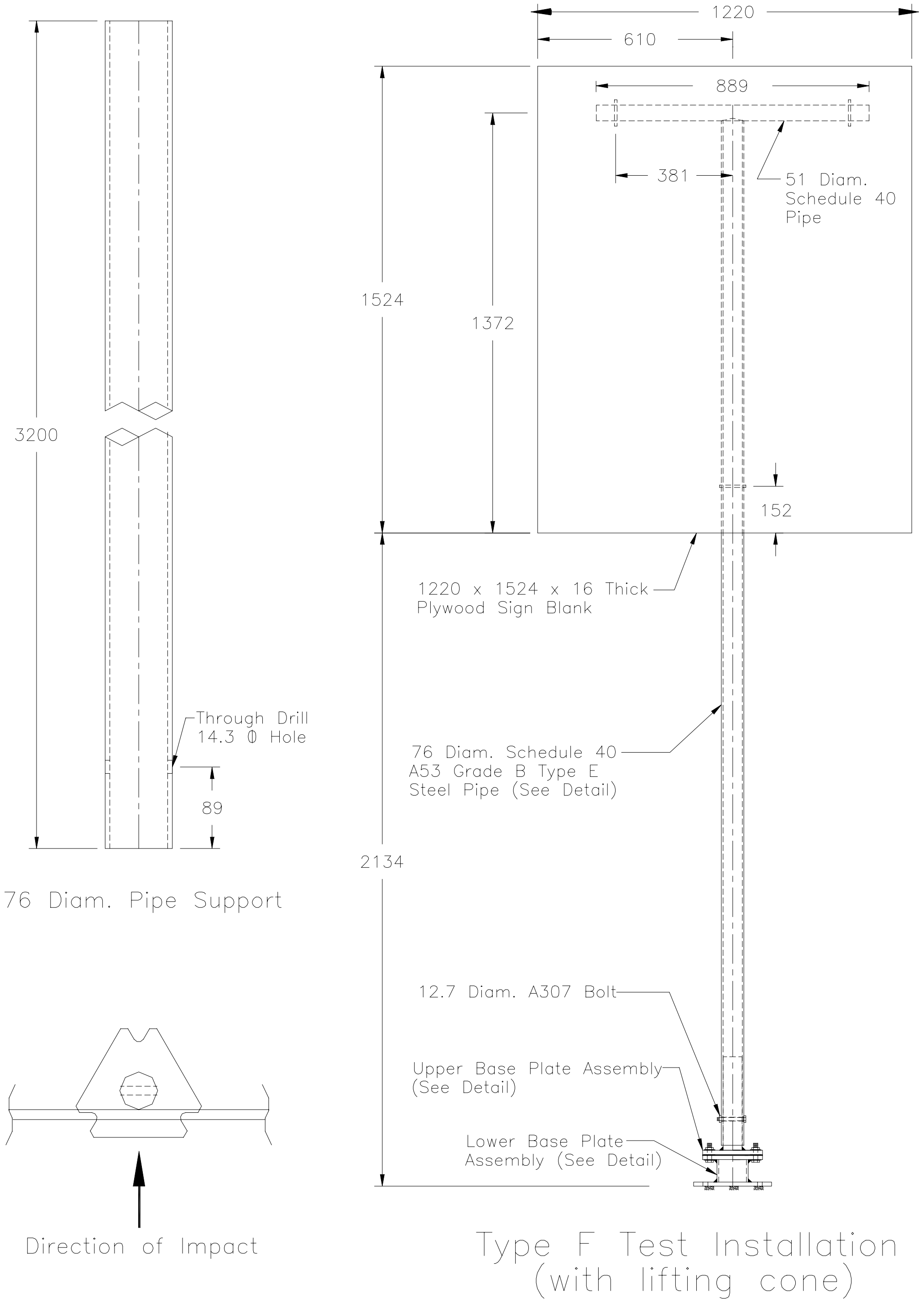
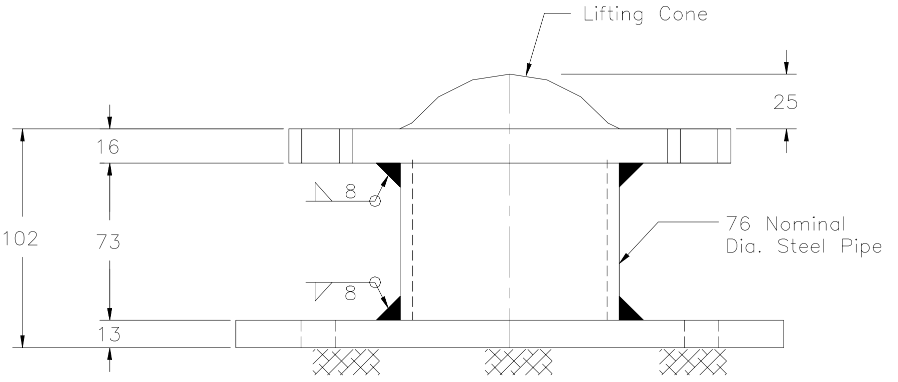
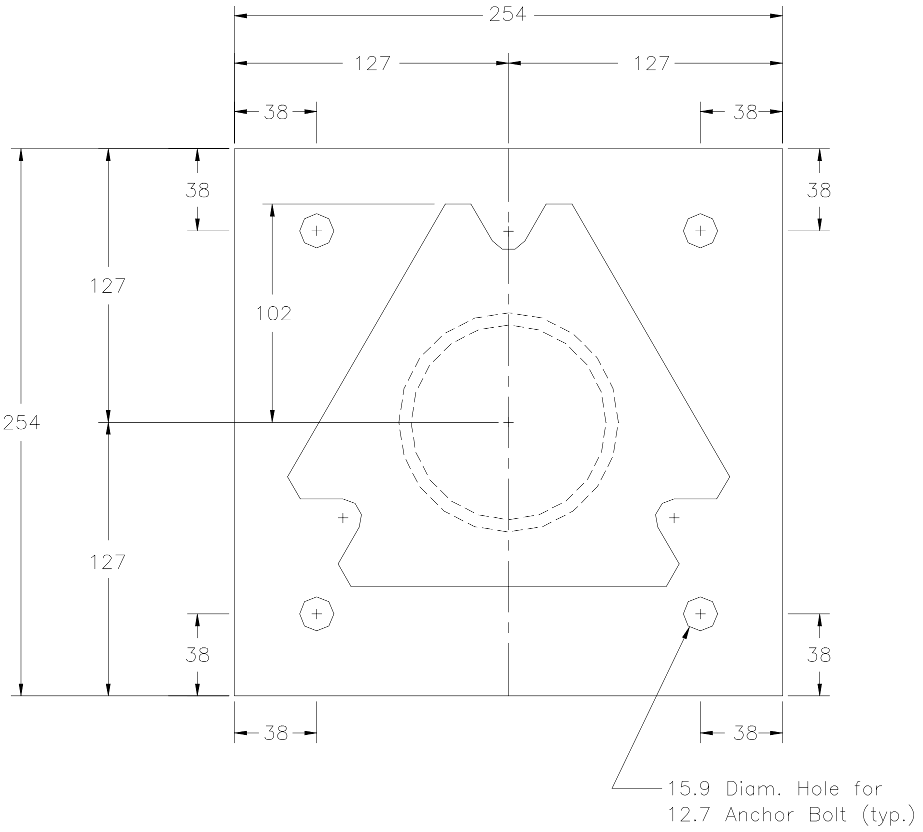


Figure 18. Details of Sign Support Installation Used for Evaluation of Lifting Cone.



Elevation



Lower Base Plate Assembly

Figure 18. Details of Sign Support Installation Used for Evaluation of Lifting Cone (Continued).

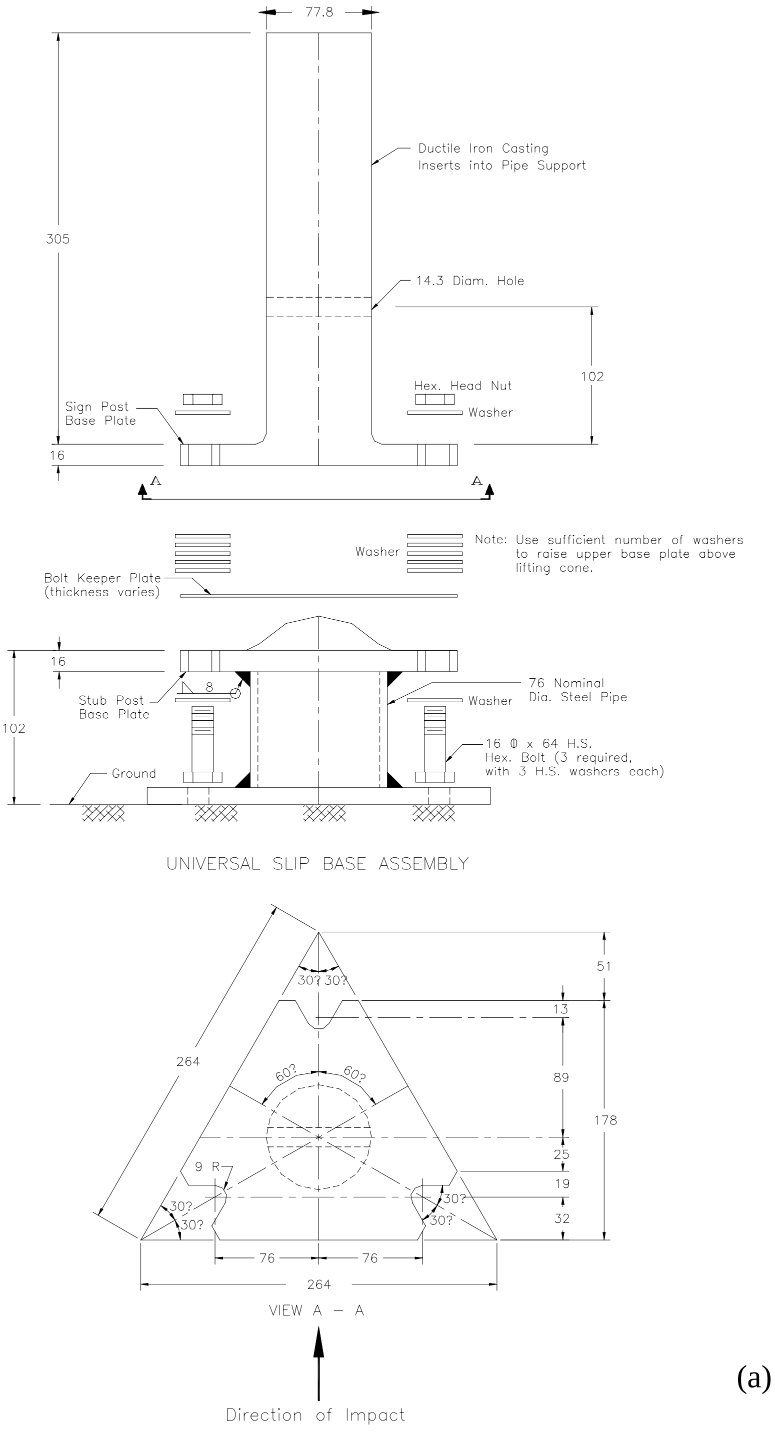


Figure 18. Details of Sign Support Installation Used for Evaluation of Lifting Cone (Continued).

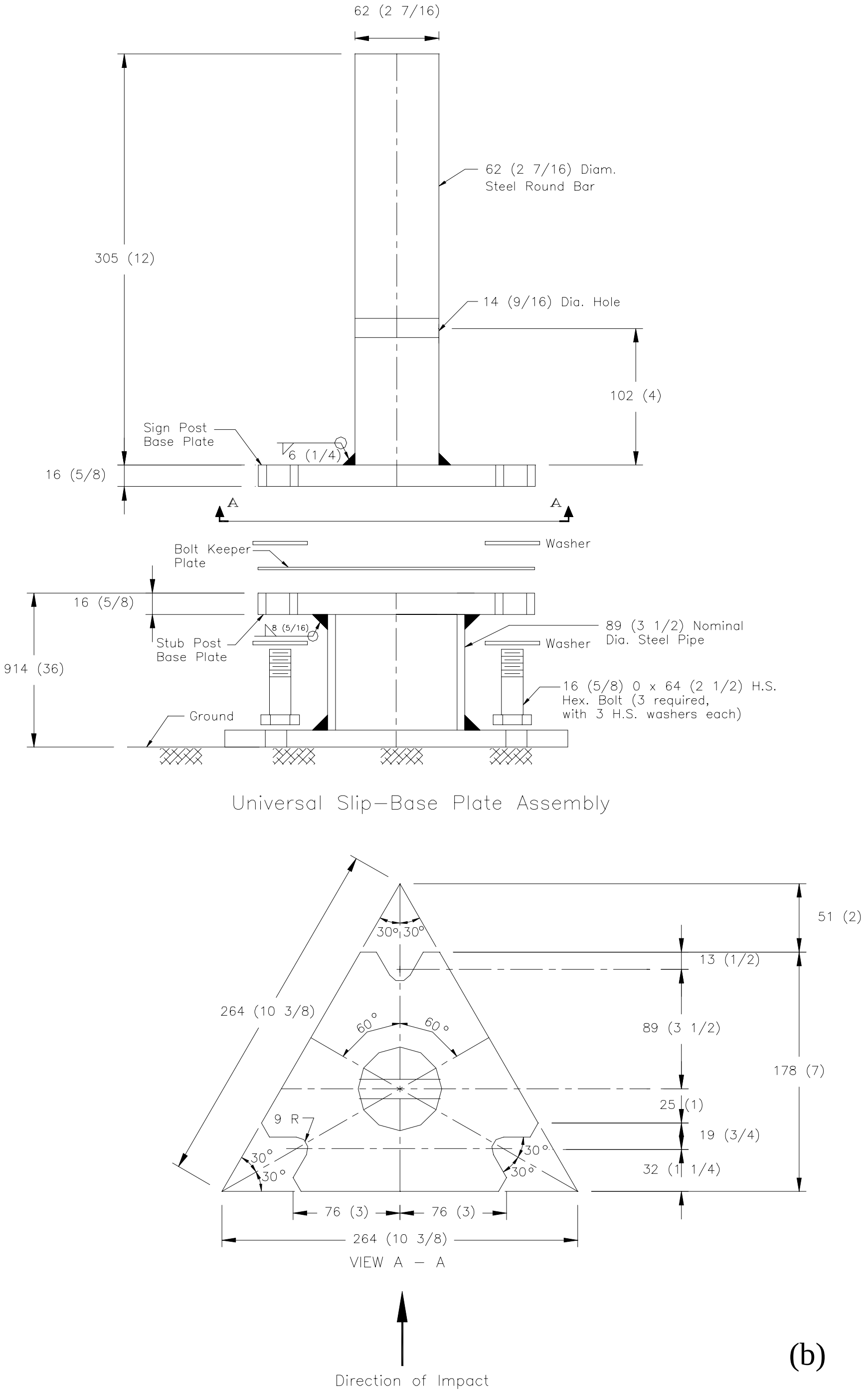


Figure 18. Details of Sign Support Installation Used for Evaluation of Lifting Cone (Continued).

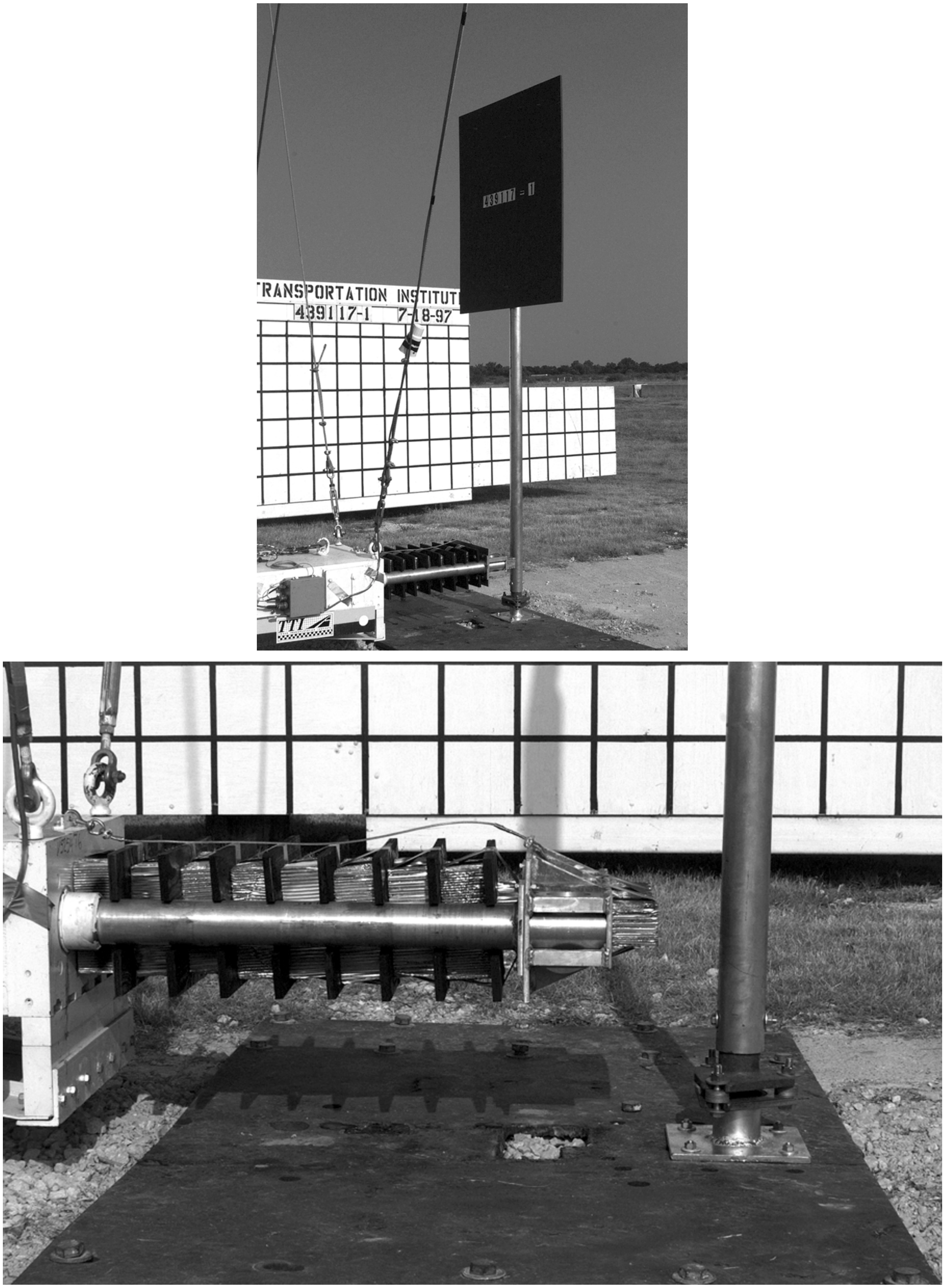


Figure 19. Typical Sign Support Installation before Pendulum Testing of Lifting Cone.

dimensions. The keeper plate with one bolt attached, the plastic spacer ring, and a second slip bolt all came to rest in the immediate vicinity of the base. The sign post, sign panel, and third slip bolt came to rest approximately 15.5 m down from the base. Maximum crush to the nose of the pendulum was 128 mm.

The configuration tested in the fourth pendulum test (test P8) was similar to that evaluated in test P7 except that a 26-gauge bolt keeper plate was substituted for the standard 30 gauge plate. Two slip bolts remained attached to the 26 gauge keeper plate which came to rest near the base. The third slip bolt was also found in the vicinity of the lower base plate. The sign support, sign panel, and plastic spacer ring came to rest approximately 12.8 m down from the point of impact. Maximum crush to the pendulum nose was 139 mm.

The acceleration-time histories for these pendulum impacts are presented in Appendix B. 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, and the occupant impact velocity which is an occupant risk evaluation criteria specified in *NCHRP Report 350*. A summary of these results is shown in Table 2. The peak accelerations, maximum 10-ms force, and kinetic energy dissipated in the activation of the slip base were higher for the stacked washers (test P1) than for the spacer ring (tests P2, P7, and P8). The values of peak acceleration, maximum 10 ms force, and kinetic energy did not vary more than 5 percent among the various tests which incorporated the spacer ring. In the tests with the plastic spacer ring, the different keeper plate thicknesses had no discernable effect on breakaway performance.

These tests indicated that both the stacked washers and steel and plastic spacer rings should demonstrate acceptable crashworthiness when used to retrofit existing slip bases with lifting cones. The acceleration levels and occupant impact velocities computed for the various configurations were within the recommended limits of *NCHRP Report 350.*

After reviewing the results of the pendulum tests, TxDOT personnel chose to use a plastic spacer ring in full-scale vehicle crash tests to further validate its performance. The installation of the spacer ring is simpler and more foolproof than the stacked washer alternative. Furthermore, the plastic spacer ring is more cost effective than the steel, and its lighter weight creates less of a potential hazard during an impact.

Table 2. Results of Pendulum Testing of Lifting Cone Retrofit Alternatives.

Test No.	Lifting Cone Retrofit	Impact Speed (km/h)	Max. Nose Crush (mm)	Peak Acceleration (g's)	Max. 10 ms Force (kN)	Kinetic Energy (N-m)	Occupant Impact Vel. (m/s)
P1	Stacked washers	35.3	143	-4.7	34.3	6718 0.040 s	2.76
P2	Steel spacer ring	35.2	133	-4.0	27.8	4563 0.049 s	2.34
P7	plastic spacer ring (30 gauge keeper plate)	35.3	128	-4.0	28.3	4418 0.052 s	2.36
P8	plastic spacer ring (26 gauge keeper plate)	35.0	139	-3.8	27.3	4524 0.050 s	2.33

FULL-SCALE CRASH TESTING

Given the favorable results of the pendulum tests, the impact performance lifting cone retrofit for slip-base sign supports 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*. 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 passenger car. Details of the crash test procedures and evaluation criteria followed in this study are provided in Appendix B.

Low-Speed Test (Test 439117-1, *NCHRP Report 350* Test No. 3-60)

Test Article

The test installations for the full-scale crash tests were similar to those used in the pendulum tests and conformed to a TxDOT Type F sign mount as shown on the standard sign mounting details for small roadside signs (SMD (1-1)-95). A 1.22 m wide by 1.52 m tall plywood sign panel was attached to a single, schedule 40, 76 mm diameter pipe support which was mounted on a triangular slip base. The support was ASTM A53, grade B, type E (electric resistance welded) pipe with a yield strength of 241 MPa. The upper slip-base plate assembly consisted of a cast ductile iron triangular slip-base plate with a 305 mm tall stub which fit inside the 76 mm diameter pipe support. The lower slip-base plate, which had a 25 mm tall lifting cone stamped into its center, was welded to a 76 mm diameter pipe stub which was embedded in a 305 mm diameter by 1.07 m deep high-density polyurethane foam footing. The bolt keeper plate was fabricated with a 108 mm diameter hole (as shown on standard drawing SMD (1-3)-95) to fit over the lifting cone and rest flat against the lower base plate. A plastic spacer ring was positioned over the lifting cone to provide the required separation between the upper and lower triangular slip plates.

The triangular slip base was oriented such that one of the sides was perpendicular to the direction of impact. The three 16 mm diameter, high-strength bolts were tightened to a prescribed torque of 51.5 N-m. Details of the test installation are shown in Figure 20. Figure 21 shows photographs of the sign support installation used in the low-speed crash test.

Test Description

The crash test used a 1992 Ford Festiva, shown in Figures 22 and 23. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 410 mm, and it was 560 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix C, Figure 62. 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.

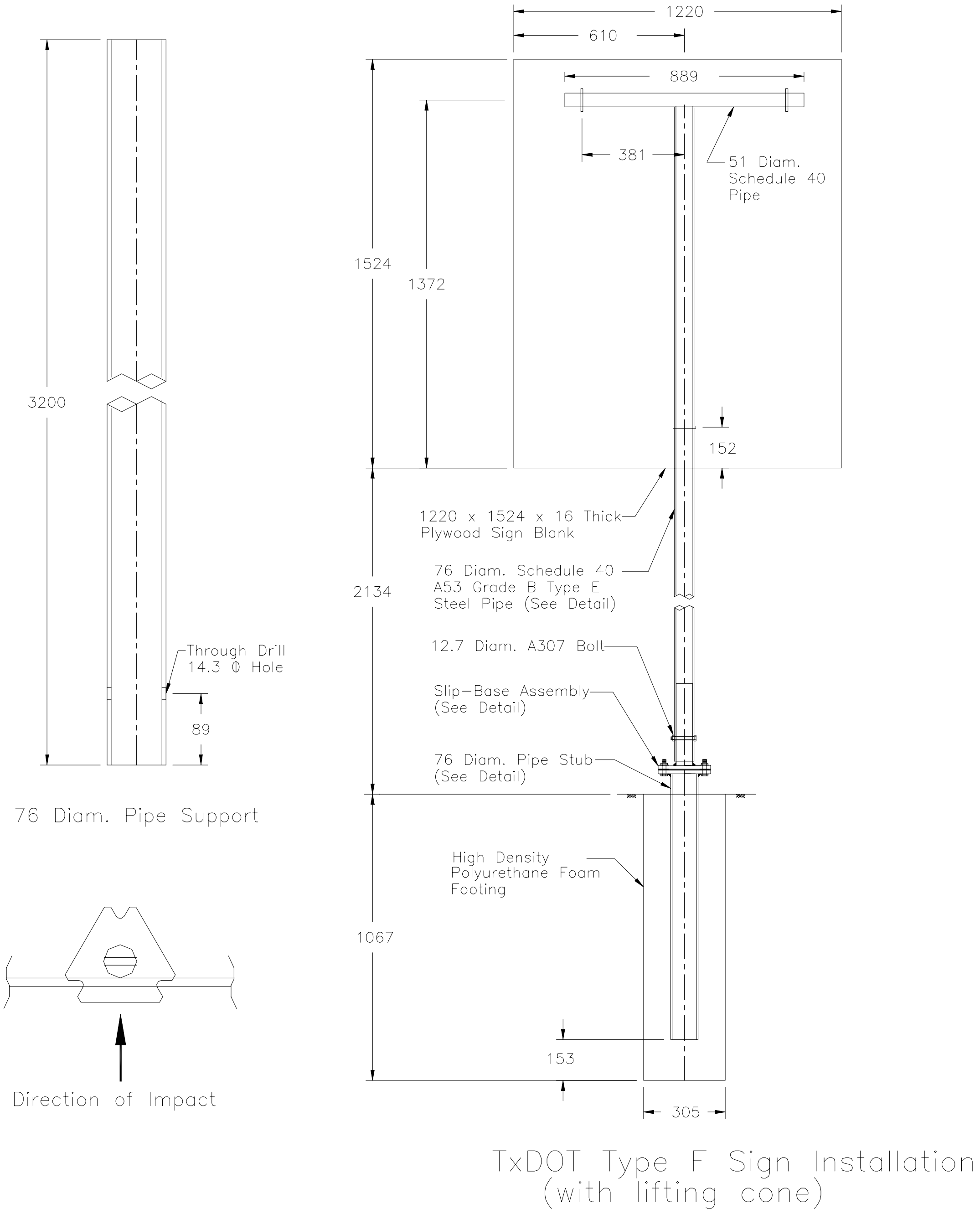


Figure 20. Details of the Installation Used for Evaluation of the Lifting Cone in Vehicle Crash Testing.

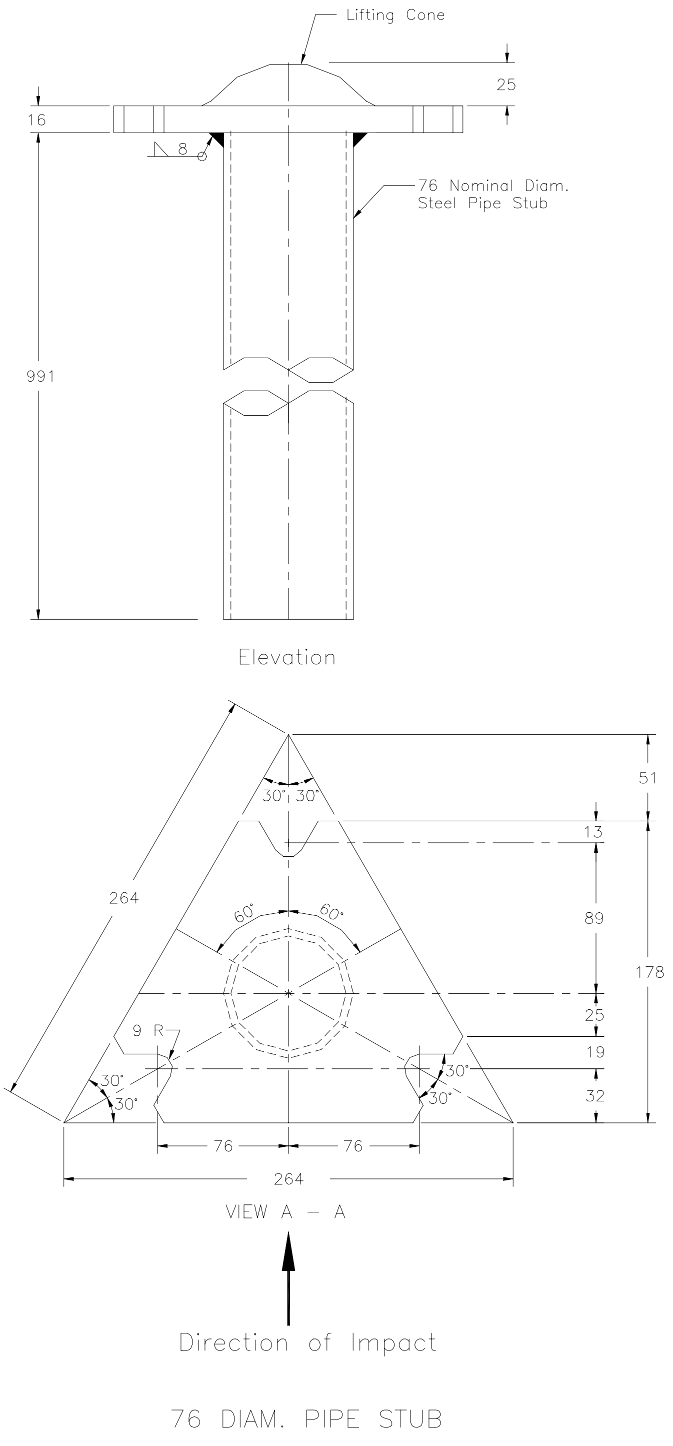


Figure 20. Details of the Installation Used for Evaluation of the Lifting Cone in Vehicle Crash Testing (Continued).

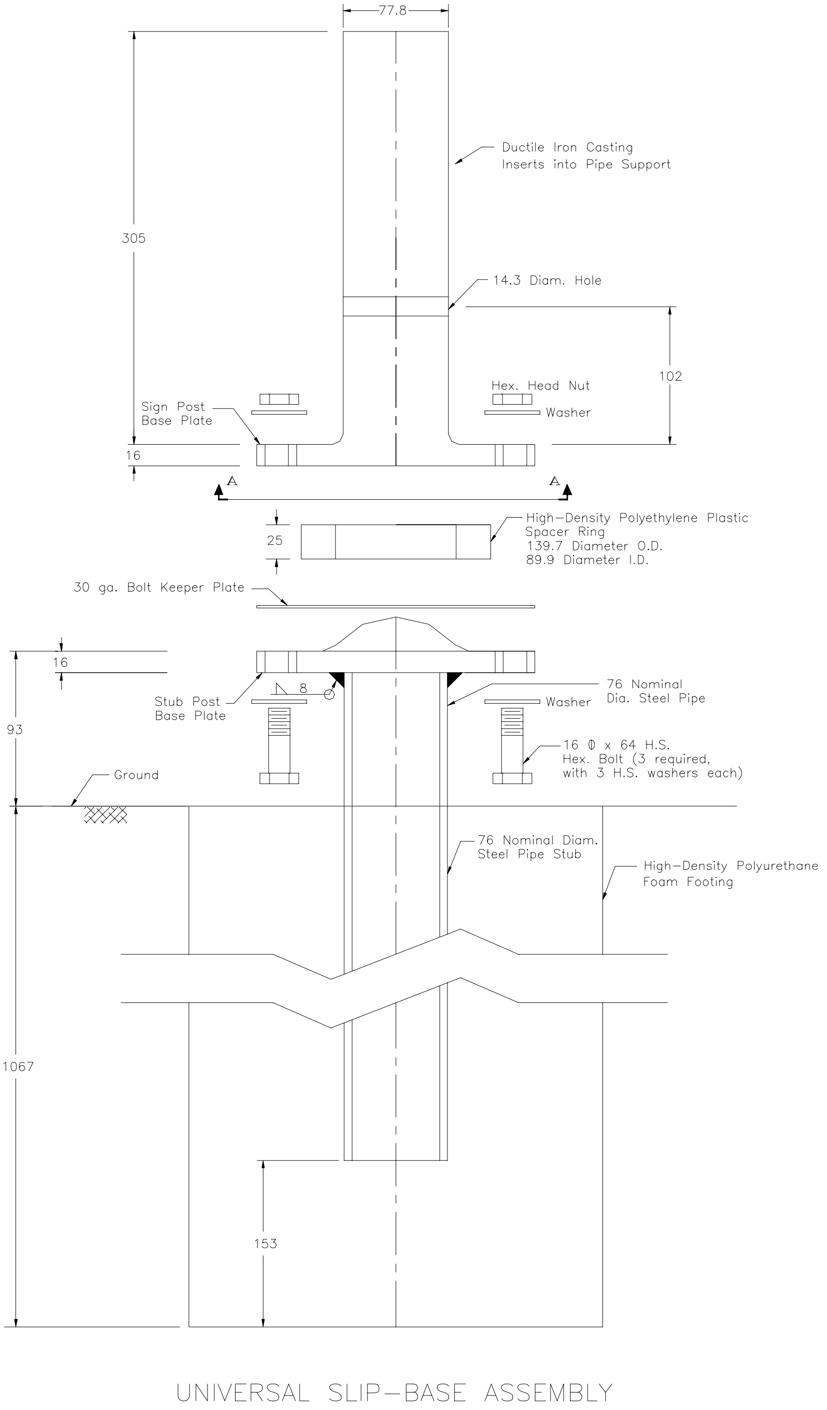


Figure 20. Details of the Installation Used for Evaluation of the Lifting Cone in Vehicle Crash Testing (Continued).

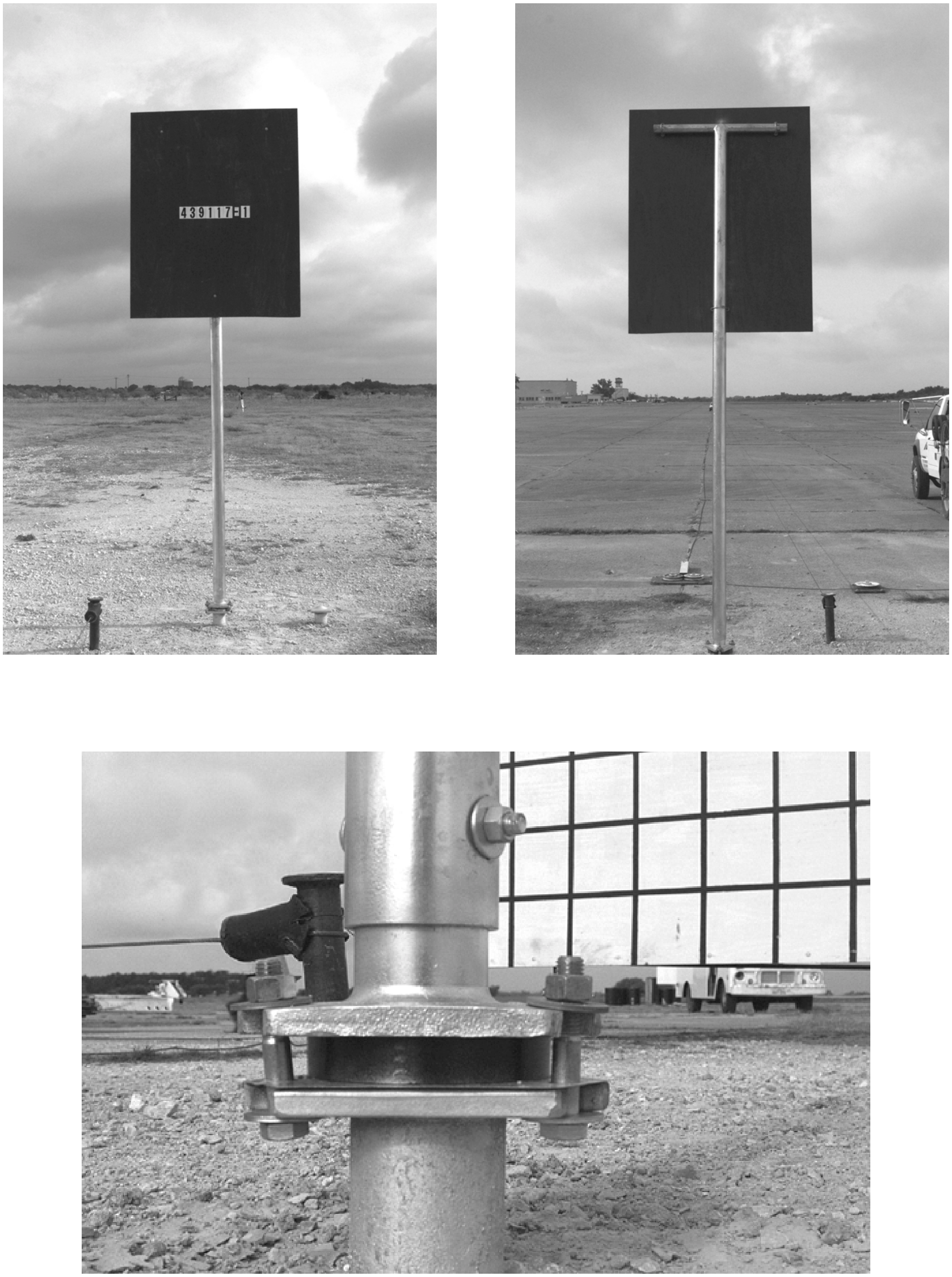


Figure 21. Installation before Test 439117-1.

Figure 22. Vehicle/Installation Geometrics for Test 439117-1.

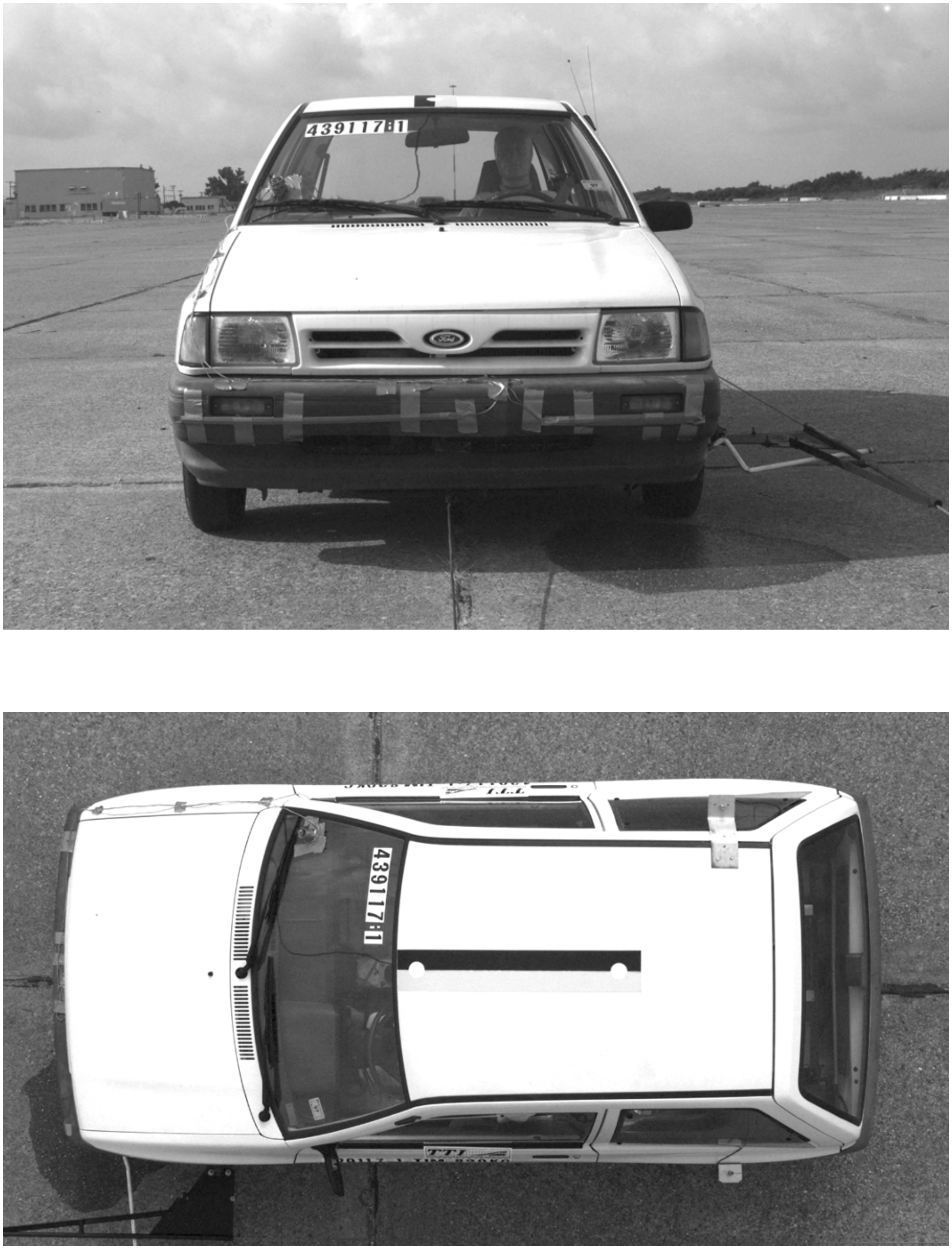


Figure 23. Vehicle before Test 439117-1.

The vehicle, traveling at 35.66 km/h, impacted the slip-base sign support at the left quarter point at 0 degrees. Shortly after impact the support and attached sign panel began to separate from the lower slip base. By 0.026 s, the support had completely detached from and cleared the lower base. At 0.326 s, the right side of the sign panel briefly contacted the vehicle's roof. The upper section of the sign panel came in contact with the rear roof section of the vehicle at 0.352 s. Shortly afterwards, the sign panel rebounded off the vehicle, and the support and panel dropped down along the driver's side. At loss of contact with the support, the vehicle was traveling at a speed of 32.31 km/h and continued in a straight path. Brakes on the vehicle were applied at 2.0 s after impact and the vehicle subsequently came to rest 33.5 m downstream from the point of impact. Sequential photographs of the impact period are shown in Appendix D, Figure 66.

Damage to Test Installation

Damage to the sign support is shown in Figures 24 and 25. The plastic spacer ring provided the needed separation between the upper and lower slip bases to accommodate the lifting cone, and the slip base activated as designed. The keeper plate remained on the lower slip base with the two front slip bolts still attached. The rear hole of the keeper plate was torn through, and the slip bolt was thrown to the left of the impact point. The sign panel remained attached to the support with one of the upper U-bolts, and both came to rest 12.8 m down from impact and in line with the base. The plastic spacer ring was found 8.2 m down and 1.8 m to the right of the impact point. There was no movement observed at the base. All parts except the keeper plate were considered reusable.

Vehicle Damage

The vehicle received only minor damage as shown in Figure 26. Small scrapes on the rear roof were observed. A 20 mm deep cut in the A-pillar was noted 70 mm back from the windshield. Maximum exterior crush to the left side at bumper height was 40 mm from contact with the support. There was no deformation or intrusion into the occupant compartment.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk. In the longitudinal direction, there was no occupant contact during impact. The maximum 0.050-s average acceleration was -0.87 g's between 0.000 and 0.050 s. There was no occupant contact in the lateral direction and the maximum 0.050-s average acceleration was -0.32 g's between 0.426 and 0.0476 s. The change in vehicular velocity during impact was 0.93 m/s. These data and other pertinent information from the test are summarized in Figure 27. Vehicle angular displacements are displayed in Appendix E, Figure 73. Vehicular acceleration versus time traces are presented in Appendix F, Figures 84 through 86.

Figure 24. After Impact Trajectory for Test 439117-1.

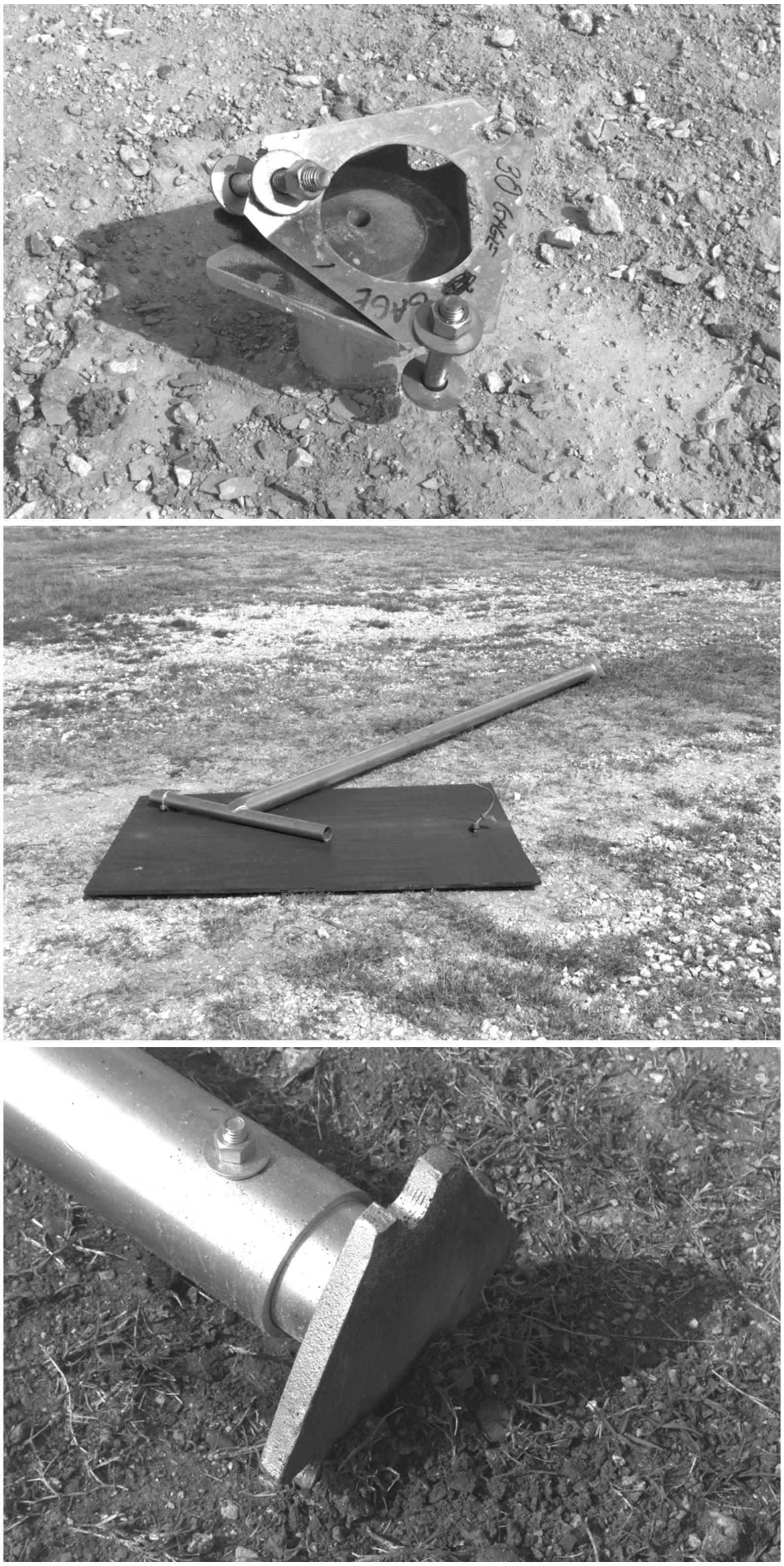
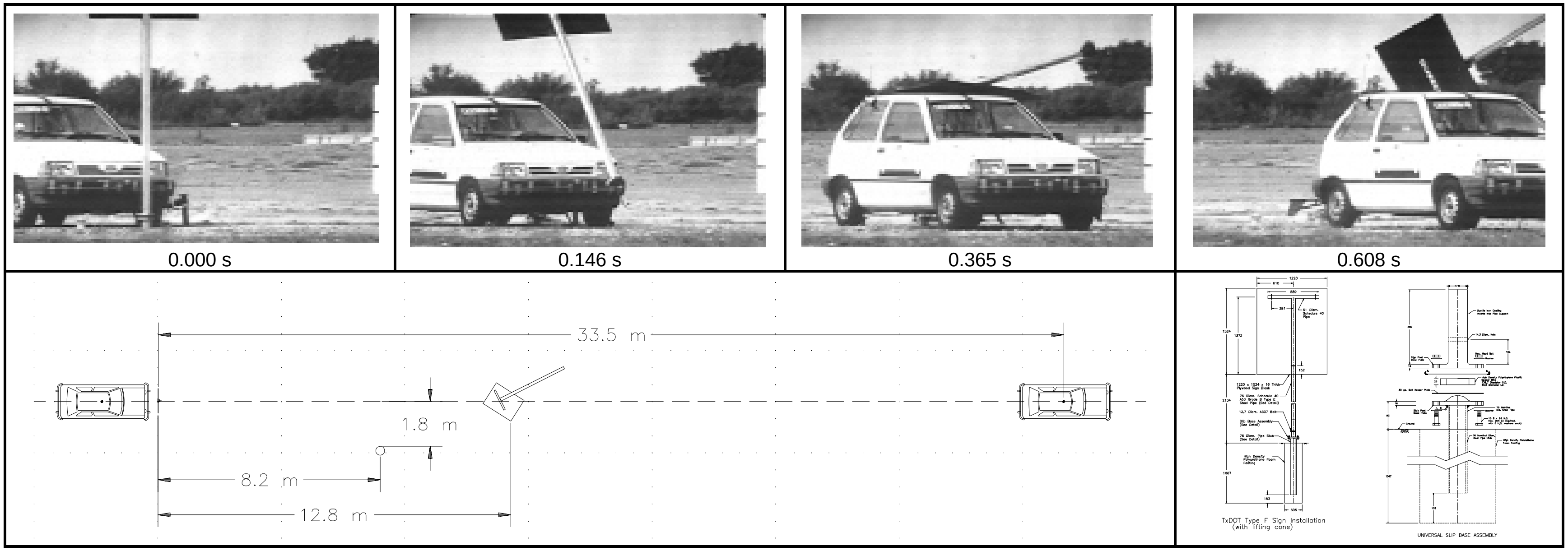


Figure 25. Installation after Test 439117-1.

Figure 26. Vehicle after Test 439117-1.



0.000 s 0.146 s 0.365 s 0.608 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-1
Date	08/07/97
Test Article	
Type	Sign Support
Name or Manufacturer	TxDOT Type F Sign Mount
Installation Height (m)	2.21
Size and/or dimension and material of key elements	Single Steel Post with plywood sign panel
Soil Type and Condition	Concrete footing, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1992 Ford Festiva
Mass (kg) Curb	815
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	35.66
Angle (deg)	0 - left qtrpt
Exit Conditions	
Speed (km/h)	32.31
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	No Contact
y-direction	No Contact
Ridedown Accelerations (g's)	
x-direction	No Contact
y-direction	No Contact
Max. 0.050-s Average (g's)	
x-direction	-0.87
y-direction	-0.32
z-direction	1.25
Veh. Change in Velocity (m/s)	0.93

Test Article Debris Pattern (m)	
Longitudinal	12.8
Lateral	1.8
Vehicle Damage	
Exterior	
VDS	12FL1
CDC	12FLEN1
Maximum Exterior Vehicle Crush (mm)	40
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	0.9
Max. Pitch Angle (deg)	-1.9
Max. Yaw Angle (deg)	-3.5

Figure 27. Summary of Results for Test 439117-1.

High-Speed Test (Test 439117-2, *NCHRP Report 350* Test No. 3-61)

Test Article

The test installation was identical to that impacted in the previous low-speed test (test 439117-1). A schematic of the test installation is shown in Figure 20. Photographs of the completed sign support system are shown in Figure 28.

Test Description

The high-speed test reused the same 1992 Ford Festiva used in the low-speed test (test 439117-1). The condition of the vehicle prior to the test is shown in Figures 29 and 30. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. Additional dimensions and information on the vehicle are given in Appendix C, Figure 62. 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, traveling at 99.72 km/h, impacted the slip base sign support at 0 degrees, with the right quarter point of the vehicle aligned with the support. Shortly following impact, the slip base began to activate and, at 0.012 s, the support post was completely free of the lower base. At 0.151 s, the post was parallel to the ground approximately 0.38 m above the vehicle. The sign panel detached from the post at 0.158 s. As the support post continued to rotate, it lightly touched the rear corner of the vehicle’s roof at 0.229 s. The “T” section at the top of the support post lightly contacted the vehicle’s rear bumper at 0.234 s and rode with the vehicle until it lost contact at 0.312 s. As the vehicle lost contact with the support it was traveling at 95.82 km/h. Brakes on the vehicle were applied at 1.3 s after impact, and the vehicle subsequently came to rest 103.3 m down and in line with the impact point. Sequential photographs of the test period are shown in Appendix D, Figure 67.

Damage to Test Installation

Damage to the sign support structure was minimal as shown in Figures 31 and 32. The spacer ring functioned as designed and allowed the slip base to activate. All three slip bolts tore through the keeper plate, and the keeper plate, plastic spacer ring, and slip bolts were found in proximity to the base. No movement of the base foundation was observed. The plywood sign panel detached from the support came to rest over the lower slip base. The support post came to rest 32.0 m down and in line with the base. All parts were reusable except for the keeper plate.

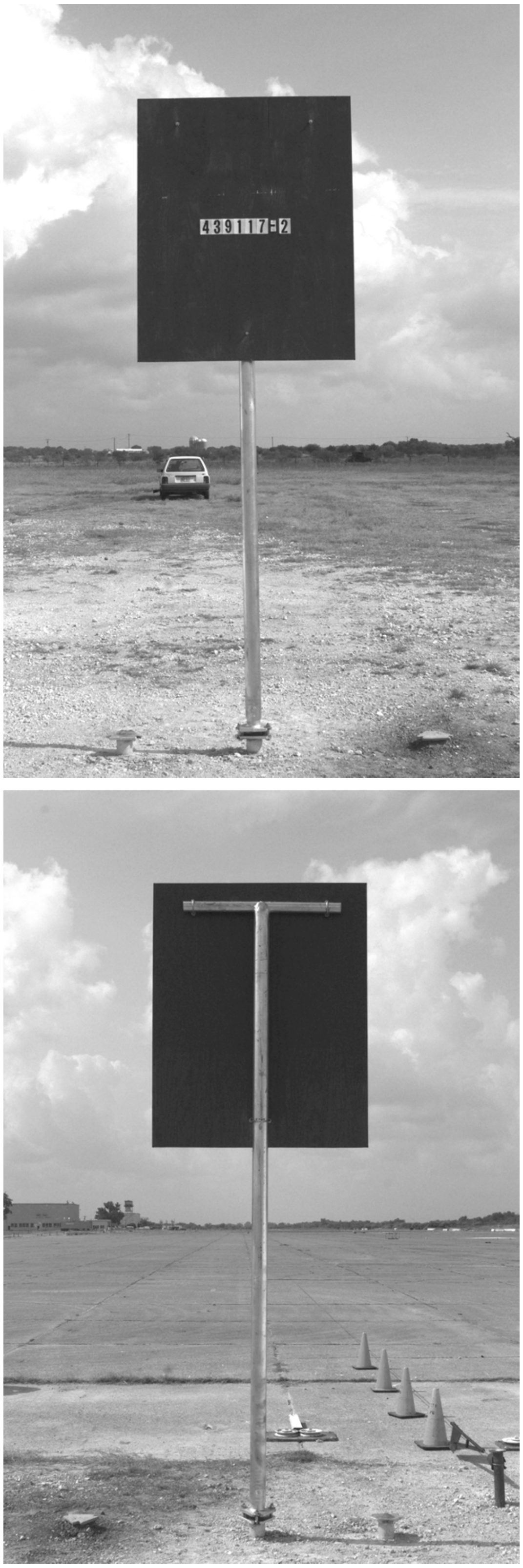


Figure 28. Sign Support Installation before Test 439117-2.

Figure 29. Vehicle/Installation Geometrics for Test 439117-2.

Figure 30. Vehicle before Test 439117-2.

Figure 31. After Impact Trajectory for Test 439117-2.

Figure 32. Installation after Test 439117-2.

Vehicle Damage

The vehicle received damage to both bumpers, the hood, and the grill, as shown in Figure 33. The hood was dented 215 mm to the right of its centerline, approximately 190 mm from the front of the vehicle. Maximum exterior crush to the vehicle at bumper height was 190 mm. There was no deformation or intrusion into the occupant compartment.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for computation of occupant risk evaluation measures. In the longitudinal direction, the occupant impact velocity was 1.03 m/s at 0.614 s, the highest 0.010-s occupant ridedown acceleration was 0.23 g's from 0.644 to 0.654 s, and the maximum 0.050-s average acceleration was -2.71 g's between 0.000 and 0.050. In the lateral direction, the occupant impact velocity was 1.08 m/s at 0.822 s, the highest 0.010-s occupant ridedown acceleration was 0.46 g's from 0.709 to 0.719 s, and the maximum 0.050-s average was -0.74 g's between 0.006 and 0.056. The change in vehicular velocity during impact was 1.08 m/s. These data and other pertinent information from the test are summarized in Figure 34. Vehicle angular displacements are displayed in Appendix E, Figure 74. Vehicular acceleration versus time traces are presented in Appendix F, Figures 87 through 89.

CONCLUSIONS

The plastic spacer ring provided the required separation between the upper and lower slip-base plates to accommodate an existing lifting cone in the center of the lower plate, and it did not impede the breakaway performance of the small sign support. The slip base activated as designed in both the low-speed and high-speed crash tests. The detached elements from the sign support did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment in either test. The vehicle remained upright and stable both during and after each collision. The occupant risk values were all 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. The vehicle came to rest directly behind the test article and did not intrude into adjacent traffic lanes. Based on these results, the use of a plastic spacer ring for retrofitting existing slip-base plates with a lifting device is considered to be in compliance with *NCHRP Report 350* and suitable for implementation when circumstances warrant during upgrade and repair operations.

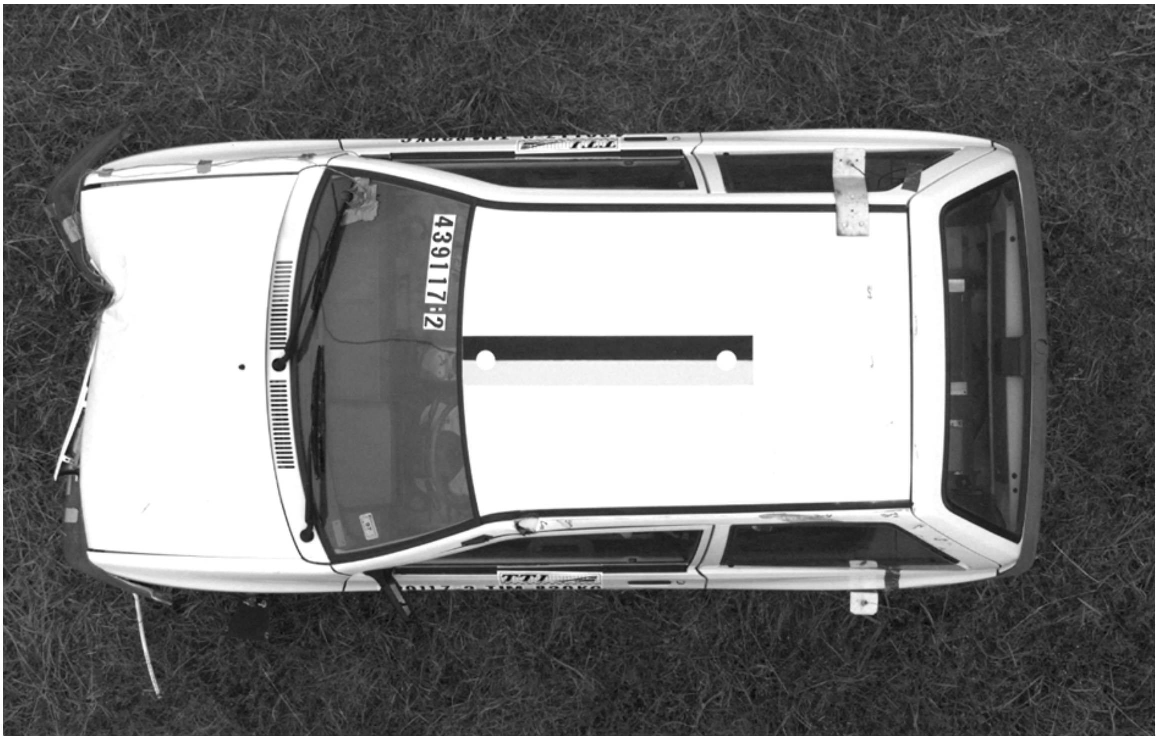
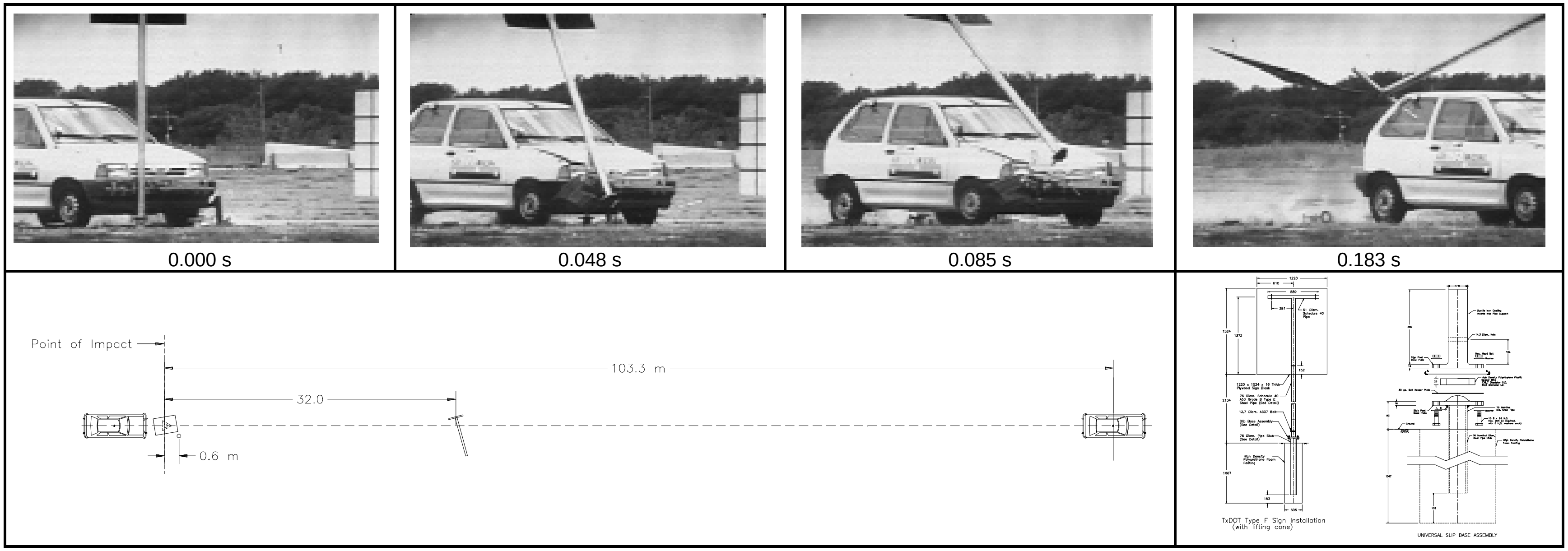


Figure 33. Vehicle after Test 439117-2.



General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-2
Date	08/07/97
Test Article	
Type	Sign Support
Name or Manufacturer	TxDOT Type F Sign Mount
Installation Height (m)	2.20
Size and/or dimension and material of key elements	Single Steel Post with plywood sign panel
Soil Type and Condition	Concrete footing, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1992 Ford Festiva
Mass (kg) Curb	815
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	99.72
Angle (deg)	0 - rt qtrpt
Exit Conditions	
Speed (km/h)	95.82
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.03
y-direction	1.08
Ridedown Accelerations (g's)	
x-direction	0.23
y-direction	0.46
Max. 0.050-s Average (g's)	
x-direction	-2.71
y-direction	-0.74
z-direction	-1.30
Veh. Change in Velocity (m/s)	1.08

Test Article Debris Pattern (m)	
Longitudinal	32.0
Lateral	1.5
Vehicle Damage	
Exterior	
VDS	12FR2
CDC	12FREN2
Maximum Exterior Vehicle Crush (mm)	190
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	-2.5
Max. Pitch Angle (deg)	10.6
Max. Yaw Angle (deg)	5.7

Figure 34. Summary of Results for Test 439117-2.

IV. EVALUATION OF MEDIAN ANCHOR FOR SMALL SIGN SUPPORTS

Typically, installation of sign supports with concrete footings require the maintenance crew or contractor to make two trips to the site, one to place the concrete foundation and one to install the support after the concrete has cured. In situations where the sign support is installed in a paved median or island, placement of the footing additionally requires breaking out the existing concrete pavement. Personnel in the Lubbock District developed a new anchor concept for installing thin-wall steel tubing and fiberglass sign support systems in paved locations such as medians. As conceived, a steel base assembly bolts directly to the concrete pavement or island, and the support pipe is then bolted or clamped to the base. By eliminating the construction of an independent concrete footing, the entire sign installation can be completed in the same trip. This procedure reduces installation cost by decreasing labor time and improves safety by minimizing the exposure of the sign crew to traffic.

Several bolt-down base concepts were developed and presented to TxDOT for review. TxDOT selected a concept developed by HwyCom, Inc. for further evaluation under this project. Design constraints for the anchor plate assembly included the embedment depth of the anchor bolts and the width of the base plate. The anchor bolt embedment depth was limited by the thickness of the sidewalk, rip rap, concrete median island, or pavement to which it is attached. After considering the typical depth of concrete for these different applications, the embedment depth was limited to 89–102 mm. Initially, TxDOT desired that the same bolt-down design also accommodate connection of small signs to the top of concrete median barrier. This effectively limited the width of the base plate to 165 mm.

During the design of the anchor plate assembly, consideration was given to both design wind loads and impact loads. For the wind load analysis, the design wind speed was assumed to be 96.5 km/h, which is based on a 10-year mean recurrence interval. Because the impact loads could not be precisely predetermined, they were estimated from previous crash tests of a ground-mounted sign support system with a similar release mechanism.(3) It was found that the impact loads controlled the design of the anchorage system.

During the course of the project, various base configurations were investigated in an attempt to achieve an anchor system that would accommodate design wind loads, be crashworthy in a vehicular collision, and have a high degree of reusability after an impact. A description of the test installations and details of the full-scale crash testing conducted on the bolt-down sign support base are presented in the following sections.

FULL-SCALE CRASH TESTING

Low-Speed Test (Test 439117-5, *NCHRP Report 350* Test No. 3-60)

Test Article

The sign support system used in the evaluation of the bolt-down base consisted of a 914 mm × 914 mm × 2 mm thick aluminum sign panel attached to a single 60 mm O.D. × 2.4 mm wall steel tube sign post using two mounting clamps. The sign post was attached to a steel base plate assembly which was anchored to an existing concrete surface. The height from grade to the base of the sign was 2134 mm.

The anchor plate assembly consisted of a base plate, pipe stub, plastic insert sleeve, and anchor cap. A 86 mm long piece of 76 mm schedule 40 pipe was welded to the center of a 165 mm × 165 mm × 16 mm thick steel plate. The steel pipe stub was fabricated with four 5 mm wide slots that extended almost the entire length of the pipe stub. These slots were located 90 degrees radially around the pipe stub. A polyethylene insert sleeve approximately 86 mm in length was inserted inside the slotted pipe stub. The steel sign post was then inserted through the cast iron anchor cap and inside the pipe sleeve and pipe stub. The polyethylene pipe sleeve was used to obtain a snug fit between the pipe stub and the support post. The sign post was secured to the anchor plate assembly by driving the cast iron anchor cap over the slotted pipe stub using a mallet. The inside diameter of the cast iron anchor cap was tapered over its length such that the diameter at the top of the cap was slightly narrower than the diameter at the bottom. Thus, as the anchor cap was driven onto the pipe stub, the tapered throat of the cap deformed the sides of the slotted pipe stub inward, thus tightly securing the sign post inside the anchor plate assembly.

The anchor plate assembly was anchored to an existing concrete apron using four 13 mm diameter × 146 mm long carbon steel hex-head Rawl-Bolt anchors (Rawl Cat. No. 6936). The concrete apron is approximately 200 mm thick and is not reinforced. A 13 mm diameter drill bit was used to core the holes in the concrete apron for the mechanical anchors. These holes were drilled slightly deeper than the 102 mm anchor embedment to ensure adequate penetration for the bolts. After the holes were drilled, the holes were cleaned with a round wire brush and compressed air to remove the dust and any loose material. After cleaning, the anchor bolts were driven through the holes in the base plate and into the anchor holes until the bolt heads were firmly seated against the base plate. The anchors were then tighten by turning the bolt heads approximately three to four turns or until adequate hand torque was obtained. Additional details of the test assembly are shown in Figure 35. Photographs of the completed test installation prior to the test are shown in Figure 36.

Test Description

A 1991 Ford Festiva, shown in Figures 37 and 38, was used for the crash test. Test inertia weight of the vehicle was 870 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 390 mm, and it was 590 mm to the upper edge of the bumper.

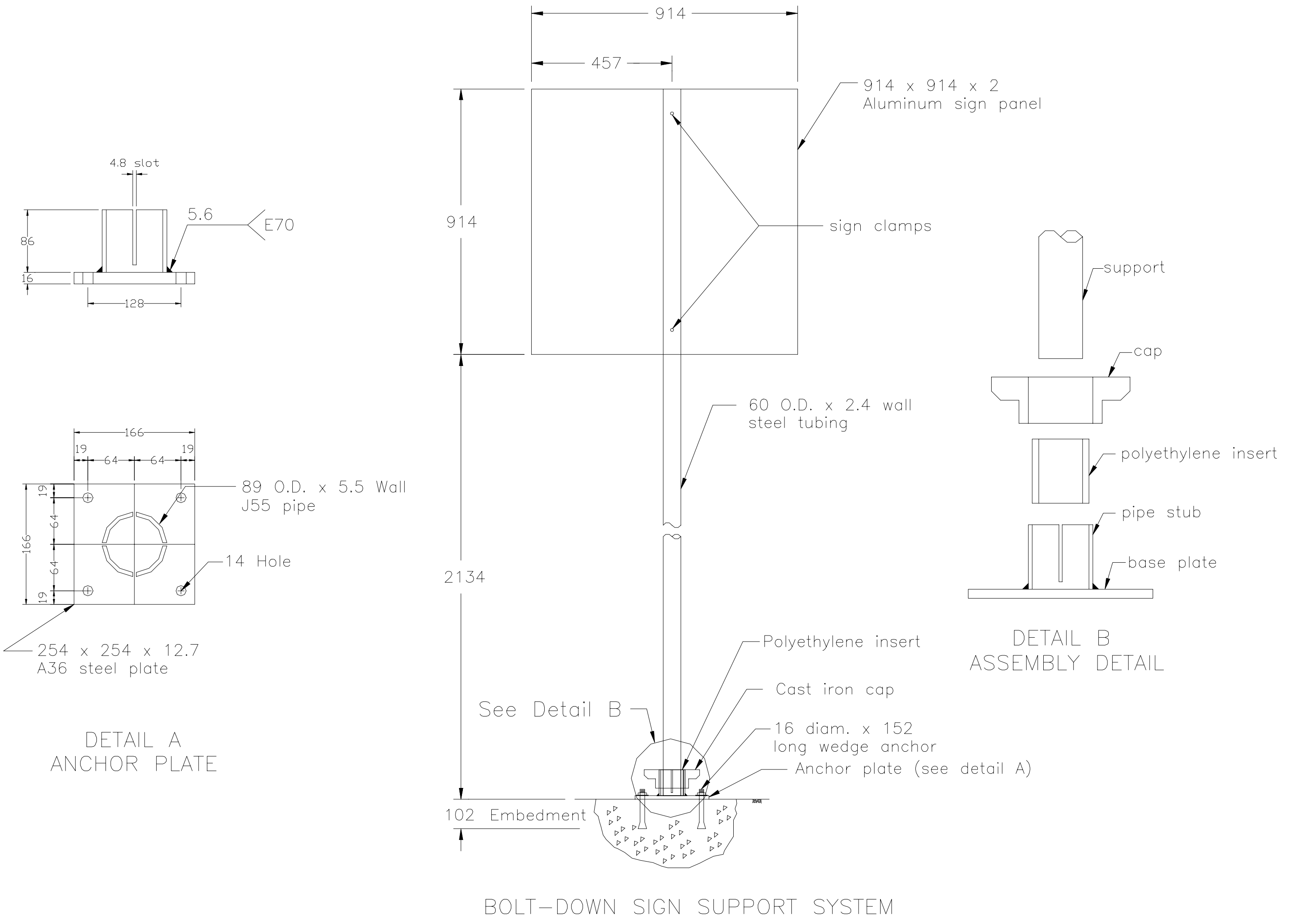


Figure 35. Details of the Installation Used for Evaluation of Support Bases Bolted to Concrete Pavement in Test 439117-5.

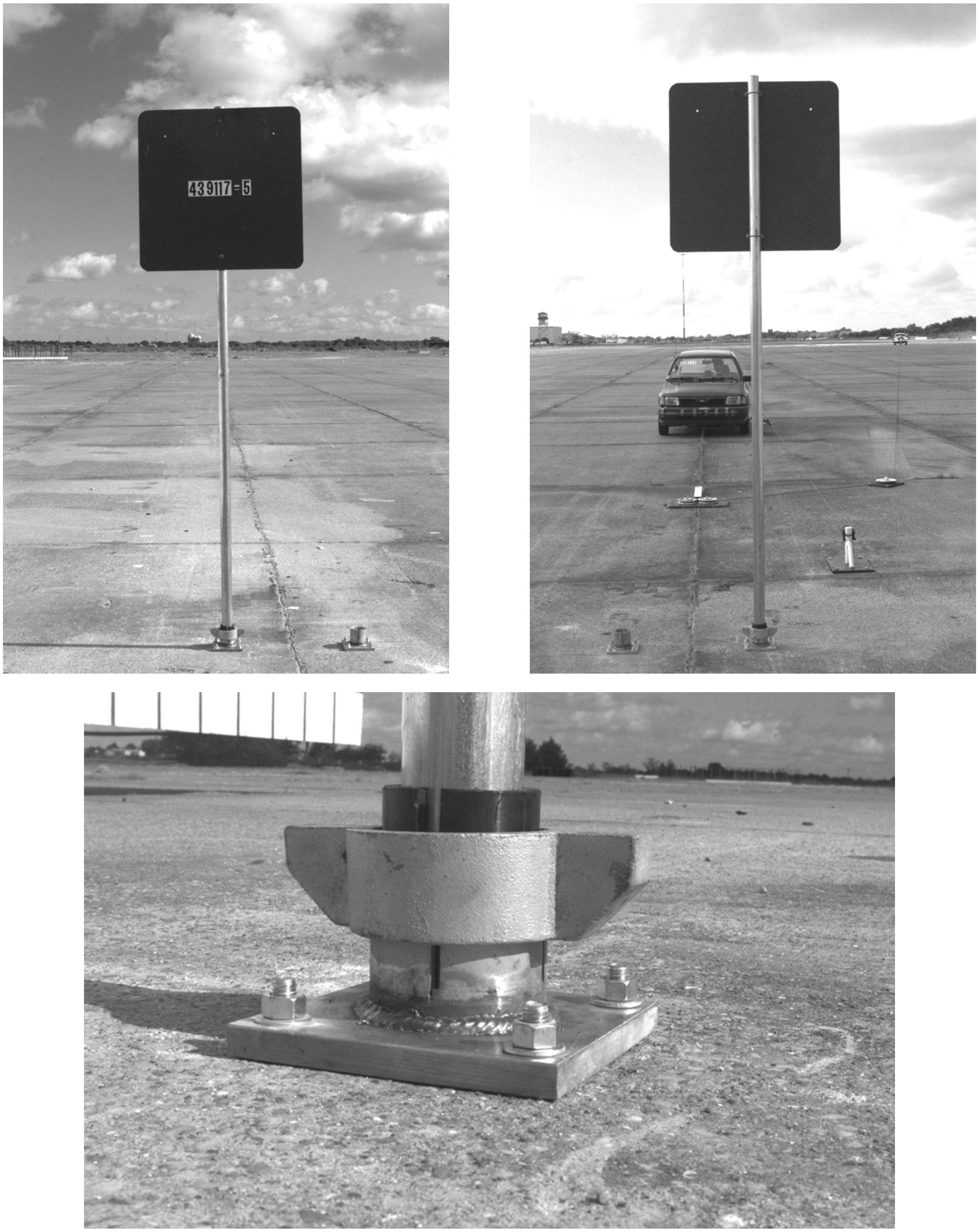


Figure 36. Sign Support Installation before Test 439117-5.

Figure 37. Vehicle/Installation Geometrics for Test 439117-5.

Figure 38. Vehicle before Test 439117-5.

Additional dimensions and information on the vehicle are given in Appendix C, Figure 63. 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, traveling at 35.92 km/h, impacted the sign support at 0 degrees with the quarter point of the vehicle aligned with the support. Shortly after impact, the post began to deform at the vehicle's bumper height. The anchor bolts on the impact side pulled out of the concrete. At 0.068 s, the post slipped out of the base. Temporarily free from the bumper, the support contacted the bumper again at 0.131 s and lost contact with it at 0.214 s. Vehicle speed at this point was 33.30 km/h. At 0.504 s the sign contacted the front of the roof and upper section of the vehicle's windshield. The sign bounced off the vehicle at 0.558 s. Vehicle speed at this time had slowed to 31.73 km/h. The rear anchors bent over, but the anchor cap and plastic spacer were still in place. An anchor bolt was found 6.1 m from the base. The sign support with attached panel came to rest 22.87 m from the point of impact. Brakes on the vehicle were applied at 2.0 s after impact, and the vehicle subsequently came to rest 31.4 m down from and in line with the point of impact. Sequential photographs of the test period are shown in Appendix D, Figure 68.

Damage to Test Installation

The anchor bolts on the impact side completely pulled out of the concrete as shown in Figures 39 and 40. The rear anchors were bent back and deformed. The plastic spacer insert and anchor cap remained attached to the base. The support post was bent 420 mm from the end. The sign support and attached panel came to rest 22.9 m from the point of impact.

Vehicle Damage

Damage to the vehicle was minor as shown in Figure 41. A small dent was noted in the roof on the driver's side. The vehicle was repaired and used for a subsequent test. There was no measurable crush to the exterior of the vehicle, and there was no deformation or intrusion into the occupant compartment.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the impact velocity was 0.43 m/s at 0.985 s, the highest 0.010-s occupant ridedown acceleration was 0.14 g's from 0.889 to 0.899 s, and the maximum 0.050-s average acceleration was -1.49 g's between 0.008 and 0.058 s. In the lateral direction, the occupant impact velocity was 0.61 m/s at 0.807 s, the highest 0.010-s occupant ridedown acceleration was -0.15 g's from 0.954 and 0.964 s, and the maximum 0.050-s average was -0.41 g's between 0.056 and 0.106 s. The change in vehicular velocity during impact was 1.16 m/s. These data and other pertinent information from the test are summarized in Figure 42. Vehicle angular displacements are displayed in Appendix E, Figure 75. Vehicular accelerations versus time traces are presented in Appendix F, Figures 90 through 92.

Figure 39. After Impact Trajectory for Test 439117-5.

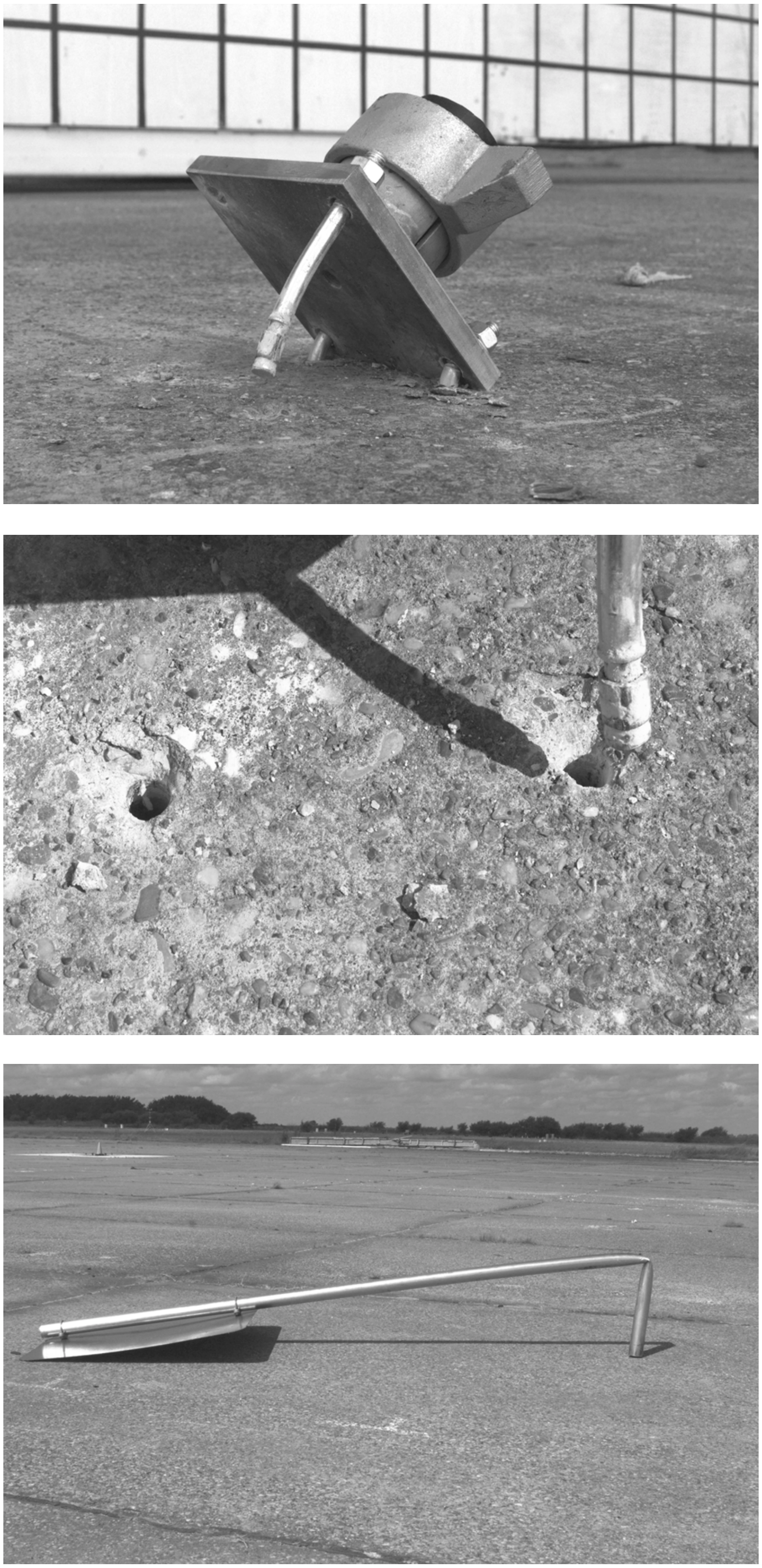
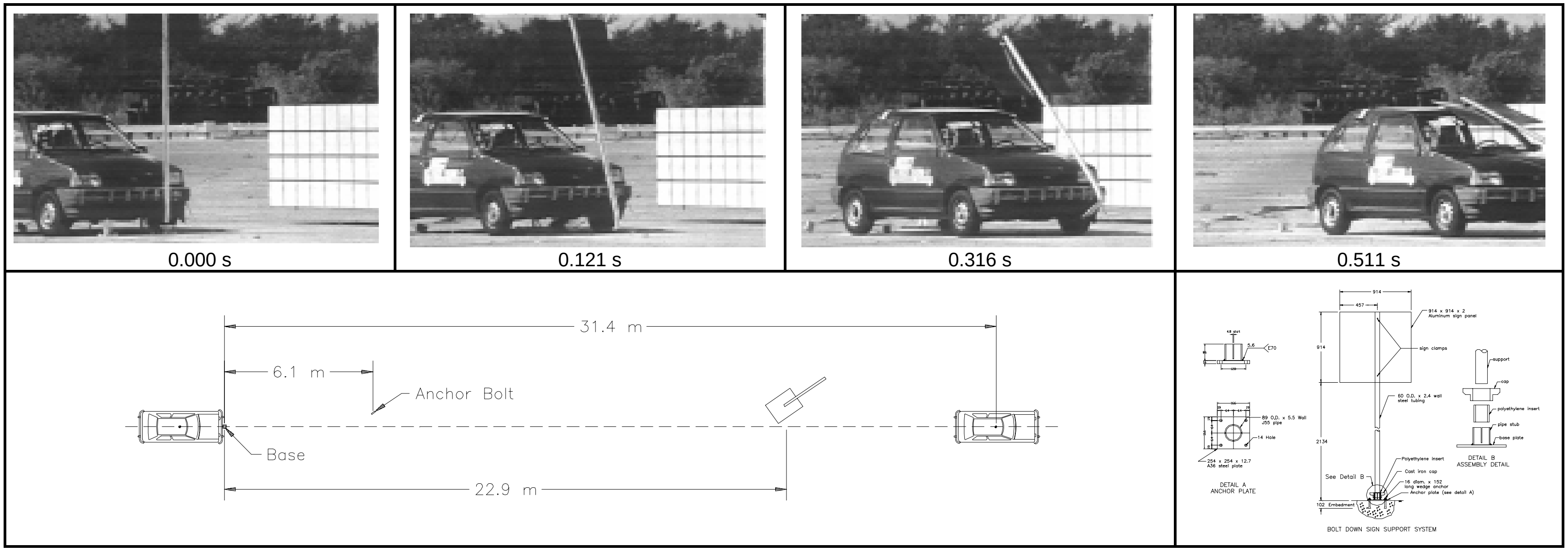


Figure 40. Installation after Test 439117-5.

Figure 41. Vehicle after Test 439117-5.



General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-5
Date	08/15/97
Test Article	
Type	Sign Support
Name or Manufacturer	HwyCom, Inc. Slip Base Sign Support
Installation Height (m)	2.14
Size and/or dimension and material of key elements	Single Steel Post with aluminum sign panel
Soil Type and Condition	Concrete pavement, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	35.92
Angle (deg)	0
Exit Conditions	
Speed (km/h)	31.73
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.43
y-direction	0.61
Ridedown Accelerations (g's)	
x-direction	0.14
y-direction	-0.15
Max. 0.050-s Average (g's)	
x-direction	-1.49
y-direction	-0.41
z-direction	-0.44
Veh. Change in Velocity (m/s)	1.16

Test Article Deris Pattern (m)	
Longitudinal	22.9
Lateral	1.8
Vehicle Damage	
Exterior	
VDS	12FL1
CDC	12FLEN1
Maximum Exterior Vehicle Crush (mm)	nil
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	1.1
Max. Pitch Angle (deg)	-1.6
Max. Yaw Angle (deg)	-1.3

Figure 42. Summary of Results for Test 439117-5.

Low-Speed Test (Test 439117-6, *NCHRP Report 350* Test No. 3-60)

Test Article

The impact loads observed in the first test of the bolt-down base (Test 439117-5) were higher than expected, resulting in pullout of the anchor bolts. For the second test of the bolt-down base the size of the baseplate and anchor bolts were increased to provide greater moment capacity. Since the forces in the previous test were limited by the capacity of the anchor plate assembly, the actual design forces were unknown and had to be estimated. The baseplate used in this test measured 254 mm × 254 mm × 13 mm thick. The modified anchor plate assembly was anchored to the concrete apron using four 16 mm diameter × 152 mm long carbon steel hex-head Rawl-Bolt anchors (Rawl Cat. No. 6945). All other details and installation procedures were similar to those used in the previous test (Test 439117-5). Additional details of the test assembly are shown in Figure 43. Photographs of the completed test installation prior to the test are shown in Figure 44.

Test Description

A 1991 Ford Festiva, shown in Figures 45 and 46, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 390 mm, and it was 590 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix C, Figure 63. 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, traveling at 34.69 km/h, impacted the sign support at 0 degrees with the right quarter point of the vehicle aligned with the support. Shortly after impact the post began to move. At 0.014 s the base plate started to pull up. By 0.036 s the support began to deform at bumper height, and by 0.061 s the support had pulled out of the base. The support rotated around the front end of the vehicle and lightly contacted the vehicle’s hood. At 0.565 s, the sign panel contacted the upper windshield and roof of the vehicle. The speed of the vehicle at this point in time was 27.12 km/h. Vehicle brakes were applied 4.55 s after impact, and the vehicle came to rest 35.07 m down from and 2.75 m to the right of the impact point. The sign and attached panel came to rest 1.22 m in front of the vehicle. Sequential photographs of the test period are shown in Appendix D, Figure 69.

Damage to Test Installation

The anchor bolts on the impact side pulled up 17 mm from the concrete pavement as shown in Figures 47 and 48. The welds on the impact (tension) side of the circular sleeve fractured but remained attached on the non-impact side. The plastic spacer insert and anchor cap remained attached to the base. The support post was bent 460 mm from the lower end. The sign support and attached panel came to rest 35.1 m downstream from the point of impact.

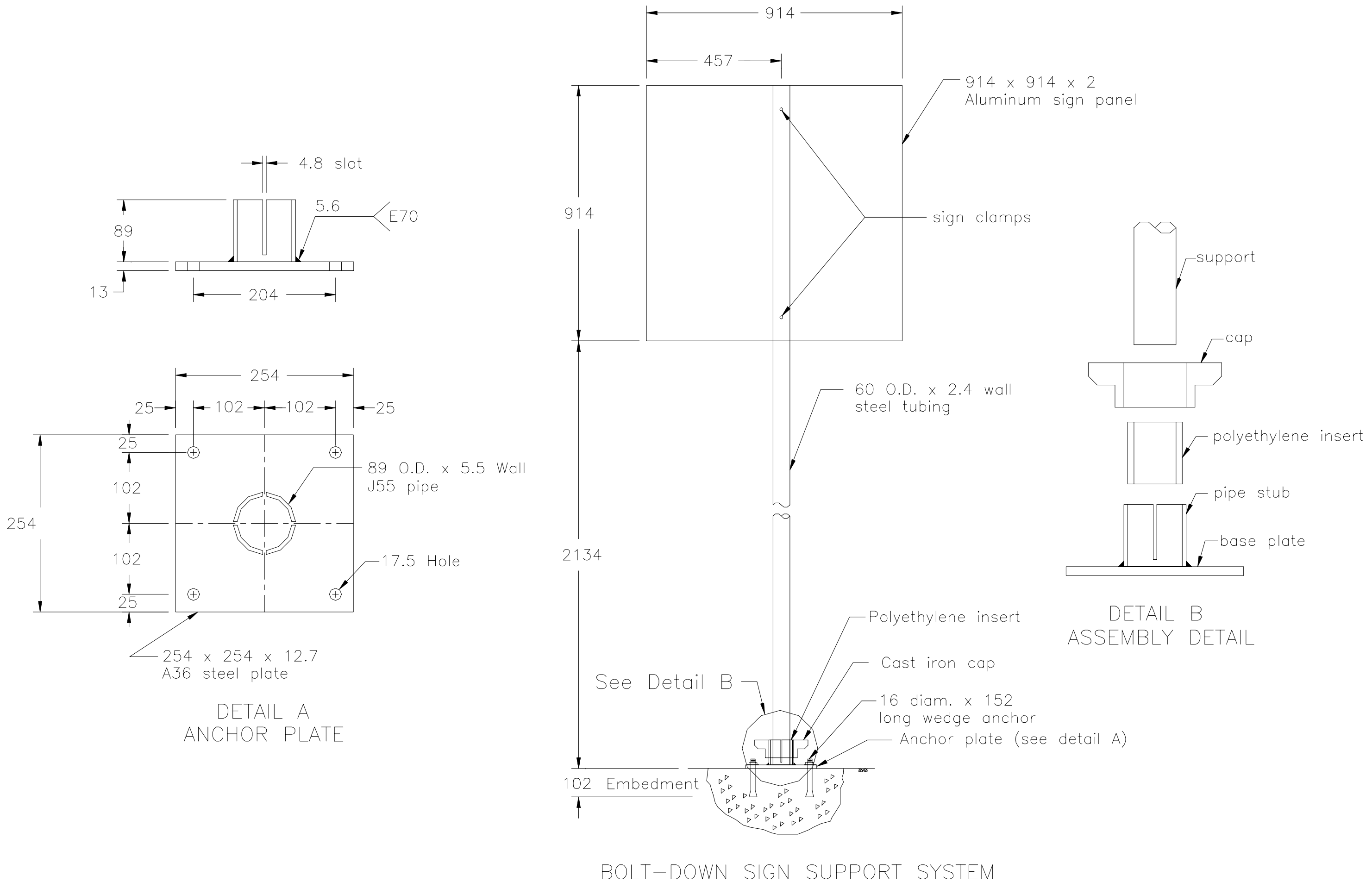


Figure 43. Details of the Installation Used for Evaluation of Support Bases Bolted to Concrete Pavement in Test 439117-6.

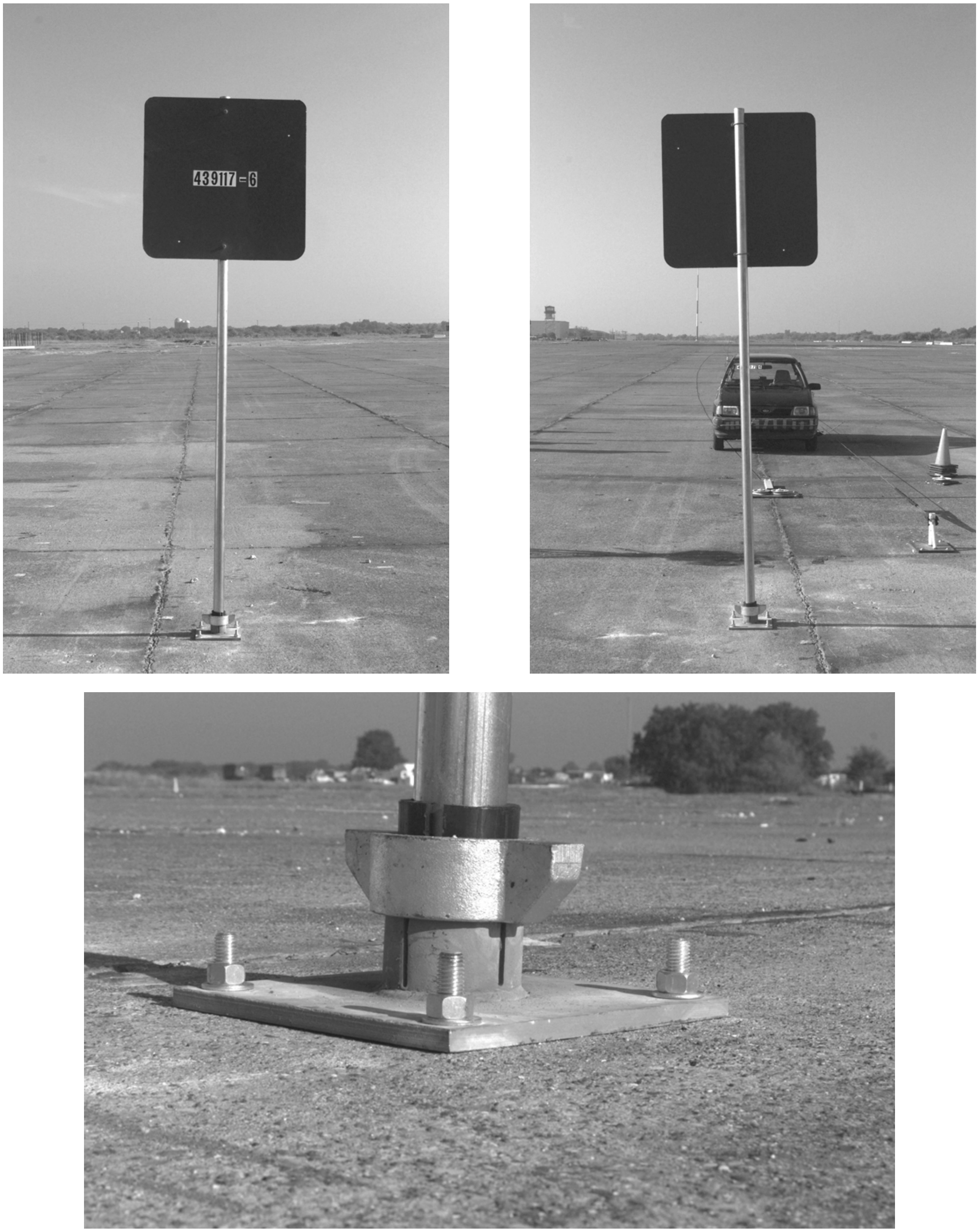


Figure 44. Sign Support Installation before Test 439117-6.

Figure 45. Vehicle/Installation Geometrics for Test 439117-6.

Figure 46. Vehicle before Test 439117-6.

Figure 47. After Impact Trajectory for Test 439117-6.

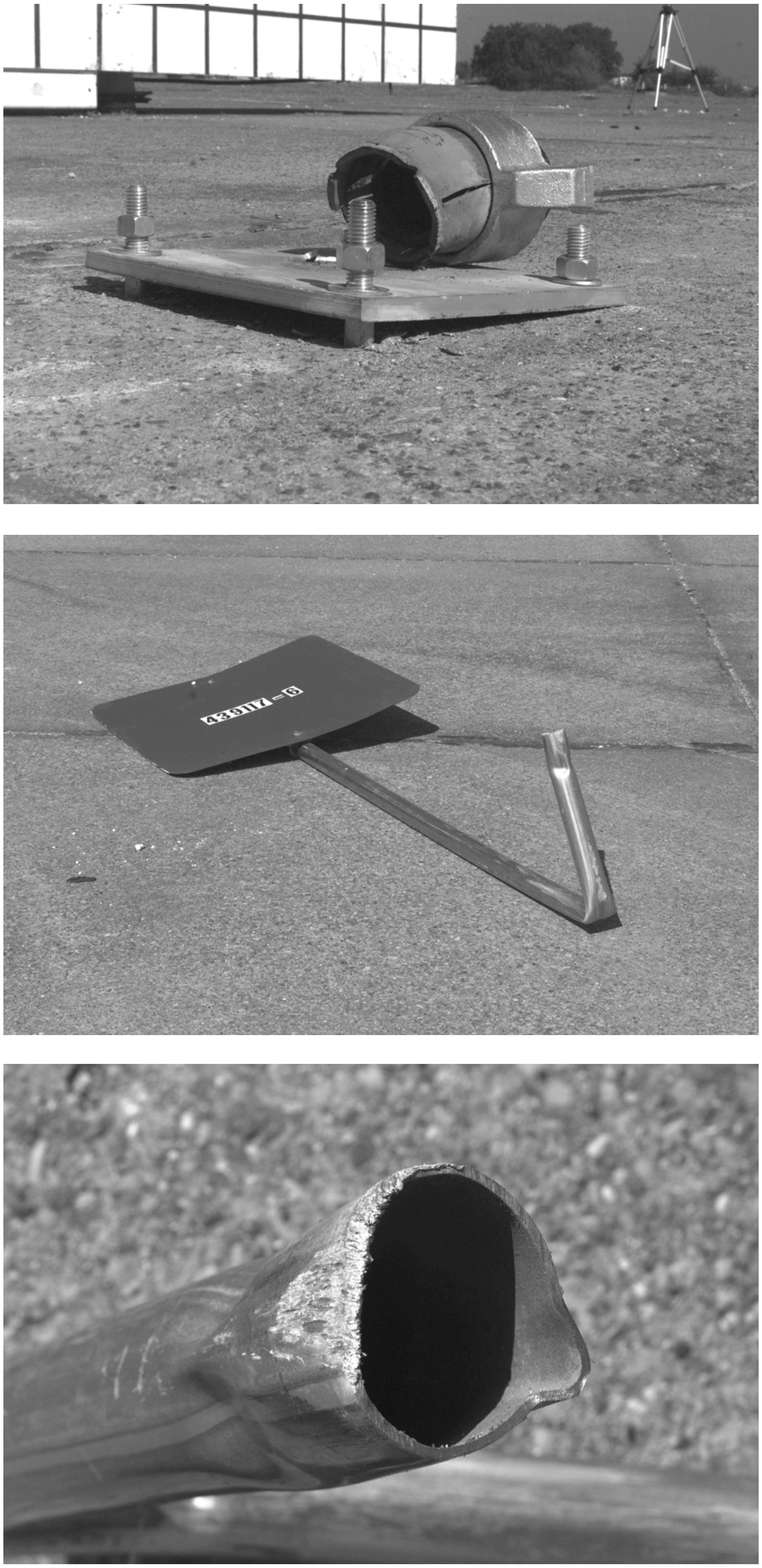


Figure 48. Installation after Test 439117-6.

Vehicle Damage

Damage to the vehicle was minor as shown in Figure 49. A small dent was noted in the hood on the passenger's side. The vehicle was repaired and used for a subsequent test. There was no measurable crush to the exterior of the vehicle, and there was no deformation or intrusion into the occupant compartment.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the impact velocity was 1.31 m/s at 0.495 s, the highest 0.010-s occupant ridedown acceleration was 0.43 g's from 0.596 to 0.606 s, and the maximum 0.050-s average acceleration was -2.55 g's between 0.008 and 0.058 s. There was no contact in the lateral direction, and the maximum 0.050-s average was -0.29 g's between 0.043 and 0.093 s. The change in vehicular velocity during impact was 2.10 m/s. These data and other pertinent information from the test are summarized in Figure 50. Vehicle angular displacements are displayed in Appendix E, Figure 76. Vehicular accelerations versus time traces are presented in Appendix F, Figures 93 through 95.

Low-Speed Test (Test 439117-7, *NCHRP Report* 350 Test No. 3-60)

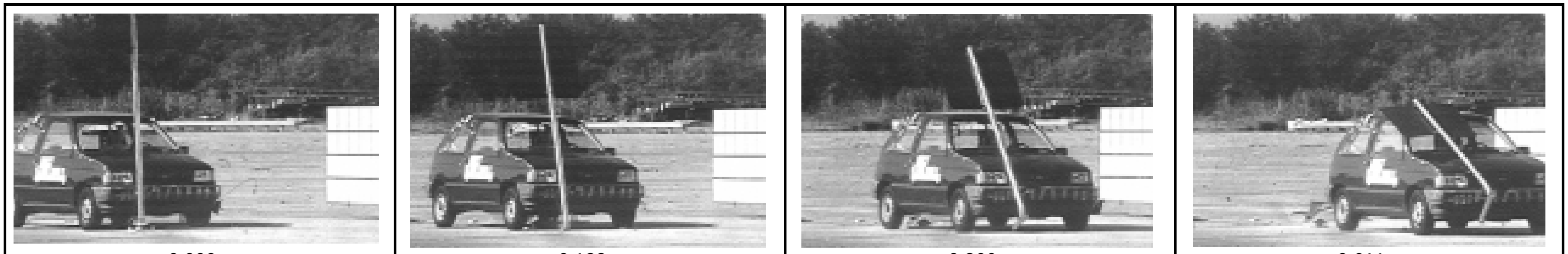
Test Article

To eliminate the failure mode observed in the previous test (test 439117-6), the connection between the pipe stub and baseplate was strengthened by inserting the pipe stub through the baseplate and fillet welding the pipe stub to the baseplate on both the top and bottom sides of the plate. To reduce base moment induced by the impact loads that must be resisted by the anchor bolts, the outside diameter of the plastic insert sleeve was reduced to reduce the sign post pullout forces. All other details and installation procedures for this test were the same as those used in the previous test (test 439117-6). Additional details of the test assembly are shown in Figure 51. Photographs of the completed test installation prior to the test are shown in Figure 52.

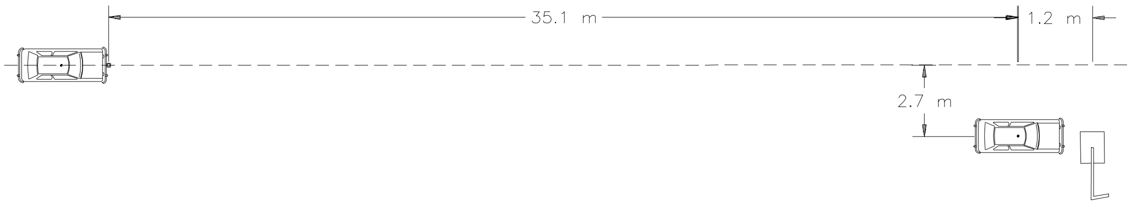
Test Description

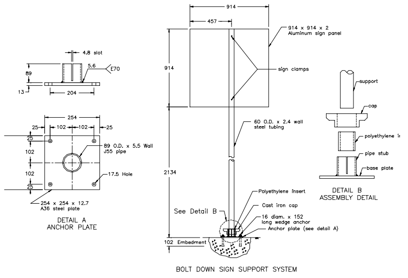
The 1991 Ford Festiva used in the previous test, shown in Figures 53 and 54, was reused for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 390 mm, and it was 590 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix C, Figure 63. 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 49. Vehicle after Test 439117-6.



0.000 s 0.122 s 0.366 s 0.611 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-6
Date	08/27/97
Test Article	
Type	Sign Support
Name or Manufacturer	HwyCom, Inc. Slip Base Sign Support
Installation Height (m)	2.14
Size and/or dimension and material of key elements	Single Steel Post with aluminum sign panel
Soil Type and Condition	Concrete pavement, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	34.69
Angle (deg)	0
Exit Conditions	
Speed (km/h)	27.12
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.31
y-direction	No contact
Ridedown Accelerations (g's)	
x-direction	0.43
y-direction	No contact
Max. 0.050-s Average (g's)	
x-direction	-2.55
y-direction	-0.29
z-direction	-0.69
Veh. Change in Velocity (m/s)	2.10

Test Article Debris Pattern (m)	
Longitudinal	36.3
Lateral	2.7
Vehicle Damage	
Exterior	
VDS	12FR1
CDC	12FREN1
Maximum Exterior Vehicle Crush (mm)	nil
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	-1.7
Max. Pitch Angle (deg)	-1.2
Max. Yaw Angle (deg)	3.7

Figure 50. Summary of Results for Test 439117-6.

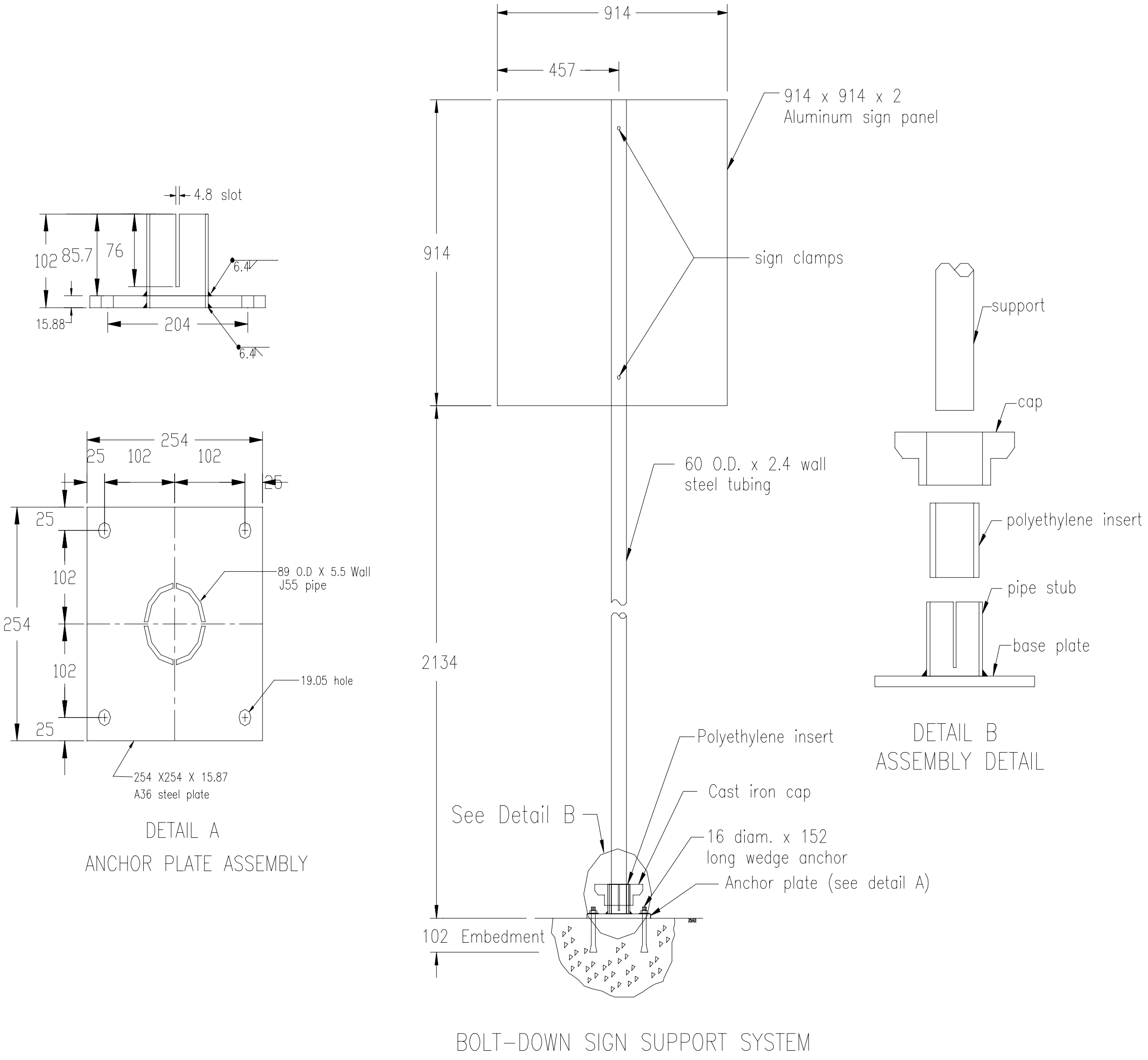


Figure 51. Details of the Installation Used for Evaluation of Support Bases Bolted to Concrete Pavement in Test 439117-7.

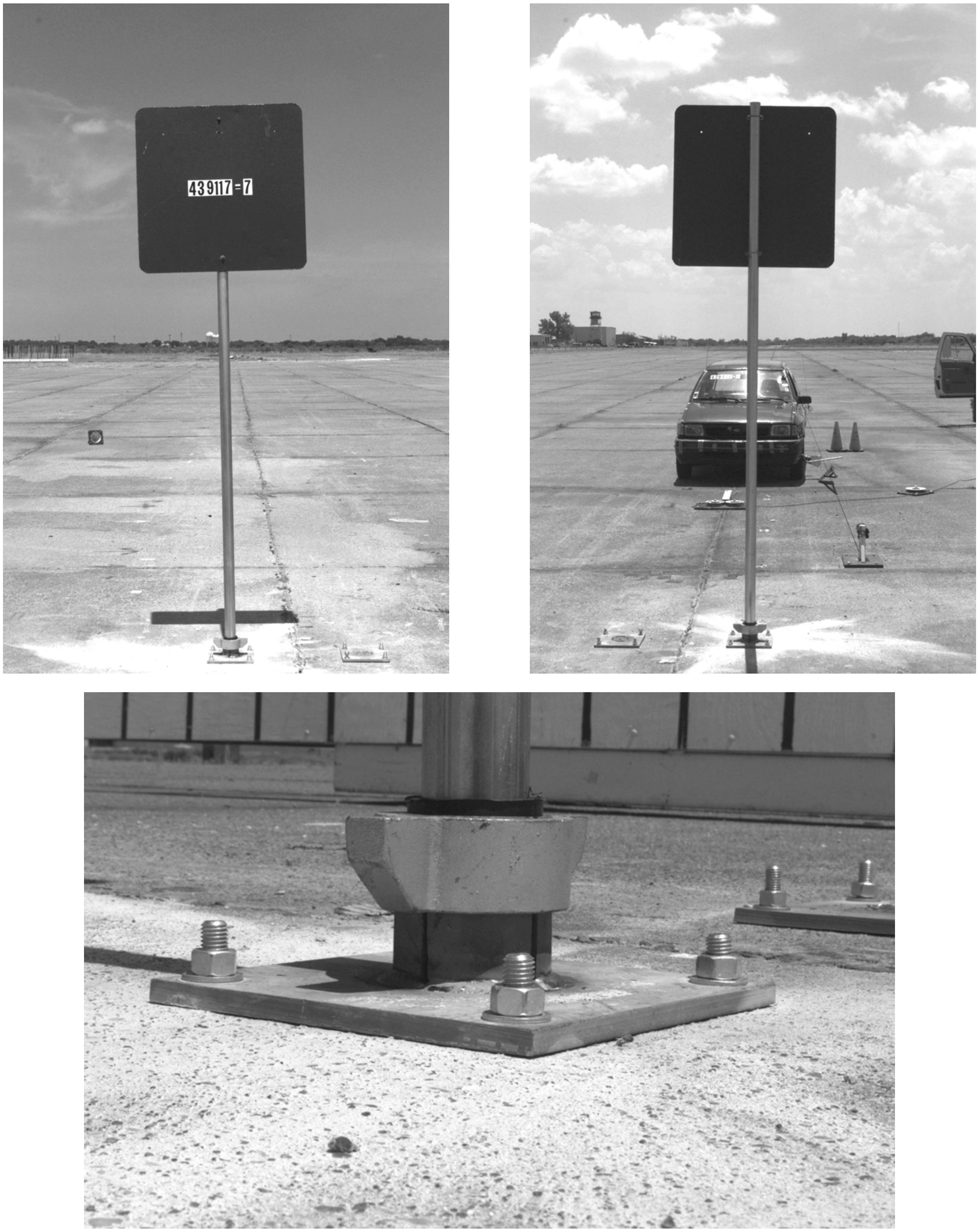


Figure 52. Sign Support Installation before Test 439117-7.

Figure 53. Vehicle/Installation Geometrics for Test 439117-7.

Figure 54. Vehicle before Test 439117-7.

The vehicle, traveling at 34.96 km/h, impacted the slip-base sign support at 0 degrees with the right quarter point of the vehicle aligned with the sign support. Shortly after impact the post began to move. At 0.009 s the base plate started to pull up. By 0.022 s, the support had deformed around the front end of the vehicle. At 0.051 s, the top of the sign blank separated from the post. At 0.064 s, a second bend began to form in the support near bumper height as the post was pulled out of the base. The lower section of the deformed support caught the undercarriage of the vehicle, and the sign rode along with the vehicle. Brakes were applied approximately 2.5 s after impact, bringing the vehicle to a stop 25.93 m down from and in line with the point of impact. The sign support came to rest beneath the vehicle. Sequential photographs of the test period are shown in Appendix D, Figure 70.

Damage to Test Installation

The anchor bolts on the impact side pulled up 8 mm from the concrete pavement as shown in Figures 55 and 56. The top section was leaning back approximately 5 mm. The plastic insert sleeve and anchor cap remained attached to the base. The support post was bent 460 mm from the end. The sign support and attached panel came to rest beneath the vehicle 25.9 m down from the point of impact.

Vehicle Damage

Damage to the vehicle was minor as shown in Figure 57. A small dent was noted in the bumper on the driver's side. There was no measurable crush to the exterior of the vehicle, and there was no deformation or intrusion into the occupant compartment.

Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the impact velocity was 1.26 m/s at 0.492 s, the highest 0.010-s occupant ridedown acceleration was -0.34 g's from 0.934 to 0.944 s, and the maximum 0.050-s average acceleration was -2.51 g's between and 0.005 and 0.055 s. In the lateral direction, the occupant impact velocity was 0.86 m/s at 0.617 s, the highest 0.010-s occupant ridedown acceleration was -0.29 g's from 0.791 to 0.801 s, and the maximum 0.050-s average was -0.61 g's between 0.091 and 0.141 s. The change in vehicular velocity during impact was 1.33 m/s. These data and other pertinent information from the test are summarized in Figure 58. Vehicle angular displacements are displayed in Appendix E, Figure 77. Vehicular accelerations versus time traces are presented in Appendix F, Figures 96 through 98.

Figure 55. After Impact Trajectory for Test 439117-7.

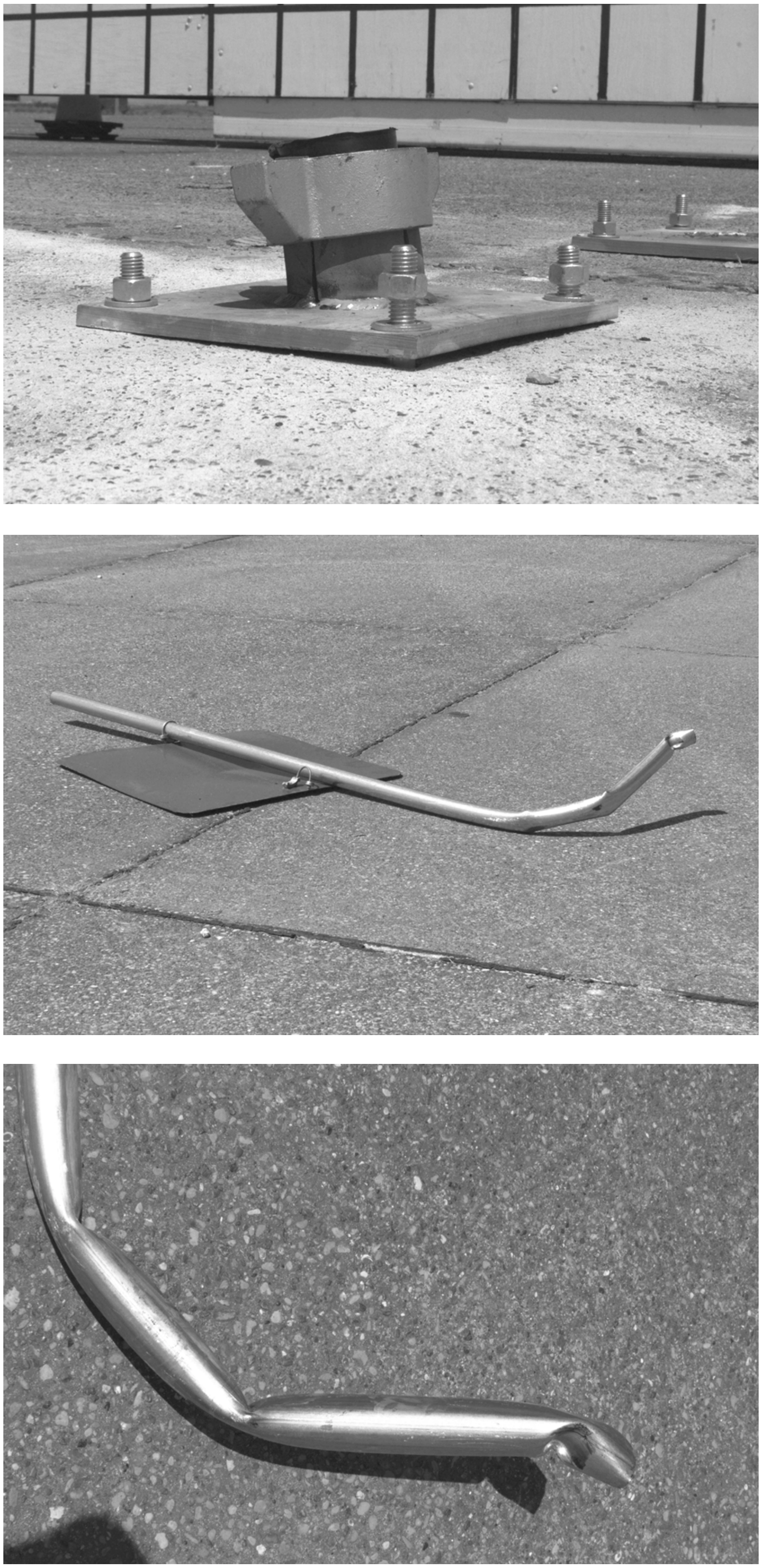
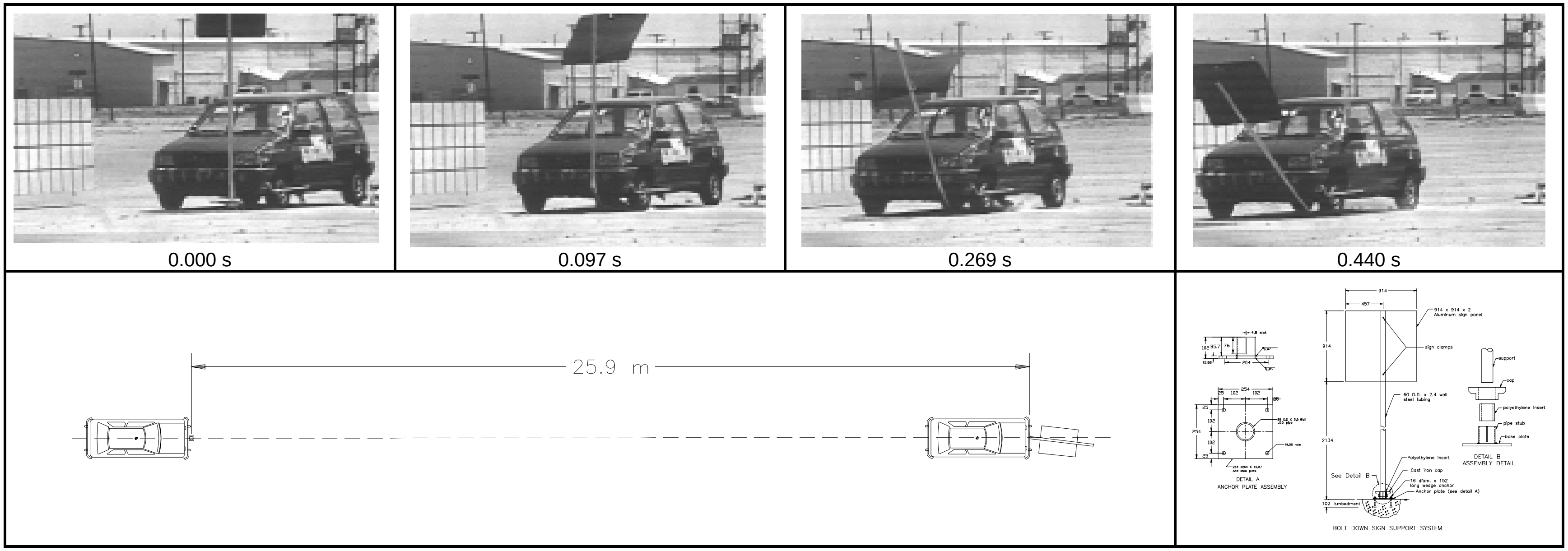


Figure 56. Installation after Test 439117-7.

Figure 57. Vehicle after Test 439117-7.



0.000 s

0.097 s

0.269 s

0.440 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	439117-7
Date	08/27/97
Test Article	
Type	Sign Support
Name or Manufacturer	HwyCom, Inc. Slip Base Sign Support
Installation Height (m)	2.13
Size and/or dimension and material of key elements	Single Steel Post with aluminum sign panel
Soil Type and Condition	Concrete pavement, Dry
Test Vehicle	
Type	Production
Designation	820C
Model	1991 Ford Festiva
Mass (kg) Curb	810
Test Inertial	820
Dummy	76
Gross Static	896

Impact Conditions	
Speed (km/h)	34.96
Angle (deg)	0
Exit Conditions	
Speed (km/h)	30.16
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.26
y-direction	0.86
Ridedown Accelerations (g's)	
x-direction	-0.34
y-direction	-0.29
Max. 0.050-s Average (g's)	
x-direction	-2.51
y-direction	-0.61
z-direction	-0.50
Veh. Change in Velocity (m/s)	1.33

Test Article Debris Pattern (m)	
Longitudinal	25.9
Lateral	0
Vehicle Damage	
Exterior	
VDS	12LR1
CDC	12FLEN1
Maximum Exterior Vehicle Crush (mm)	nil
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Roll Angle (deg)	1.6
Max. Pitch Angle (deg)	0.6
Max. Yaw Angle (deg)	-2.2

Figure 58. Summary of Results for Test 439117-7.

CONCLUSIONS

During the first low-speed test, the sign post pulled out of the anchor plate assembly as designed, and the bolt-down system met all *NCHRP Report 350* evaluation criteria. There was no deformation or intrusion into the occupant compartment, the vehicle remained upright and stable, occupant risk values were within the preferred limits, and the change in vehicular velocity was below the preferred value contained in the 1994 AASHTO specifications. However, the impact loads were higher than expected resulting in pullout of the anchor bolts securing the anchor plate assembly to the concrete pavement.

The bolt-down base was redesigned in an effort to reduce the required maintenance after an impact. Since the forces in the previous test were limited by the capacity of the anchor plate assembly, the actual design forces were unknown and had to be estimated. The modified design incorporated a larger baseplate and larger anchor bolts to provide greater moment capacity. During the second low-speed test, the sign post pulled out of the anchor plate assembly as intended, and the modified bolt-down base met all *NCHRP Report 350* evaluation criteria. There was no deformation or intrusion into the occupant compartment, the vehicle remained upright and stable, occupant risk values were within the preferred limits, and the change in vehicular velocity was below the preferred value contained in the 1994 AASHTO specifications. However, although the degree of damage to the anchor plate assembly was reduced from the previous test, the impact still resulted in partial pullout of some of the anchor bolts and damage to the anchor plate assembly.

For the third low-speed test, additional modifications were made to the bolt-down base to further reduce the required maintenance after an impact. The outside diameter of the plastic insert sleeve was decreased to reduce the sign post pullout forces, and the connection between the pipe stub and baseplate was strengthened. During the test, the sign post once again pulled out of the anchor plate assembly as intended, and the modified bolt-down base met all *NCHRP Report 350* evaluation criteria. There was no deformation or intrusion into the occupant compartment, the vehicle remained upright and stable, occupant risk values were within the preferred limits, and the change in vehicular velocity was below the preferred value contained in the 1994 AASHTO specifications. Although the degree of damage to the anchor plate assembly was further reduced from the previous test, the anchor plate assembly still experienced some damage.

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 one-year project several issues related to the performance of small sign supports were investigated. These issues include: the effect of keeper plate thickness on the impact performance of slip-base sign supports, an evaluation of methods for retrofitting slip-base stubs which incorporate a lifting ramp or cone, and investigation of a bolt-down anchor design for direct attachment of small signs to concrete pavement or median islands.

EVALUATION OF KEEPER PLATE THICKNESS

The use of a thicker keeper plate is desired to reduce the occurrence of bolt tear out during installation and the incidence of sign installations blowing down while in service. However, because tear out of the keeper plate is necessary to permit the slip-base mechanism to function properly, any change in keeper plate thickness must be properly evaluated to ensure that impact performance is not adversely affected.

Dynamic pendulum testing was conducted on slip-base sign supports incorporating keeper plates of varying thickness ranging from 24 gauge to the standard 30 gauge. As expected, the force required to activate the slip base increased as the keeper plate thickness increased. After reviewing the results, a sign support installation incorporating a 26-gauge keeper plate was subjected to full-scale crash testing. The 26-gauge keeper plate did not impede the breakaway performance of the small sign support, and the slip base activated as designed in both the low-speed and high-speed tests. The occupant risk values were all 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. A summary of the results for the low-speed and high-speed crash tests on the 26-gauge keeper plate is presented in Table 3 and Table 4, respectively. Based on these results, the use of a 26-gauge keeper plate in conjunction with a triangular slip-base small sign support system complies with *NCHRP Report 350* evaluation criteria and is considered suitable for implementation.

LIFTING-CONE RETROFIT

For many years, the TxDOT slip-base design has incorporated a lifting device on the lower base plate. The purpose of the lifting ramp is 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. Under TxDOT research project 7-1971, it was determined that the lifting cone was unnecessary and, in some instances, detrimental to overall impact performance. The lifting cone was therefore removed from the current slip base design.

Table 3. Performance Evaluation Summary for Test 439117-3, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute	Test No.: 439117-3	Test Date: 08/11/97

<table>
<tr><th><i>NCHRP Report 350</i> 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 slip-base mechanism activated as designed and permitted the support to release from the base.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was minimal deformation (10 mm) into the occupant compartment at the rear passenger roof area, but was not considered to be a probable cause of serious injury to the occupants.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</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 impact velocity = 1.51 m/s
Lateral impact velocity = 0.92 m/s</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration = -0.99 g's
Lateral ridedown acceleration = 0.89 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 did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 45.8 m behind the test article.</td><td>Pass</td></tr>
</table>

Table 4. Performance Evaluation Summary for Test 439117-4, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute | Test No.: 439117-4 | Test Date: 08/11/97

<table>
<tr><th><i>NCHRP Report 350</i> 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 slip-base mechanism activated as designed and permitted the support to release from the base.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was minimal deformation (50 mm) into the occupant compartment at the rear passenger roof area, but was not considered to be a probable cause of serious injury to the occupants.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</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 impact velocity = 0.96 m/s
Lateral impact velocity = 1.03 m/s</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration = -2.18 g’s
Lateral ridedown acceleration = 0.71 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 did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 122.6 m behind the test article.</td><td>Pass</td></tr>
</table>

This change in design created a need to develop retrofit alternatives that would enable existing slip-base foundations with lifting cones to be utilized when repair or upgrading of the sign support is needed. The basic concept investigated was to provide sufficient space between the upper and lower plates of the slip base such that the current slip-base system can be installed on an existing foundation without interference from the lifting cone. The impact performance of several options, including a series of stacked washers and various types of spacer rings, were investigated through dynamic pendulum tests of slip-base sign support systems. While each option performed acceptably, 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.

The plastic spacer ring provided the required separation between the slip plates to accommodate an existing lifting cone, and it did not impede the breakaway performance of the small sign support in either the low-speed or high-speed crash tests. The occupant risk values were all 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. A summary of the results for the low-speed and high-speed crash tests on the plastic spacer ring is presented in Table 5 and Table 6, respectively. Based on these results, the use of a plastic spacer ring for retrofitting existing slip-base plates that incorporate a lifting device is considered to be in compliance with *NCHRP Report 350* and suitable for implementation when circumstances warrant during upgrade and repair operations.

BOLT-DOWN ANCHOR

Typical sign support installations with concrete footings require the sign crew to make two trips to the site, one to place the concrete foundation and one to install the support after the foundation has cured. In situations where the sign support is installed in a paved median or island, placement of the footing additionally requires breaking out the existing concrete pavement. Various configurations of a bolt-down base for small sign supports were tested in an attempt to achieve an anchor system that would accommodate design wind loads, be crashworthy in a vehicular collision, and have a high degree of reusability after an impact.

A summary of the results for the three low-speed crash tests performed on the bolt-down sign support anchorage is presented in Table 7 through Table 9. As shown in these tables, the bolt-down base met all *NCHRP Report 350* evaluation criteria. There was no deformation or intrusion into the occupant compartment, the vehicle remained upright and stable, occupant risk values were within the preferred limits, and the change in vehicular velocity was below the preferred value contained in the 1994 AASHTO specifications. However, the anchor plate assembly experienced some damage and was not completely reusable after impact. Although the system was acceptable from a crashworthiness standpoint, it is recommended that the base be further strengthened to increase reusability and decrease maintenance after an impact.

Table 5. Performance Evaluation Summary for Test 439117-1, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute | Test No.: 439117-1 | Test Date: 08/07/97

<table>
<tr><th colspan="4">NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="6">Structural Adequacy</td></tr>
<tr><td>B.</td><td colspan="3">The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The slip-base mechanism activated as designed and permitted the support to release from the base.</td><td>Pass</td></tr>
<tr><td colspan="6">Occupant Risk</td></tr>
<tr><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</td><td>Pass</td></tr>
<tr><td>H.</td><td colspan="3">Occupant impact velocities should satisfy the following:</td><td rowspan="4">There was no contact in the longitudinal or lateral direction.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal</td><td>3</td><td>5</td></tr>
<tr><td>I.</td><td colspan="3">Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">There was no contact in the longitudinal or lateral direction.</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Ridedown Acceleration Limits (g’s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="6">Vehicle Trajectory</td></tr>
<tr><td>K.</td><td colspan="3">After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N.</td><td colspan="3">Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 33.5 m behind the test article.</td><td>Pass</td></tr>
</table>

Table 6. Performance Evaluation Summary for Test 439117-2, *NCHRP Report 350* Test 3-61.

Test Agency: Texas Transportation Institute Test No.: 439117-2 Test Date: 08/07/97

<table>
<tr><th><i>NCHRP Report 350</i> 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 slip-base mechanism activated as designed and permitted the support to release from the base.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</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 impact velocity = 1.03 m/s
Lateral impact velocity = 1.08 m/s</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration = 0.23 g's
Lateral ridedown acceleration = 0.46 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 did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 103.3 m behind the test article.</td><td>Pass</td></tr>
</table>

Table 7. Performance Evaluation Summary for Test 439117-5, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute Test No.: 439117-5 Test Date: 08/15/97

<table>
<tr><th><i>NCHRP Report 350</i> 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 slip-base mechanism permitted the support to release from the base; however, not as designed.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</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 impact velocity = 0.43 m/s
Lateral impact velocity = 0.61 m/s</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration = 0.14 g’s
Lateral ridedown acceleration = -0.15 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 did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 31.4 m behind the test article.</td><td>Pass</td></tr>
</table>

Table 8. Performance Evaluation Summary for Test 439117-6, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute Test No.: 439117-6 Test Date: 08/27/97

<table>
<tr><th colspan="4"><i>NCHRP Report 350</i> Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="4"><u>Structural Adequacy</u></td><td></td><td></td></tr>
<tr><td>B.</td><td colspan="3">The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The slip-base mechanism permitted the support to release from the base; however, not as designed.</td><td>Pass</td></tr>
<tr><td colspan="4"><u>Occupant Risk</u></td><td></td><td></td></tr>
<tr><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</td><td>Pass</td></tr>
<tr><td>H.</td><td colspan="3">Occupant impact velocities should satisfy the following:</td><td rowspan="4">Longitudinal impact velocity = 1.31 m/s
Lateral impact velocity = No contact</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Velocity Limits (m/s)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal</td><td>3</td><td>5</td></tr>
<tr><td>I.</td><td colspan="3">Occupant ridedown accelerations should satisfy the following:</td><td rowspan="4">Longitudinal ridedown acceleration = 0.43 g's
Lateral ridedown acceleration = No contact</td><td rowspan="4">Pass</td></tr>
<tr><td></td><td colspan="3">Occupant Ridedown Acceleration Limits (g's)</td></tr>
<tr><td></td><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
<tr><td colspan="4"><u>Vehicle Trajectory</u></td><td></td><td></td></tr>
<tr><td>K.</td><td colspan="3">After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N.</td><td colspan="3">Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 35.1 m behind the test article.</td><td>Pass</td></tr>
</table>

Table 9. Performance Evaluation Summary for Test 439117-7, *NCHRP Report 350* Test 3-60.

Test Agency: Texas Transportation Institute Test No.: 439117-7 Test Date: 08/27/97

<table>
<tr><th><i>NCHRP Report 350</i> 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 slip-base mechanism permitted the support to release from the base.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached elements did not penetrate nor show potential for penetrating the occupant compartment, nor were they judged to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright and stable during and after the collision.</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 impact velocity = 1.26 m/s
Lateral impact velocity = 0.86 m/s</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr>
</table></td><td>Longitudinal ridedown acceleration = -0.34 g’s
Lateral ridedown acceleration = -0.29 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 did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest 25.9 m behind the test article.</td><td>Pass</td></tr>
</table>

REFERENCES

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

2. "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.

3. A. G. Arnold, W. L. Menges, and J. R. Morgan, "NCHRP Report 350 Compliance Testing of HwyCom Sign Supports," Contract No. 270687-MOR, Texas Transportation Institute, College Station, TX, December 1996.

APPENDIX A. PENDULUM TESTING PROCEDURES

PENDULUM TEST FACILITY

Pendulum testing on the sign support samples was performed using the Texas Transportation Institute (TTI) outdoor pendulum testing facility. A pendulum body is suspended by wire cables from 13 m tall wooden poles. The pendulum body consists of reinforced concrete sandwiched between two 76 mm steel plates. The plates are connected by nose guide tube housings and by steel all-thread rods that are post-tensioned to keep the concrete in compression. The heavy steel plates spread the load to minimize the peaks in the compressive stress in the concrete during impact. A sweeper plate, constructed of steel angles and a steel plate, was attached to the body of the pendulum with a ground clearance of 152 mm. The sweeper plate, designed to replicate roughly an automobile’s undercarriage, may easily be replaced if damaged.

The pendulum sliding nose tubes are attached to the striking plate and slide into guide tubes in the body of the pendulum. Figure 59 presents a drawing of the pendulum body and sliding nose. The honeycomb nose, used to simulate vehicle crush in the pendulum, was configured to represent an 840 kg 1979 Volkswagen Rabbit two-door sedan with manual transmission. Four types of honeycomb with static strengths of 172.4 kPa, 896.3 kPa, 1585.8 kPa, and 2757.9 kPa were used. The cross-sectional areas of some modules were reduced by pre-crushing portions of the modules. This gives a progressively increasing strength throughout the honeycomb modules. A drawing of the nose assembly, showing each honeycomb cartridge, is displayed in Figure 60. The honeycomb was replaced following each test. Weight of the pendulum was 842 kg.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The pendulum was instrumented with two uniaxial accelerometers placed at the center of the rear plate to measure longitudinal acceleration levels of the pendulum body. The accelerometers were Endevco Model 2262CA-100. Both produce a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers were transmitted to a remote 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 are recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. A pressure-sensitive switch on the nose of the pendulum was actuated within 1 m of impact by a wooden dowel and then again at impact with the sign support, to indicate the elapsed time over a known distance. This provided a measurement of impact velocity. The switch contact also produced an “event” mark on the data record to establish the exact instant of contact with the rigid frame.

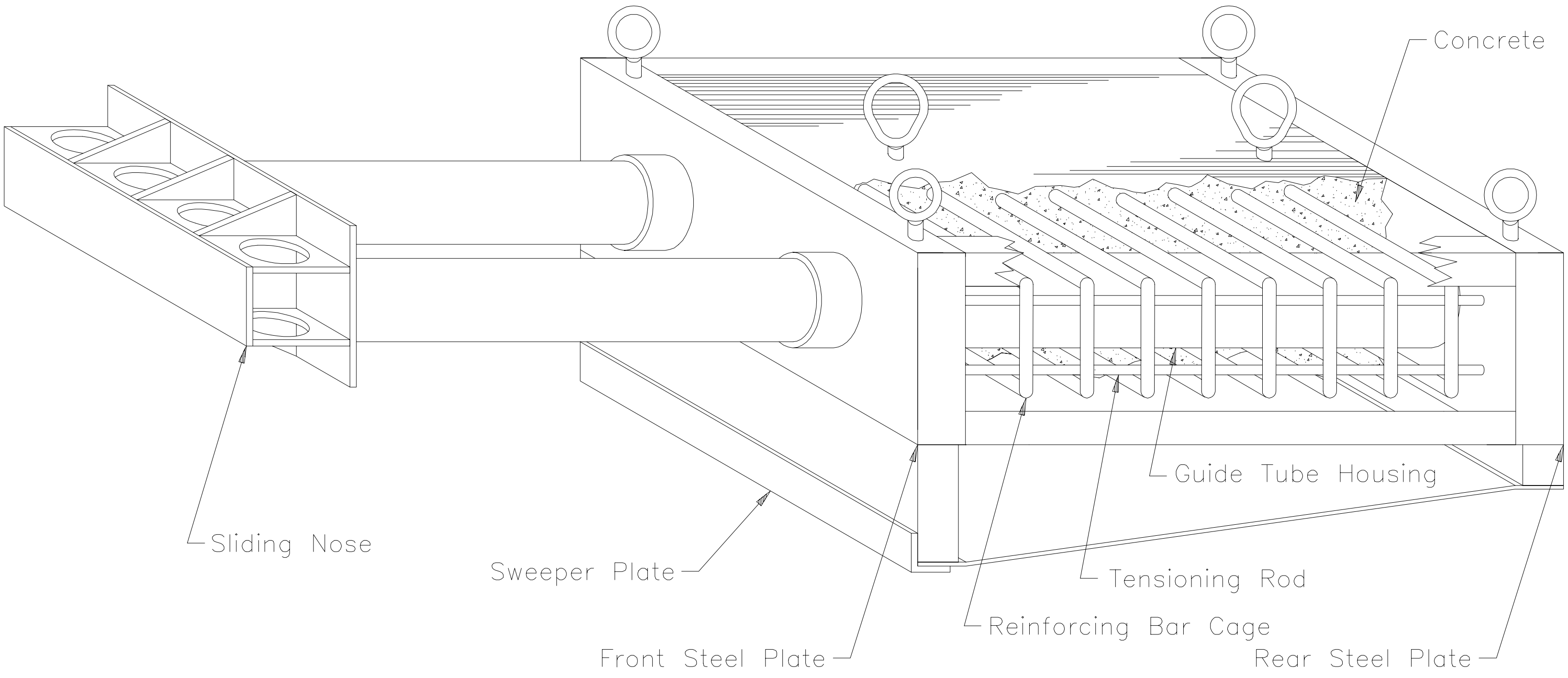
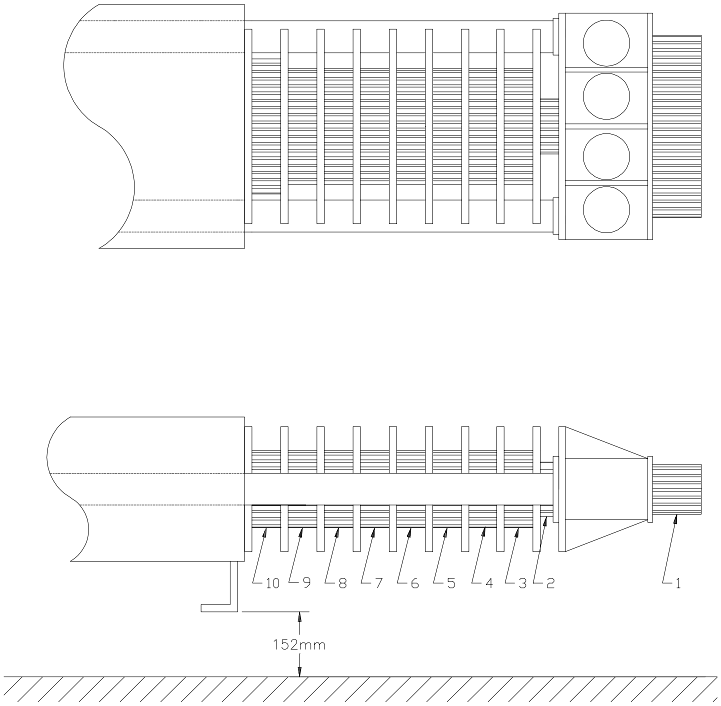


Figure 59. Sketch of Pendulum Body and Sliding Nose.



Cartridge Number	Size (mm)	Area Effectively Removed by Crushing (mm^2)	Static Crush Strength (kPa)	Total Crush Strength for Each Module (kN)
1	953 × 406 × 76		896.3	34.6
2	102 × 127 × 51		172.4	2.2
3	203 × 203 × 76	13549	1585.8	24.8
4	203 × 203 × 76	9678	1585.8	50.0
5	203 × 203 × 76	3871	1585.8	59.2
6	203 × 203 × 76		1585.8	65.3
7	203 × 203 × 76	13549	2757.9	76.3
8	203 × 203 × 76	7742	2757.9	92.3
9	203 × 203 × 76		2757.9	113.6
10	203 × 254 × 76		2757.9	142.3

Figure 60. Pendulum Nose Configuration.

The telemetered multiplex of data channels, transmitted on one radio frequency, is received at the data acquisition station, and demultiplexed onto separate tracks of an Inter-Range Instrumentation Group (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with a Butterworth low pass filter with a cutoff frequency of 100 Hz and imported into a computer spreadsheet for analysis.

PHOTOGRAPHIC INSTRUMENTATION

Photographic coverage of the test included a Betcam placed perpendicular to the pendulm path/sign installation and a VHS video camera placed at a 45 degree angle behind the sign installation. The films from these video cameras are used to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. The video cameras and still cameras are used to record and document conditions of the test vehicle and sign installation before and after the test.

APPENDIX B. FULL-SCALE CRASH TESTING PROCEDURES

IMPACT CONDITIONS

According to *NCHRP Report 350*, two crash tests are recommended for the evaluation of small sign supports for test level three (TL-3)

> ***NCHRP Report 350* test designation 3-60**: This test involves an 820 kg passenger car impacting the support structure at a nominal speed of 35 km/h with the vehicle bumper at an impact angle between 0 and 20 degrees. The primary purpose of this test is to evaluate the breakaway, fracture, or yielding mechanism of the support as well as occupant risk. Tests 439117-1, 439117-3, 439117-5, and 439117-6 correspond to this *NCHRP Report 350* test.
>
> ***NCHRP Report 350* test designation 3-61**: This test involves an 820 kg passenger car impacting the support structure at a nominal speed of 100 km/h with the vehicle bumper at an impact angle between 0 and 20 degrees. This test is intended to evaluate occupant risk, vehicular stability, and test article trajectory. Tests 439117-2, 439117-4 and 439117-7 correspond to this *NCHRP Report 350* test.

EVALUATION CRITERIA

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

- **Structural Adequacy**

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

- **Occupant Risk**

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

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

H. Occupant impact velocities should satisfy the following:

Longitudinal Occupant Impact Velocity - m/s

Preferred	Maximum
3	5

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations - g's

Preferred	Maximum
15	20

- **Vehicle Trajectory**

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

N. Vehicle trajectory behind the test article is acceptable.

In addition, the 1994 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.

CRASH TEST AND DATA ANALYSIS PROCEDURES

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

Electronic Instrumentation and Data Processing

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

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

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

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

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10 ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 0.050-s 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 a commercially available software package (Excel 7).

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

Anthropomorphic Dummy Instrumentation

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 uninstrumented.

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 the vehicle path/installation. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A Betcam, a ¾-inch video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

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

APPENDIX C. VEHICLE PROPERTIES

DATE: 8-11-97 TEST NO.: 439117-3 & 4 VIN NO.: KNJPT05HXP6128657

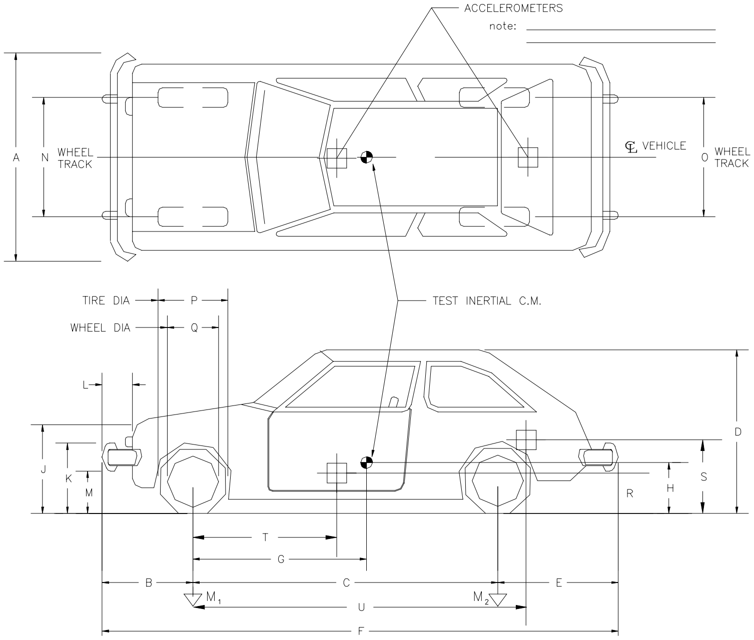
YEAR: 1993 MAKE: FORD MODEL: FESTIVA

TIRE INFLATION PRESSURE: ODOMETER: 66116 TIRE SIZE: 155R12

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

MASS DISTRIBUTION (kg) LF 263 RF 252 LR 156 RR 149

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1500	E	570	J	740	N	1390	R	415
B	640	F	3505	K	525	O	1385	S	500
C	2295	G	853.6	L	115	P	520	T	905
D	1450	H		M	380	Q	325	U	2400

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	525	515	552
M_2	280	305	344
M_T	805	820	896

Figure 61. Vehicle Properties for Test 439117-3 and 439117-4.

DATE: 8-7-97 TEST NO.: 439117-1 & 2 VIN NO.: KNJPT05H5P6112205

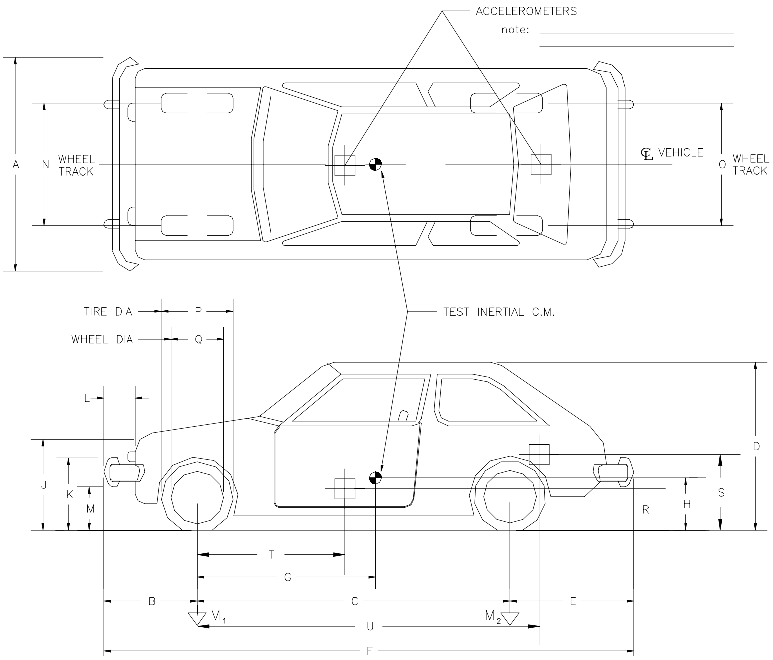
YEAR: 1992 MAKE: FORD MODEL: FESTIVA

TIRE INFLATION PRESSURE: ODOMETER: 76838 TIRE SIZE: 145 SR12

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

MASS DISTRIBUTION (kg) LF 261 RF 252 LR 162 RR 145

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1500	E	530	J	775	N	1370	R	380
B	670	F	3500	K	560	O	1390	S	470
C	2300	G	861.1	L	120	P	545	T	890
D	1460	H		M	410	Q	330	U	2420

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	512	513	551
M_2	303	302	345
M_T	815	820	896

Figure 62. Vehicle Properties for Test 439117-1 and 439117-2.

DATE: 8-15-97 TEST NO.: 439117-5, 6 & 7 VIN NO.: KNJPT05H7N6121564

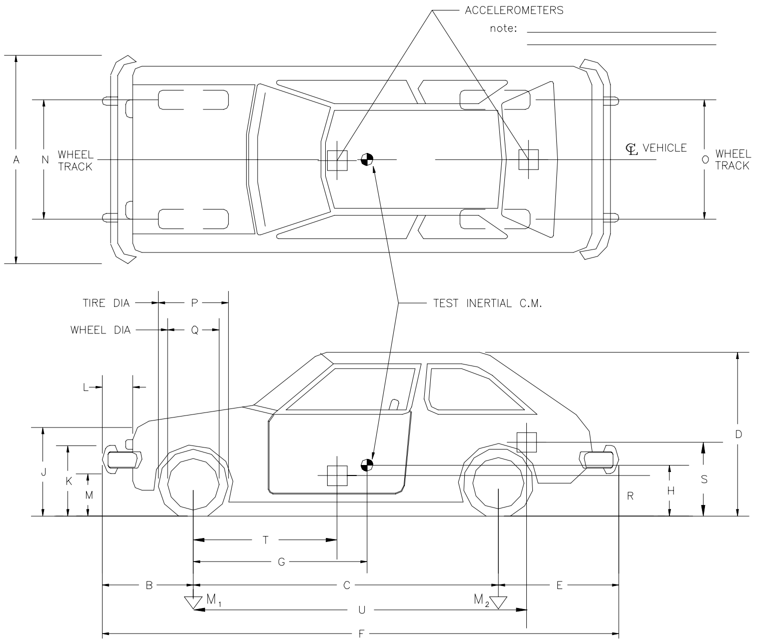
YEAR: 1991 MAKE: FORD MODEL: FESTIVA

TIRE INFLATION PRESSURE: ODOMETER: 99019 TIRE SIZE: 155R12

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

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

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

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

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

Figure 63. Vehicle Properties for Test 439117-5, 439117-6, and 439117-7.

APPENDIX D. SEQUENTIAL PHOTOGRAPHS

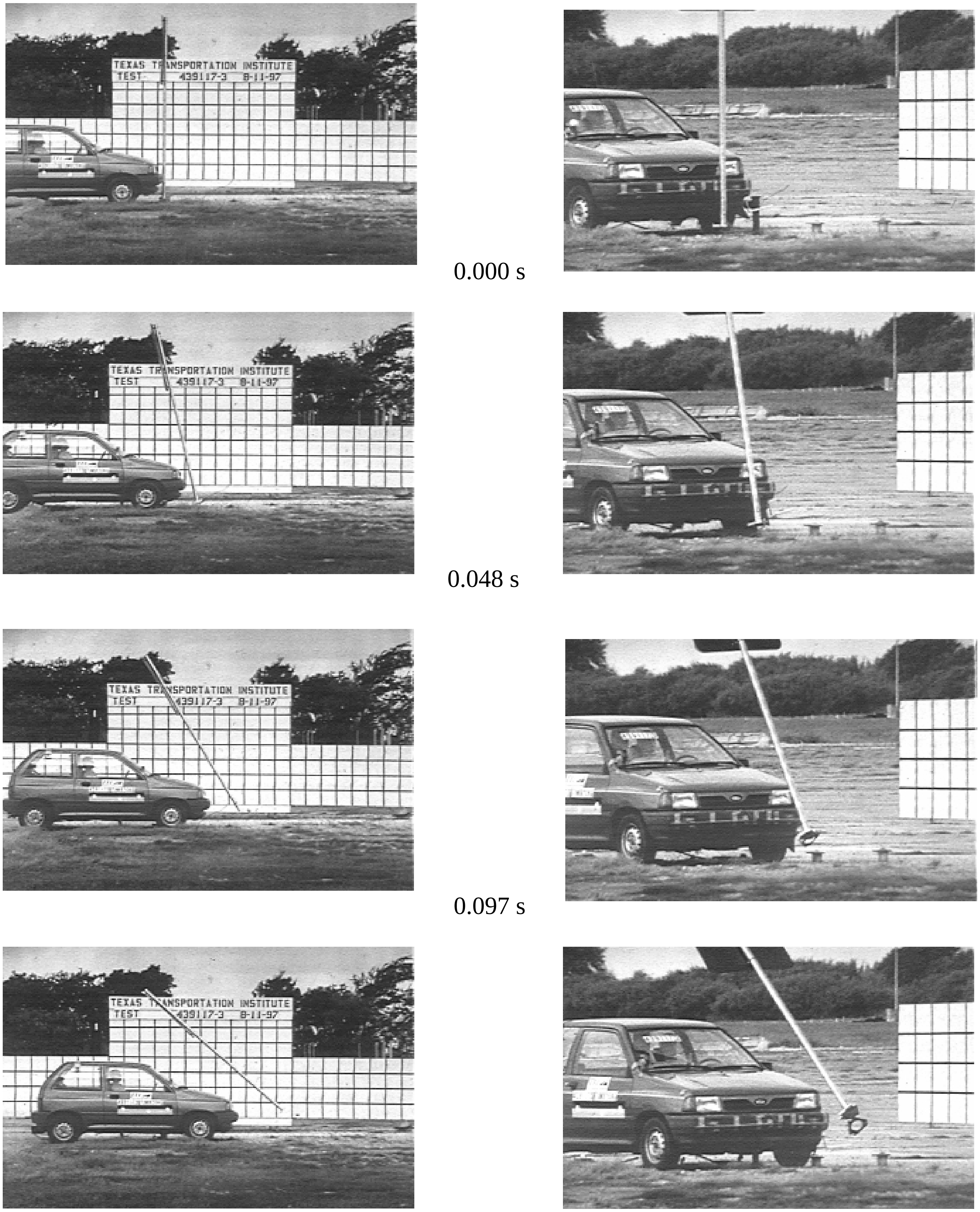
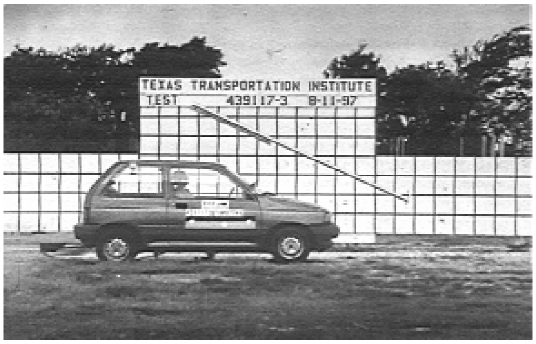


Figure 64. Sequential Photographs for Test 439117-3 (Perpendicular and Oblique Views).



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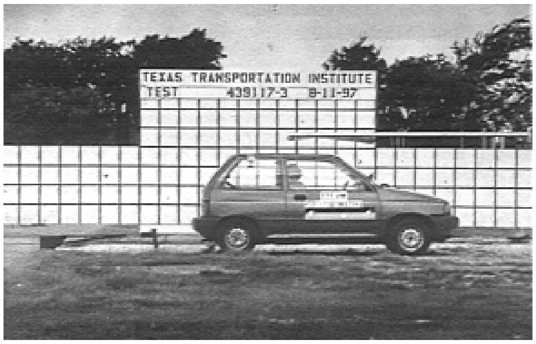

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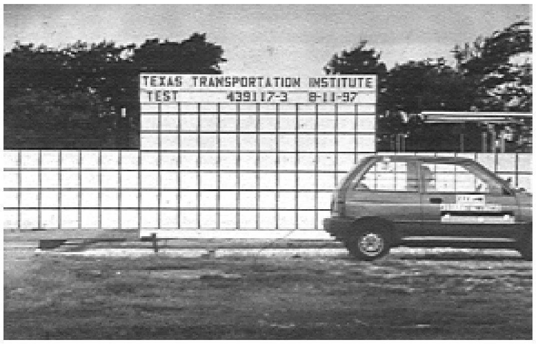
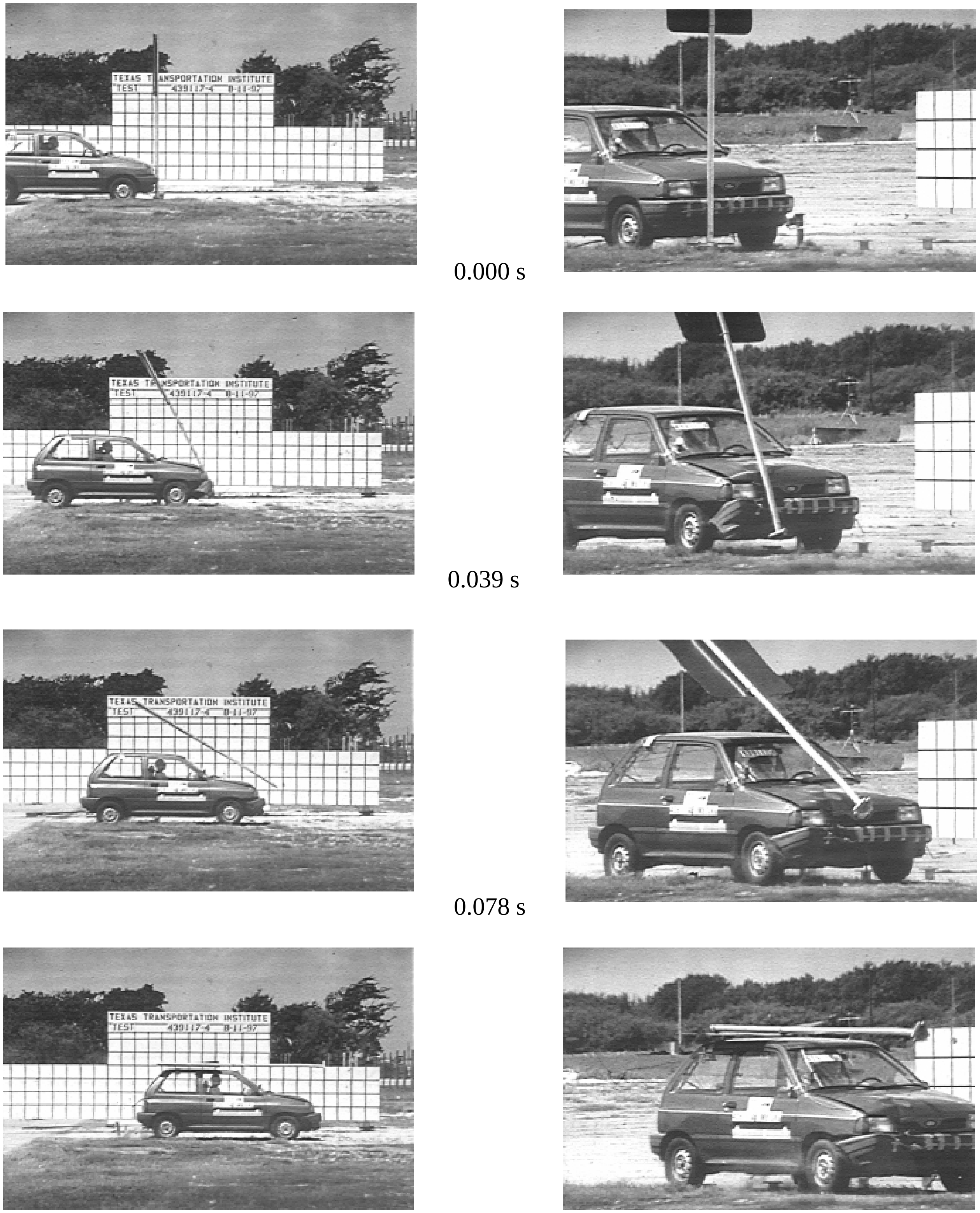


0.559 s

Figure 64. Sequential Photographs for Test 439117-3 (Perpendicular and Oblique Views) (Continued).



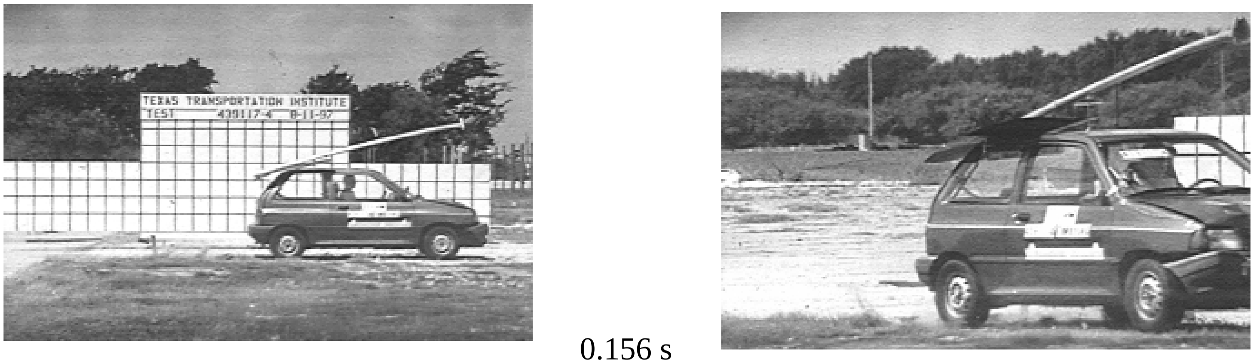
0.000 s

0.039 s

0.078 s

0.117 s

Figure 65. Sequential Photographs for Test 439117-4
(Perpendicular and Oblique Views).



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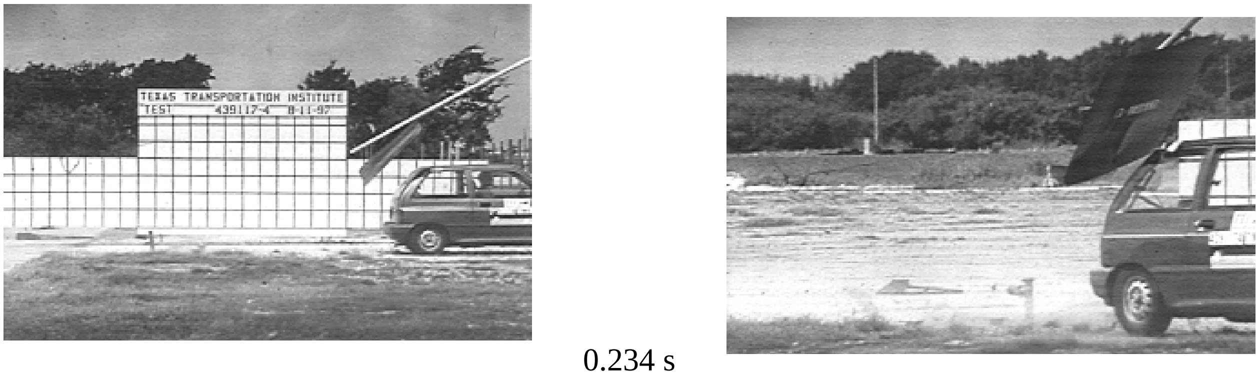
0.195 s



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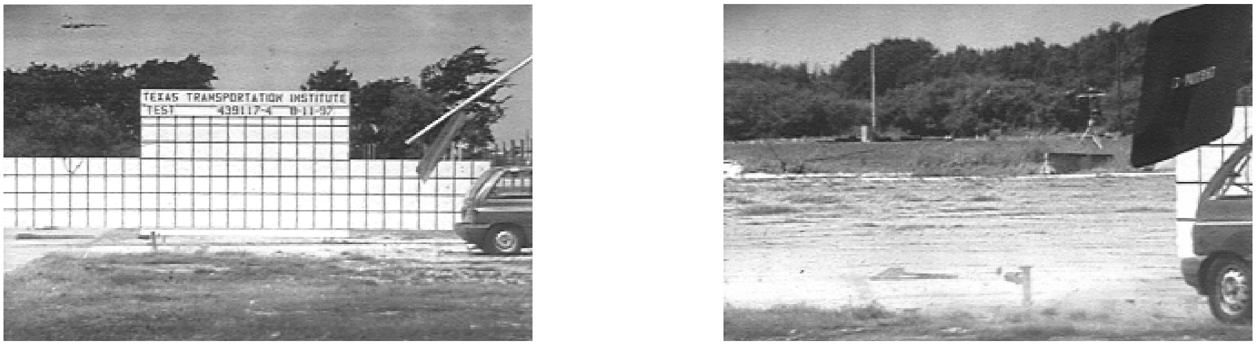

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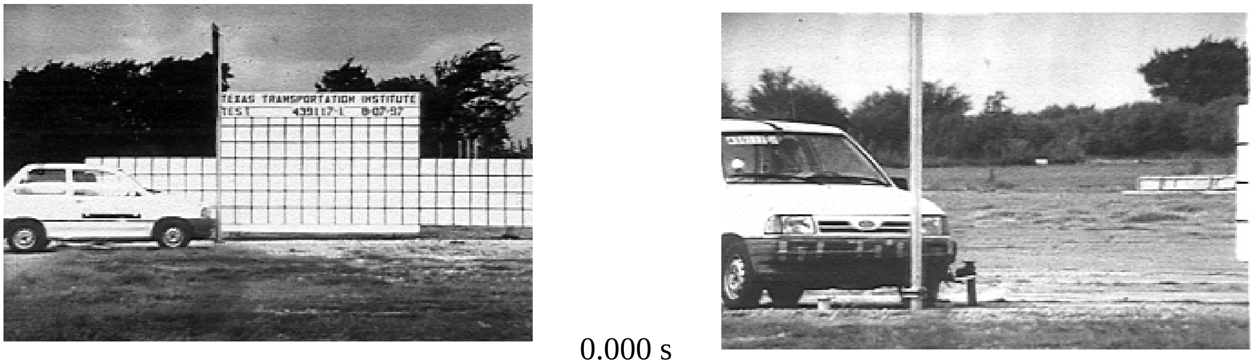
Figure 65. Sequential Photographs for Test 439117-4 (Perpendicular and Oblique Views) (Continued).



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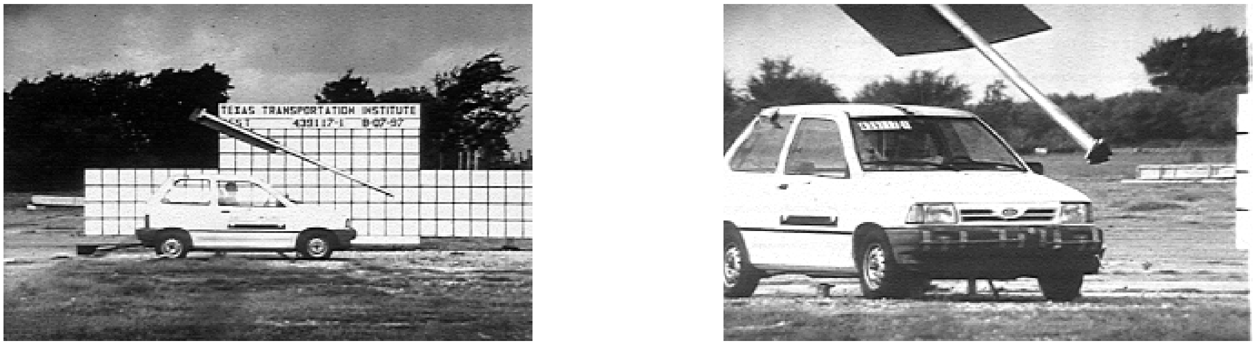

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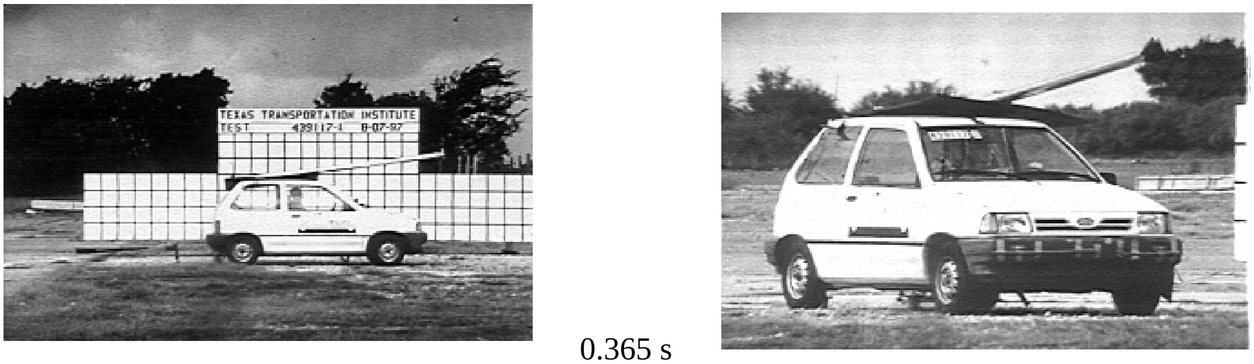
Figure 66. Sequential Photographs for Test 439117-1 (Perpendicular and Oblique Views).



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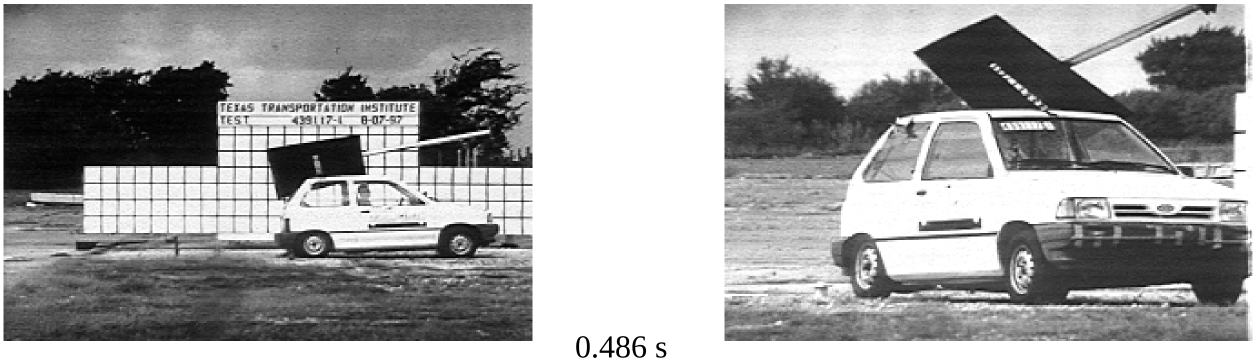

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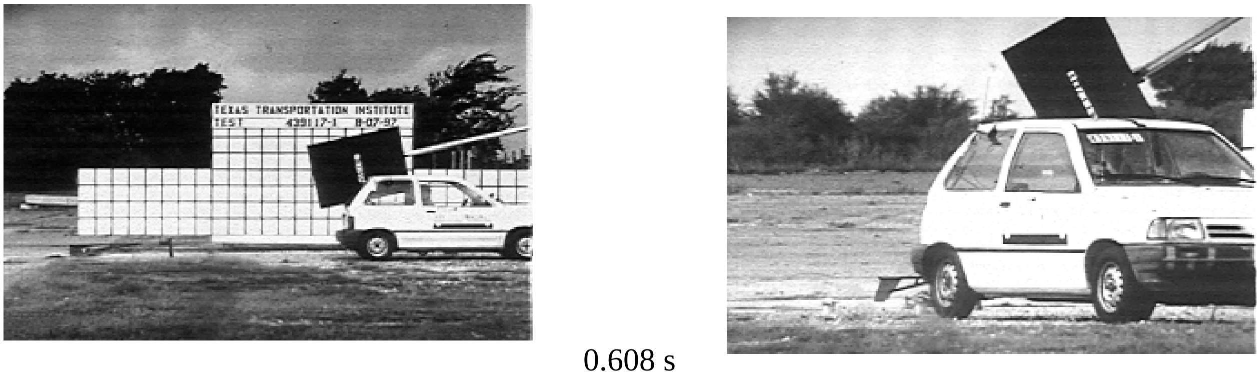

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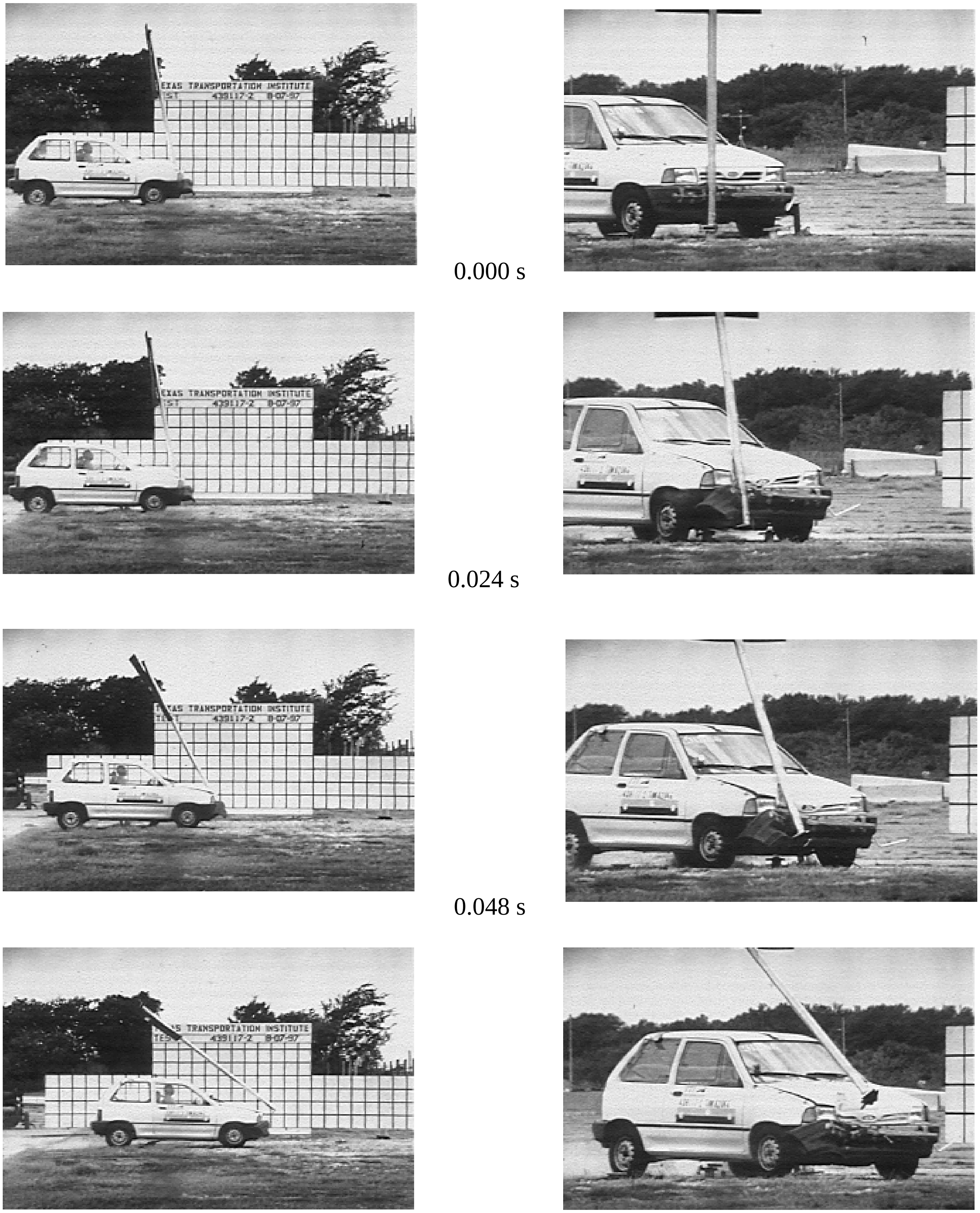
0.851 s

Figure 66. Sequential Photographs for Test 439117-1 (Perpendicular and Oblique Views) (Continued).



0.000 s

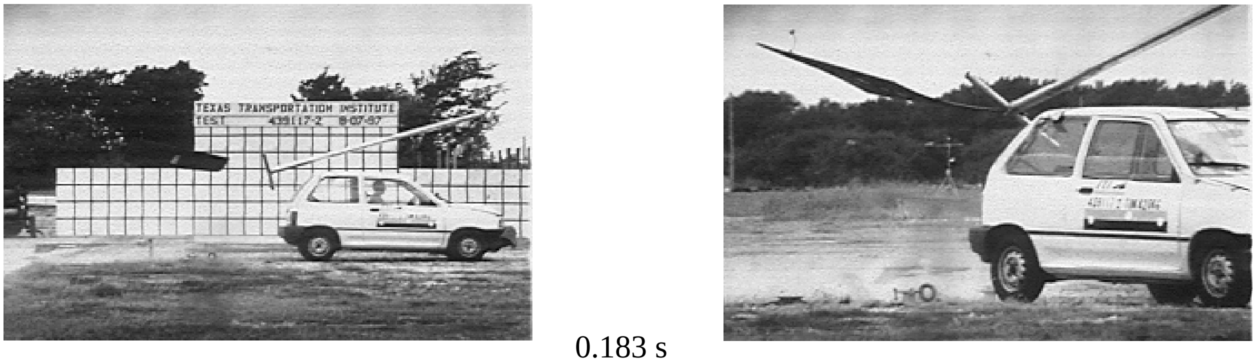
0.024 s

0.048 s

0.085 s

Figure 67. Sequential Photographs for Test 439117-2 (Perpendicular and Oblique Views).

0.122 s



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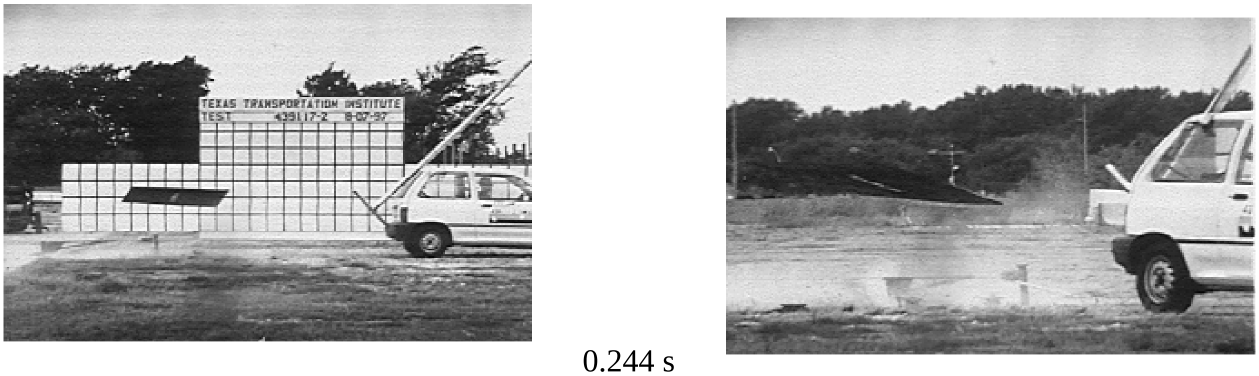

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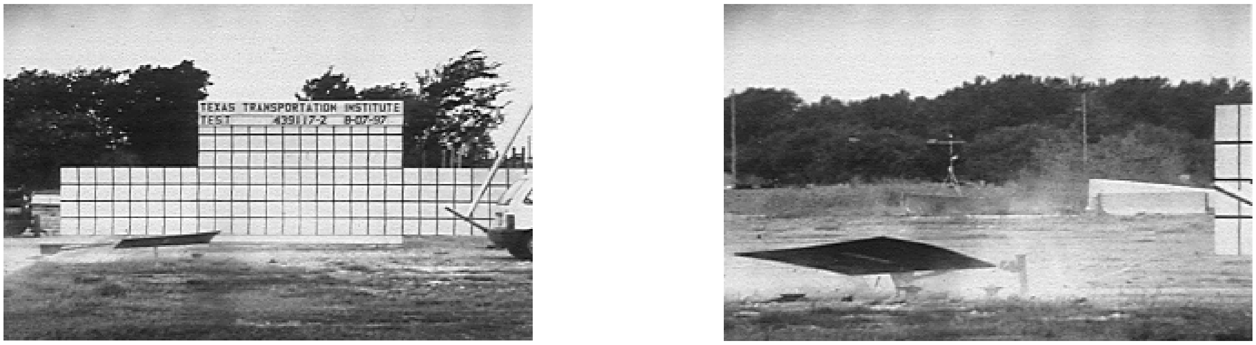

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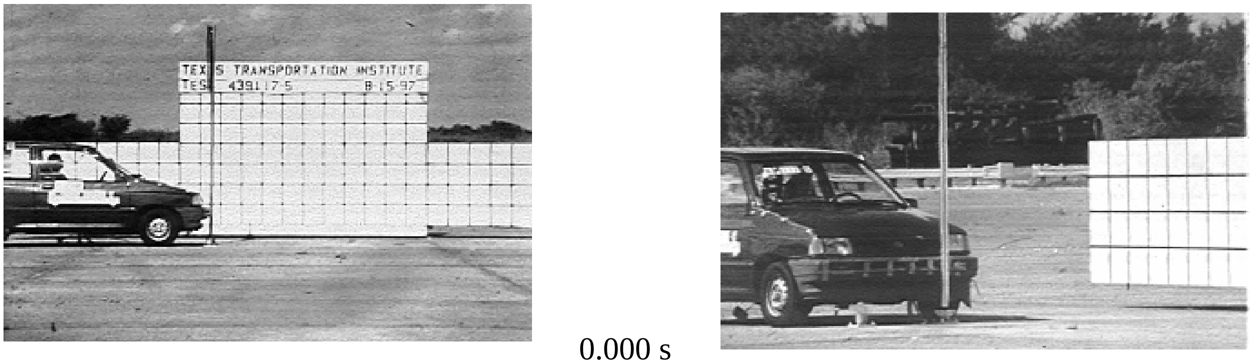
Figure 67. Sequential Photographs for Test 439117-2 (Perpendicular and Oblique Views) (Continued).



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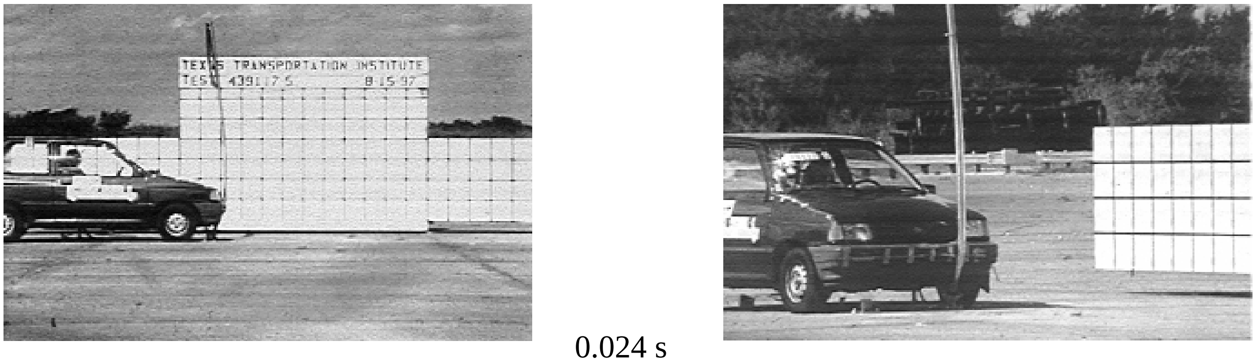

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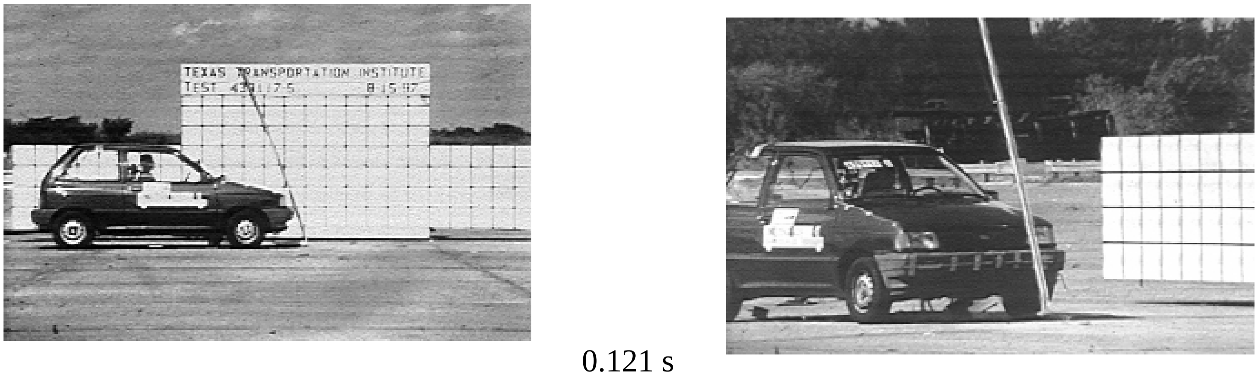

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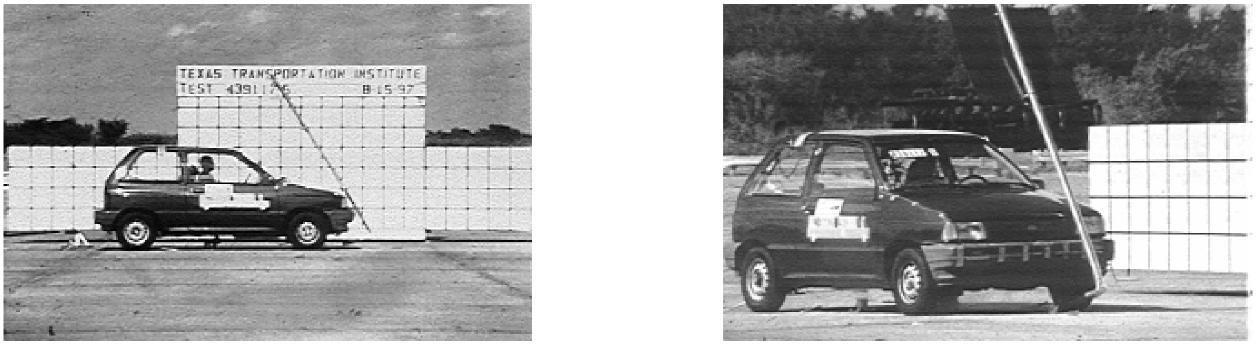

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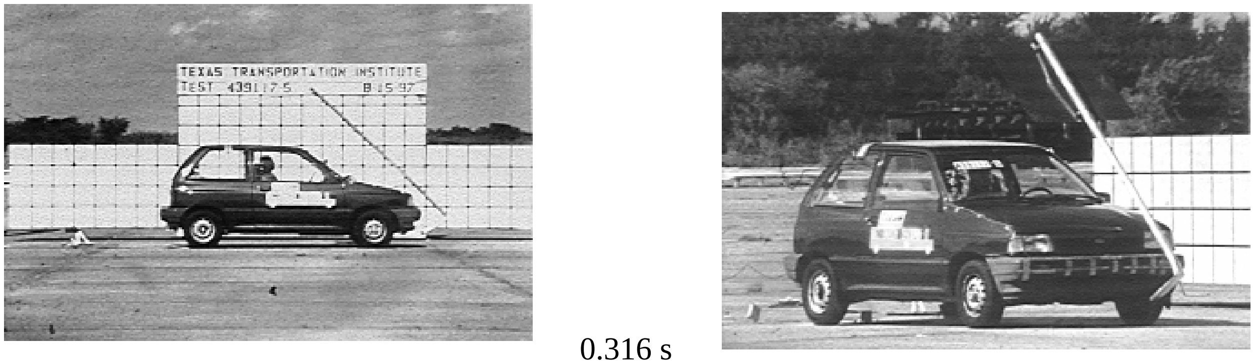
Figure 68. Sequential Photographs for Test 439117-5 (Perpendicular and Oblique Views).



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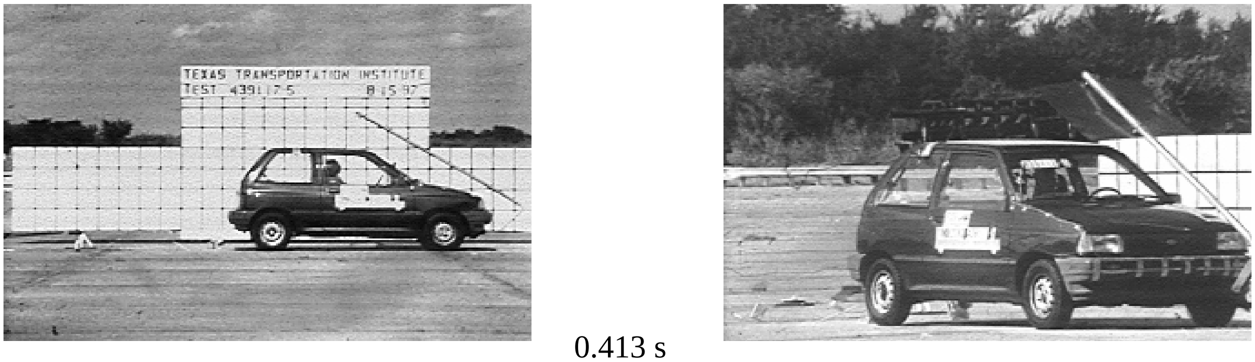

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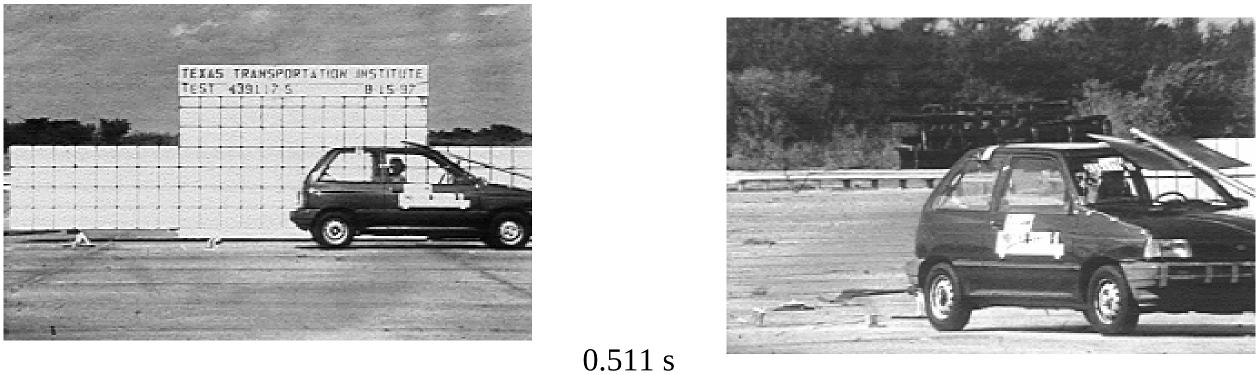

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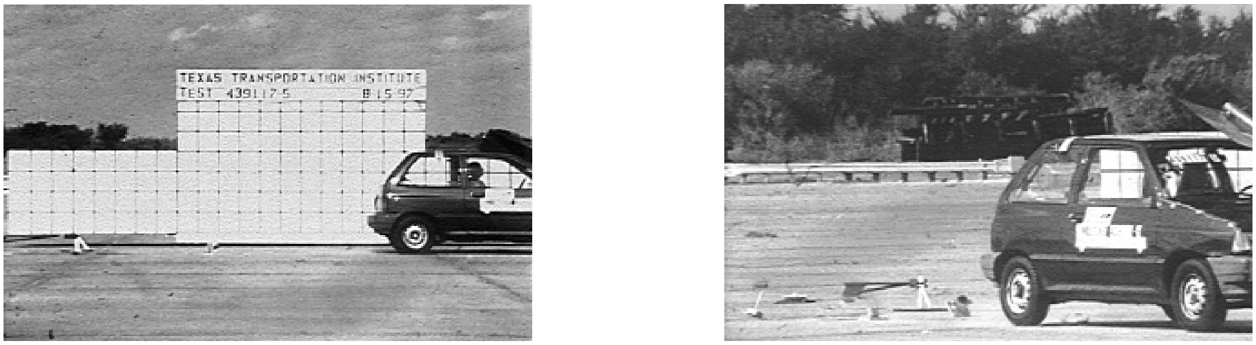

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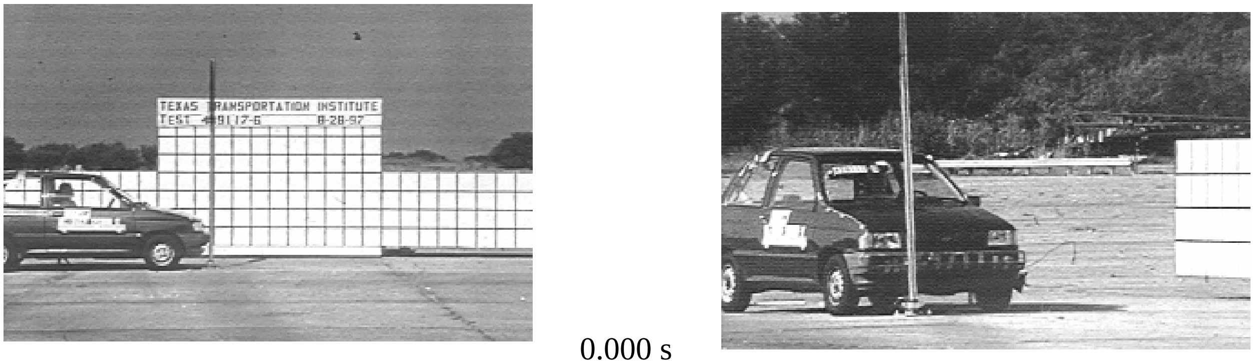
Figure 68. Sequential Photographs for Test 439117-5 (Perpendicular and Oblique Views) (Continued).



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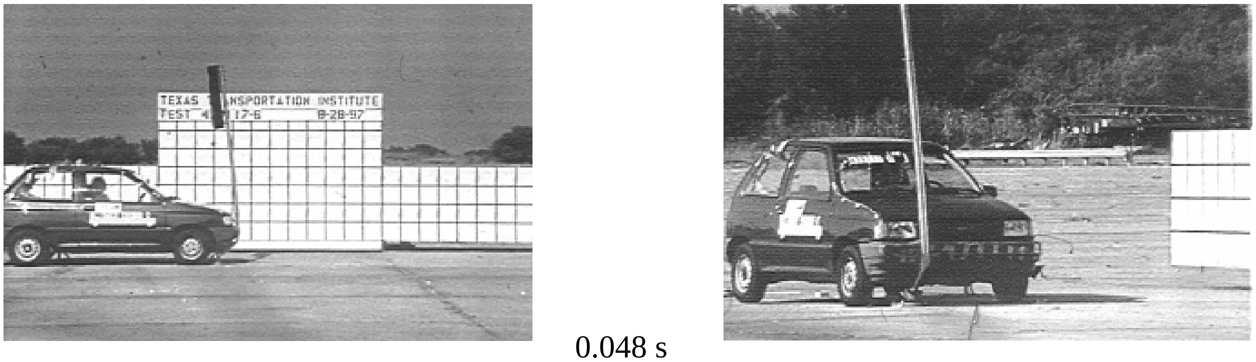

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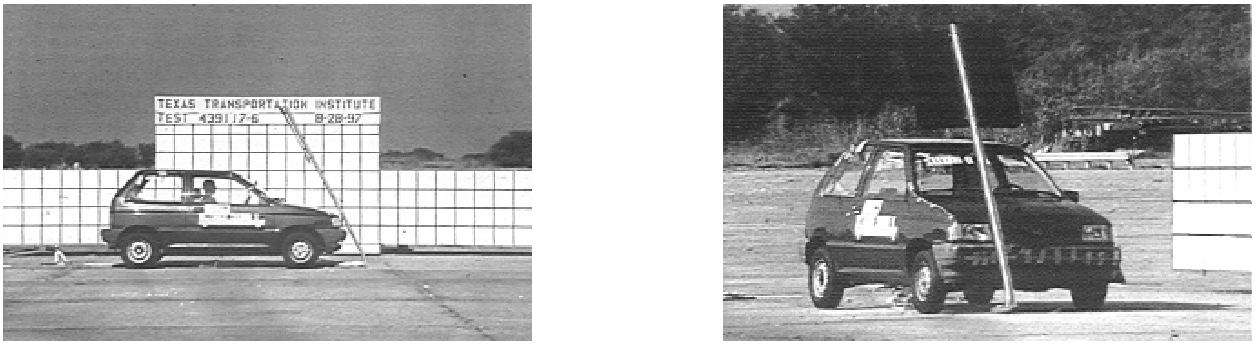
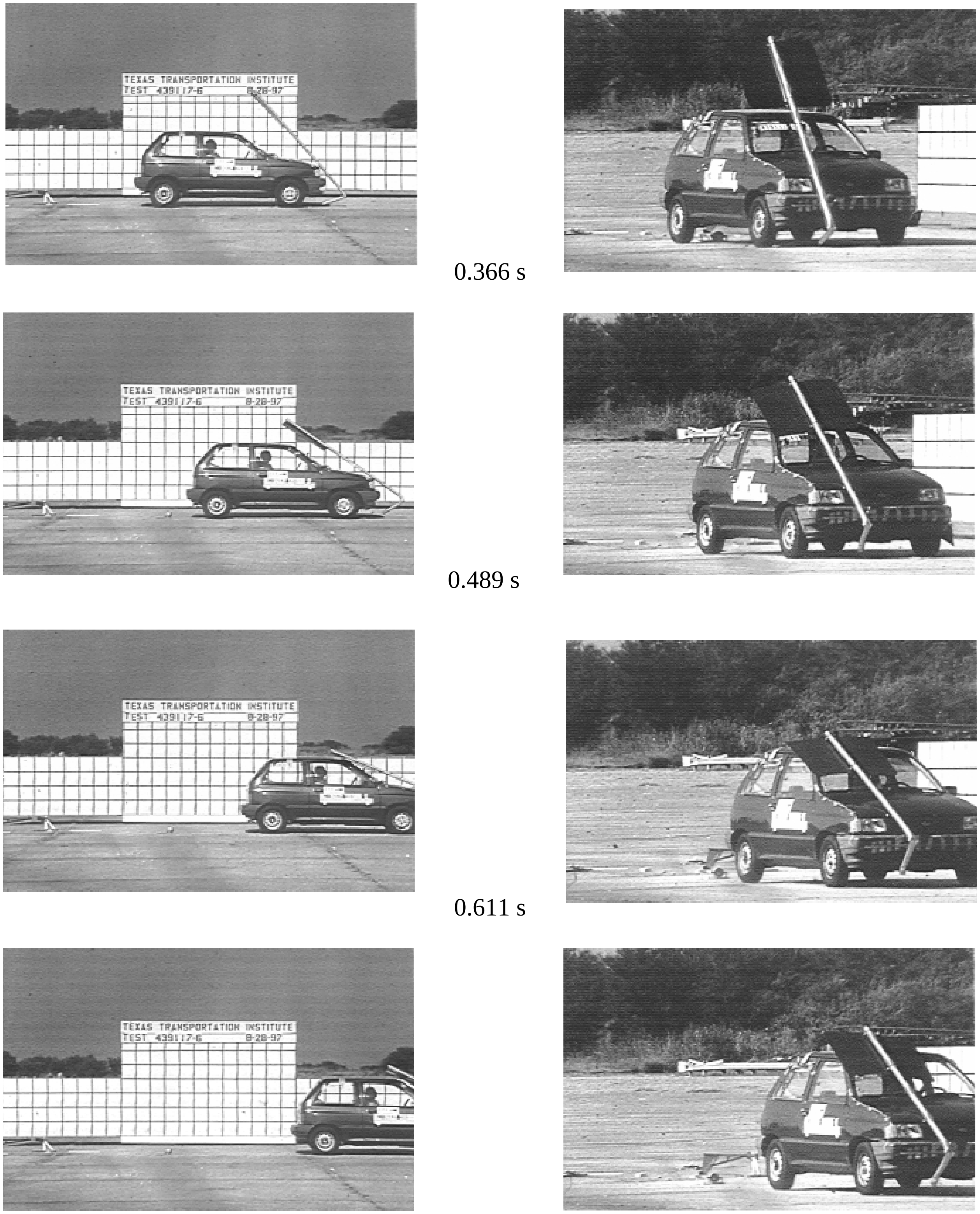
0.122 s



0.244 s

Figure 69. Sequential Photographs for Test 439117-6 (Perpendicular and Oblique Views).



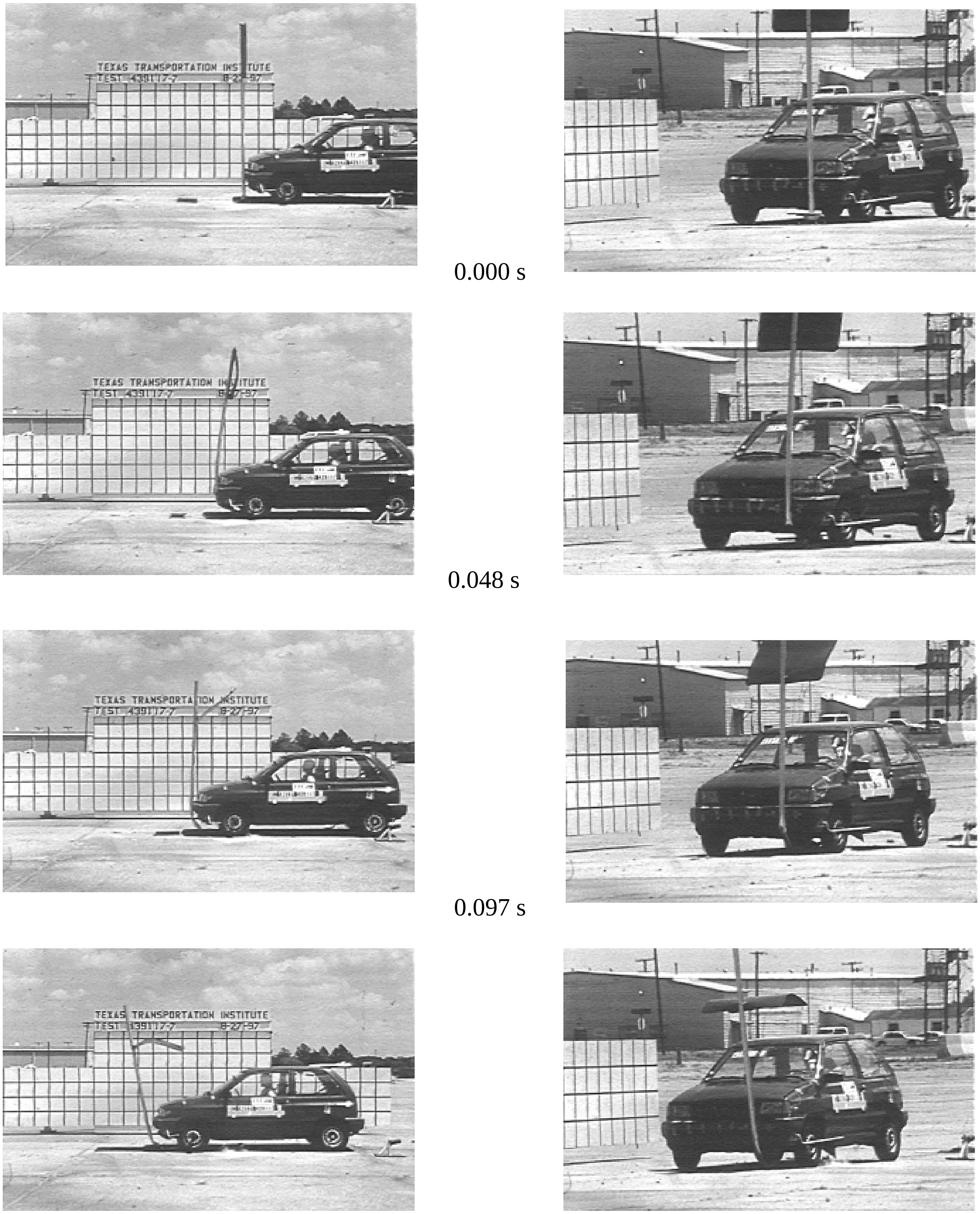
0.366 s

0.489 s

0.611 s

0.733 s

Figure 69. Sequential Photographs for Test 439117-6 (Perpendicular and Oblique Views) (Continued).



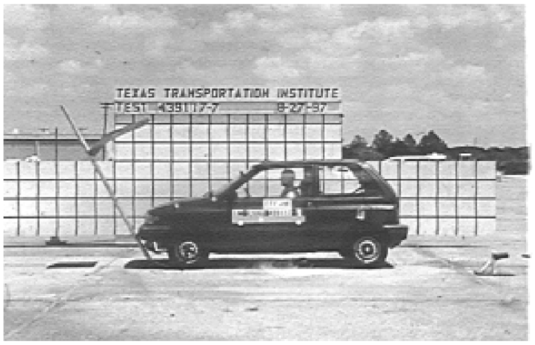
0.000 s

0.048 s

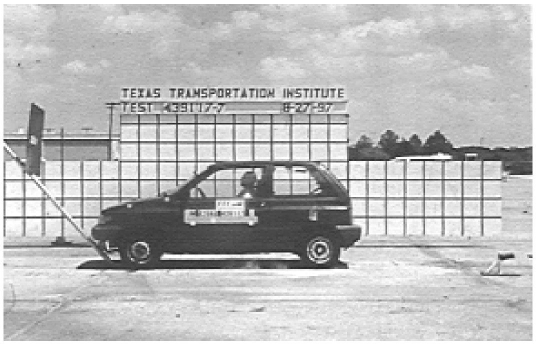
0.097 s

0.183 s

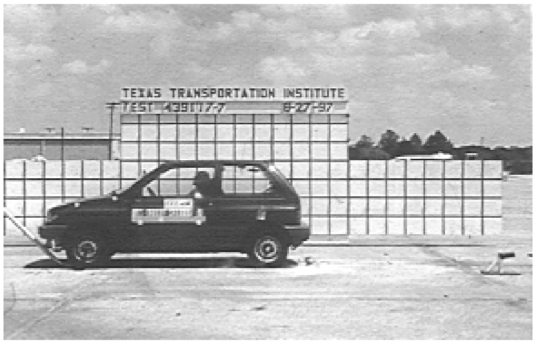
Figure 70. Sequential Photographs for Test 439117-7 (Perpendicular and Oblique Views).



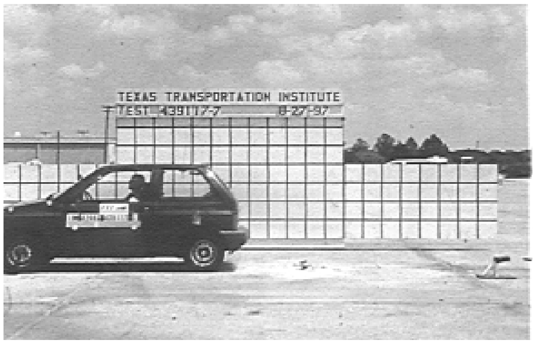
0.269 s



0.355 s



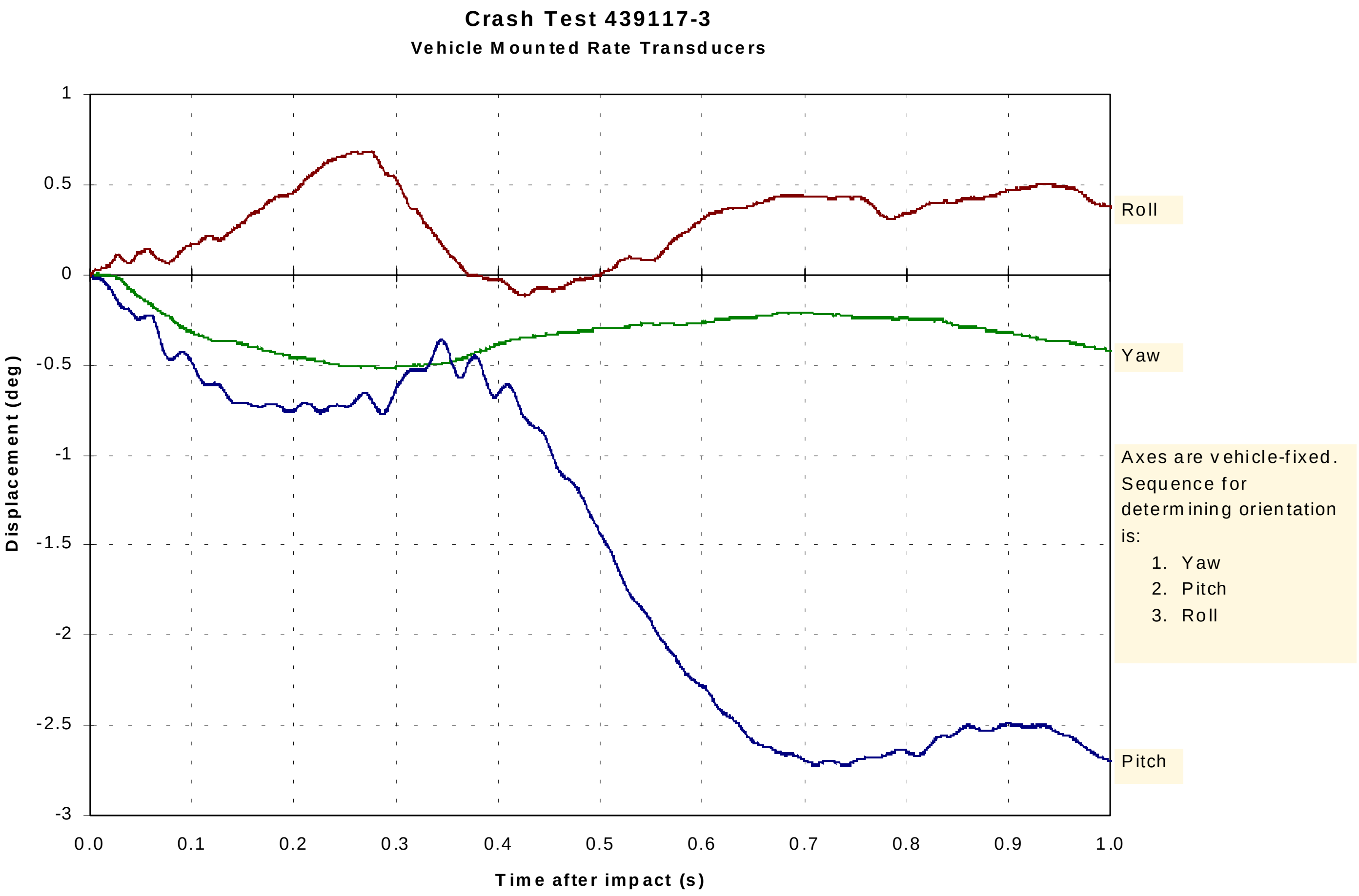
0.440 s



0.538 s

Figure 70. Sequential Photographs for Test 439117-7 (Perpendicular and Oblique Views) (Continued).

APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

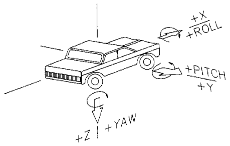
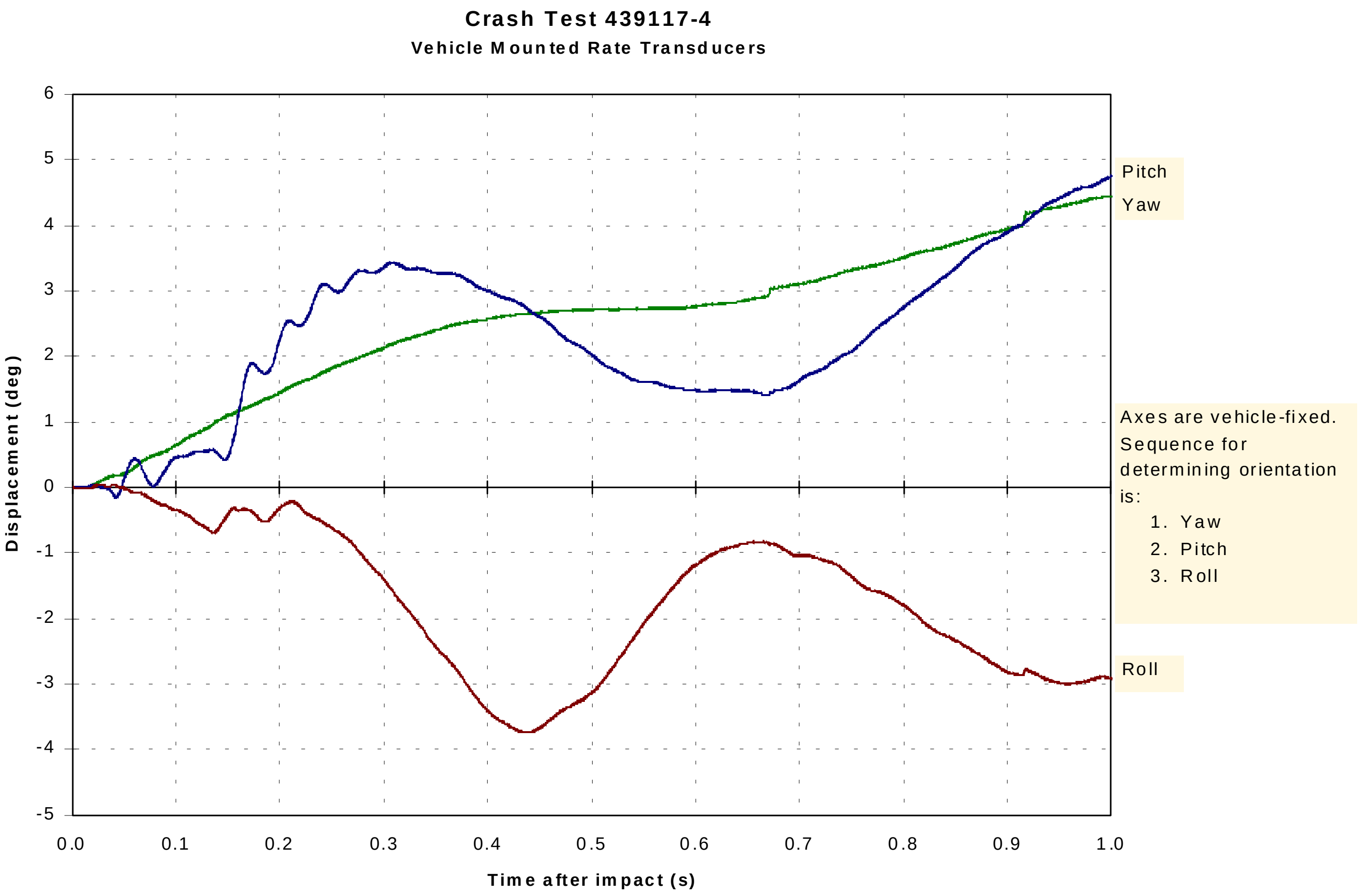


Figure 71. Vehicle Angular Displacements for Test 439117-3.



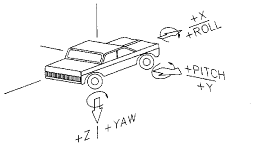
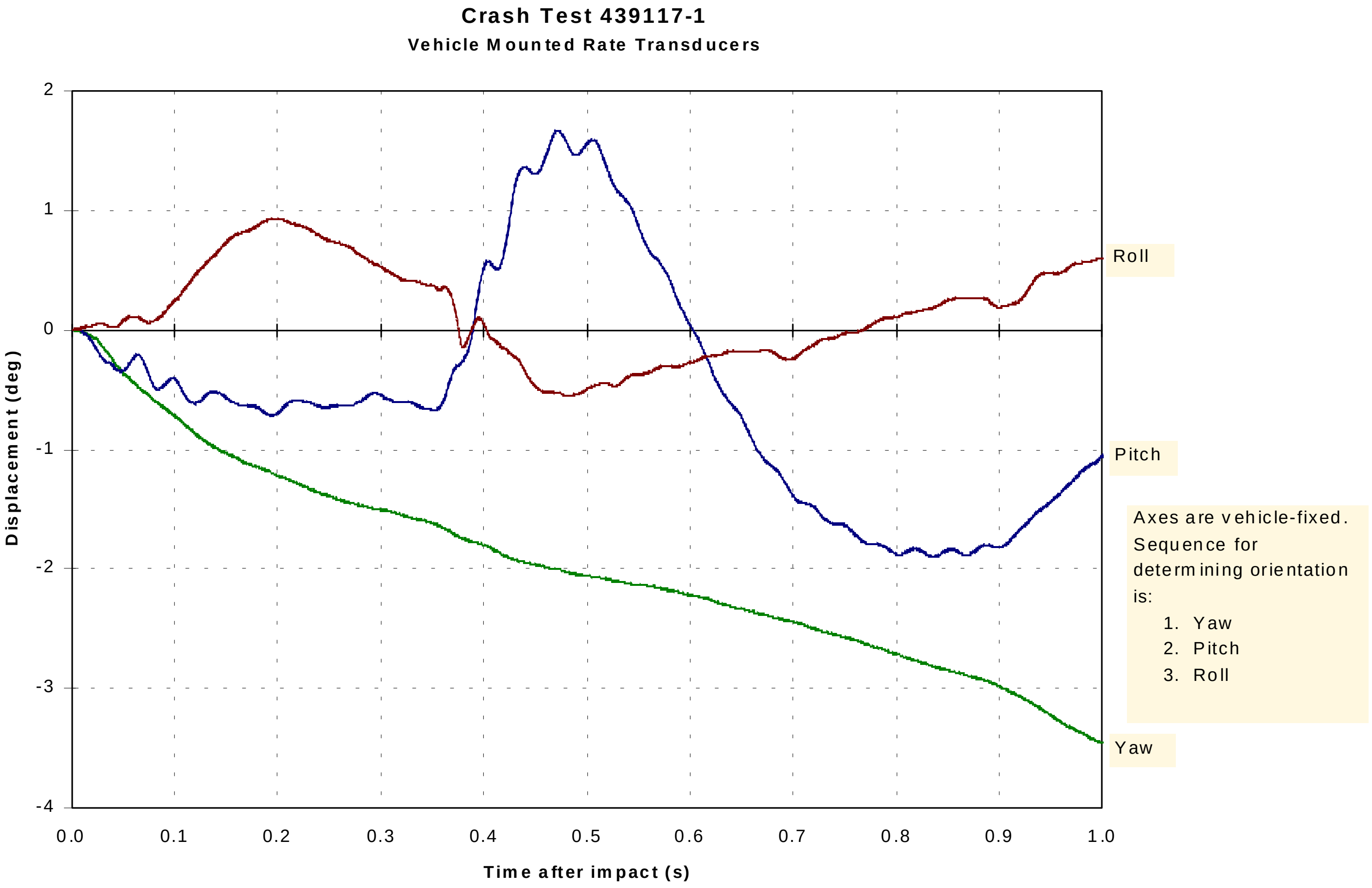


Figure 72. Vehicle Angular Displacements for Test 439117-4.



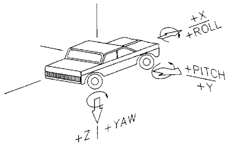
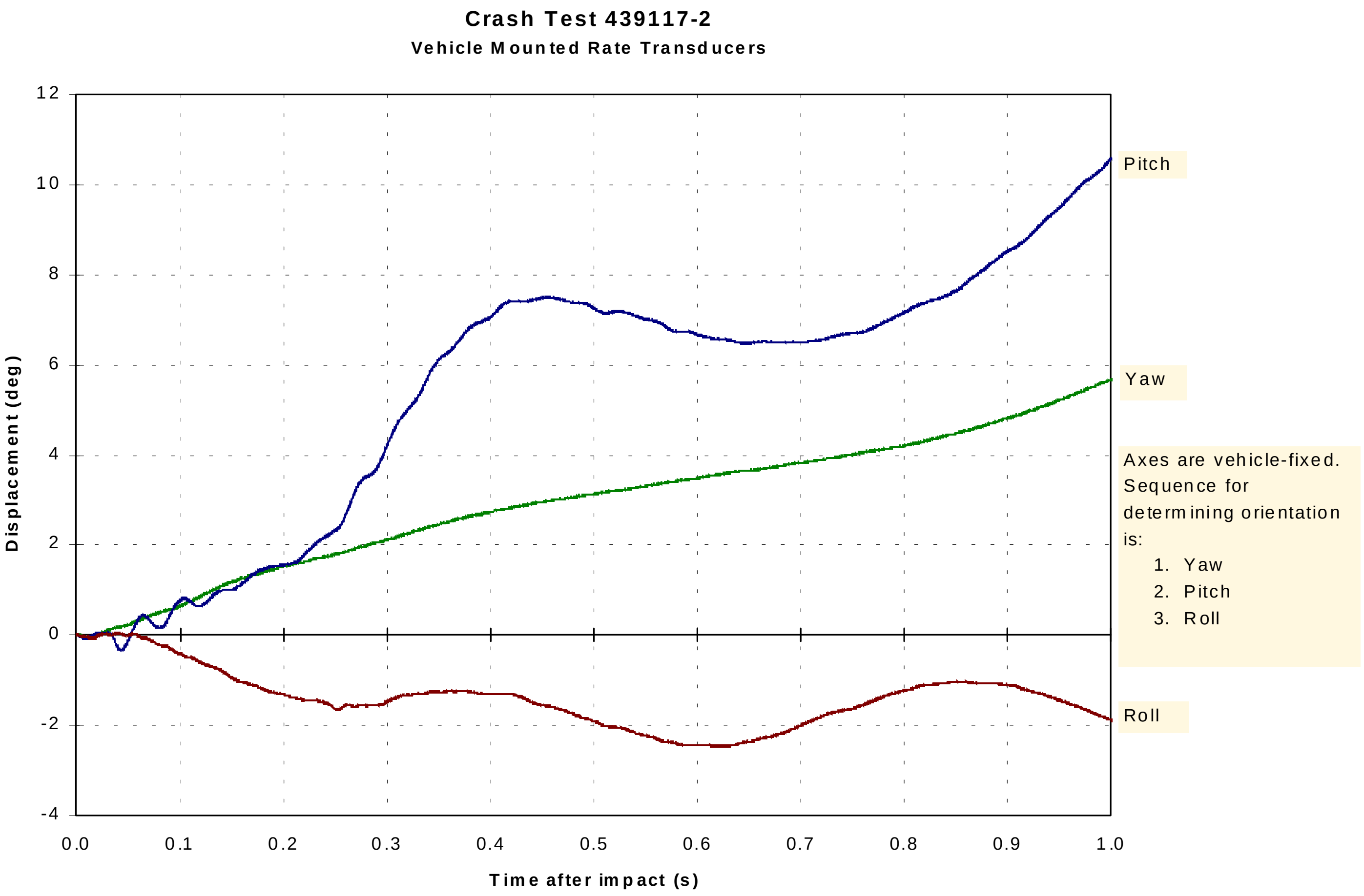


Figure 73. Vehicle Angular Displacements for Test 439117-1.


Crash Test 439117-2

Vehicle Mounted Rate Transducers

Axes are vehicle-fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

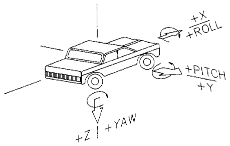
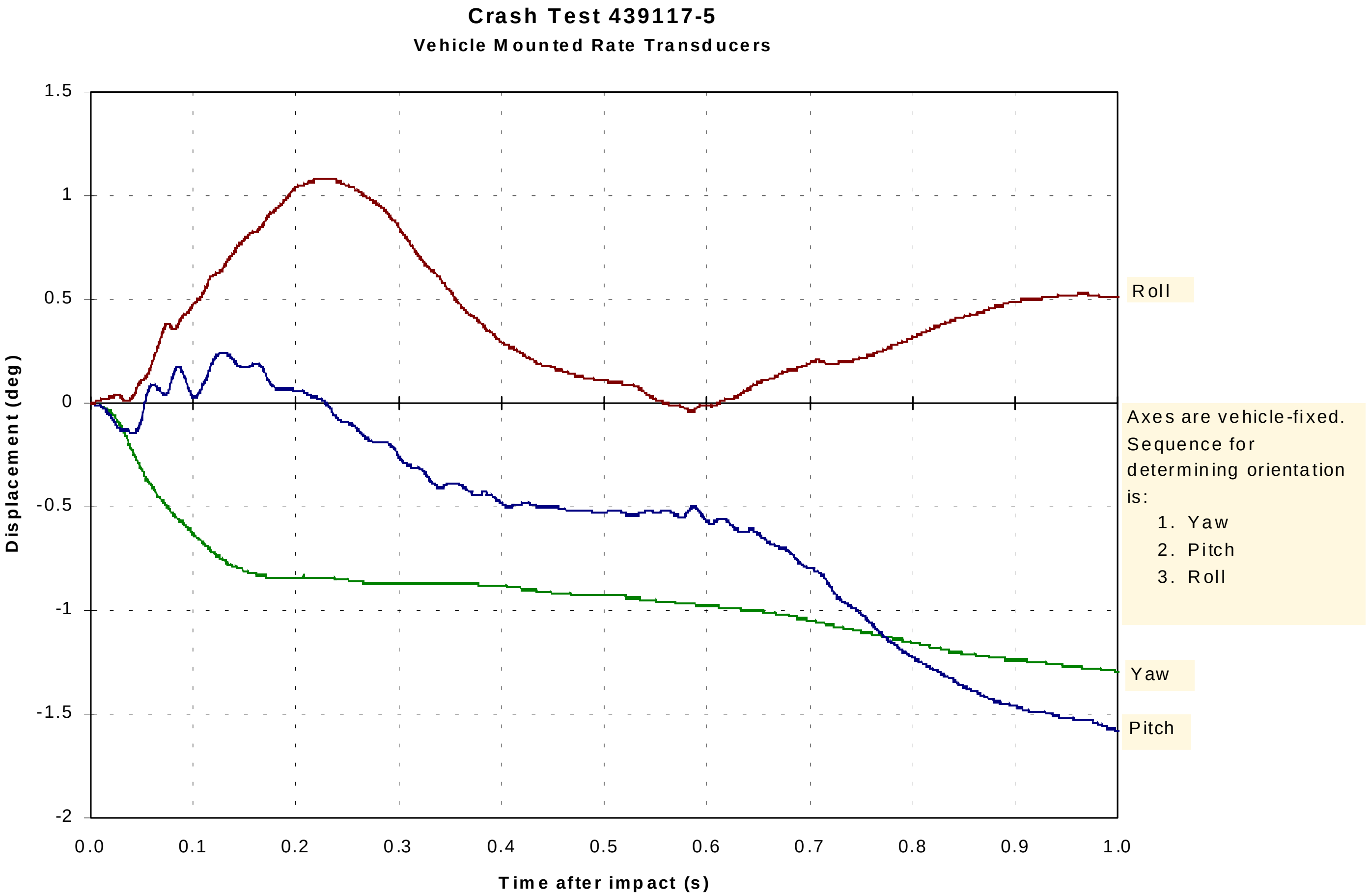


Figure 74. Vehicle Angular Displacements for Test 439117-2.



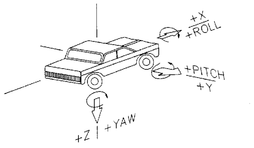
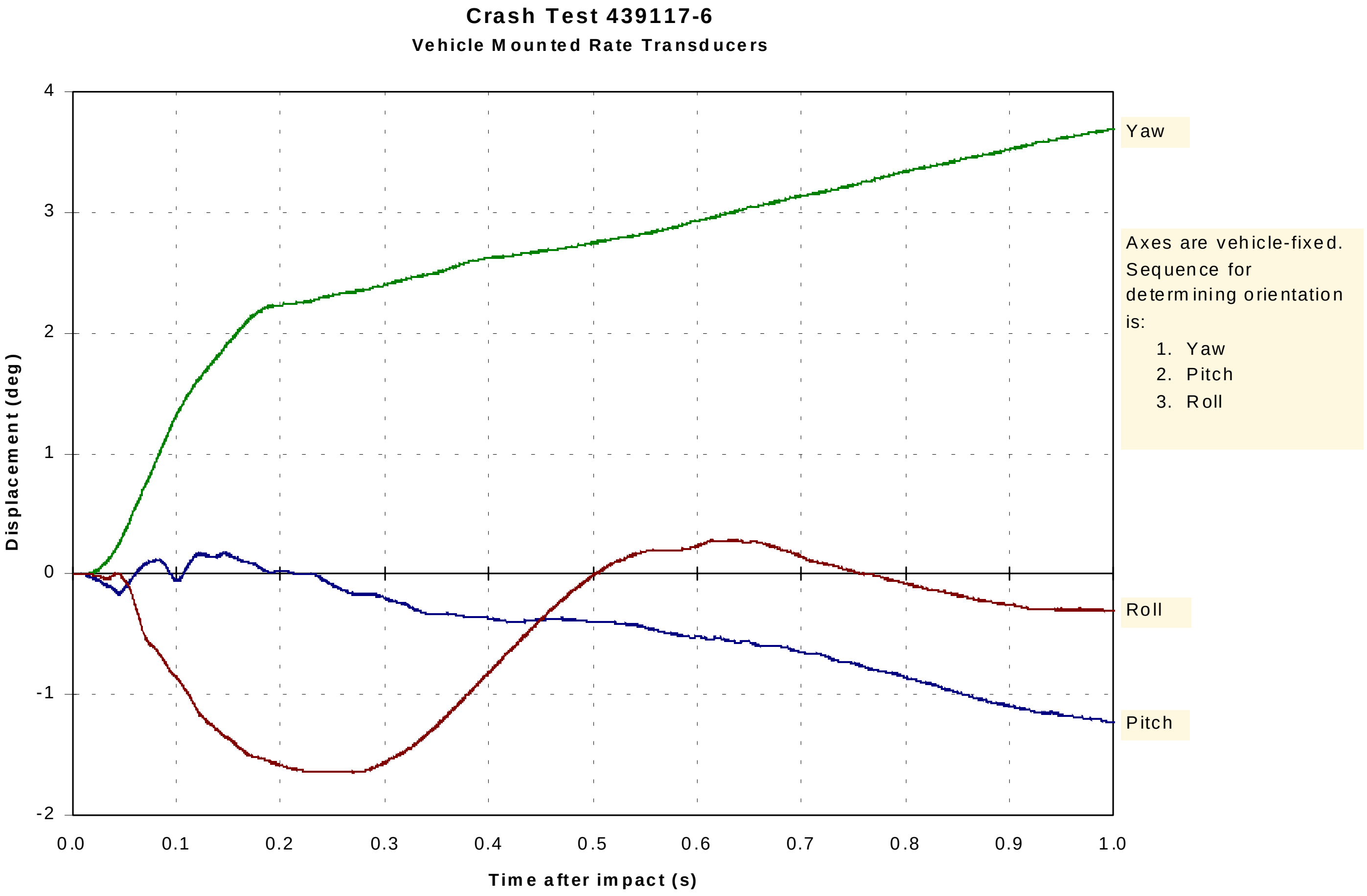


Figure 75. Vehicle Angular Displacements for Test 439117-5.



Axes are vehicle-fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

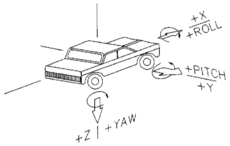
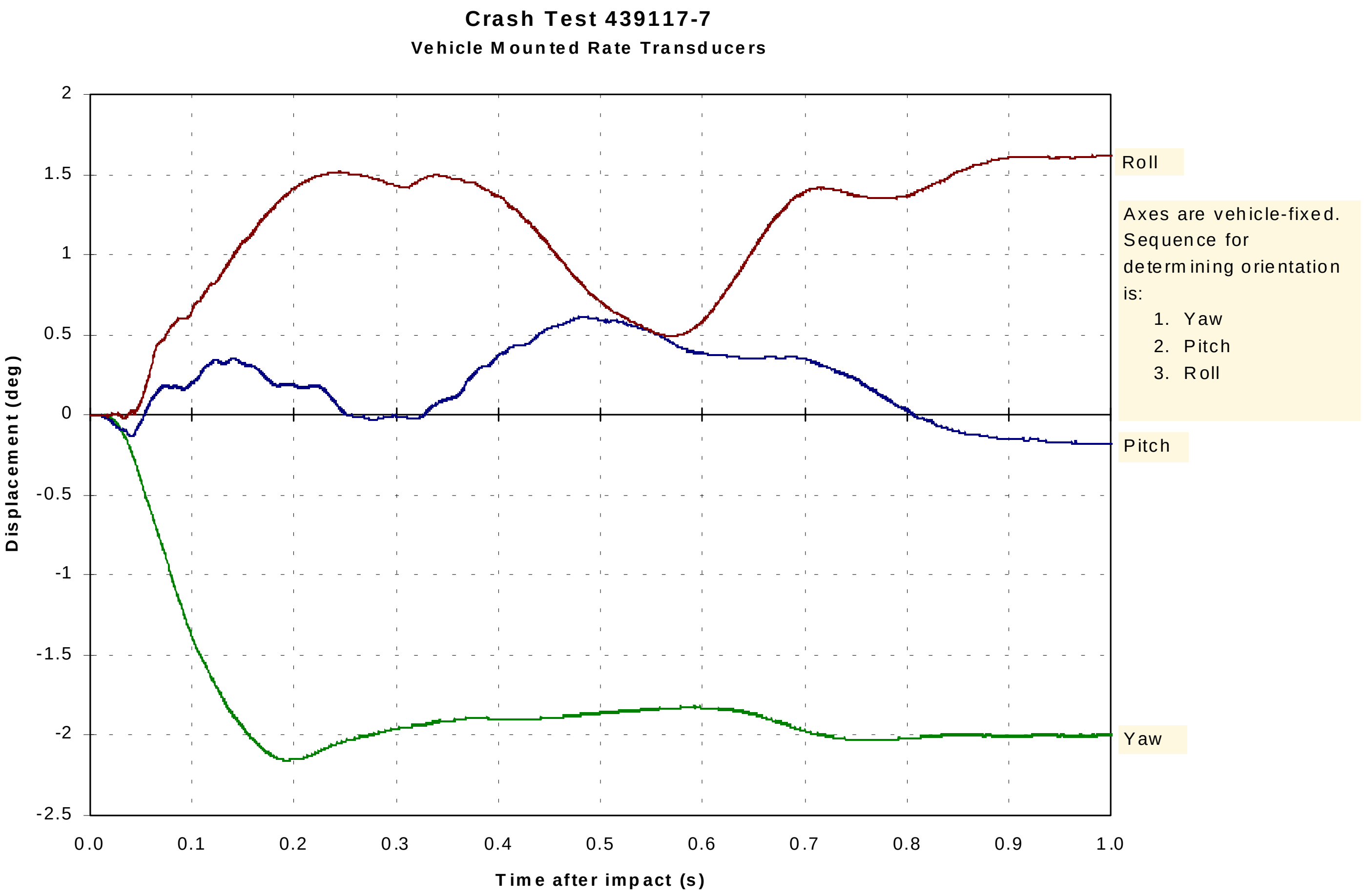


Figure 76. Vehicle Angular Displacements for Test 439117-6.



Axes are vehicle-fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

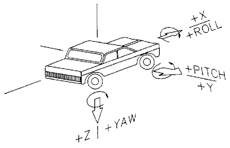


Figure 77. Vehicle Angular Displacements for Test 439117-7.

APPENDIX F. VEHICLE ACCELEROMETER TRACES

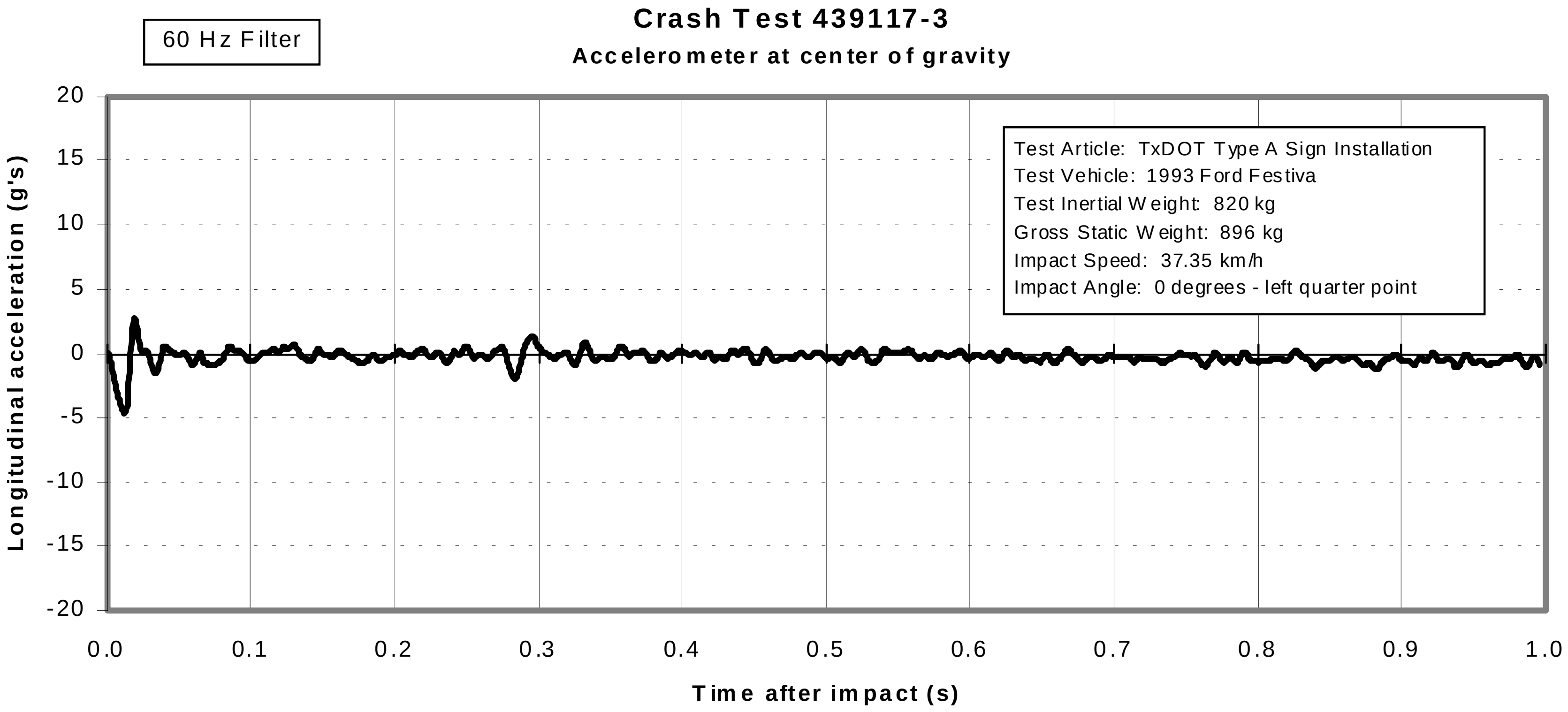


Figure 78. Vehicle Longitudinal Accelerometer Trace for Test 439117-3.

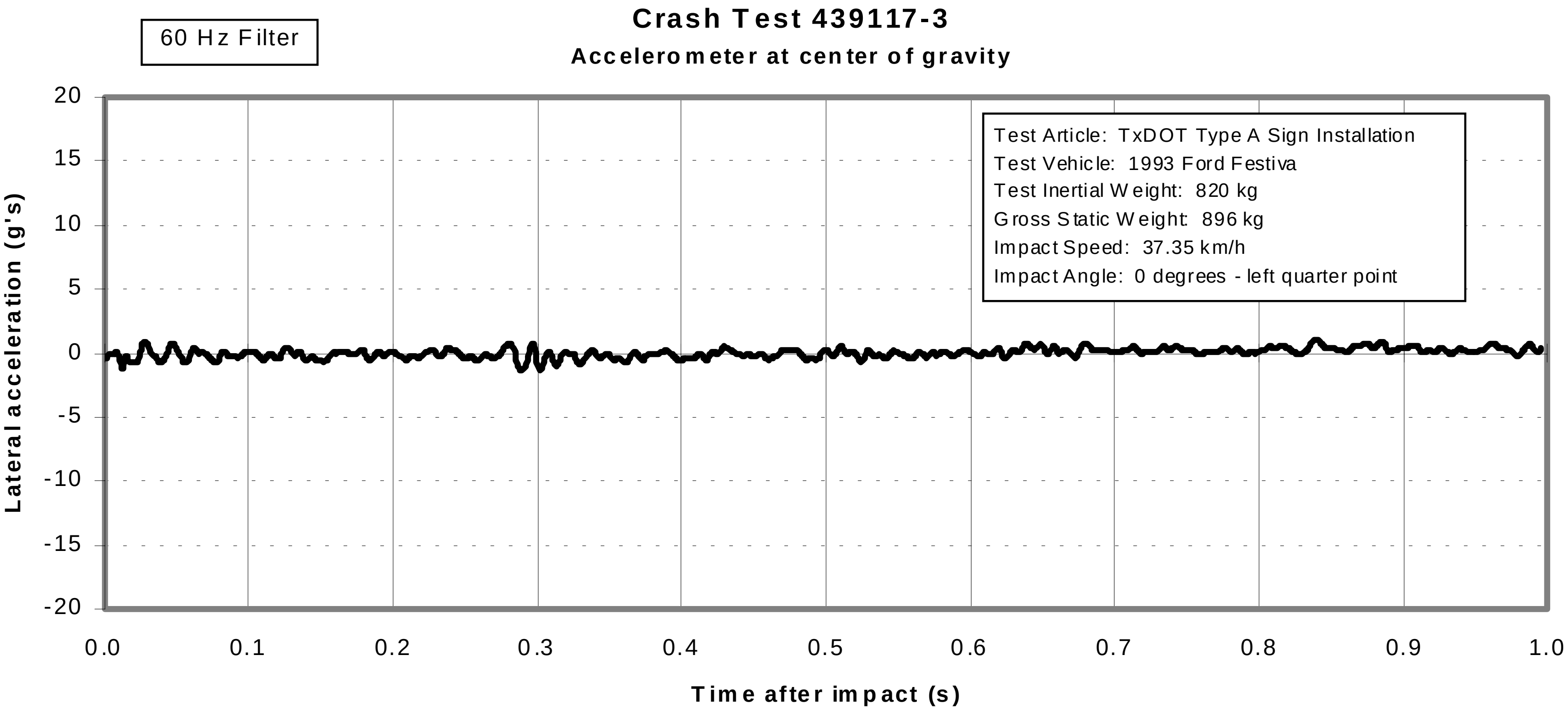


Figure 79. Vehicle Lateral Accelerometer Trace for Test 439117-3.

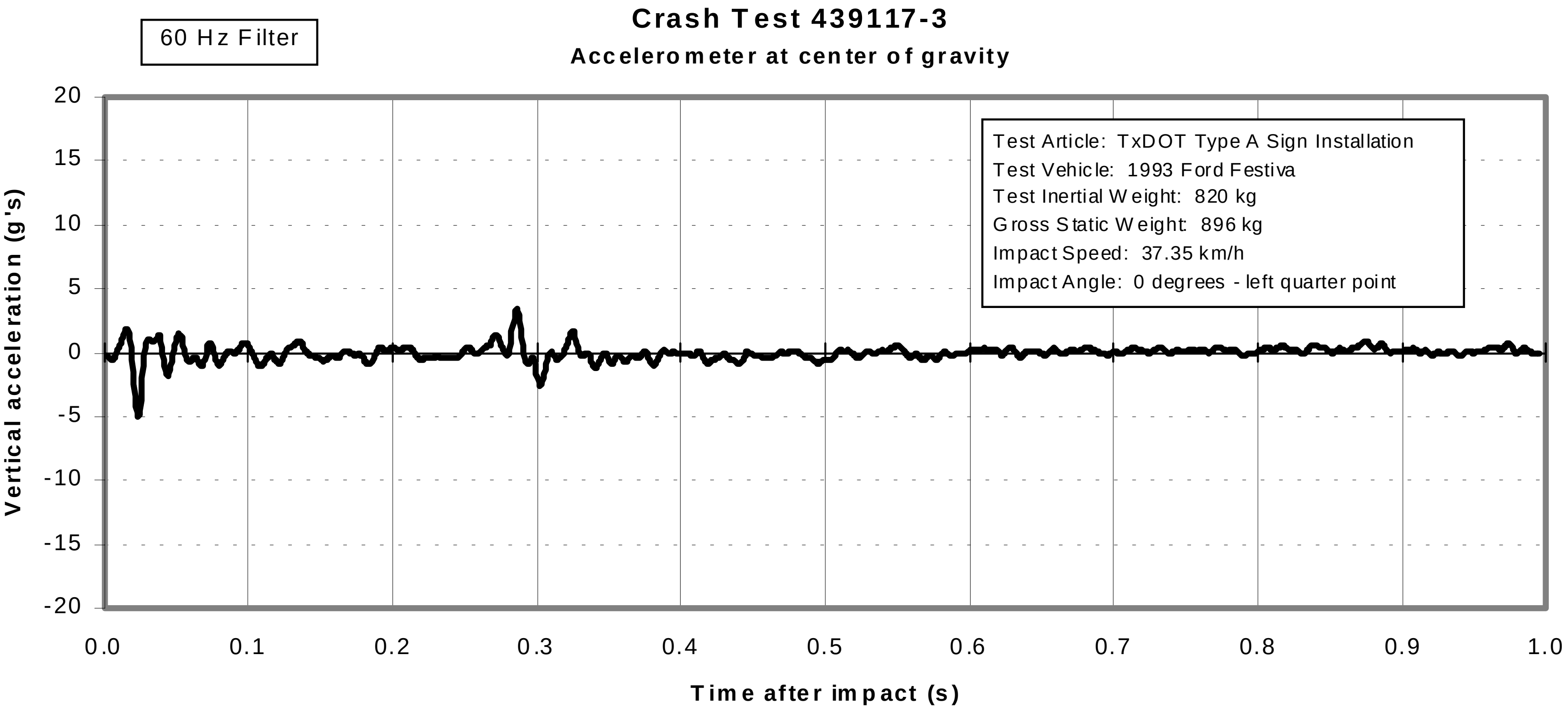


Figure 80. Vehicle Vertical Accelerometer Trace for Test 439117-3.

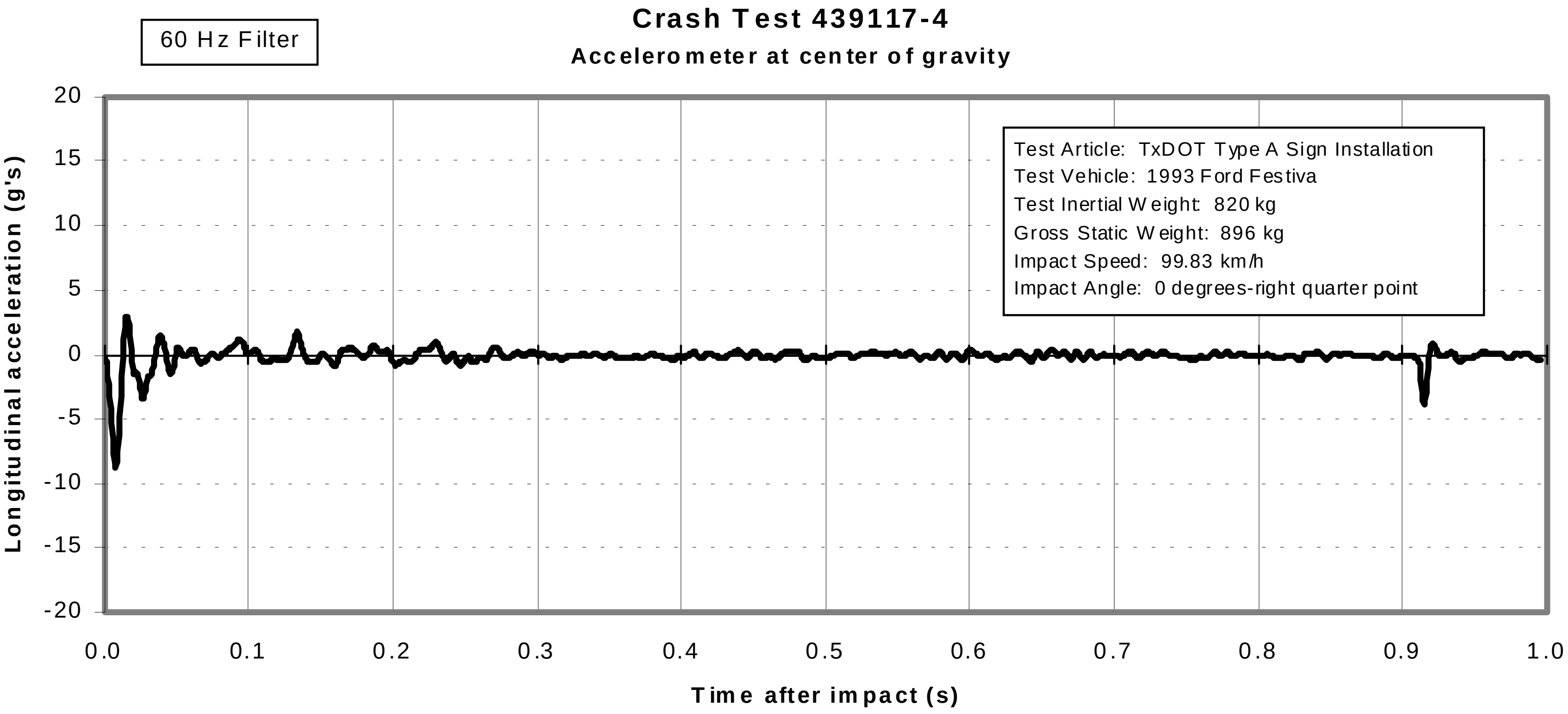


Figure 81. Vehicle Longitudinal Accelerometer Trace for Test 439117-4.

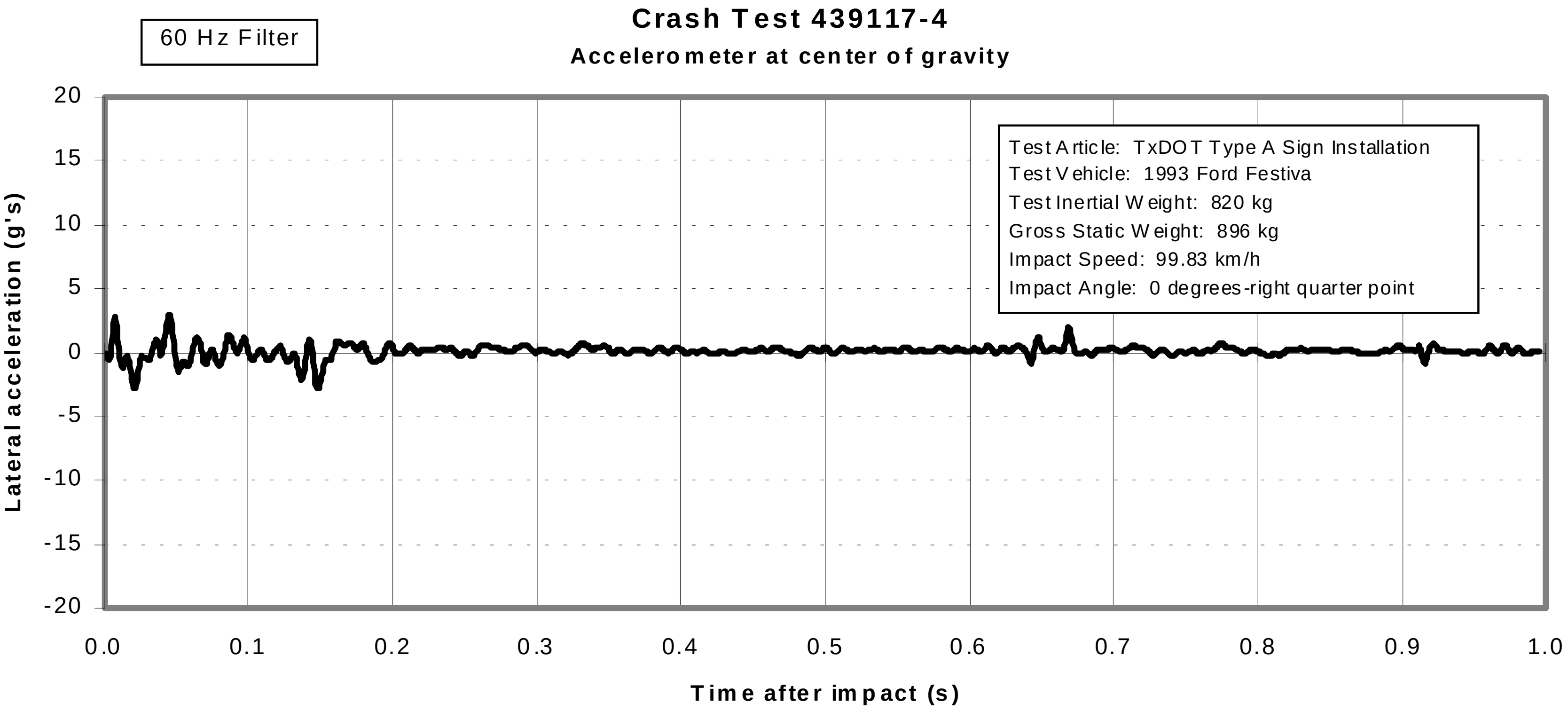


Figure 82. Vehicle Lateral Accelerometer Trace for Test 439117-4.

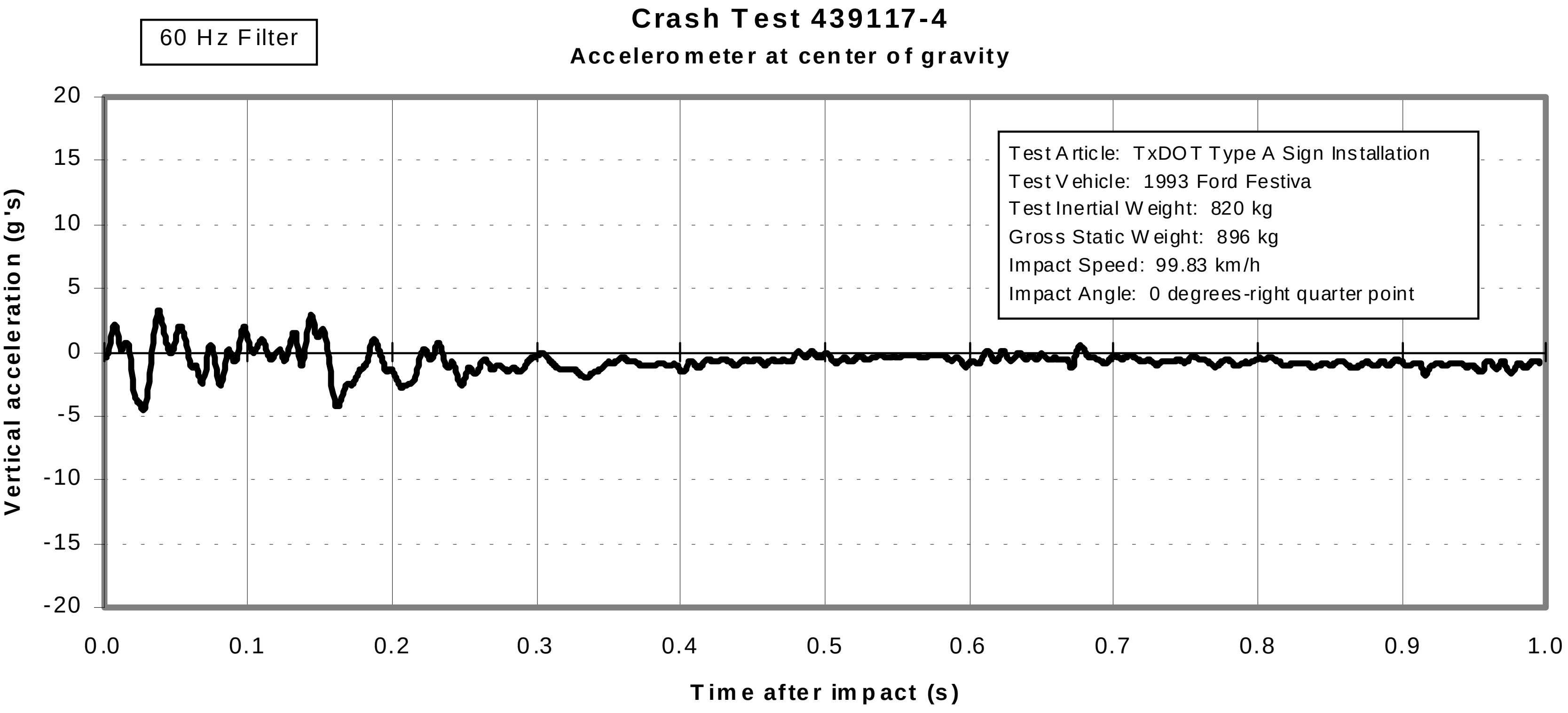


Figure 83. Vehicle Vertical Accelerometer Trace for Test 439117-4.

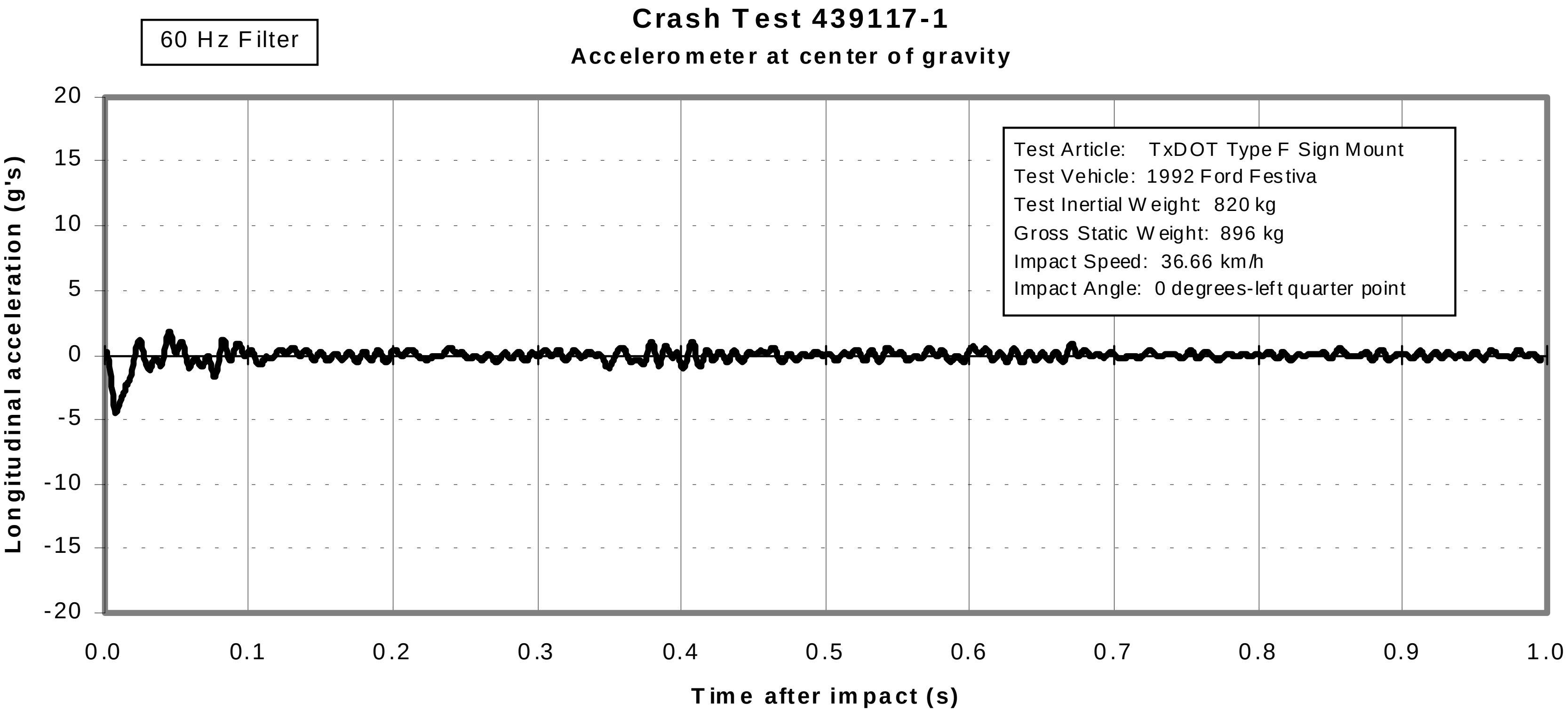


Figure 84. Vehicle Longitudinal Accelerometer Trace for Test 439117-1.

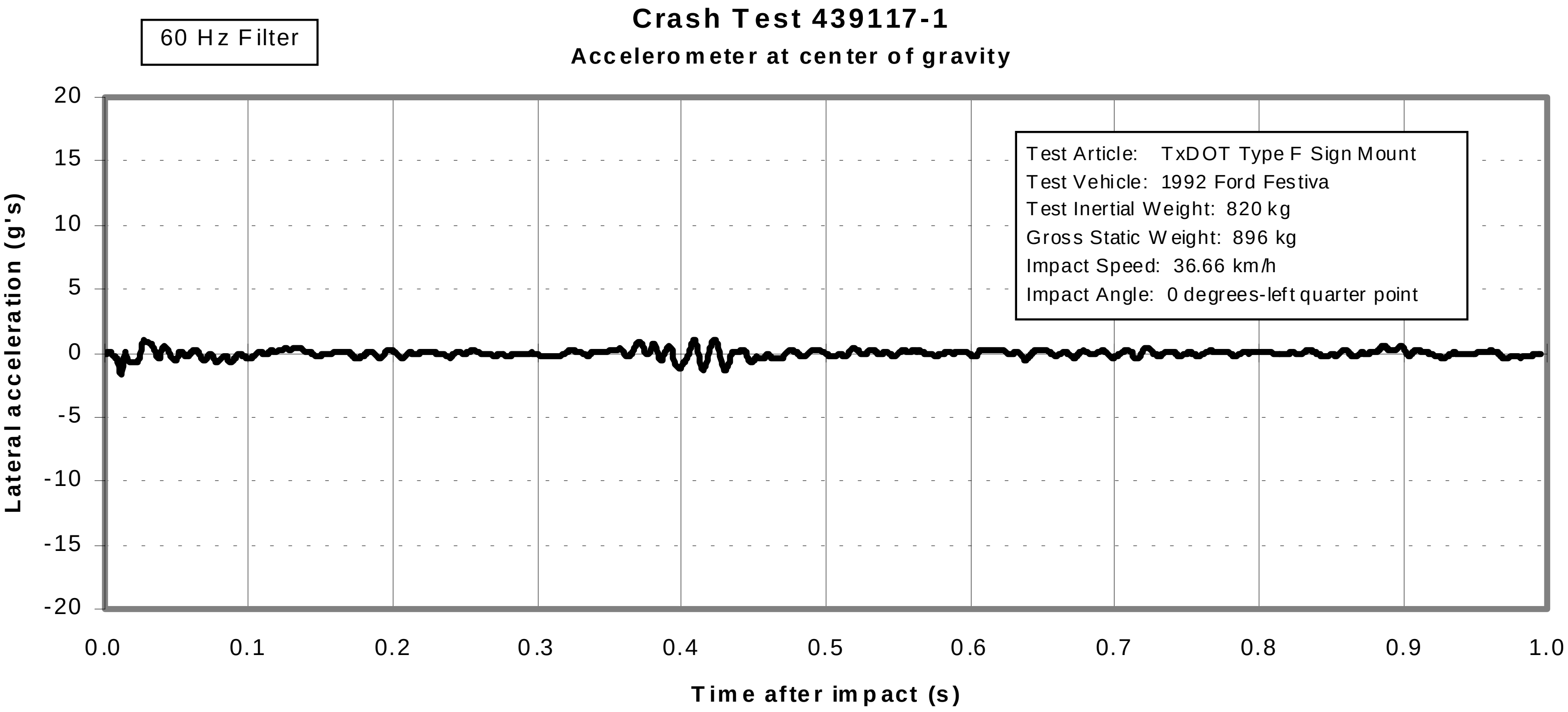


Figure 85. Vehicle Lateral Accelerometer Trace for Test 439117-1.

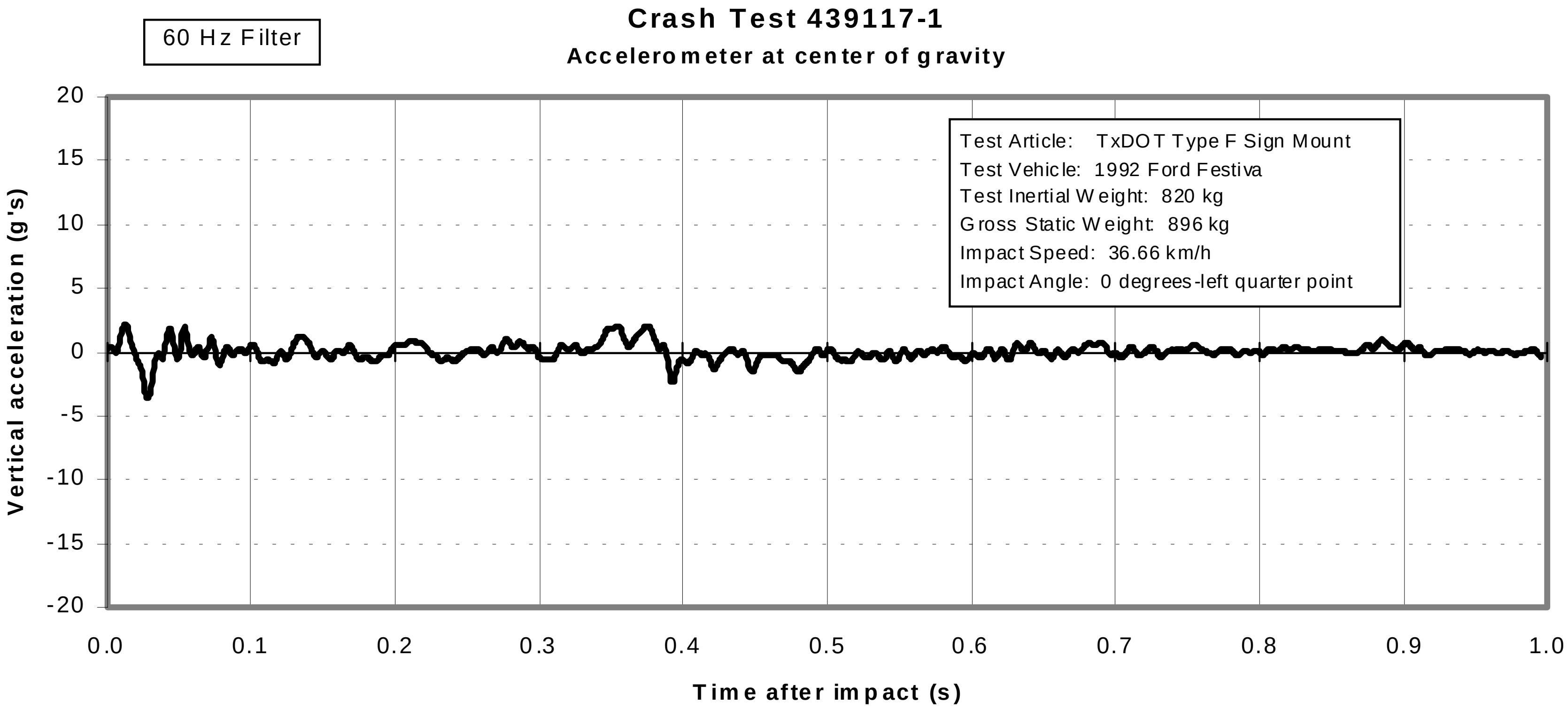


Figure 86. Vehicle Vertical Accelerometer Trace for Test 439117-1.

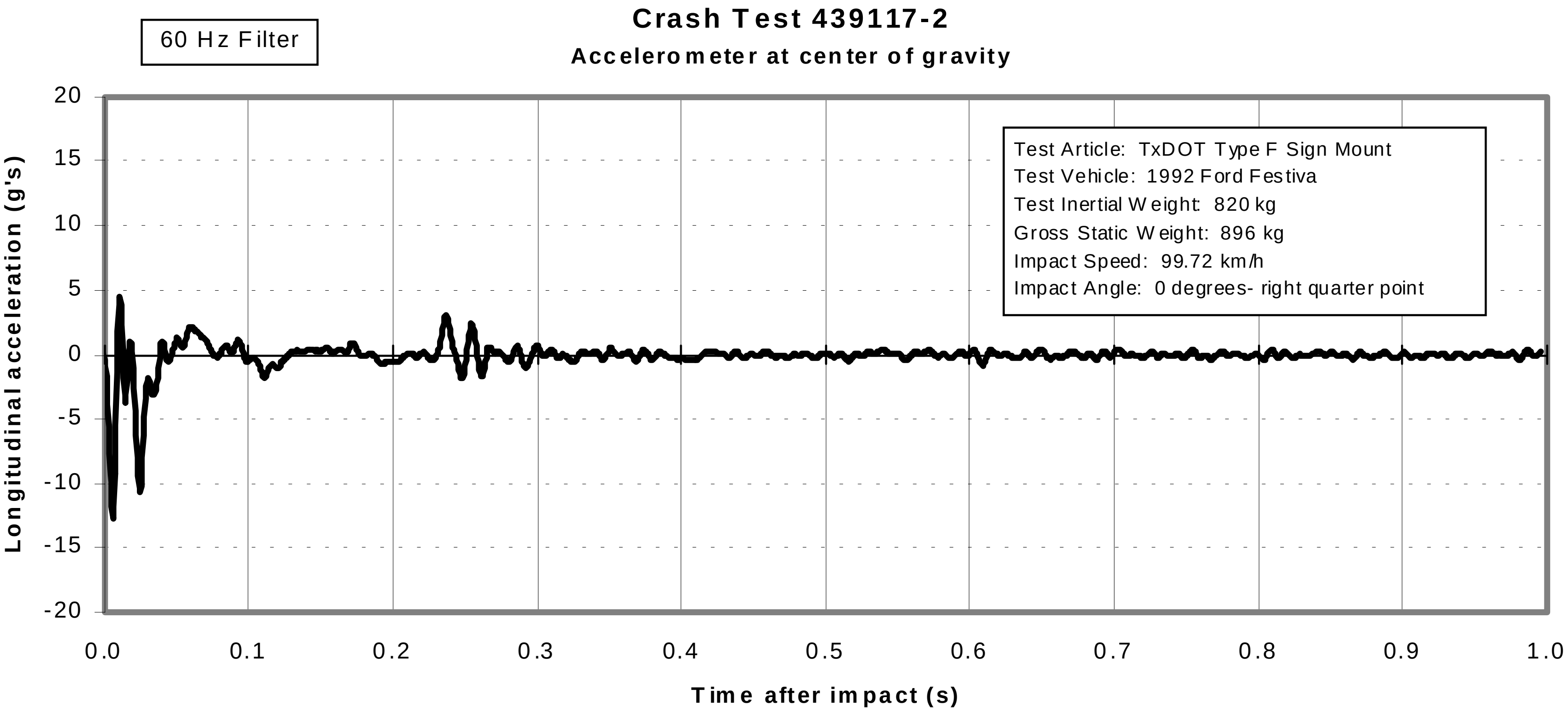


Figure 87. Vehicle Longitudinal Accelerometer Trace for Test 439117-2.

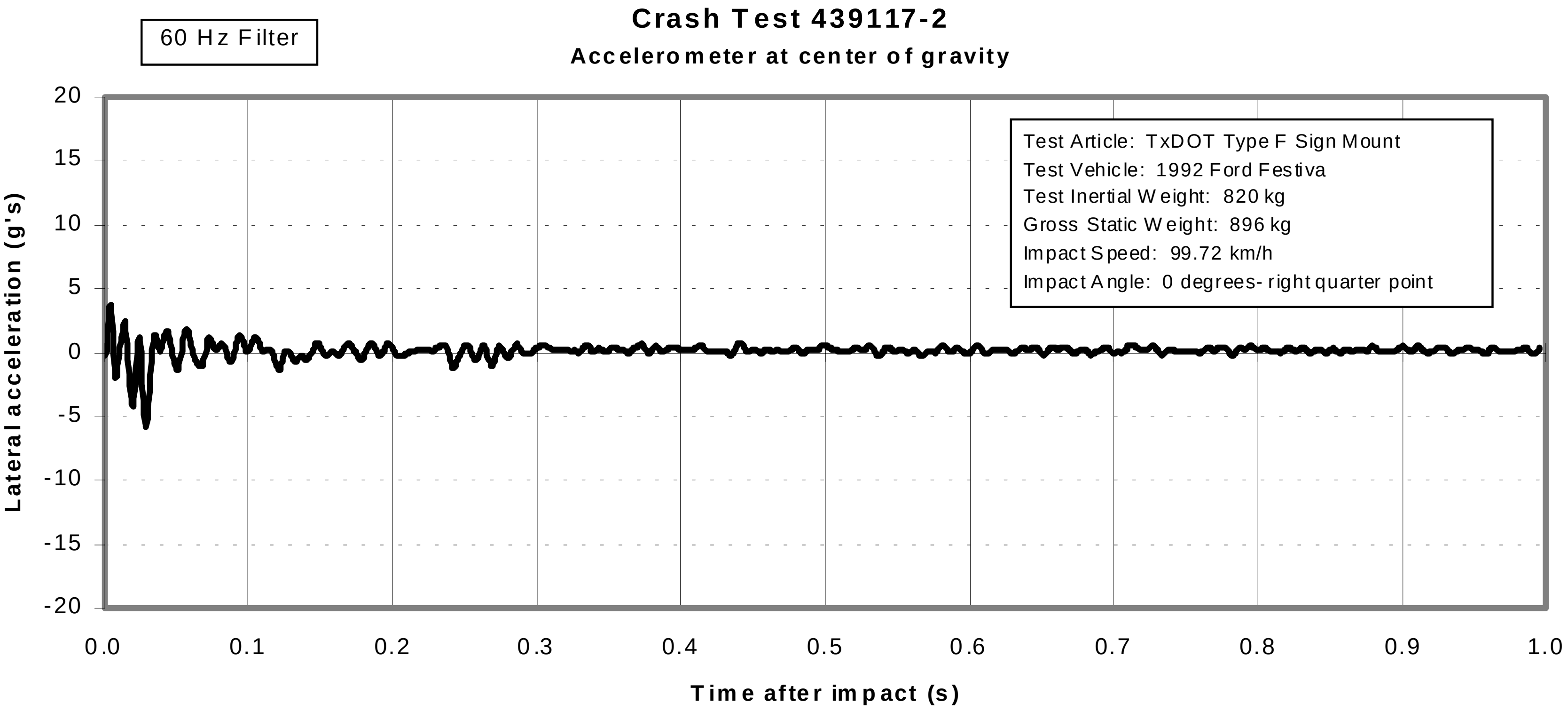


Figure 88. Vehicle Lateral Accelerometer Trace for Test 439117-2.

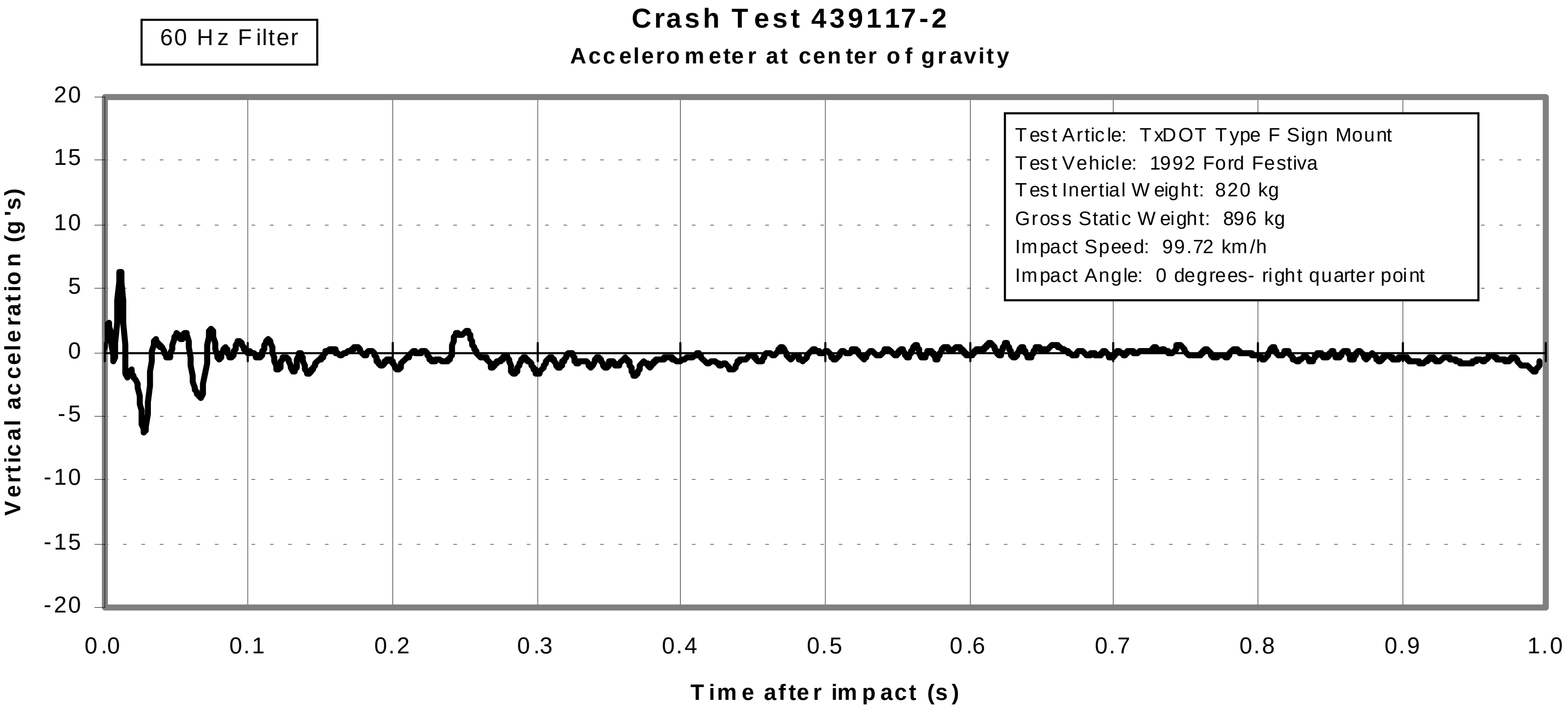
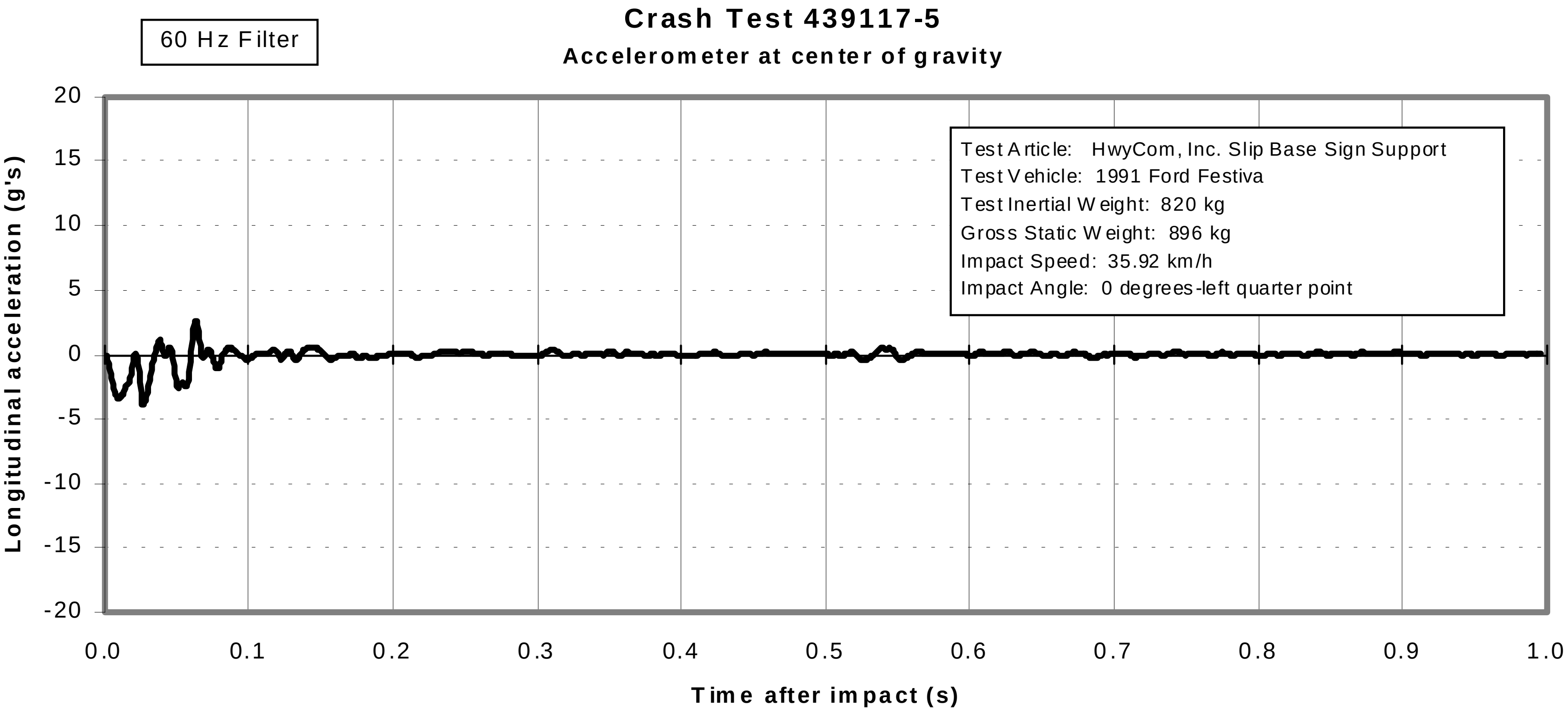


Figure 89. Vehicle Vertical Accelerometer Trace for Test 439117-2.



Test Article: HwyCom, Inc. Slip Base Sign Support
Test Vehicle: 1991 Ford Festiva
Test Inertial Weight: 820 kg
Gross Static Weight: 896 kg
Impact Speed: 35.92 km/h
Impact Angle: 0 degrees-left quarter point

Figure 90. Vehicle Longitudinal Accelerometer Trace for Test 439117-5.

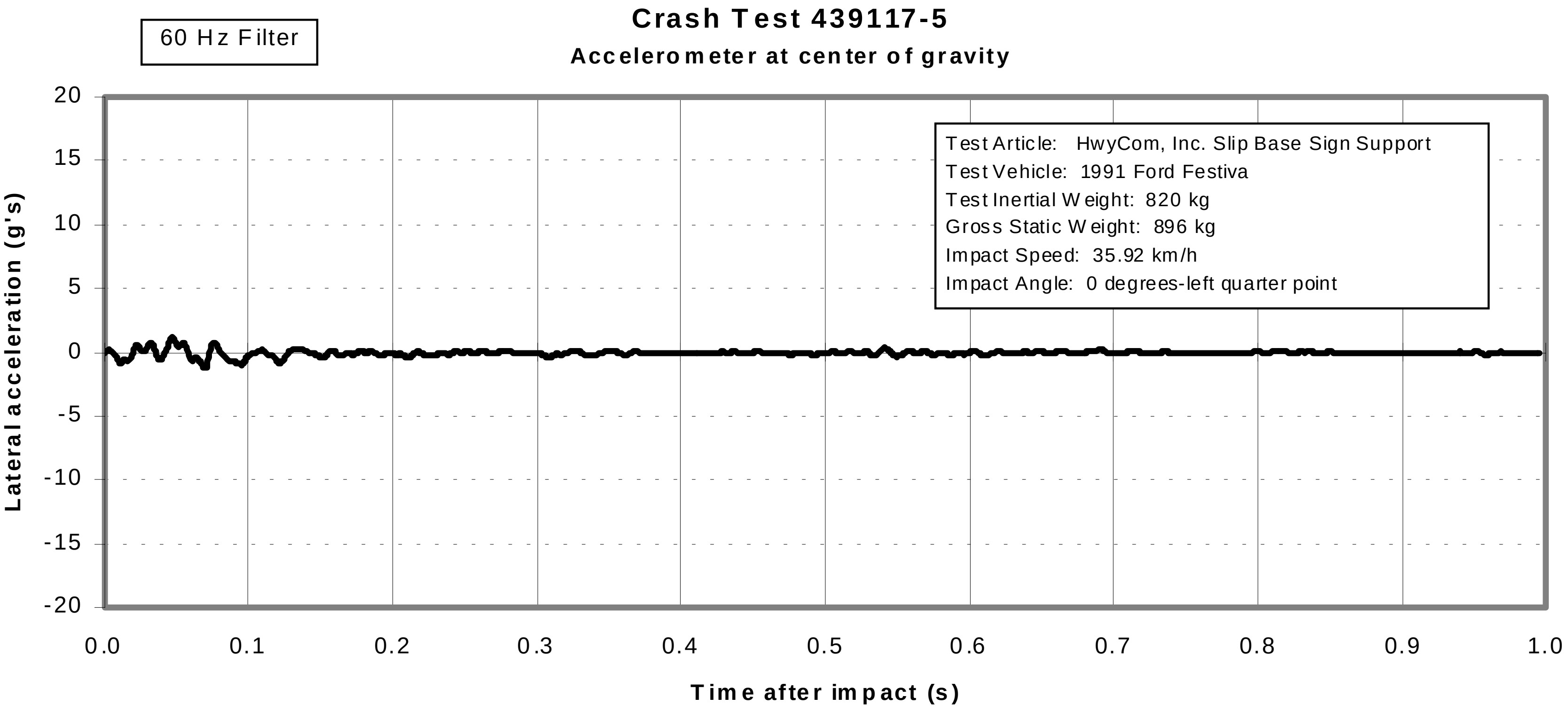


Figure 91. Vehicle Lateral Accelerometer Trace for Test 439117-5.

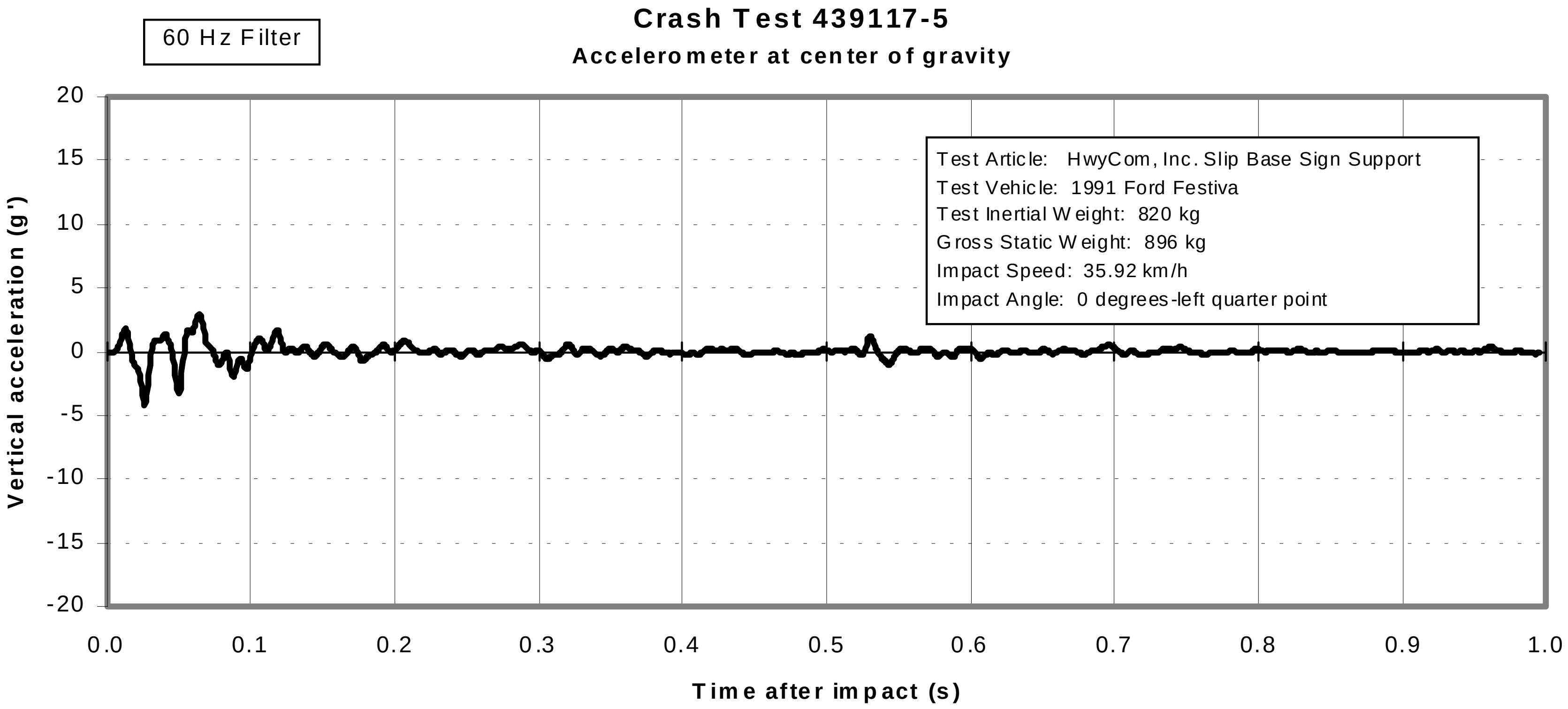


Figure 92. Vehicle Vertical Accelerometer Trace for Test 439117-5.

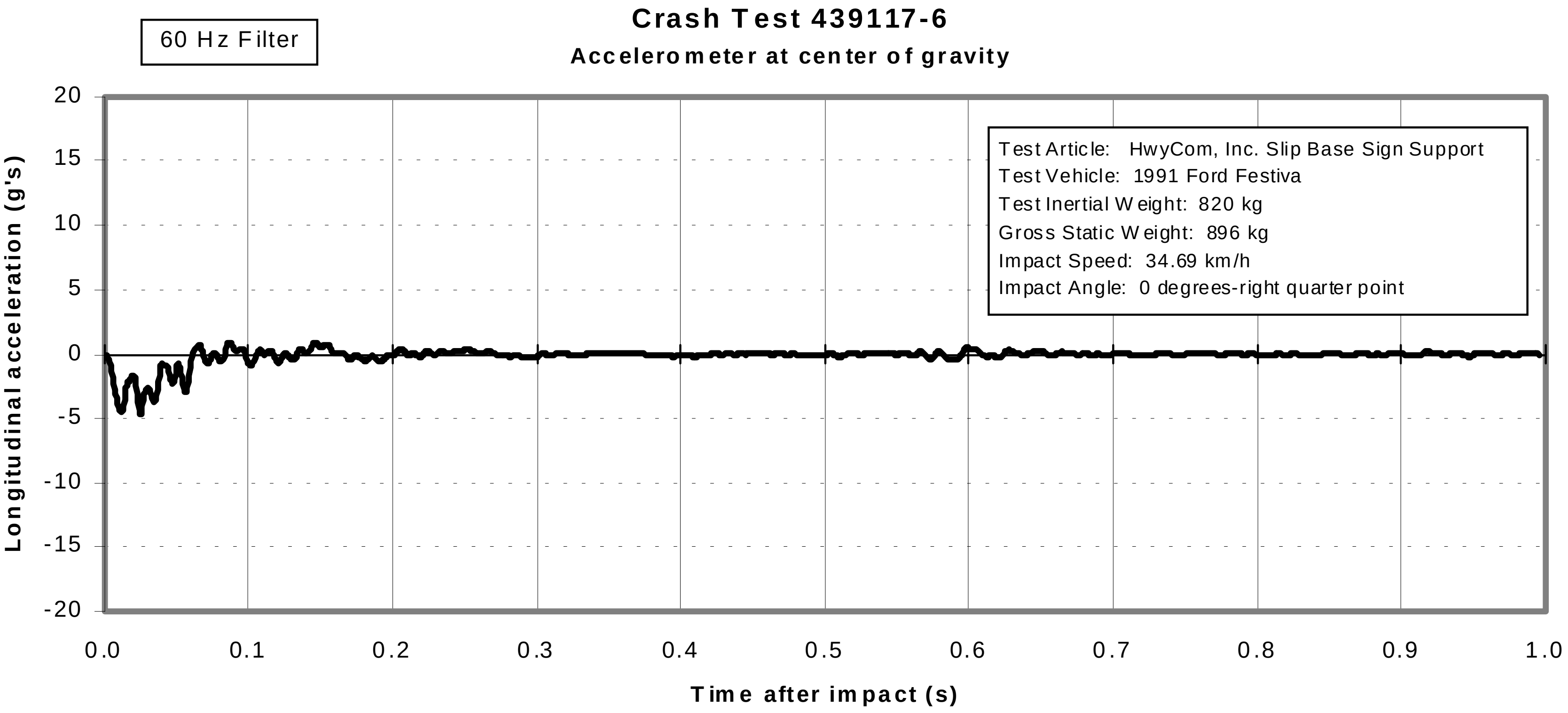


Figure 93. Vehicle Longitudinal Accelerometer Trace for Test 439117-6.

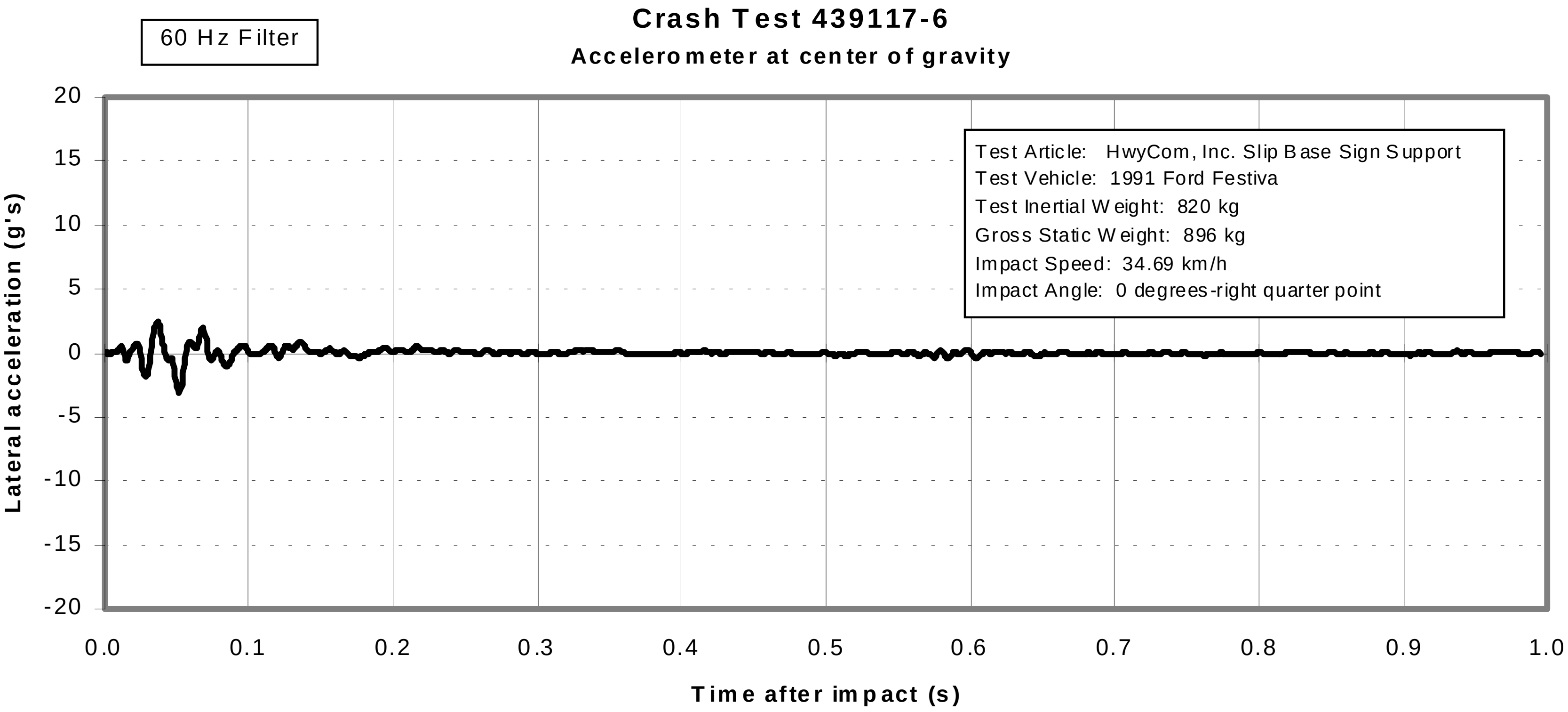


Figure 94. Vehicle Lateral Accelerometer Trace for Test 439117-6.

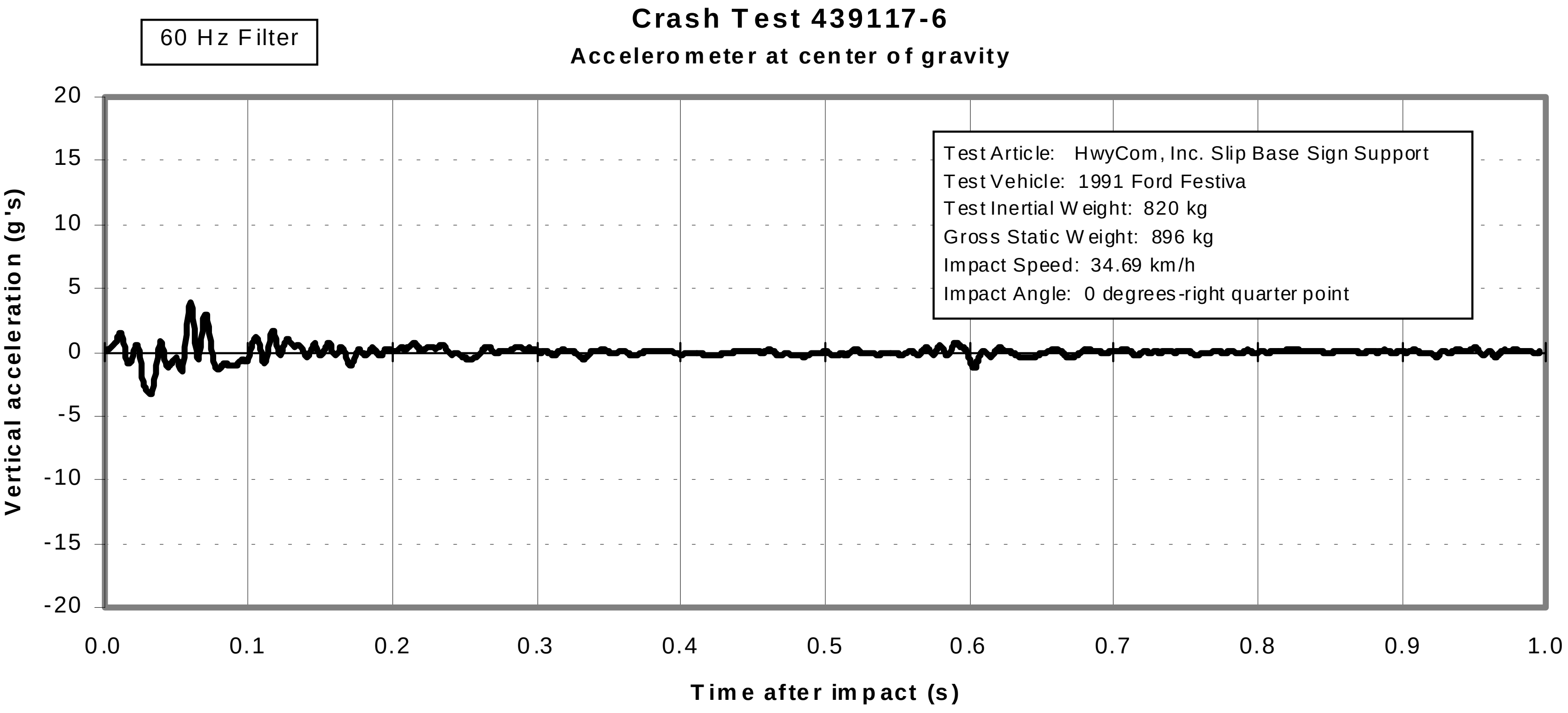


Figure 95. Vehicle Vertical Accelerometer Trace for Test 439117-6.

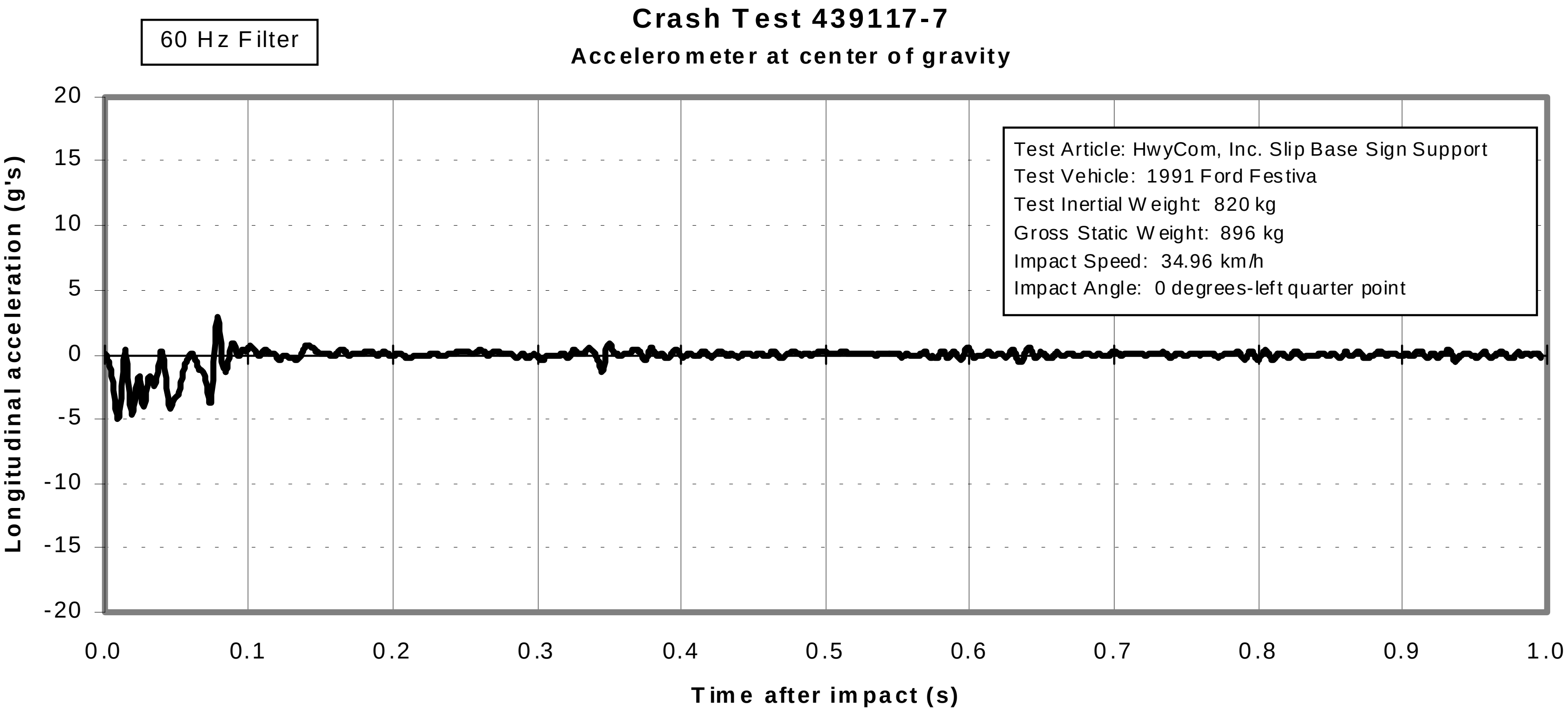


Figure 96. Vehicle Longitudinal Accelerometer Trace for Test 439117-7.

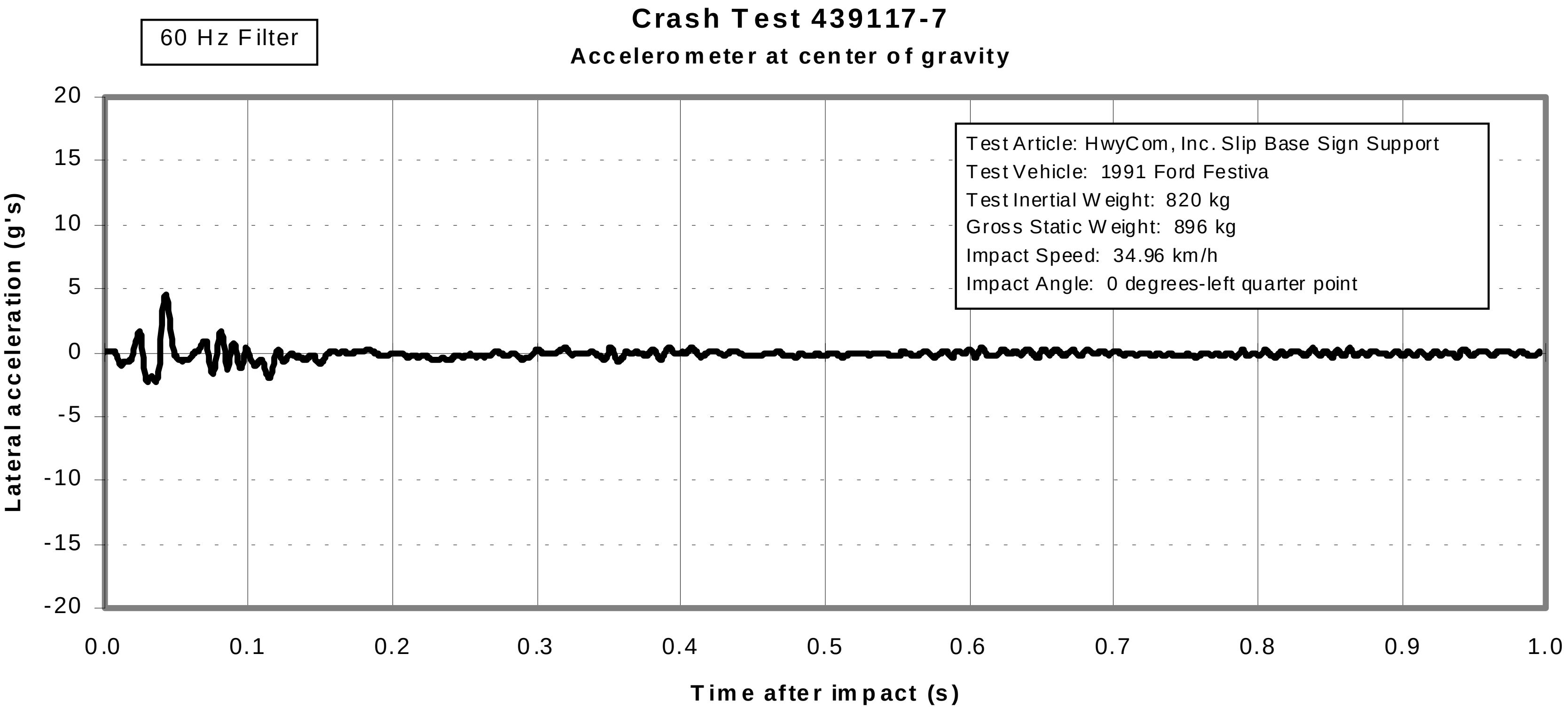


Figure 97. Vehicle Lateral Accelerometer Trace for Test 439117-7.

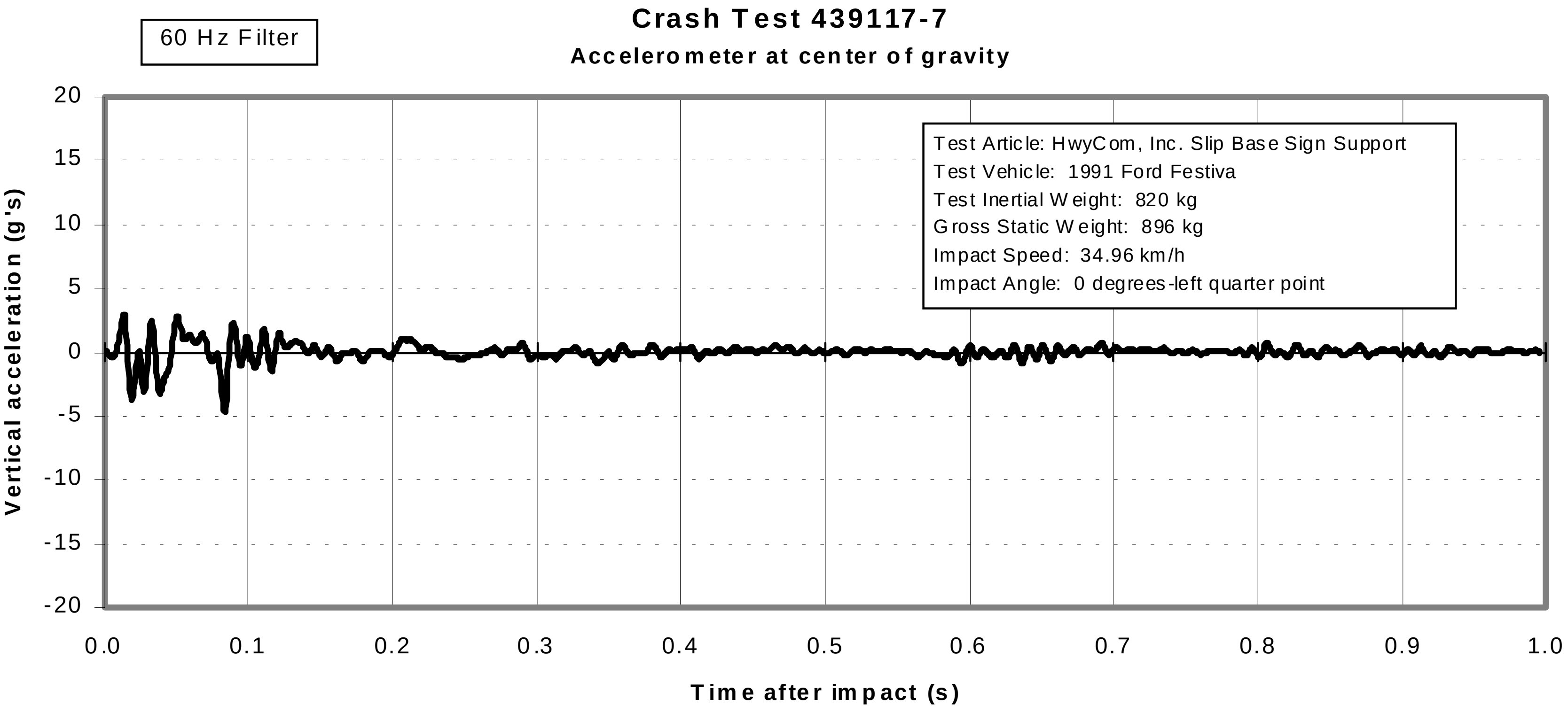


Figure 98. Vehicle Vertical Accelerometer Trace for Test 439117-7.